BATTLE CREEK: LESSONS LEARNED FROM TINKERING AT A CONFLUENCE

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Abstract

In the Autumn of 2008 a stream restoration project was constructed in Battle Creek just above the confluence with the Little Snake River, on the border between Colorado and Wyoming. Relevant structures were cross vanes and stream barbs, with the objectives apparently being bank stabilization and habitat enhancement for game fish. After construction, floods occurred in 2009, 2010, and 2011, including a 100-year flood in the Little Snake. With this flooding, a substantial volume of sediment was deposited in the vicinity of the Battle Creek cross vanes, forcing a channel avulsion and rapid bank erosion along multiple reaches. A review was performed to determine the likely causes of this problem. Based on a site assessment, an evaluation of historic aerial imagery, and a hydraulic model, it was concluded that the installed structures did not cause the sediment deposition and resulting bank erosion. Decreased sediment transport capacity due to backwater effects imposed by the Little Snake flooding was most likely the cause of the deposition, with the problem compounded by riparian grazing reducing the quality of the vegetative condition. Structural measures should not have been installed on Battle Creek in the vicinity of the confluence due to periodic aggradation induced by Little Snake River flooding. While these structures likely did not worsen the aggradation problem, they also provided little benefit since bank destabilization is primarily the result of backwater-induced sediment deposition and insufficient vegetative cover. Instead, riparian fencing and grazing management should have been the focus, to encourage robust riparian vegetation growth that can resist destabilization induced by the periodic sediment deposition. This project illustrates an example where livestock management should have been the core approach used in riparian restoration, rather than an engineered approach; more detailed analysis and planning by a stream-focused group of specialists was needed early in this project.

INTRODUCTION

Of particular need in the stream restoration community is enhanced understanding of where structural bank stabilization measures are needed versus where livestock grazing management alone is instead adequate to address instability issues. To help inform a discussion of this issue, this case study of a bank stabilization project constructed in 2008 on Battle Creek, in Northwest Colorado, was developed. This reach of Battle Creek is immediately upstream of its confluence with the Little Snake River. Key project features were two cross vanes constructed in Battle Creek; one stream barb constructed in Battle Creek; and one additional cross vane constructed on the Little Snake downstream of the confluence. Riparian grazing management was not included as a part of this project. Following construction, floods occurred in 2009, 2010 and 2011, including a 100-year flood in the Little Snake. With this flooding, a substantial amount of sediment was deposited on and just upstream of the upper cross vane installed on Battle Creek, which forced a stream channel avulsion and rapid bank erosion. An additional bar was deposited downstream of this location, on the west bank between the two cross canes, with a second rapidly-eroding bank on the opposite bank. An investigation was performed to develop an understanding of how this problem could have been avoided. This paper provides an overview of the condition of this stream reach, as well as a historical and analytical assessment of dominant fluvial geomorphological processes that led to the resulting undesired state. From this postmortem assessment, conclusions are drawn to reduce the chances that such a result will be repeated in similar future situations.

ASSESSMENT METHODS

The stream condition was assessed and a forensic analysis was performed using a combination of methods, including a visual assessment of current geomorphic and hydraulic condition, identification and elevation measurements of high flow indicators, a flow frequency analysis, historic aerial photo interpretation, a greenline vegetation assessment, topographic surveying, and hydraulic modeling.

The flow frequency analysis for the Little Snake was performed using a logPearson analysis of streamgage records. For Battle Creek, a regional regression approach was implemented (Capesius and Stephens, 2009), through the Streamstats web application. Historic aerial photos were downloaded from the U.S. Geological Survey's Earth Explorer (http://earthexplorer.usgs.gov) and orthorectified in ArcGIS. The Greenline vegetation assessment was performed using the methods presented in Burton et al. (2011). Topographic surveying was performed using Trimble survey-grade GPS, with an Online Positioning User Service (OPUS) solution used to establish the benchmark.

The hydraulic analysis was performed using 1-dimensional gradually-varied flow modeling, using HEC-RAS. To assess the impacts of backwater effects on sediment transport, stream power and shear stress were computed within the reach of interest in Battle Creek. The sediment transport rate is directly proportional to stream power and shear stress, with reductions in these variables reflecting decreased sediment transport capacity and the potential for sediment deposition. This deposition causes channel aggradation and bank instability. Stream power is computed as $\Omega = \gamma Q S_f$, where Q is the discharge, γ is the specific weight of water, and S_f is the friction slope. Average boundary shear stress is computed as $\tau = \gamma R S_f$, where τ is the shear stress and R is the hydraulic radius. Backwater effects cause a reduction in energy slope, which reduces stream power and shear stress. This in turn reduces the sediment transport rate, causing deposition and aggradation. Channel flow resistance, as Manning's *n*, was estimated using photographic guidance (Barnes, 1967; Aldridge and Garrett, 1973) as well as through the use of a quantitative approach (Jarrett, 1984).

STREAM CONDITION

On-the-ground conditions were documented in April and June of 2012. With a drainage area of 302 mi^2 at the Battle Creek confluence, the Little Snake River is a snowmelt-dominated stream that drains portions of Northern Colorado and Southern Wyoming. Average annual precipitation varies from 19 to 55 inches (from PRISM; Daly et al., 2008). Battle Creek, at its confluence with the Little Snake, has a drainage area of 83.3 mi^2 and average annual precipitation that also varies from 19 to 55 inches. Both streams carry a substantial quantity of sediment load, with frequent bars within the channels (Figure 1 and 2). Both the Little Snake and Battle Creek have a mature cottonwood gallery. Battle Creek enters the Little Snake with an atypical upstream orientation. Substantial sediment deposition is evident in Battle Creek just above the confluence (Figure 2). Combined with the impacts of grazing practices on riparian vegetation, this deposition resulted in rapid bank erosion rates that are problematic for the landowner.

In the Autumn of 2008 a project was constructed in Battle Creek and the Little Snake River, in vicinity of the confluence. The objectives of this project were unclear in the project documentation, but apparently the principle objectives were streambank protection and fish habitat enhancement. The project consisted of a series of cross vanes, J-hook vanes and other barbs, and minor channel realignments. Key features relevant to Battle Creek are: two cross vanes constructed in Battle Creek and one stream barb constructed in Battle Creek, armoring the channel with a continued upstream confluence orientation; one cross vane constructed on the Little Snake downstream of the confluence (Figure 2), and a few willow clump transplants along Battle Creek. During the next three years, out-of-bank flow occurred each year.

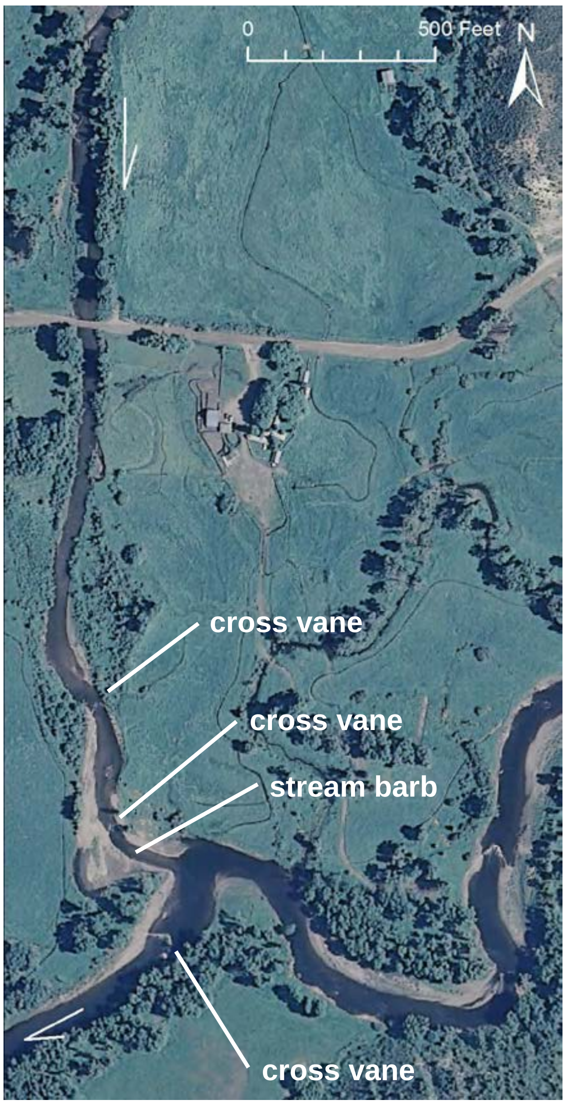

Figure 1: Battle Creek at the Little Snake River confluence (7/23/2009).

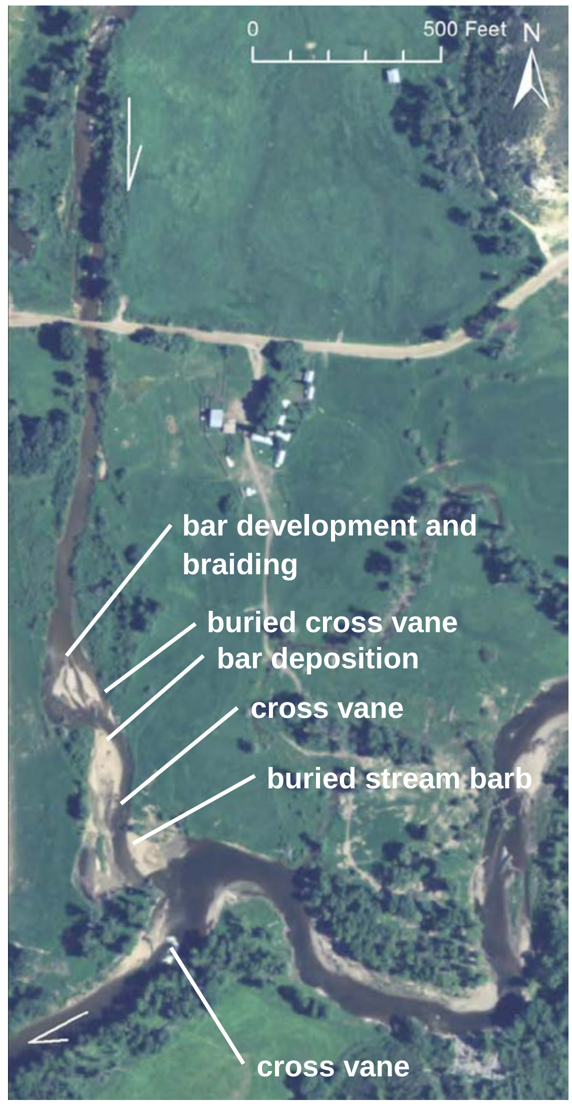

Figure 2: Battle Creek at the Little Snake River confluence (7/23/2011).

A substantial amount of sediment was deposited on and just upstream of the upper cross vane installed on Battle Creek (Figures 2 and 3). This local aggradation extends for a length of about 200 feet. This deposition forced an avulsion of the stream channel to the west of its previous location (Figure 1). The channel has a braided form within this short extent, with the preferential flow channel currently on the west edge of this depositional bar. A meander bend and point bar is forming to the east of this channel. In the vicinity of this depositional bar, both sides of the channel have willows along much of the banks, but coverage is patchy with grazing apparent on both banks, negatively impacting willow- and sedge-induced bank stability. The streambank on the west side of the depositional bar, adjacent to the principal flow channel, is actively eroding (Figure 4). A few of the patchy willows that were once present along this bank were laying in the channel. The fenceline and aerial imagery indicate rapid bank erosion rates.

An additional bar has been deposited downstream of this location, on the west bank between the two cross canes (Figures 2 and 5). Opposite this point bar, a second rapidly-eroding bank is present (Figures 5) as the stream attempts to increase its meander planform. A cross vane that appears to be functioning properly is located just downstream of this eroding bank. No willows are present on this bank. The aerial imagery (Figures 1 and 2) indicate that this bank is not eroding as quickly as the upstream bank. Heavy grazing was apparent along this bank, along with indications of additional feeding in this pasture.

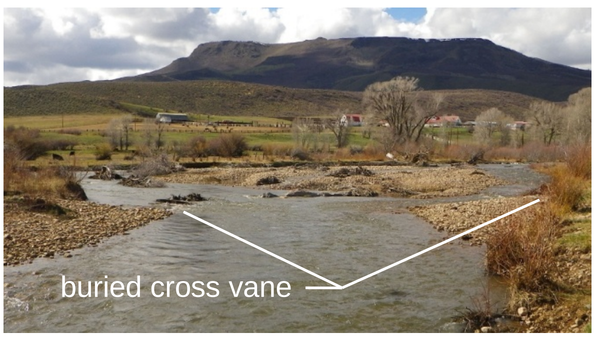

Figure 3: Upper cross vane, with sediment deposition and braiding just upstream.

Figure 4: Rapidly-eroding streambank adjacent to depositional bar.

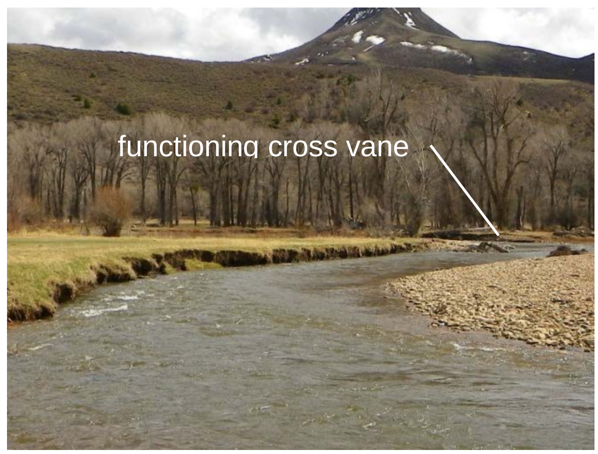

Figure 5: Rapidly-eroding streambank, opposite of an additional depositional bar.

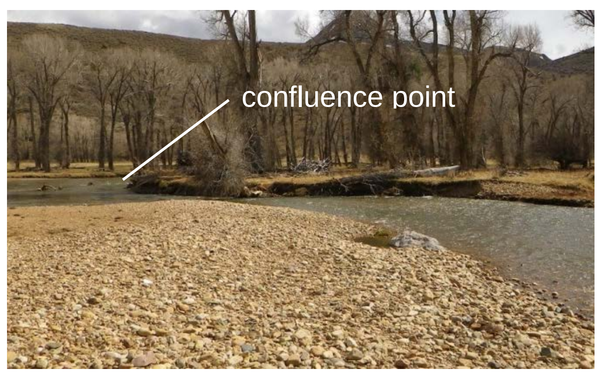

Figure 6: Confluence bar, with variable bed material size.

The third and final depositional bar is at the confluence (Figures 2 and 6), with the bar extending from north to south across the constructed channel location. This bar consists of multiple sediment sizes, with coarse material deposited on fines. A portion of a stream barb can be seen protruding from the bar (Figure 6). The growth of this bar mirrors the erosion of 20 to 30 feet of the confluence point between 2009 and 2011. Alongside this erosion the pool in the Little Snake just upstream of the confluence has been reported to have filled substantially. Additionally, flood debris is present on the fenceline on the west side of Battle Creek, showing the approximate high flow elevation for the Little Snake in 2011.

RESULTS AND DISCUSSION

Flood-Frequency Analysis

On the Little Snake, a streamgage (USGS 09253000, Little Snake near Slater, CO) is located approximately 5 miles upstream of the confluence, measuring discharge from 253 mi^2 (compared to 302 mi^2 at the confluence). With 65 years of record, the results of the log-Pearson flow-frequency analysis are provided (Table 1). A 1.5-year event, which is likely similar in magnitude to the bankfull discharge, is about 1700 cfs. Peak flow typically occurs from mid-May through early June. In 2011, peak flow of 4890 cfs occurred on June 6th. This was a ~100-year flood. In 2010, peak flow of 3230 cfs occurred on 5/29/2010, which is between a 5- and 10-year flood. In 2009, peak flow of 2710 cfs occurred on 6/3/2009, which is between a 2- and 5-year flood.

Flow frequency results for Battle Creek, from Streamstats, are provided (Table 1). With prediction errors ranging from 74 percent (100-year) to 110 percent (2-year) and application of the StreamStats equations to the Little Snake streamgage indicating accurate estimates of frequent events and substantially underestimated infrequent events, confidence in these estimates is moderate throughout the return interval range. Extrapolated from these estimates, a 1.5-year event is about 600 cfs. Rick Dornfeld, of River Fixer LLC, estimated bankfull flow to be about 500 cfs (Dornfeld, 2008). A streamgage was operated on Battle Creek (USGS 09253400, Battle Creek near Encampment, WY) approximately 15 miles upstream of the confluence. It measured discharge from only 13 mi^2 of the total 83.3 mi^2 catchment. This gage was operated from 1956 to 1963 and 1985 to 1988. While not relevant for computing flow frequency at this site, these data do indicate that peak flow timing occurs from mid May through early June, similar to the Little Snake. Local SNOTEL snowpack monitoring sites (Battle Mountain, 317; Sandstone RS, 732) indicate that Battle Creek peaked a bit later than average in 2011 and a bit earlier than average in 2010.

Table 1: Flow-frequency estimates for Battle Creek and the Little Snake River.

Return Interval (years)	Battle Creek (cfs)	Little Snake River (cfs)	Peak Flow Years in Range
1.25	----	1490	
2	660	2200	
5	1030	3090	
10	1260	3610	1943, 1952, 1957, 1958, 1997, 2008, 2010
25	1610	4210	1974, 1995, 1996
50	1850	4610	1983 (~25-year flood)
100	2140	4980	1984, 2011

Historic Aerial Photography

An important component of an assessment is an understanding of the historical range of variability; understanding the range of variability of past conditions can provide insight on what future conditions can be expected. Aerial imagery from 1953 to 2004 is illustrated (Figure 7 to 10). Throughout this 58 year record Battle Creek and the Little Snake have fairly consistent morphology but some interesting cycles and shifts in form are observable.

Over this period, the aerial images indicate cyclic sediment deposition and vegetative colonization along the last 1000 feet of Battle Creek upstream of the confluence. In 1953 (Figure 7), an upper depositional bar is apparent in Battle Creek (orange oval). This bar is in a similar location as the bar deposed in 2010 and 2011. A couple of small unvegetated bars are also visible in the lowest portion of Battle Creek (red circle). By 1968 (Figure 8) the upper depositional bar (orange oval) has become well vegetated though an avulsion across the bar is visible. Flow appears to be split at this point in time. The lower depositional bar has enlarged a bit, with a short series of exaggerated meanders at the confluence. Between 1968 and 1980 (Figure 9) the (streamwise) left channel has filled in the formerly unvegetated upper bar (orange oval) and Battle Creek flows in a single, relatively strait channel through this upper reach. This portion of the floodplain appears to be well vegetated. The increasing meandering form indicated in 1953 and 1957 straitened in 1968 and maintained this form in 1980. The lower depositional bar (red circle) has again increased in size and maintained little vegetative growth, with a growing point

Figure 7: Aerial image (8/23/1953).

Figure 8: Aerial image (9/1/1968).

Figure 9: Aerial image (7/28/1980).

Figure 10: Aerial image (8/4/2004).

bar and increasing meander extent along the well-vegetated confluence point (green oval). In 2004 (Figure 10), the upper reach in Battle Creek is again increasing its meander form while the meander at the lower reach (red circle) is becoming tortuous, as Battle Creek attempts to flank the dense stand of vegetation at the confluence point. Side bars are apparent in the upper reach. Following the flood events of 2010 and 2011, the 2011 image (Figure 2) shows Battle Creek above the confluence to be once again increasing its meander form and depositing substantial quantities of sediment in similar locations as those indicated in 1953 (upper depositional bar) and 1968 and 1980 (lower depositional bar). Some of the vegetated confluence point has eroded, despite the armoring provided by the dense vegetation. The cyclical sediment deposition, vegetative colonization, and erosion is likely due to decreased velocities, shear stress and stream power from backwater effects induced by the Little Snake, with the location varying due to relative peak flow timing, flood magnitude, and flood duration. This bar material is subsequently colonized by vegetation, with a slightly sinuous form repeatedly initiating and straightening.

Vegetation Assessment

A green line assessment (Winward, 2000) of the last ~1000 feet of Battle Creek, at the confluence with the Little Snake River, was completed on June 19, 2012. Plant communities were identified and quantified in three separate, 343 feet transects (two on the east bank, one on the west bank). Approximately 20% of the footage surveyed on the east side of Battle Creek consisted almost entirely of introduced cool season grasses, as part of a pasture. Upstream of this area, seedlings and young saplings of narrow leaf cottonwood, coyote willow, and other woody species, and herbaceous wetland plants (Carex spp. primarily), were encountered much more frequently. The west bank of Battle Creek included a large expanse of cobble and sand, and willow seedlings or sprouts, along with introduced cool season grasses. Some narrow leaf cottonwood sprouts/saplings and a few other mature woody species (shrubs) were also present in this area.

Percent composition of each community type was determined for the reach, and each community was assigned a stability class and index. A stability index of the reach was calculated. Overall, the stability of this reach is rated as moderate to poor. The plant communities were also assigned a successional rating, and a percent late seral type was calculated based on the capability group value of this stream type. Approximately 11 percent of the identified plant communities are classified as late seral, and the successional status of the reach was determined to be very early seral to early seral.

A woody species regeneration assessment was also completed by evaluating numbers of seedlings, sprouts, mature, decadent, and dead woody species in each of the two transects on the east bank of Battle Creek, just upstream of the confluence with the Little Snake. Numerous seedlings and young saplings (123 or 75% of total number of individuals) of narrow leaf cottonwood and coyote willow were found, primarily upstream of the pasture area. Several moderately to severely grazed individuals of these species were also found. A few dead individuals were noted. Approximately 41% of all individuals were browsed, which is considered moderate grazing pressure. The woody plant community of the area upstream of the pasture is healthy in that numerous seedlings and saplings were found, but grazing pressure, if continued, could slow recovery. Few woody plants were found adjacent to the pasture area.

The cottonwood gallery along the Little Snake at the confluence with Battle Creek was not quantified, but observed. It appears to consist of numerous seedlings, sprouts, and young trees, several large mature trees, and a few dead trees. This community appears healthy.

Hydraulic Modeling

For this assessment, a relatively-simple model was created for Battle Creek from the bridge to the confluence for ~bankfull flow, as well as the 10-year and 100-year flows. Eighteen cross sections were implemented. The downstream boundary condition was assumed to be the peak water surface elevation in the Little Snake, as indicated by flood debris. This elevation was 6694.5 feet. The estimated Manning's *n* values for this reach are provided (Table 2).

Table 2: Battle Creek channel Manning's *n* estimates. Implemented *n* = 0.040.

	Manning's *n*
Barnes 1967	0.045
Aldridge and Garrett 1973	0.040
Jarrett 1984	0.025
Average:	0.037

Modeled stream power and shear stress for the ~bankfull, 10-year, and 100-year flows in Battle Creek are illustrated (Figure 11 through 13). In all tested cases, stream power and shear stress decrease substantially at the point where deposition in the stream channel occurred in 2010 and 2011. Since sediment transport capacity is directly proportional to stream power, the modeling results indicate that the sediment deposition (and subsequent bank instability) is the result of backwater effects from the Little Snake reducing flow velocity and sediment transport capacity.

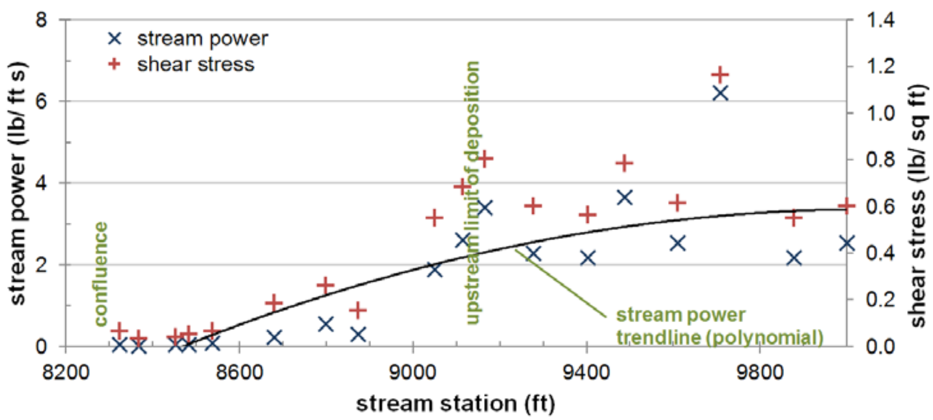

Figure 11: Modeled stream power and shear stress, ~bankfull flow in Battle Creek.

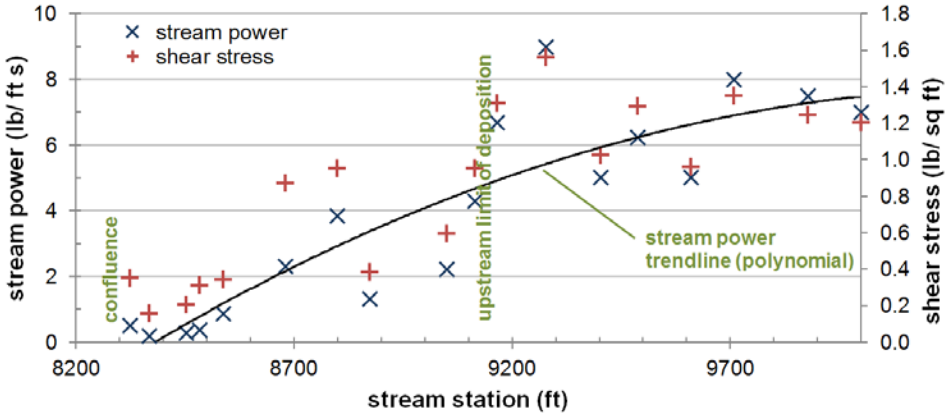

Figure 12: Modeled stream power and shear stress, 10-year flow in Battle Creek.

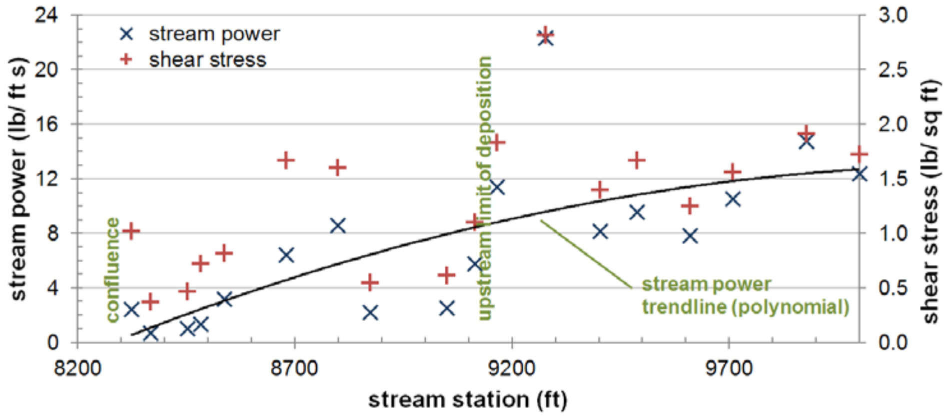

Figure 13: Modeled stream power and shear stress, 100-year flow in Battle Creek.

Interpretation of Dominant Mechanisms

Observations of current conditions, a historic aerial photography interpretation, and hydraulic modeling indicate that the Battle Creek aggradation problem and resulting bank instability that occurred since the structural stabilization measures were installed in 2008 are likely the result of backwater effects from high flow on the Little Snake River. Specifically, during high flow increased water surface elevations in the Little Snake result in increased flow depths and decreased velocities, shear stress, and stream power for the portion of Battle Creek immediately above the confluence. In turn, this results in reduced sediment conveyance capability and bedload deposition throughout the reach of concern. This deposition then encourages channel bank erosion, as new flow paths form through the deposited material. Bank erosion is facilitated by grazing practices that have discouraged robust and diverse vegetative growth along portions of the reach. The upstream-oriented confluence and Little Snake cross vane both cause increased water surface elevations at the confluence, worsening the problem.

Structural measures should not have been installed on Battle Creek in the vicinity of the confluence. While these structures likely did not worsen the aggradation problem, they also provided little benefit since bank destabilization is primarily the result of backwater-induced sediment deposition and insufficient vegetative cover. Instead, riparian fencing and grazing management should have been the focus of the Battle Creek portion of this project, to encourage robust vegetation growth that can resist destabilization induced by the periodic sedimentation. Additionally, a much more substantial revegetation component should have been included in the project.

Review of historic aerial imagery and development of hydraulic modeling prior to the project implementation would have indicated the problematic nature of stream work on Battle Creek just above the confluence. Review of the recent aerial imagery would have also shown that the channel had been recently relocated. This work should have been performed by qualified staff during the planning phase of the project. The lack of such planning resulted in the needless use of limited restoration funding, highlighting the importance of proper planning by staff with the expertise to understand fluvial processes and riparian vegetation.

CONCLUSIONS

A postmortem was performed on a failed streambank stabilization project, to assess the most likely causes. Using the results of a site assessment, a greenline vegetation assessment, an evaluation of historic aerial imagery, and hydraulic modeling, it was found that the installed project did not address the cause of the bank instabilities. These structural features on lower Battle Creek should not have been installed, due to periodic aggradation induced by backwater effects from the Little Snake during flood flow. Instead, riparian fencing and grazing management, combined with a revegetation component, should have been the focus of the project within this reach. Proper project planning by qualified staff could have identified the most appropriate strategy for addressing the landowners resource concerns prior to project implementation; this project illustrates the need for specialists to be available for the proper implementation of stream projects, to reduce the inefficient use of government funds.

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REFERENCES

Aldridge, B. N., and J. M. Garrett (1973). “Roughness Coefficients for Stream Channels in Arizona,” U.S. Geological Survey Open-File Report, Tucson, Arizona.

Barnes, H.H. (1967). “Roughness Characteristics of Natural Channels,” U. S. Geological Survey Water-Supply Paper 1849.

Burton, T.A., Smith, S.J., and Cowley, E.R. (2011). "Multiple Indicator Monitoring (MIM) of Stream Channels and Streamside Vegetation," U.S. Department of the interior, Bureau of Land Management, Technical Reference 1737-23.

Capesius, J.P., and Stephens, V.C. (2009). "Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado," U.S. Geological Survey Scientific Investigations Report 2009–5136, 46 p.

Daly, C., Halbleib, M., Smith, J.I., Gibson, W.P., Doggett, M.K., Taylor, G.H., Curtis, J., and Pasteris, P.A. (2008). "Physiographically-sensitive mapping of temperature and precipitation across the conterminous United States," International Journal of Climatology, 28: 2031-2064.

Dornfeld, R. (2008). "Battle Creek Restoration at the Fran Marsh Diversion," River Fixer LLC, Lakewood, CO.

Jarrett, R.D. (1984). "Hydraulics of High-Gradient Streams," Journal of Hydraulic Engineering 110 (11), 1519–1539.

Winward, A.H. (2000). "Monitoring the Vegetation Resources in Riparian Areas," U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, RMRS-GTR-47.