Final Report

Channel Restoration Planning for Lulu Creek and Colorado River in Rocky Mountain National Park

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Introduction

Additional field work was completed during summer 2010 to support channel restoration planning along Lulu Creek and the Colorado River in Rocky Mountain National Park (RMNP). The objectives of the field work include: 1) to further quantify water and sediment discharge following the 2003 Grand Ditch breach, 2) to continue monitoring changes in bed sediment grain size, 3) to quantify grain size distributions of bedload transport, 4) to complete resurveys to measure channel change since the last survey in 2007, and 5) to establish two sentinel sites in cooperation with the Rocky Mountain Network Inventory and Monitoring (I&M) Program. All activities were completed to provide critical data in support of restoration planning and design. A compilation of five years of data on channel processes helps to specify the fluvial system constraints on channel recovery and define the geomorphic context of the 2003 event relative to the historical range of variability of depositional processes (Rathburn et al, 2008; Rathburn and Rubin, 2009; Rubin et al., 2009). This report describes the 2010 field work, results of the field work, interpretations, discussions, and recommendations related to continued channel restoration planning for Lulu Creek and the Colorado River.

Field Work

Field work began on April 17, 2010 with the installation of six, automated pressure transducers at the Little Yellowstone, Lower Lulu Creek, Crooked Tree, and Gravel Beach, Shipler Park, and Lost Creek sites (Figure 1). At this time, a barometer (Barologger) was also installed near the Little Yellowstone cross section to provide barometric corrections for the pressure transducer data. The pressure transducers continuously measured water depth (stage) from April 17 until they were removed on September 25, 2010. On August 12, 2010, the Upper Lulu Creek gauge was decommissioned and a sentinel site cross section was established on the Colorado River downstream from the Lulu City wetland (Lower Sentinel, LS in Figure 1; Figure 2). A second sentinel site coincides with the existing Little Yellowstone cross section. Water quality probes were installed downstream from both of the gauges at the two sentinel sites in support of the larger I&M effort in RMNP.

Seven single- or multi-day field outings were completed during summer and fall 2010, during which time the flow was gauged, and suspended and bedload samples were measured. At other times during the summer and fall, pebble counts were completed at all sites, and the resurveying was completed.

Flow Gauging

Flow gauging involves measuring flow velocity along the sampling cross sections using a one-dimensional Marsh-McBirney flow meter at intervals of the cross section. Instantaneous discharge is calculated from the velocity measurements. During field work where the flow is gauged, stage on the staff plate was recorded at each cross section and eventually calibrated to pressure transducer measurements recorded by the Levelogger. The pressure transducers were downloaded every month to track their proper functioning. During flow data analysis, a rating curve is developed and regressions equations are developed to translate 15-minute pressure transducer readings into discharge measurements.

Sediment Transport

In addition to stream gauging, suspended and bedload samples were collected at intervals along the sampling cross sections throughout the snow melt hydrograph. Suspended sediment was collected using a DH-48 depth integrated sampler, and bedload was sampled with a 76-mm Helley-Smith. Sampling was completed following USGS sediment transport sampling protocol (USGS, 1999). Suspended and bedload samples were filtered, dried, weighed, and processed in the Sedimentology Lab at CSU.

Pebble Counts

Pebble counts quantify the distribution of grains sizes on the bed of a channel and can detect pulses of sediment moving downstream as a river adjusts to an imposed sediment load. Pebble counts were completed at all sampling cross sections during the 2010 field season and provide a fourth year of data on bed material grain size changes as the sediment from the 2003 event propagates downstream. A gravelometer and grid system was used to conduct the pebble counts, and approximately 100 pebbles were sampled at each site for continuity with the 2009 counts.

Results

Data collected during the 2010 field season are presented first, and where necessary, as a compilation of all available data. In this way, the 2010 results can be viewed in the context of fluvial system recovery over the five years of data collection.

Flow Gauging

Snowmelt 2010 produced the highest discharges observed since 2003 with abundant overbank flow, channel avulsions, wetting of the floodplain in areas that have been dry since 2003, and extensive erosion and aggradation throughout the study reach. In all, the 2010 snowmelt generated a discharge with a 30-year recurrence interval (Q_{30}).

Rating curves were developed for all four sampling cross sections, two of which are shown in Figure 3 and 4. A shift in the rating curve at Crooked Tree is evident between the years of 2004 and 2005, and again in 2008, with smaller shifts in 2009 and 2010. A shift in the rating curve, as seen in stage-discharge data from Crooked Tree, suggests a change in channel capacity, and may be caused by aggradation of the channel bed. Aggradation has been observed and measured in the field at Crooked Tree beginning in 2008, with maximum aggradation of 23 cm occurring at the gauge on 9/24/10 (Figure 5). This loss of channel capacity is typical of disturbed systems that receive a steady supply of sediment, and underscores the importance of tracking sediment transport and its influence on channel capacity to convey flow.

The rating curve for Gravel Beach (Figure 4) includes the third year of reliable data, and also shows a pronounced shift in the rating curve from 2008-2009 to 2010. Another cause of loss of channel capacity, and hence a shift in the rating curve, may be due to a downstream control such as aggradation causing backwater effects. At the Gravel Beach cross section, extensive erosion of up to 20 cm scoured out a deep pool during peak flow because of a width-spanning log that became lodged against the gauge (Figure 6). Immediately downstream from the scour hole a large bar was deposited, causing a backwater condition at the gauge.

Mean daily discharge at all sites is shown in Figure 7. The point measurements of cross sectional averages of flow measured in the field (symbols in Figure 7) correspond well with continuous measurements attained by the Leveloggers. The snowmelt hydrograph peaked on 6/8/10, and discharge remained high for approximately one week, before dropping abruptly on 6/24/10 due to regulation of the Ditch. Our field measurements on 6/7/10 are a minimum estimate of peak discharge because only a portion of the channel was wadeable at the highest velocities. From the pressure transducers at our sample cross sections, peak flow was measured at 3.55 m^3/s (125 ft^3/s) at Gravel Beach. Due to erosion beneath the gauge at Gravel Beach during peak flow (Figure 6), all subsequent pressure transducer recordings were minimum estimates of stage because of the unmeasured depth of water below the pressure transducer. The pressure transducer at Gravel Beach will be readjusted during field season 2011 to ensure accurate stage measurements are collected.

An extremely rapid rise in the hydrograph on Lulu Creek on 6/8/10 (Figure 7) caused extensive erosion including undercutting of the banks, and mobilization of large quantities of unconsolidated sediment from the Lulu Creek fan. The rapid rise of the hydrograph also destabilized banks through undercutting on Sawmill Creek, a reference reach that was unaffected by the 2003 event.

At the reference reaches further downstream on the Colorado River (Shipler Park, and Lost Creek; Figure 1), discharge increases with increased drainage area, with the highest discharges in 2010 recorded at Lost Creek (6.0 m^3/s; 212 ft^3/s). Channel morphologic characteristics and sediment transport at the Shipler Park and Lost Creek references reaches were less directly impacted by the 2003 event, and hence, these sites will provide important data on channel, floodplain, and surface water/groundwater interactions for restoration purposes.

Sediment Transport

Suspended sediment transport along the upper Colorado River varies over five orders of magnitude (Figure 8), and shows strong correlation with discharge through regression analysis (R^2 ranging from 0.60 to 0.89). Generally, suspended sediment transport is more strongly linked to discharge than bedload transport because suspended sediment is well mixed throughout the water column and moves in less of a stochastic manner (Knighton, 1998). It is evident that suspended sediment (silt and clay) is moving downstream over time, and that the highest loads (~9 metric tons/day) have been measured at Gravel Beach (Figure 8), the sample cross section upstream from the Lulu City wetland. Assuming a mass density of 2,650 kg/m^3 for quartz particles, the 9 metric tons/day of suspended sediment transport at Gravel Beach is equivalent to 3.40 m^3/day of sediment discharge.

Bedload transport of sand and larger-sized material is equally well correlated with discharge (R^2 of 0.69-0.79) as is suspended load, especially at the Gravel Beach cross section (Figure 9). In summer 2010, bedload transport was the dominant mechanism of sediment movement measured at the sample cross sections. On 6/7/10, bedload concentrations were an order of magnitude higher than during any previous field season, with a maximum load of 1000 g/s (compared to the next largest load of 140 g/s passing through Gravel Beach during 2008). As the most downstream sample cross section, bedload transport at Gravel Beach indicates substantial amounts of sand and coarser grain sizes are being transported downstream toward the Lulu City wetland. The D_{50}, or median grain size of bedload in transport on 6/7/10 was 1.2 mm in size (very coarse sand). Because of the vast supply of sediment upstream along Lulu Creek and stored in the Lulu Creek fan, the sediment transport potential is extremely high throughout the study site, and does not follow expected rules of supply-limited transport common along mountain rivers (Wohl, 2000). The low threshold for sediment mobility translates into high bedload transport rates given sufficient discharge.

Results of the sieve analysis of bedload transported through the Crooked Tree cross section (Figure 10) indicate that sediment moving along the bed during summer 2010 ranged in median grain size (D_{50}) from very coarse sand to medium gravel (1.5-11 mm). Using the three years of data available at Crooked Tree (2008, 2009, 2010), a pattern of the grain size changes over snowmelt is observed. The grain sizes in transport as bedload fines during the first onset of snowmelt, when stored sediment is mobilized from the bed, compared to later in the hydrograph, when the D_{50} coarsens.

Pebble Counts

In a comparison of changes in the D_{50} of bed material grain size at the Crooked Tree and Gravel Beach sample transects (Figure 11) it is evident that bed coarsening occurred at Gravel Beach (to coarse gravel), with little change at Crooked Tree in 2010 (still very coarse gravel). Bed material at Gravel Beach is now comprised of similar sizes to what was originally measured in 2005. Observations, measurements, and repeat photographs support both the increased bedload transport and coarsening of the bed material (Figures 6 and 9).

Cross Section Resurvey

Six cross sections from the original 2003 survey were resurveyed in late August-early September 2010. The resurveys corroborate other sources of data documenting the extensive changes in channel morphology that occurred in 2010. At Cross Section 3 for example, immediately upstream from Gravel Beach, downstream migration of the mid-channel bar towards the Gravel Beach gauge is evident (Figure 12), and underscores the highly dynamic nature of the system with the potential for abundant coarse sediment transport during overbank flows. Aggradation of 35 cm occurred between 2007 and 2010 at Cross Section 3.

Sentinel Sites

Two sentinel sites were established in collaboration with the Rocky Mountain Network I&M Program during the summer 2010 field season. Water quality data were collected over one month at each site, and pressure transducer measurements were collected over the same time period. A survey of the Lower Sentinel cross section was completed, as was a longitudinal profile of the Colorado River up and downstream of the cross section. All data will be shared with the various groups working collaboratively at the Lower Sentinel and Little Yellowstone sites.

Discussion and Conclusions

Snowmelt runoff of 2010 was higher than during any time in the past seven years, with a peak discharge of 25.8 m^3/s (912 ft^3/s) recorded at the Bakers Gulch gage, equivalent to a 30-year recurrence interval flow The 15-minute continuous stage measurements of the Leveloggers provide excellent long-term records of changes in flow, especially when flow is too swift and turbulent to gauge. The pressure transducers also provide data on Ditch releases, and assist with interpreting channel changes on tributaries most influenced by Ditch regulation, such as occurred on Lulu Creek and Sawmill Creek during 2010. Erratic releases of flow destabilize banks and cause excessive erosion and transport of sediment to downstream reaches on the Colorado River.

Repeat surveys, bedload sediment measurements, and grain size analyses indicate major channel morphologic changes along the Colorado River, depending on location in the valley. An overall increase in sediment load transported, and measured aggradation in the downstream direction, was detected over snow melt runoff in 2010. Gravel Beach is the most downstream cross section sampled, and the largest quantity of bedload, by an order of magnitude, was sampled on 6/7/10. Grain sizes in the coarse sand to medium gravel range were transported downstream, resulting in bed aggradation at the sampling cross sections, which decrease channel conveyance of flow or backwater conditions.

Future Work

Given that the hydrology drives all key structuring processes in rivers, coupled with the entrained sediment, continued flow and sediment sampling at all sample cross sections over the entire snow melt hydrograph will occur in 2011 and 2012. With permanent staff gauges installed at eight sites, four of which represent reference sites (Upper Lulu Creek, Sawmill Creek, Colorado River at Shipler Park, and Colorado River at Lost Creek), substantial additional data on discharge and sediment transport are available to inform restoration planning with a minimum of field effort.

Establishment of the sentinel sites represents collaboration among diverse groups and programs in RMNP, beyond just the restoration of 2003 impacts. Long-term data sets on critical indicators of ecosystem health will benefit many efforts to ensure proper management of the Park’s natural resources.

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Wohl, E., 2000. Mountain Rivers, Water Resources Monograph 14, American Geophysical Union, Washington, D.C., 320 p.

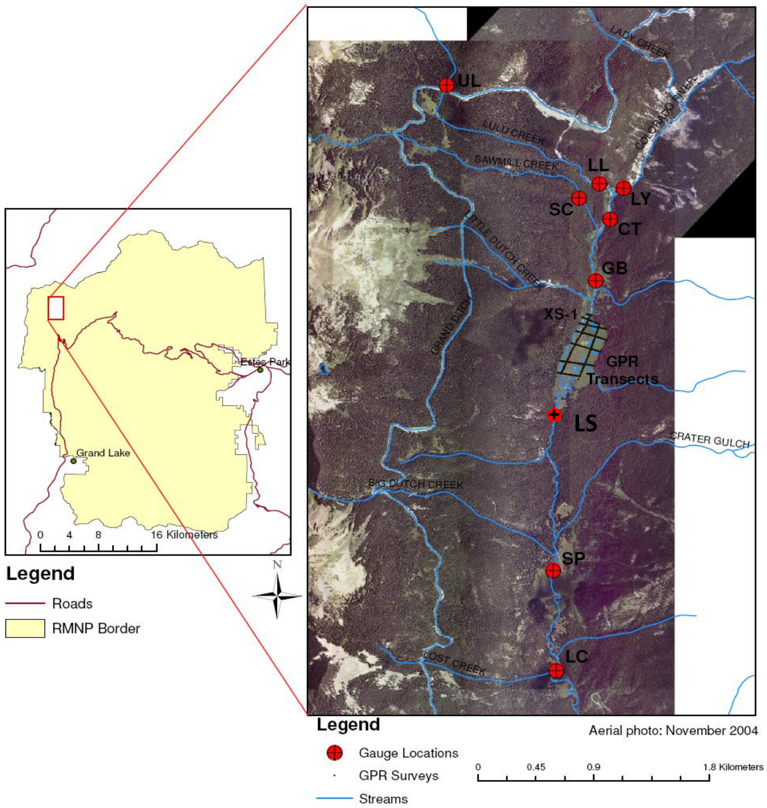

Figure 1. Aerial photograph showing locations of sampling cross sections (LL=Lower Lulu, LY=Little Yellowstone, CT=Crooked Tree, GB=Gravel Beach), reference reaches (UL=Upper Lulu, SC=Sawmill Creek, LS = Lower Sentinel, SP=Shipler Park, LC=Lost Creek). (Image modified from Rubin et al., 2009)

Figure 2. Lower Sentinel site (LS, Figure 1) on the Colorado River downstream from the Lulu City wetland. The gauging station was installed in collaboration with the I&M program. View is downstream.

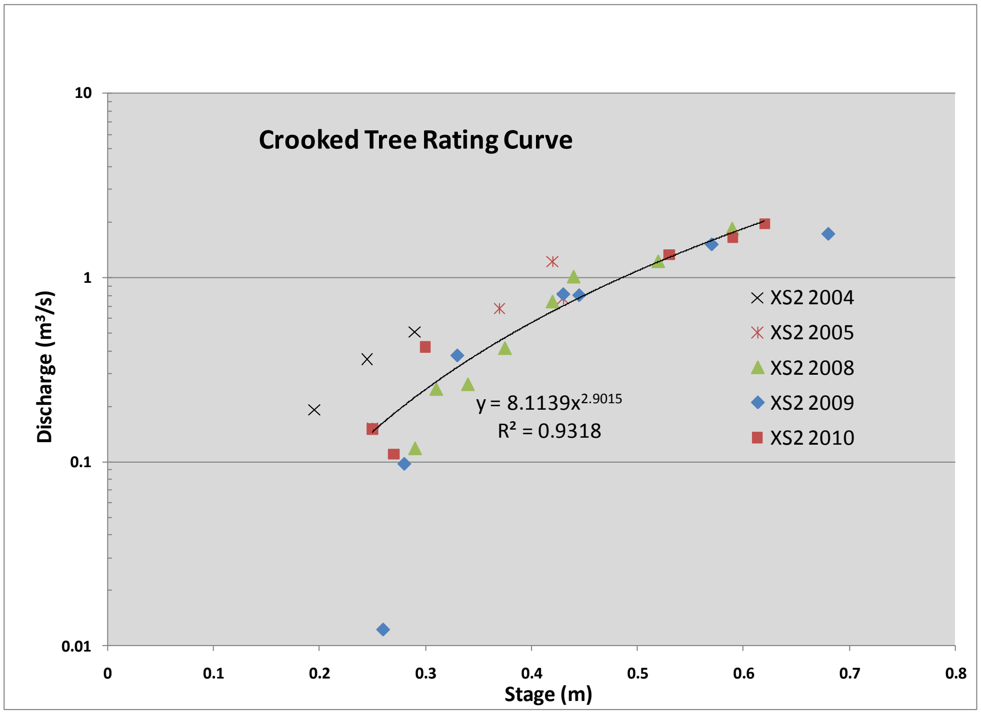

Figure 3. Rating curve for Crooked Tree on the Colorado River showing the regression equation fit to the 2010 data.

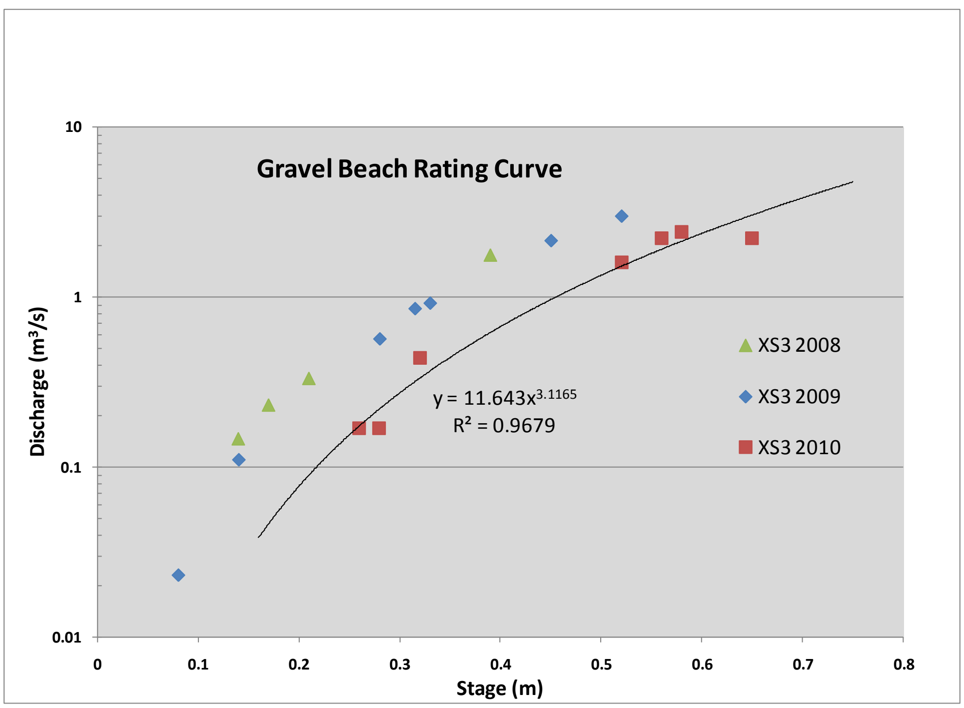

Figure 4. Rating curve for Gravel Beach representing three years of reliable flow data and the regression data equation fit to the 2010 data. There is a shift in the rating curve possibly due to downstream control from deposition and backwater conditions.

Figure 5. Repeat photographs from Crooked Tree Cross Section on 8/31/08 (A), and 9/18/09 (B) and 8/28/10 (C) showing growth of coarse bar beneath tree near right bank. View is downstream. Aggradation around the gauge in 2010 reached a maximum of 23 cm on 9/24/10, with boulders wedged against the staff plate.

Figure 6. Repeat photographs from Gravel Beach Cross Section on 6/7/10 (A), and 8/29/10 (B) showing formation of a scour hole during high flow due to a log abutting the staff plate. Erosion beneath the gauge reached a maximum of 20 cm on 9/24/10. View is downstream.

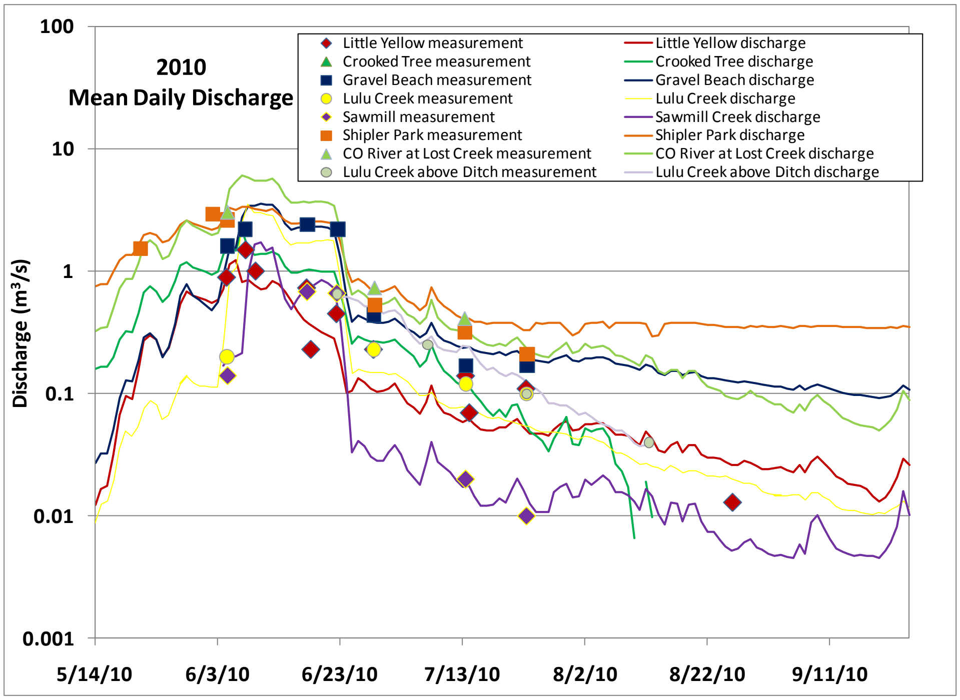

Figure 7. Hydrograph showing mean daily flow at sample cross sections. Peak flow of 6.0 m^3/s occurred at Lost Creek on 6/8/10. Locations of gauges shown in Figure 1.

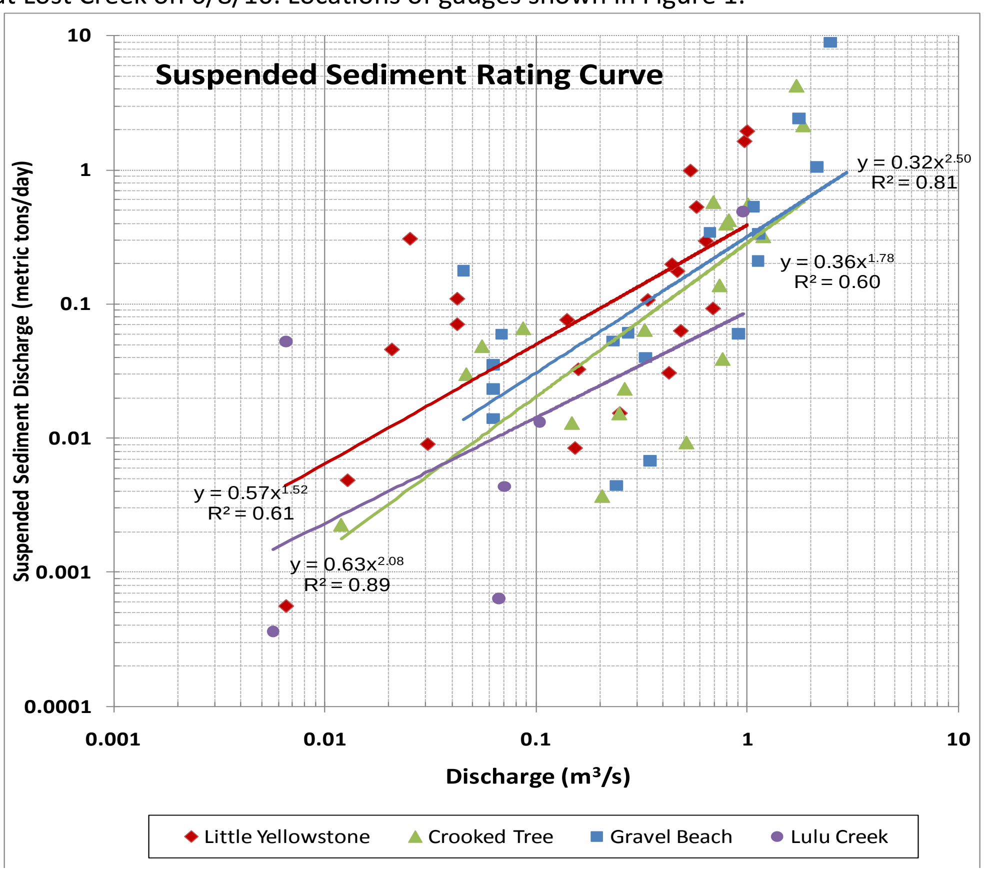

Figure 8. Suspended sediment transport versus water discharge for all four sampling cross sections with regression equations fit to five years of data (2004, 2005, 2008, 2009, 2010).

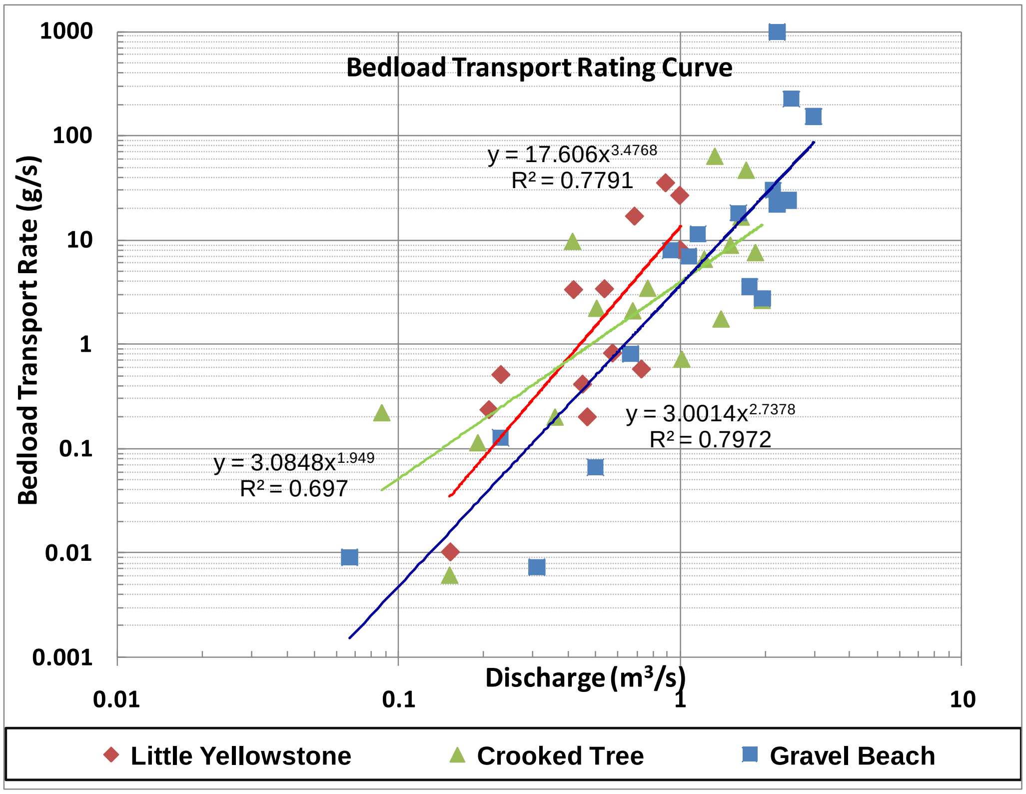

Figure 9. Bedload transport versus water discharge for three sampling cross sections during 2004, 2005, 2008, 2009, and 2010. Bedload transport is not measured along Lulu Creek because of turbulent flow.

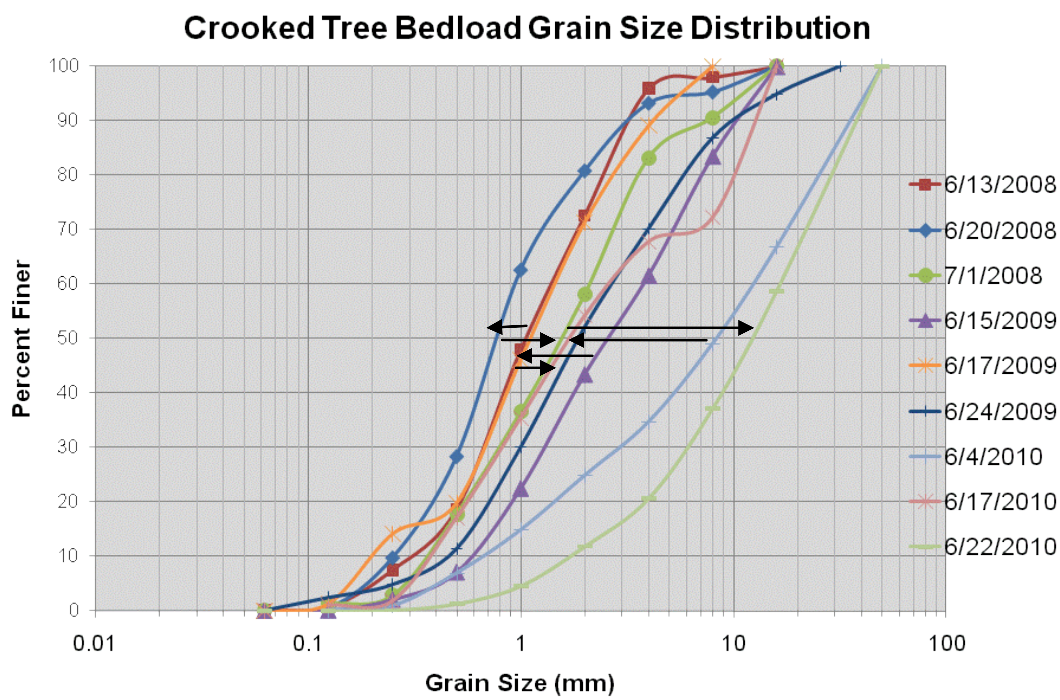

Figure 10. Cumulative frequency plot of bedload sediment in transport at the Crooked Tree cross section over the 2008 and 2009 field seasons. Black arrows show a pattern of fining of the bedload at the onset of snow melt, with a coarsening during or after peak flow.

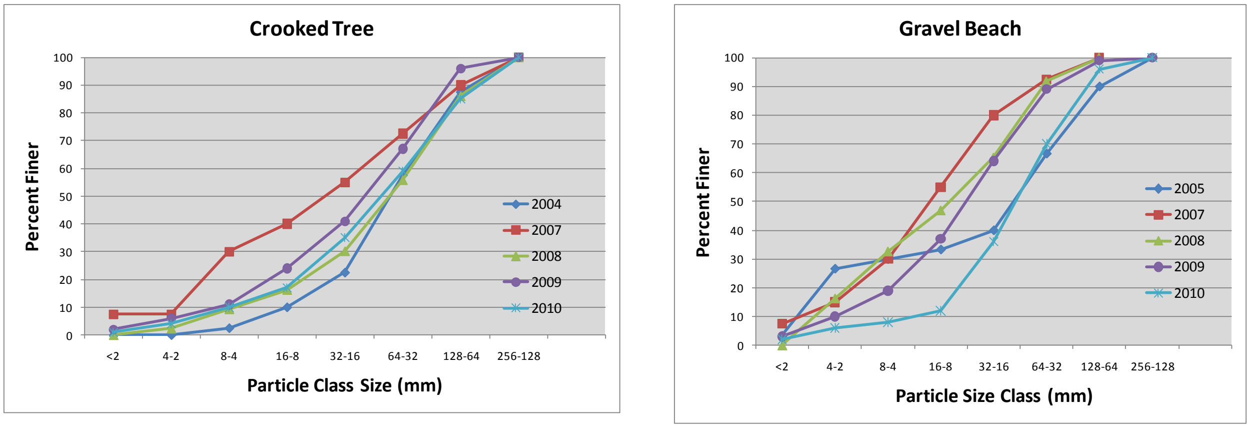

Figure 11. Bed material D_{50} changes over time at Crooked Tree and Gravel Beach. Bed material at the end of snowmelt 2010 is as coarse as in 2004 or 2005, the first year of a pebble counts at the sites, respectively. Bed coarsening is illustrated in Figures 5 and 6.

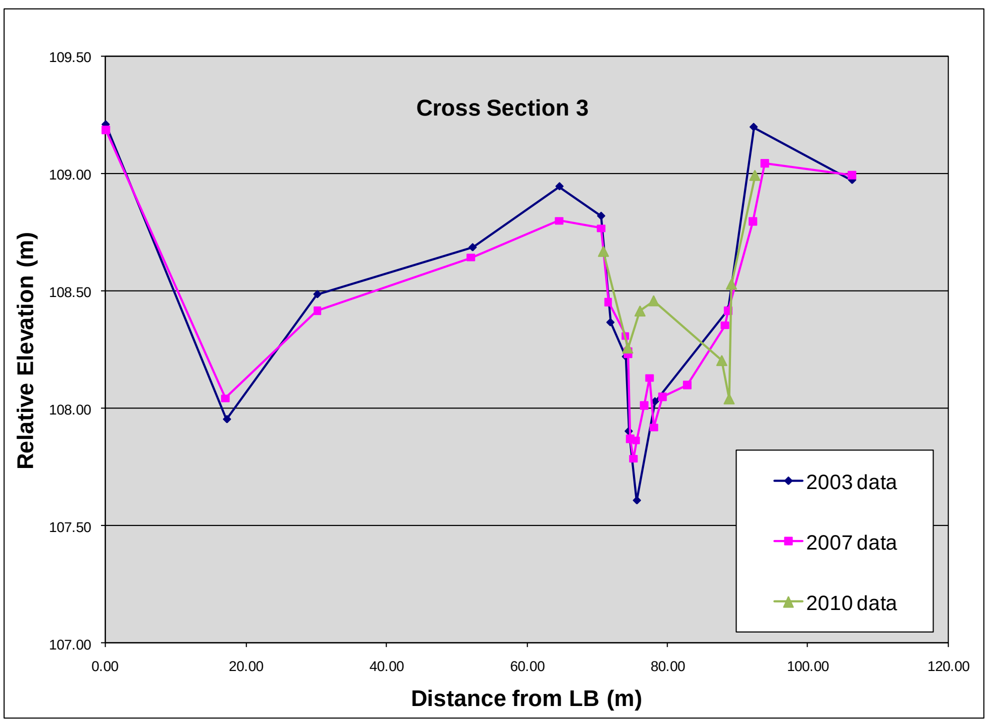

Figure 12. Relative elevation versus distance from left bank, Cross Section 3 (immediately upstream from Gravel Beach). Aggradation of 35 cm occurred in the thalweg between 2007 and 2010 due to downstream transport of sediment of a mid-channel bar. Bar is shown in Figure 6A, right bottom.