PERFORMANCE OF LOG CRIBS FOR BLUFF STABILIZATION

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INTRODUCTION

Erosion of valley walls and terraces associated with channel migration often produce high, steep erosional features, known as bluffs, along channels. In some rivers and streams, bluff erosion can add a disproportionate volume of sediment to the overall load, creating a host of ecological and sediment conveyance problems (Fitzpatrick et al., 1999; Belmont et al., 2011). A range of stabilization techniques are applied to bluffs with various levels of success. An approach that targets the toe of the bluff using natural log materials, often available on site, appears to be a low cost and effective approach to stabilization.

The technique involves constructing a log crib that mimics natural wood accumulation and provides the foundation for a floodplain bench at the toe of the bluff. The wood forms a rigid, structural treatment while also providing organic material and complexity similar to habitat features in natural streams. The creation of a floodplain bench above the wood impedes rotational failure of the upper bluff and allows recruitment of vegetation that will provide long-term stabilization. The bench also catches material that erodes from the untreated upper bluff. The approach is being applied to streams in the Midwest as (1) the benefits of woody material in streams have been shown to improve aquatic and riparian habitat (Flebbe, 1999; Zorn and Nuhfer, 2007; Kratzer and Warren, 2013), (2) it works with a natural process whereby eroding bluffs in forested watersheds contribute woody debris that impedes further erosion of the toe, and (3) the method is relatively cost effective as materials can be locally sourced and the upper bluff is not directly stabilized.

The installation and performance of the log crib and bench approach has not been well documented. While the log crib approach has been used in the past, it has been primarily used for stabilizing eroding banks rather than higher terraces or bluffs (Krymer and Robert, 2013). Furthermore, these designs have been based on a symmetrical form rather than one that mimics natural debris accumulations. We have developed an approach using log cribs with a bench that is based on more natural wood recruitment patterns to improve fish habitat while also providing bluff stabilization.

Clark Creek is a small, step-pool and plane-bed stream that meanders through glacial sands and gravels. The channel contains cold water and provides habitat for native brook trout (*Fontinalis salvelinus*). Avulsion and channel migration during floods in recent decades have resulted in stream migration toward bluffs at the edge of the valley, creating sedimentation problems and impacting aquatic and riparian habitat. To address these problems while improving aquatic habitat, we have installed log cribs and monitored their performance. Construction occurred in October, 2013, and subsequent surveys continue to provide information on the performance of the design.

REGIONAL SETTING

Clark Creek lies along the north-facing slope of the Baraboo Hills in south-central Wisconsin. The headwaters of the stream consist of hillslope debris overlying Baraboo Hills quartzite bedrock (Clayton and Attig, 1990). The middle of the watershed is located in a glacial ice-margin lake basin that filled a valley within the Baraboo Hills as the Green Bay Lobe of the Wisconsin Glaciation prevented drainage to the north. The lower watershed is located in glacial till (Clayton and Attig, 1990). Sediments throughout the middle and lower part of the watershed are primarily sand with some gravels, cobbles and localized varved clay deposits.

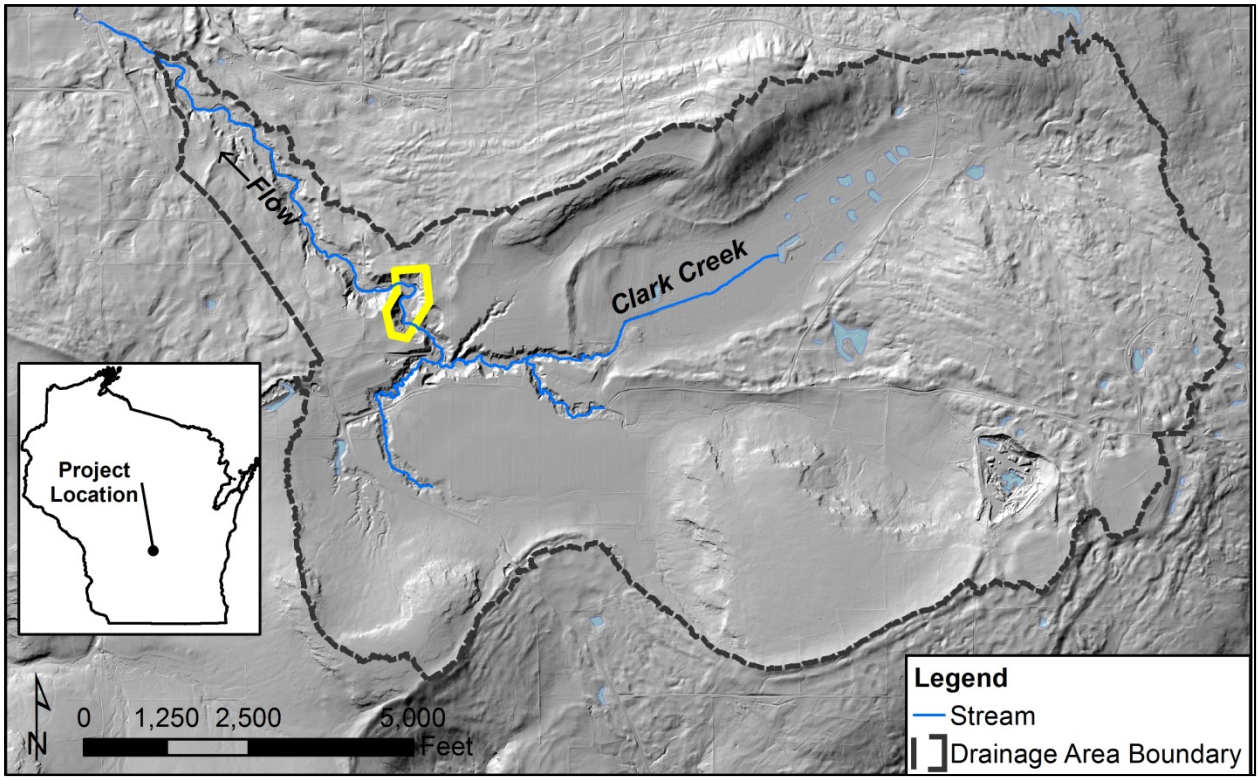

Figure 1 Clark Creek location, watershed topography and perennial flow reaches (blue lines).

GEOMORPHIC HISTORY

Clark Creek runs through a relatively confined valley in the transitional area between the glacial ice-margin lake and tills. Valley widths through the site average 150 feet. Longitudinal valley slopes are 1-2%.

Large flood events in 1993 and 2008 initiated incision and channel avulsion (Figure 3). The 1993 flood was estimated to have a recurrence interval of 500 years and the 2008 flood was estimated to have a recurrence interval of 100 years (Montgomery Associates, 2011). Based on evidence from former channel locations and an abandoned culvert, bed elevations dropped three to five feet. Incision was greatest in the eroded bluff reach due to the removal of riparian vegetation within the last century. In less disturbed reaches, riparian vegetation and other roughness features provided natural resiliency that impeded further incision.

In 2013, channel slopes varied depending on location relative to the bluffs. Adjacent to the eroding bluffs, the channel had a step-pool morphology with slopes up to 7%. Between the bluffs, the channel had a plane-bed morphology with gradients around 1-2%. The steeper slopes developed as cobbles and boulders in the glacial till comprising the bluffs deposited at the toe. This larger material, lag, was immobile and allowed the grade to steepen as fine sediment transported downstream. Despite the coarse material contributed to the channel by the bluffs, the majority of the material in the bluffs consists of sand (see Figure 2).

Reaches downstream of the eroding bluff reach did not experience the same depth of incision. The bankfull channel appeared to be adjusted to recent discharge and sediment supply regimes. Relatively low benches had formed adjacent to the channel which supported vegetation at least three years old and some minor sand deposition. The average width of the channel in this reach was around 16 ft with a depth of 1.5 ft.

Figure 2 Photo of Bluff 1 in April, 2013 (looking upstream). Note the coarse lag material deposited in the channel and bluff toe that has formed steps. Exposed sediments along the inside of the bend are from the 2008 flood.

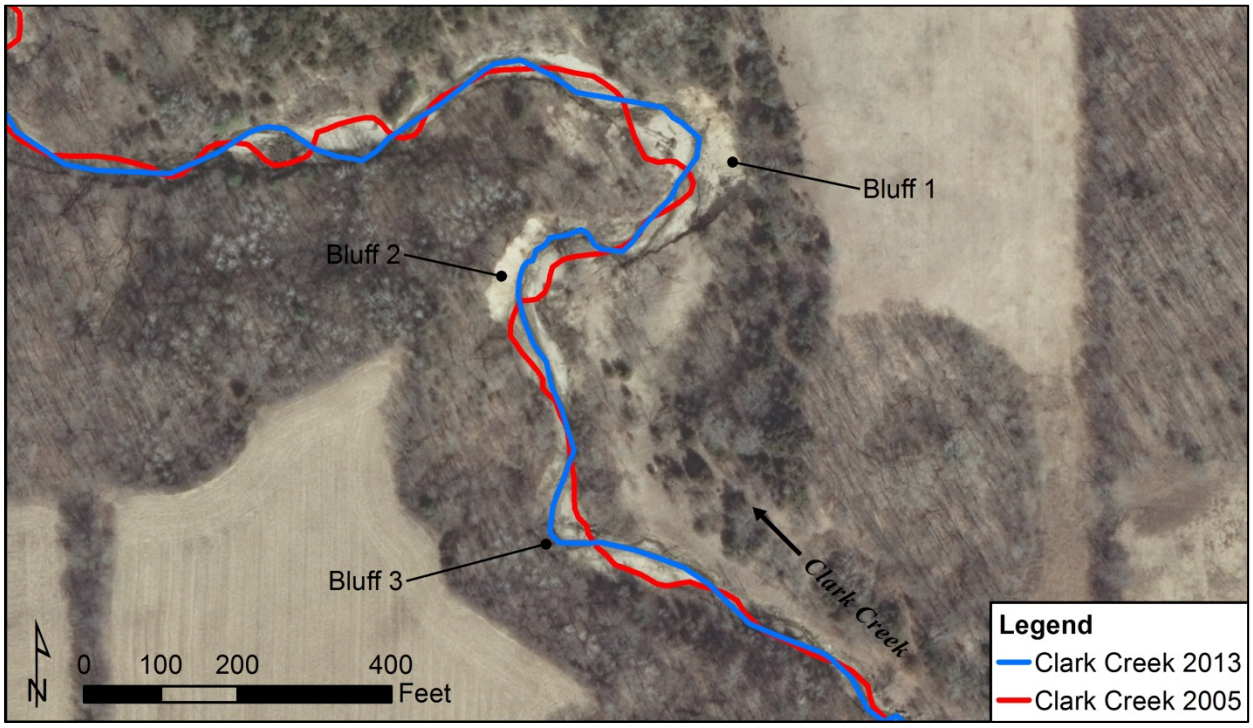

Figure 3 Channel alignments in 2013 and in 2005 before the 2008 flood event that created multiple avulsions.

PROJECT DESIGN

Stabilization of the bluffs involved three major design components: (1) re-aligning the channel away from the bluff toe, (2) building a log crib as the foundation for a floodplain bench at the toe of the bluffs, and (3) re-building the channel with native stone.

Channel Design

The channel was re-located away from each bluff toe to accommodate the log crib and bench (Figure 4). The width of the bankfull channel was based on the 16 ft average width observed along the downstream reference reach. The design called for a bank height along the log crib side of the channel of 3 ft; however, this value varied at Bluffs 2 and 3 where heights around 5 and 4 ft were constructed, respectively. The higher banks were due to the larger diameters of logs available to construct the cribs. Opposite the bluffs, channel bank heights were 1.5 ft, similar to the downstream reference reach.

Log Crib Design

Log cribs were constructed to impede erosion of the banks near the bluffs and provide a framework to contain soil for the constructed bench at the bluff toe. The benches were designed to (1) catch eroded material from the upper bluff, (2) create an area for vegetation establishment, and (3) resist rotational failure of the bluff. Constructed bench widths were approximately 23 ft at Bluff 1, 18 ft at Bluff 2, and 14 ft at Bluff 3. Each log crib was built at least 3 ft deeper than the channel bed elevation to account for local scour and additional minor incision that could occur in the future (Figure 4).

The cribs were comprised of four to five layers of logs. The angle of the logs in each layer was varied to provide habitat complexity and to better replicate the configuration of a natural log jam. Slash was incorporated into the jams to provide smaller interstitial spaces and additional organic substrate for macroinvertebrates and small fishes. Logs were sourced from nearby uplands and varied in diameter from 1 to 3 ft with lengths between 20 and 35 ft.

Channel Substrate Design

Stone from the original channel, supplemented with rock from nearby farm fields, was utilized for construction of the new channel. The median grain size of the existing channel bed material was 0.16 ft in plane-bed reaches and most stones in the step-pool reaches had diameters between 1 and 2 ft. The incipient grain size for the designed channel was 0.8 ft during the 100-year flood (Bathurst, 1987), thus imported stone had diameters between 1 and 2.5 ft to ensure stability. Natural steps in step-pool channels were replicated with the imported rocks. The stones were also extended laterally into the floodplain opposite each log crib to provide resistant material should the channel migrate. The constructed channel slope was 4.1% at Bluff 1, 3.0% at Bluff 2, and 2.5% at Bluff 3. Distances between the steps averaged 15 ft at Bluff 1, 19 ft at Bluff 2, and 22 ft at Bluff 3. These distances were consistent with the existing channel and other comparable streams (Chin et al., 2009).

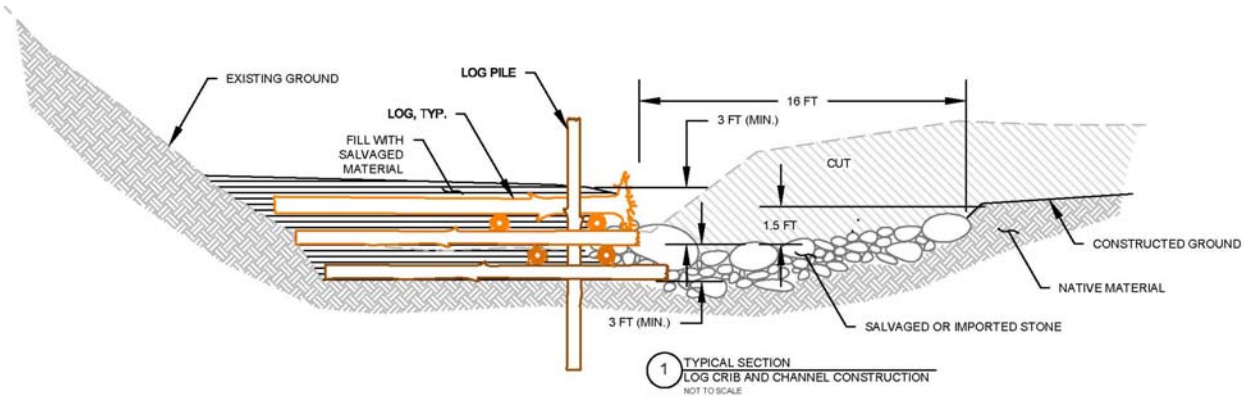

Figure 4 Typical cross section detailing the dimensions and materials used for construction of the log cribs, benches and channel.

Figure 5 Upstream view of Bluff 1 in November, 2013, immediately after construction. Logs with root wads form one side of the channel and steps and pools were constructed in the channel.

MONITORING METHODS

The topography of the bluffs and channel were surveyed at each of the three sites with a survey grade real time kinematic global positioning system. An as-built survey was completed in November, 2013, immediately after

construction. In June, 2014, a post-construction survey was completed to document changes following a six month period that included a flood with a 2.5-year recurrence interval. A final survey was completed in November, 2014, one year after construction. The final survey did not include complete coverage of Bluff 1 as snowfall inhibited characterization of the site.

Each survey included sufficient detail to construct a three dimensional surface model of the sites. The surveys included all breaks in grade along the channel, banks, adjacent floodplain, and the crib bench. With these data, triangulated irregular network (TIN) surface models were built in AutoCAD® Civil 3D®. Geomorphic changes between each survey were analyzed by creating volumetric TIN models that subtracted one survey from the previous. Geomorphic units were delineated in the models to quantify erosion and deposition patterns.

RESULTS

Bluff 1 experienced the greatest geomorphic change between November, 2013 and June, 2014 with about 60 cubic yards of material eroded from the left floodplain (Figure 6). The sandy sediments from the un-vegetated floodplain transported downstream during the 2.5-year flood and a new side channel formed. The eroded and designed channels conveyed water during base flow conditions in June. The extension of the rock steps into the left floodplain limited further downcutting into the floodplain. Within the main channel, 13 cubic yards of material deposited in pools while 18 cubic yards of material was eroded as the left bank adjusted. The bench above the crib experienced 36 cubic yards of deposition and 31 cubic yards of erosion. The erosion was likely a result of fill material settling after construction and the freeze-thaw cycle during the winter. Deposited material originated from erosion of the upper bluff.

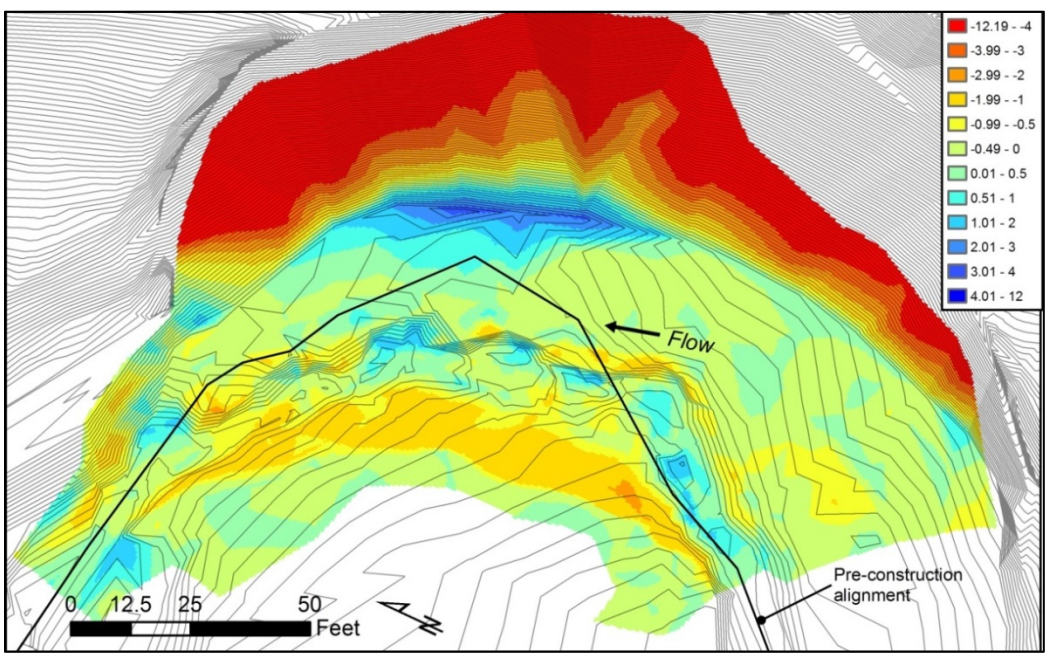

Figure 6 Erosion (red) and deposition (blue) at Bluff 1 between November, 2013, and June, 2014 (in feet). The 0.5 ft contours (gray lines) represent the November, 2013 topography integrated with LiDAR data. Note the erosion of the deposition of eroded upper bluff material on the bench. Deposition is also evident in the channel pools. Along the inside of the bend, up to 3 ft of erosion occurred.

At Bluff 2, 25 cubic yards of sediment filled the pools in the channel between November, 2013 and June, 2014 (Figure 7), and 22 cubic yards of material eroded from the channel as the right bank adjusted. Along the log crib toe,

11 cubic yards of deposition occurred. The constructed bench experienced 19 cubic yards of erosion and 12 cubic yards of deposition. The right floodplain had 58 cubic yards of erosion and 3 cubic yards of deposition.

A total of 35 cubic yards eroded from the site and 86 cubic yards deposited between June, 2014 and November, 2014. The bench at the bluff toe experienced 39 cubic yards of deposition, the channel experienced 11 cubic yards, and the right floodplain experienced 26 cubic yards.

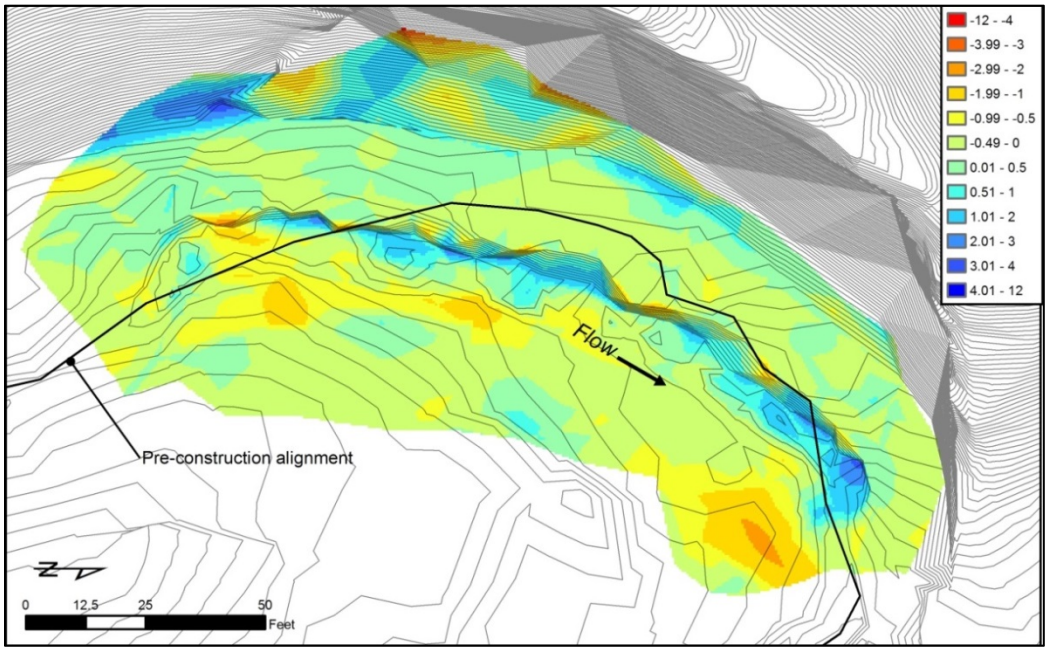

Figure 7 Erosion (red) and deposition (blue) at Bluff 2 between November, 2013 and June, 2014 (in feet). The 0.5 ft contours (gray lines) represent the November, 2013 topography integrated with LiDAR data. Sediment deposited in the channel pools and at the toe of the log crib. Erosion occurred along the inside bend floodplain.

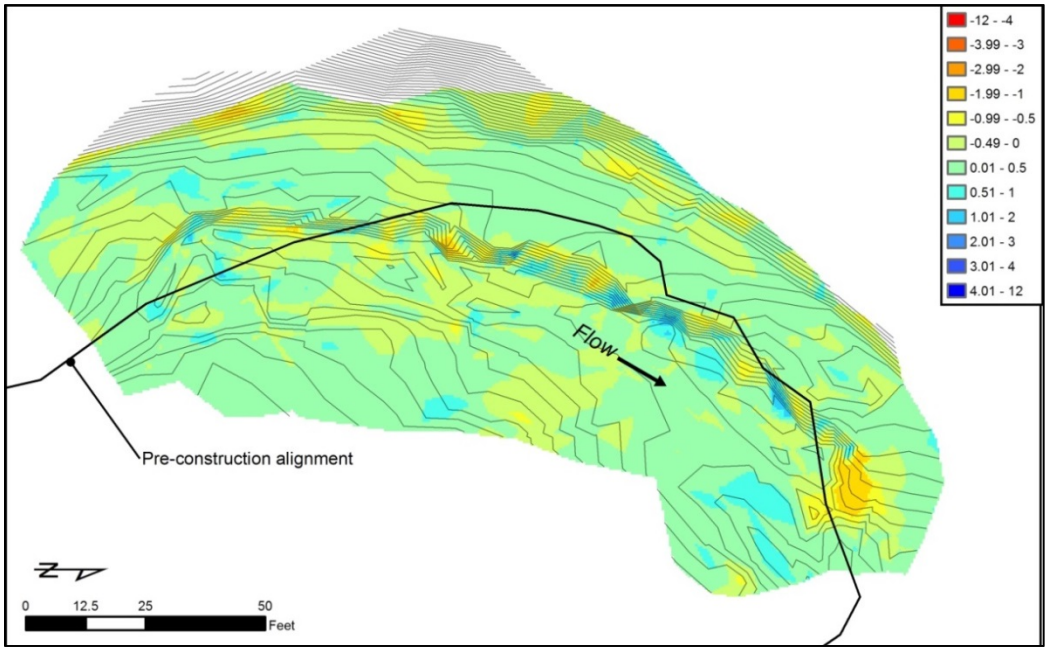

Figure 8 Erosion (red) and deposition (blue) at Bluff 2 between June, 2014 and November, 2014. The 0.5 ft contours (gray lines) represent the June, 2014 topography. Relatively little erosion and deposition took place during this time period compared to the previous 6 months.

At Bluff 3, pools in the channel and the log crib toe experienced 25 cubic yards of deposition between November, 2013 and June, 2014. Some erosion occurred just upstream of the log crib along the channel banks. The right floodplain generally degraded during this time period except for the furthest upstream area. Three logs were placed on the floodplain at this location to provide roughness and to impede avulsion.

Between June, 2014, and November, 2014, the channel accumulated 15 cubic yards of sediment and the right floodplain accumulated 30 cubic yards of sediment.

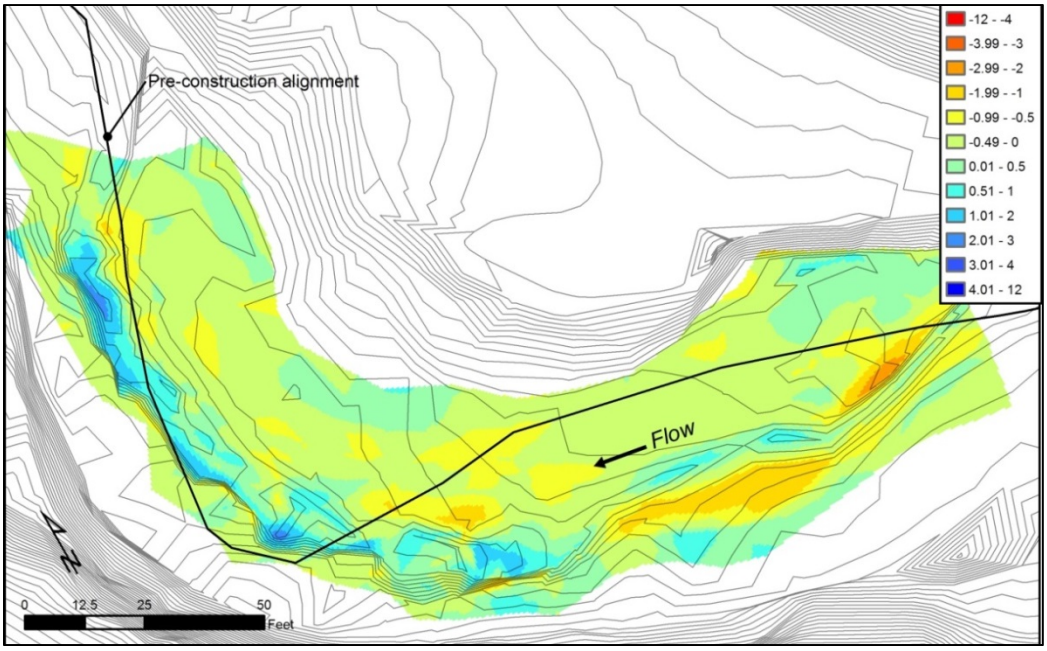

Figure 9 Erosion (red) and deposition (blue) at Bluff 3 between November, 2013 and June, 2014. The 0.5 ft contours (gray lines) represent the November, 2013 topography integrated with LiDAR data. Sediment deposited in the channel pools and at the toe of the log crib.

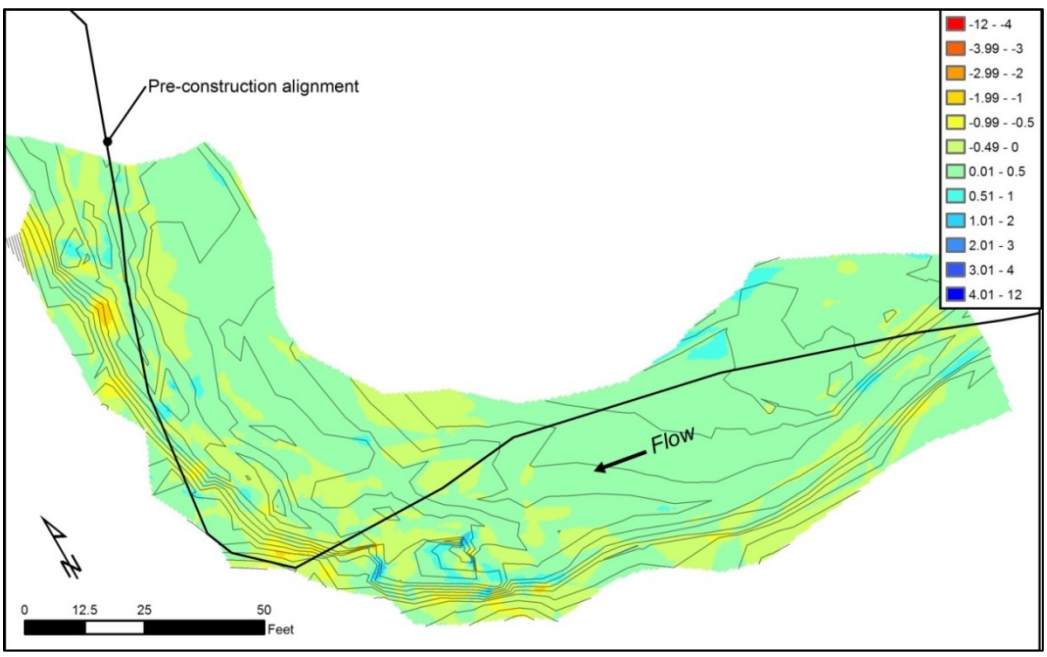

Figure 10 Erosion (red) and deposition (blue) at Bluff 3 between June, 2014 and November, 2014. The 0.5 ft contours (gray lines) represent the June, 2014 topography.

DISCUSSION

The log cribs and benches performed as designed during the first year after construction. Material eroded from the upper bluffs was deposited on the benches (Figure 12). Most of the geomorphic change occurred between November, 2013 and June, 2014 indicating that more material eroded from the upper bluff during spring thaw rather

than precipitation-induced erosion in the summer. Similarly, we noted active erosion at all of the bluff sites the previous year in April, 2013.

Soil contained in the log crib remained in place and provided resistance against channel migration. In addition, the roughness provided by the logs and root wads promoted some deposition around the toe of the structure.

The quantities and locations of erosion and deposition varied between the bluff sites. The bench at Bluff 1 experienced the greatest accumulation of sediment. This was probably due to the larger exposed area and the greater bluff height compared to Bluffs 2 and 3.

Vegetation on the benches grew closer to the channel bank where deposition did not occur (Figure 12). Additional monitoring will continue to provide information on the sustainability of vegetation in this depositional area.

Figure 11 Photo of the Bluff 1 immediately after construction in October, 2013 (looking downstream).

Figure 12 Photo of Bluff 1 in June, 2014 from the same location as Figure 11. Note the deposition on top of the bench and the secondary channel along the inside of the bend.

Channel change was relatively rapid within the first six months of construction. Sand filled in pools and deposited at the toe of the logs. Pool deposition was expected as they were over-excavated to ensure larger, immobile bed material would not limit depths. Nevertheless, the filling of the pools probably reduced the habitat available for macroinvertebrates by creating unstable substrates and for fish by concealing boulders that provided cover. Deposition around the log banks also filled in areas of habitat complexity. The sediment accumulations did not appear to be systemic as the reaches up- and downstream did not have noticeable changes. Instead, the channel form adjusted to match local hydraulics.

The lack of vegetation cover on the floodplain opposite the log cribs contributed to instability. Late autumn construction did not provide sufficient time for vegetation growth. Funds for construction and worker availability were limited to this time frame, however. The deposition surrounding the logs on the floodplain at the upstream end of Bluff 3 provides a useful reference for stabilization in these situations. Additional placement of logs throughout the floodplain would impede erosion until vegetation establishes to provide erosion resistance during floods.

CONCLUSIONS

The log cribs and benches have performed as designed after one year of construction. The benches provide a trap for sediment falling from the upper bluff while also providing an area for vegetation to establish and provide long-term lateral stability for the channel. The log cribs have impeded channel migration into the bluffs during a flood with a 2.5-year recurrence interval. The project, however, has not been tested by a significant flood event and performance measures are ongoing.

Channel adjustments have suggested improvements to the design. Placement of logs throughout the floodplain would impede erosion and maintain primary flow in the constructed channel. It is also possible that occluding some flow on the floodplain with the logs would force larger pools in the channel to minimize localized aggradation. Creating a relatively stable channel is important for bluff stability in Clark Creek. Avulsion instigated bluff erosion during the floods of 1993 and 2008. An unstable floodplain in the years immediately following construction could

lead to the initiation of bluff erosion in other areas should a large flood occur. In addition, part of the reason for utilizing a log crib was to improve aquatic habitat. Creating a channel that maximizes the habitat potential should therefore be considered an important part of the design.

Acknowledgements

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