RECLAMATION
Managing Water in the West

Reservoir Debris Management

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Introduction

Many dams in Reclamation's inventory, and likely abroad, are not designed to pass woody debris that floats and deposits in reservoirs as the reservoirs fill with sediment. During low reservoir levels or periods when sediment arrives to an outlet works or hydropower intake, woody debris can rack on grated intakes, impacting reservoir operations. After the woody debris blocks the intake, sediment then deposits behind the racked members, beginning the process of limiting sediment passage during flushing and sluicing, and increasing the potential for eventual burial of the intake.

For example, when Paonia Reservoir was completely drained in November 2014 to inspect the reservoir outlet works trashrack, a significant amount of saturated (waterlogged), submerged woody debris racked against the outlet works trashracks. During the clearing of the reservoir outlet works trashracks, a headcut moved upstream in the bottom of the reservoir, creating a low flow channel. The incision and lateral migration of the low flow channel exposed and further transported saturated debris to the outlet works, continuing the racking and plugging process. During this process of clearing the outlet works and the formation of a low flow channel, the dam operator estimated that 700 to 1,000 cubic yards of debris was re-oriented to pass through the outlet works or removed during the emergency maintenance in November 2014 (Reclamation, 2016).

Developing a knowledge base and new technologies to deal with reservoir floating and submerged wood debris that inhibits the passage of sediment downstream is key in reducing the need to re-design outlet works to pass both sediment and debris downstream, which is a benefit to dam owners and users that would have the burden of retrofitting their dam to pass sediment downstream.

A literature review was performed on how to assess and mitigate against the effects of waterlogged debris at hydraulic control structures. The best source of information was a document written for the Army Corps of Engineers in 1997 known as “Debris Control at Hydraulic Structures in Selected Areas of the United States and Europe” (Wallerstein et al., 1997). This study mainly focused on the management of floating debris at reservoirs, and at lock and dam facilities. Many options were given for the containment of floating debris, but less so for submerged and waterlogged debris. Recommendations for submerged debris management options are included in the final section of the report.

Process of Debris Accumulation

The debris accumulation problem can be separated into three phases: (1) debris recruitment, (2) debris transport, and (3) debris accumulation.

Debris Recruitment

The obstruction of hydraulic infrastructure due to floating debris is prevalent in any run-of-river structures. Debris enters a system as floating debris and will sink when it becomes waterlogged if it is not removed. A wealth of published research has proven the crucial ecological and physical role wood debris plays in the health of rivers in forested landscapes. Wood debris accumulation can shape a river's channel size, planform, slope, and ecological diversity (Abbe & Montgomery, 2003; Zimmerman et al., 1967; Bibly & Ward, 1989; and Keller & Swanson, 1979). Understanding the processes that drive debris accumulation is the first step in engineering a solution. For each case knowledge of the debris sources, input mechanisms, and volume is essential in designing an appropriate management plan.

Processes that deposit debris in river systems include, but are not limited to (Wallerstein et al., 1997; Nakamura & Gresswell, 2003; Latterell & Naiman, 2007):

- Windthrow can deposit bushy debris (sagebrush and tumbleweed) and numerous, uprooted trees into the channel.
- Slope instability can result in mass wasting, which in a forested watershed, will result in woody debris, sediment, and other debris entering the channel.
- Forest litter and natural mortality will input leaves and dead tree trunks/limbs.
- Bank erosion can undercut tree roots near the channel bank, resulting in recruitment with sufficient migration.
- Beaver activity contributes an unknown, but perhaps substantial, quantity of wood recruitment.
- Man-made infrastructure such as piers and wharves located within the floodplain can be swept into the channel during large events.
- Forestry practices greatly impact debris inputs into a river. Forested land absorb precipitation and protect the hillsides from erosion during large storm events. When vegetation is removed, mass wasting, surficial soil erosion, and bank erosion are more likely to deposit sediment into the river; however, the volume of woody debris will decrease.

Estimating the rate of wood recruitment is site specific and dependent on various factors. Several tools are available to develop an understanding of wood recruitment, storage and transport depending on the site and available data. Similar to other environmental systems with definable inputs, outputs, and storage, a mass balance account for material fluxes over time and space can be developed. Benda et al. (2003) developed a wood budgeting framework which provides numerical expressions for wood recruitment processes identified in the previous paragraph. A numerical model, Riparian-in-a-box (RIAB), was developed in 1998 to predict wood recruitment and its impacts on fish habitat. Its inputs include: stand characteristics at various time increments (species composition, diameter, height, and stem density) and site characteristics (height, hillslope, elevation and aspect). RIAB output data includes the number of large wood debris per channel width and several other metrics not relevant to this study (Kennard et al., 1998 and Beechie et al., 2000).

Debris Transport

Similar to sediment, the mobilization and conveyance of wood debris downstream is dependent on the both the physical and hydraulic characteristics of the debris and river. Size and orientation of the debris as compared to that of the river (channel width, depth and to a lesser degree slope; Lagasse, 2010) will determine if the debris is likely to mobilize. Studies report that pieces are more likely to be transported downstream if the length is less than the channel width and diameter is less than bankfull depth (Bilby, 1984 and Bilby & Ward, 1989).

The stability of in-stream wood is also influenced by orientation. Logs secured to the bank by rootwad or burial are less likely to move downstream (Bryant, 1983). Evidence shows that submerged debris is influenced by slower, diverging flow near the bed, transported to banks or point bars (Diehl, Potential Drift Accumulation at Bridges, 1997). Floating woody debris are often transported as individual logs, which travel along the stream thalweg (Chang, 1979). However, woody debris can aggregate moving downstream. Often, these short-term clusters are broken apart by turbulence or colliding with stationary features as they move downstream. A study conducted in the West Harpeth River Basin concluded that curved woody debris were more likely to intertwine with other debris, forming jams (Diehl & Bryan, 1993).

Debris Accumulation at Structures

Debris accumulation at structures is dependent on the geometry of the woody debris and the hydraulic structure. Current literature focuses on debris accumulation at bridge piers (Lagasse, 2010; Diehl, Potential Drift Accumulation at Bridges, 1997). While accumulation at bridges is not the focus of this report, the same concepts can be applied to submerged debris at reservoir outlet structures.

Debris trapping has been suggested to be a function of tree height, trunk diameter, canopy/bole diameter, and, pier span distance (Downs & Simon, 2001). In the case of reservoir outlet structures, the pier span distance can be replaced by the width of the outlet gates and their spacing. Most debris jams fall into one of the following categories: single-pier accumulation and span blockages. If a debris budget has been developed for the location of interest, channel width and debris characteristics can estimate the probable maximum width (Diehl, 1997). The longest debris piece can predict the maximum width of the debris accumulation (Lagasse, 2010).

Debris width predictions are dependent on the type of debris accumulation. Single-pier accumulations typically contain one or more logs spanning the width of the accumulation, perpendicular to the flow, supporting the lateral forces that would typically break apart the accumulation. Diehl (1997) report compiled data of debris width versus upstream channel width for sites in Tennessee and Indiana. Figure 1 Figure 2 suggest that the maximum debris accumulation width at single piers is less than 50 ft (15 m) and debris/drift width decreases with channel width in channels that are greater than 50 ft wide. Span blockages develop when the length of the transported debris exceeds the pier span distance, resulting in a single log bridging the span between two piers. Often these accumulations extend to the channel bank. Diehl (1997) collected data for “pier-to-pier-spanning” debris accumulations in the Pacific Northwest, Figure 3. The results indicate that the maximum span blockage is approximately 80 ft (24 m).

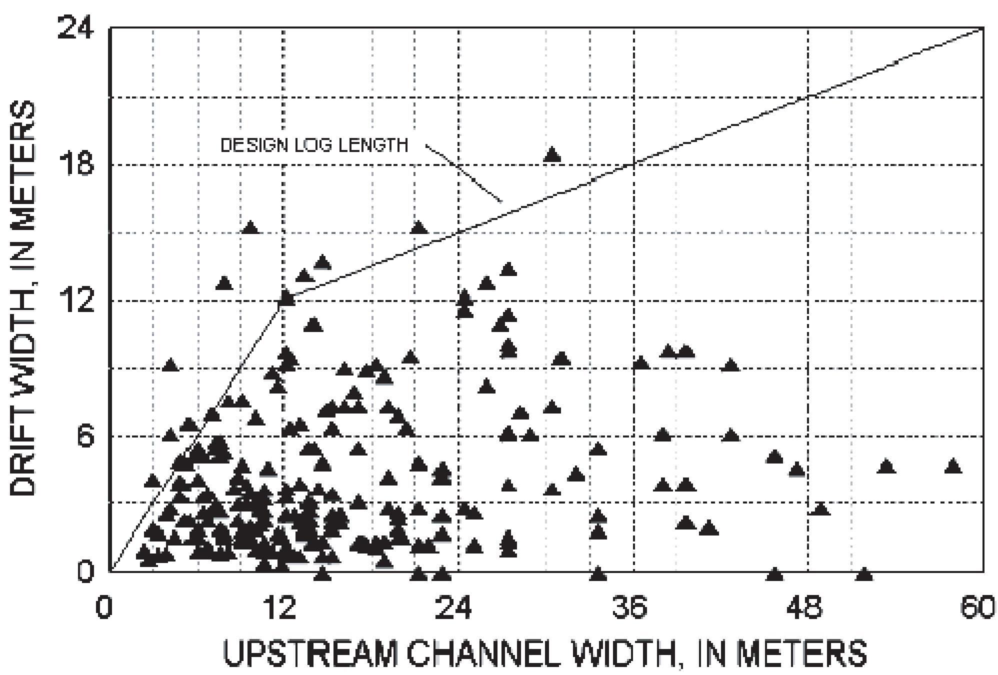

Figure 1: Width of inferred single-pier drift accumulations at scour-potential (e.g. bridge pier) sites in Indiana. A design log length for use in estimating the potential for drift accumulation is inferred from the width of the largest single-pier accumulations and the longest blocked spans; plot source: Diehl, 1997

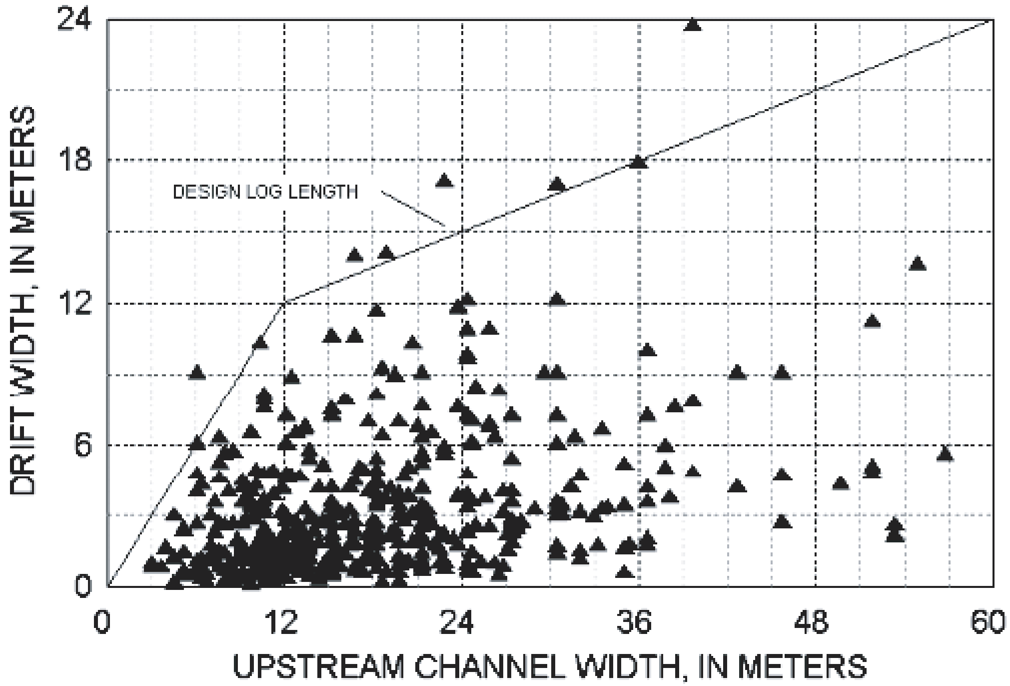

Figure 2: Width of inferred single-pier drift accumulations at scour-potential sites in Tennessee; plot source: Diehl, 1997

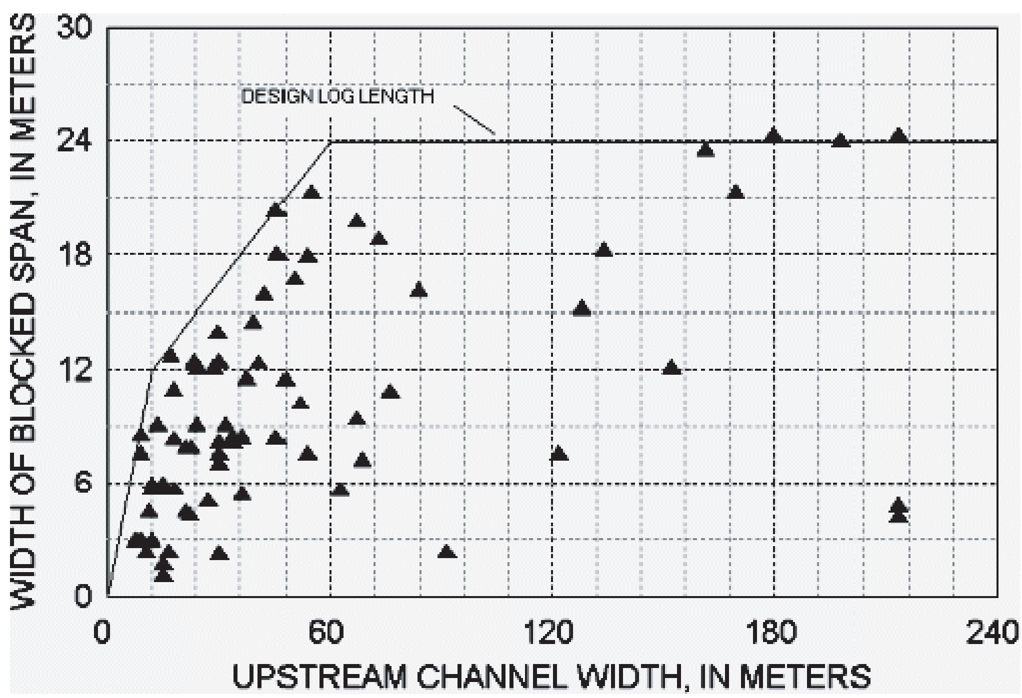

Figure 3: Effective width of drift-blocked spans outside the Pacific Northwest; plot source: Diehl, 1997

Current Debris Management Options

Currently, there are limited management options for retaining woody debris upstream of reservoir outlet works. Literature recommends utilizing log booms as a first line of defense against floating debris, and trash racks should be installed at the outlet structures (Jansen et al., 1988). If debris accumulates regardless of preventative infrastructure, physical removal using barges and cranes and manual labor is conventional. Trash booms are generally designed to manage floating debris and aren't designed to manage submerged debris. If captured floating debris is not removed, then it may become waterlogged and then submerge. Furthermore, physical debris removal is labor intensive, time consuming, and costly.

Much research has been done to understand the impacts of debris accumulation on bridges (Chang, 1979), piers (Lagasse, 2010), and trash racks (Patent No. 4,709,804, 1987). In considerations of passing debris through open or closed conduits, such as outlet works systems, Wallerstein et al. (1997) did furnish several recommendations from other literature. Hartung and Knauss (1976) recommends that clogging can be avoided in closed conduits if three conditions are adhered to: smooth walls, no contractions or obstructions, and no sharp bends. Although not noted in the literature, the recommendation assumes that no trashracks are present on the intake of the closed conduit. Some of the recommendations provided by Wallerstein et al. (1997) and other authors are provided in sections below.

Trash Rack Structures Directly Upstream of Outlet

Trash rack structures are the most common means of debris control at hydraulic structures. It has prolifically been applied to many hydropower and diversion structures, with patents dating back to 1926 (United States Patent No. 1,586,753, 1926). Stationary trash racks are most common, but they require manual cleaning to prevent unnecessary head loss and/or structure overtopping. Since 1983, several patents have been published with self-cleaning mechanisms. These mechanisms often include rakes or bars which collect debris accumulated and deposit it downstream. However, many of the current automated cleaning systems are not economically viable.

The Bureau of Reclamation is researching the development of a self-cleaning, low-head, low-energy, and affordable self-cleaning trash rack. Unlike other self-cleaning trash racks, the rack bars themselves function as the cleaning mechanism. Each bar can shift back and forth along the rack slope. When a cleaning cycle is initiated, the bars can move in different sequences depending on the programming (Gill, 2014). While self-cleaning trash racks are a viable option for handling submerged debris accumulation in reservoirs, it would require new, likely costly, retrofits to outlet infrastructure.

Unconventional trash racks have been documented by Wallerstein et al., (1997). Wood and debris are routinely deposited into the Columbia, Jonesville, and J.H. Overton Lock and Dam. Instead of trash racks, air bubbles have been installed at the miter gates to avoid debris accumulation at the gate face. Log booms are occasionally employed at the Jonesville Lock and Dam. When the debris mass is adequately large, barges and cranes guide debris to the miter gates.

Upstream Debris Catchment Structures

Log booms are the most prominent type of debris catchment structure. Located far upstream of the intake, they can prevent floating debris from reaching the spillway. As log booms are well understood, this study will focus on more uncommon debris catchment structures.

Rivers in the Bavarian Alps receive high wood inputs due to steep, saturated terrain, many coniferous trees, and management practices are necessary. An extreme flood event occurred in 1990 in the Lainbach and Arzbach River Subbassins resulted in large debris accumulation at bridges, which damaged the bridges and flooded residential areas. To avoid repeating this catastrophic flood, debris retention devices in the form of cylindrical piles, were designed to protect the conveyance capacity of the bridges. Circular posts installed in the channel bed to allow the passage of water and sediment, while retaining larger debris. Several configurations were tested in a laboratory study, Figure 4. The posts spacing was set to match the minimum length of the debris. The optimum alignment was a downstream pointing “V,” which best retained debris with minimal backwater effects. Both structures require periodic cleaning of debris and sediment (Wallerstein et al., 1997).

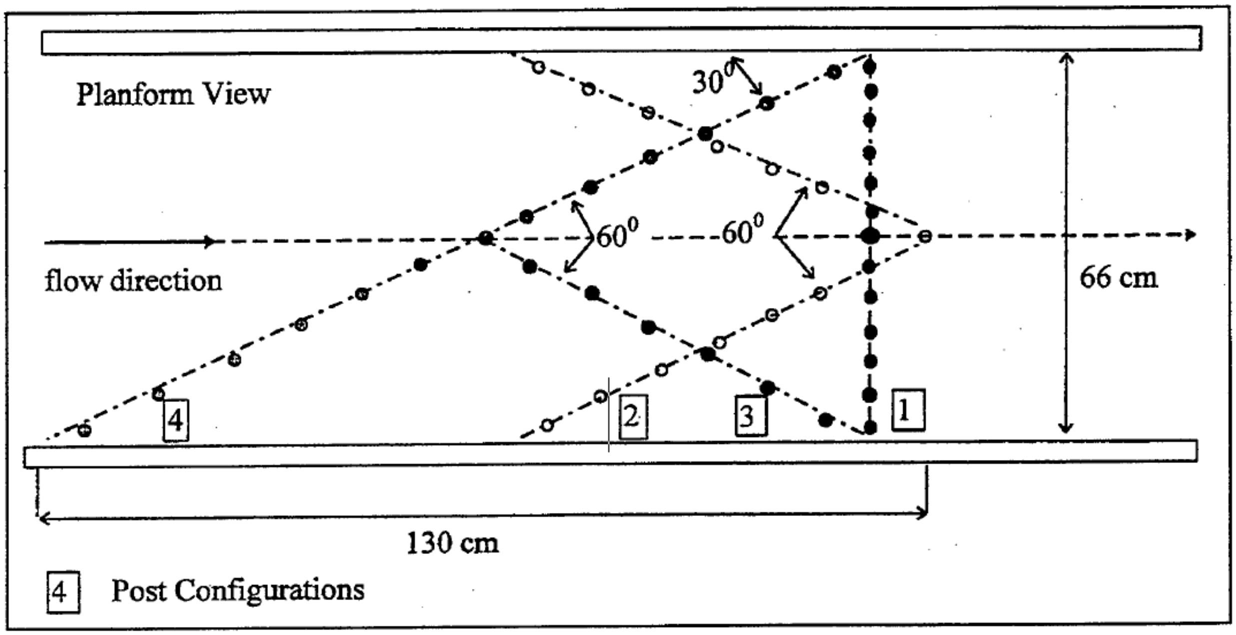

Figure 4: Tested flume post alignments (Wallerstein, Thorne, & Abt, 1997). Alignment 2 (a downstream pointing "V") had the best debris retention with the least backwater.

In 1980, the Mount St. Helens eruption bursting the top of the mountain and depositing over 3 billion cubic yards of debris into the surrounding slopes. To mitigate impacts of debris flow into the Toutle, Cowlitz, and Columbia rivers, Congress tasked U.S. Army Corps of Engineers – Portland District with finding short- and long-term solutions. Many solutions were proposed and constructed including grade building structures, intended to trap sediment upstream of a reservoir built to trap fine sediment, known as the Sediment Retention Structure (SRS). The grade building structures include three features (U.S. Army Corps of Engineers, 2016):

1) A cross valley structure, "step-weir and baffle" system, is constructed of posts and pannels. The structure creates a backwater effect, decreasing water velocity which allows sediment and debris to deposit;
2) Engineered log jams (ELJ) placed in the center of the channel, intended to create islands which will produce more stable channels and allow debris to be deposited upstream of the ELJ; and
3) A diversion berm, sediment-filled geotextile tube, was built to direct flow through the ELJs and cross valley structure.

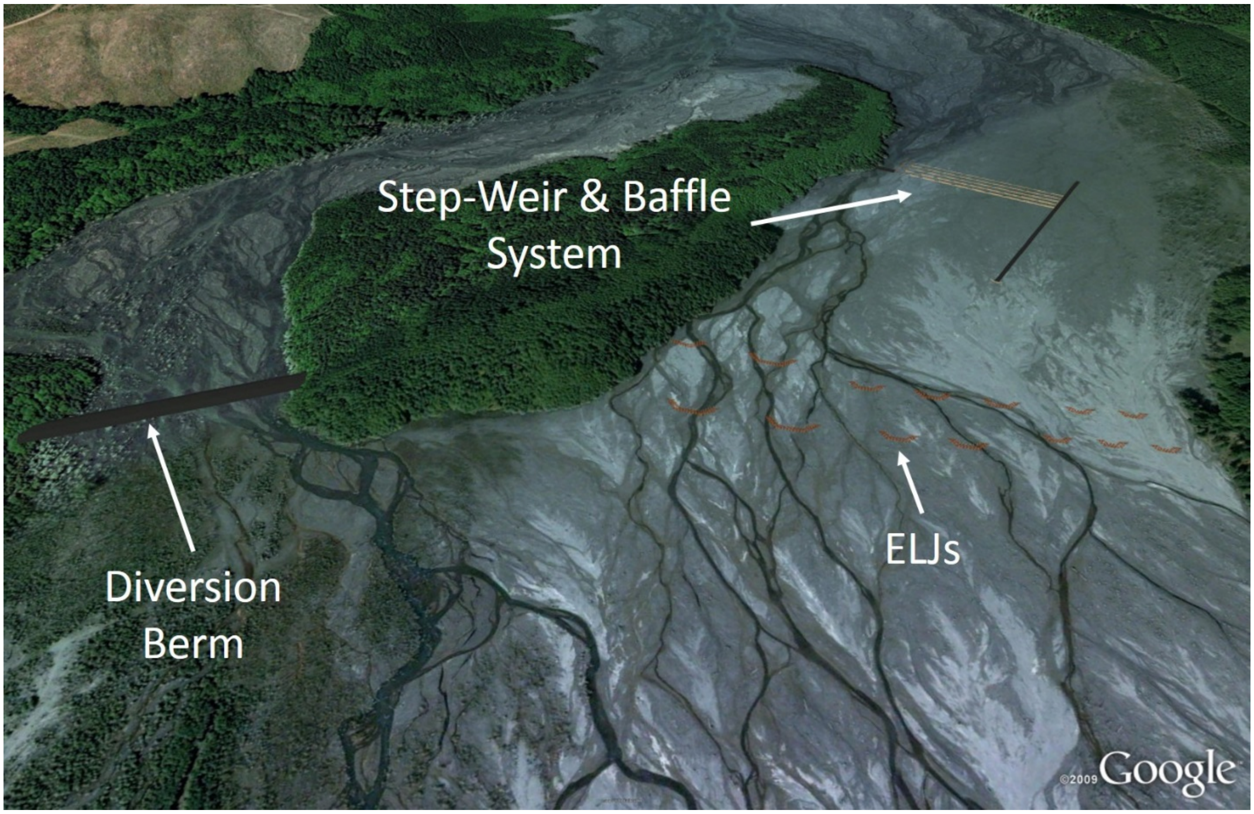

Figure 5: Sediment Retention and Grade Building structures (U.S. Army Corps of Engineers, 2016)

Debris Conveyance Structures

Contrary to debris catchment structures, structures intended to orient the debris to move downstream have been reported in literature by Wallerstein et al. (1997).

Landslides in the town of Campo Vallemaggia, along the Rovana River, on the Swiss border of Italy is a historical management issue which threatened a nearby village. To protect the village, a diversion tunnel was built around the village. High debris loads coming from the forested catchment area threatened to accumulate at the tunnel entrance. Physical modeling was performed in 1987-88 to determine the hydraulic impact of a steel and concrete pile installed upstream of a tunnel entrance. The pile was intended to rotate debris to be parallel to the direction of flow, forcing the debris to flow downstream through the tunnel, Figure 6. Model results showed that more debris rotated parallel to the flow when the pile was present and small debris did not accumulate in the tunnel.

Figure 6: Pile upstream of tunnel entrance, intended to rotate debris to pass through the tunnel (Photo credit: Eberhardt et al., 2007).

A diversion tunnel was proposed to divert flow from the Clover Fork River around the central business district in Harlan, KY for flood protection. The catchment is known for having a large debris supply in the form of dead brush, trailer homes, trash, and stockpiles of logs (Martin, 1989). A study was proposed to evaluate the design of the entrance for passing debris while maintaining a design freeboard. Seven entrance configurations were tested. The conclusions of interest to this paper were: 1) transition from natural channel to diversion canal should be curved to prevent flow separation, 2) blockage could be prevented with the appropriate approach configuration and radius, and 3) flat surfaces and abrupt transitions develop eddies which can gather debris.

Debris Flushing

The most common form of debris management is manual removal or sluicing/flushing. Removal of debris by barge has been reported in many cases; however, this approach is expensive and not sustainable. If the proper infrastructure is in place, debris flushing can be a less expensive and laborious approach.

An example application is Bluestone Dam. Bluestone Dam completely spans the width of New River Valley, Figure 7. The basin is mountainous, with wooded terrain that receives intense rainfall-runoff events. During these events, 15,000 tons of debris may accumulate in the reservoir. The primary means of passing debris through the dam is through a coordinated flushing operation. When the flood crest approaches the dam, an intake tower is opened, allowing all discharge to be released through a single intake. Sediment and debris is intended to be flushed downstream. However, records show that debris can compact against the dam face. The United States Army Corps of Engineers (USACE) – Huntington District designed a debris bypass modification for Bluestone Dam. A new sluice and penstock is planned to be constructed in the center of the dam.

Figure 7: Aerial of Bluestone Dam looking upstream (Photo Source: U.S. Army Corps of Engineers - Huntington District, 2010)

Potential Solutions

The above management options have been proven successful for floating debris; however, some of them could also be applied to submerged debris. As the next step, Reclamation could identify dams that may have debris management issues or concerns. Submerged debris management options include: prevention, debris passing, and finally debris grinding.

Prevention and Removal

As a first line of defense, accumulation of debris at outlet works or headworks should be prevented until long-term management practices are implemented. Debris management practices will vary between reservoirs due to differences in dam operations, location, size, use, and the quantity of incoming debris and sediment. An emphasis should be placed on exploring debris management techniques that do not require dam modifications or alterations.

In reservoirs where upstream debris management is possible, pile posts or log booms are recommended. Debris could accumulate in specified areas and be mechanically removed in large quantities. Typically, log booms are placed immediately upstream of the outlet structure. Placing the log booms further upstream within the reservoir or at the river outlet would prevent debris from accumulating immediately upstream of the outlet works, easing the removal process. Similarly, pile post configuration placed far upstream of the outlet would trap floating and submerged debris without jeopardizing the outlet structure. Post configurations would be specific to each application, and laboratory testing would conclude the best pile arrangement. Other options may include creating artificial eddies where woody debris would collect to later be mechanically removed.

If debris continues to accumulate upstream of the outlet works despite prevention measures, an additional low level outlet could ease cleaning efforts. Water needs downstream must still be met during debris cleaning operations. The additional pressure of flowing water on the debris makes cleaning operations more difficult. With two low level outlets, the outlet being cleaned could be closed while the other outlet allows flow to pass, meeting water demands downstream.

Debris Passing

In cases where upstream management practices are insufficient, debris could be passed through or around the dam. These options depend on the type of debris and valve and trashrack configurations at the outlet. If debris is to be passed through the low level outlets, the valve or gate must be able to fully open. Therefore, pressure-reducing valves are not recommend; slide or radial gates would be more effective. Post or piles could be placed upstream of the outlet to properly orient debris to pass through the outlet, as was done along the Campo Vallemaggia.

Lake Lynn Dam is an excellent debris passing example where trash gates were replaced with crest gates to allow water to flow over it. A debris boom was installed across the spillway section (Schadinger et al., 2013). Log booms and dam operation changes could help manage debris flows in some reservoirs. Switching outlet gates to provide more capacity or better efficiency for debris flushing is something to consider in reservoirs that flush periodically.

To avoid retrofitting outlet structures, debris could also be passed around the dam through a tunnel or bypass system. Similar systems have been very effective for flood and/or sedimentation mitigation. The tunnel entrance must be properly designed and sized with the appropriate gate/trashrack system. Lessons learned from the Clover Fork River and Bluestone Dam projects could improve the design to prevent flow separation and eddies which may collect debris. Upstream infrastructure can be installed to ensure proper debris orientation to enter the bypass system.

Debris Grinding

If debris passing and prevention are lacking compared to the debris load and log size, a large-scale grinder could be installed at a low level outlet to pulverize the debris into passable pieces. Depending on the debris load, the grinder could be programmed to operate on a regular or as-needed basis. There are several companies that manufacture large-scale grinders for sewage, pump stations, or wood recycling.

The Channel Monster, developed by JWC Environmental, and TASKMASTER Titan Grinder, Franklin Miller, are two examples of grinders on the market that pulverize waste, rocks, wood, and trash into smaller pieces that pass easily through pumps and pipes. Both machines were developed for wastewater solids reduction at pump stations. Therefore, the incoming debris must be digested into relatively small pieces. The Channel Monster, Figure 8, has a grinder with a capacity of approximately 91 cubic feet per second (cfs) and dimensions of 8.2ft by 4.5ft (JWC Environmental, 2016). The TASKMASTER Titan Grinder is a slightly larger grinder in size but with a reduced capacity of 18.4 cfs. The grinder is about 11.5ft wide and 5ft wide (Franklin Miller, 2016). Both machines are able to operate under partially or fully submerged conditions.

Figure 8: JWC Environmental has a couple grinders on the market that shred waste such as the Channel Monster, left photo, and 7-SHRED Grinder, right photo (JWC Environmental, 2016).

There are several case studies for these grinder and its use in solid waste management but using a grinder to protect hydraulic equipment at dams could be a possibility (JWC Environmental, 2016). The potential for using grinders at headworks or pump stations to assist in managing large debris should be further investigated. Neither grinder is designed for application at a reservoir outlet; therefore, a new grinder would need to be designed for debris management applications. The grinder would need to be close to the size of the outlet, capable of passing high water flowrates, and be functional when submerged under tens of feet of water. The size of the particles passing could be significantly larger, on the order of feet rather than inches. In addition, the impacts to passing sediment (e.g. sand particles) and possible abrasion through large-scale grinders needs to be assessed in a reservoir setting. Furthermore, accessibility for maintenance must be considered. The efficacy of grinders for debris management at reservoirs should be tested in a laboratory setting. Environmental impacts should be considered as well as effects on aquatic life.

It is likely that a combination of prevention, passing, and grinding would be the most adequate means of debris management. Log booms and piles could be added upstream of the dam as a first line of defense. Should debris still pass to the outlet structure, piles and debris passing infrastructure could direct debris downstream. Should the debris passing infrastructure become clogged, grinders could break the debris into smaller, more manageable pieces and potentially prevent excess debris from building up around outlet structures.

Conclusions

The purpose of this report was to determine if there are new technologies developed to manage woody debris at grated outlet works intakes. Developing a knowledge base is key to reducing the need to re-design outlet works to pass both sediment and debris. Several debris management options exist within literature; however, these options focus on floating debris and are not necessarily applicable to submerged debris. Current debris management options include: trashracks, upstream debris catchment structures, debris conveyance structures, and debris sluicing/flushing, and dredging. Prevention and debris conveyance options are ideal as it would prevent dam owners from the burden of retrofitting outlet infrastructure and is more sustainable than a relatively costlier dredging alternative. If debris conveyance is impossible, grinders could be installed at outlet structures which are abrasion-resistant. As very little information has been discovered, the future work should include a case study and the development of new techniques to manage submerged debris.

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