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 2009 to support channel restoration planning along Lulu Creek and the Colorado River in Rocky Mountain National Park (RMNP), and to satisfy the current contract for an additional ground penetrating radar (GPR) transect in the Lulu City wetland. 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 identify additional reference reaches for channel morphologic surveys, and 5) to complete a pilot GPR survey to evaluate the effectiveness of delineating the spatial extend of the 2003 deposit. All activities were completed to provide critical data in support of restoration planning and design. A compilation of four 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 2009 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 May 2, 2009 with installation of the four, automated pressure transducers (Leveloggers by Solinst) at the Little Yellowstone, Lower Lulu Creek, Crooked Tree, and Gravel Beach sites (Figure 1). At this time, a barometer (Barologger) was also installed at the Little Yellowstone cross section to provide barometric corrections for the pressure transducer data. The pressure transducers continuously measured water depth (stage) from May 2 until they were removed on September 18, 2009. During Summer 2009, four additional cross sections were established to provide improved reference data on Upper Lulu Creek, above Grand Ditch, Sawmill Creek, on the Colorado River within Shipler Park, and the Colorado River at Lost Creek (Figure 1). The reference reaches were selected in conjunction with D. Cooper to satisfy data needs for reference information, and surface water/groundwater fluctuations.

Seven single- or multi-day field outings were completed during summer and fall 2009, during which time the flow was gauged, and suspended and bedload samples were measured. At other times during the summer, pebble counts were completed at all sites. The pressure transducers were removed from all sites during the week of pit digging in the Lulu City wetland.

Flow Gauging

The additional Leveloggers at the four new reference reaches were secured below water level inside 2-inch, gray PVC pipe connected to a metal fence post and programmed to measure stage at 15-minute intervals. A staff plate was mounted to the outside of each PVC pipe to provide a fixed datum (Figure 2). In this way, stage on the staff plate was recorded at each cross section during field outings and calibrated to pressure transducer measurements recorded by the Leveloggers, similar to the set-up at the other sites. Flow velocity was measured along the sampling cross sections during each field outing to allow calculation of instantaneous discharge and development of rating curves (Figure 3 and 4). The equations for the rating curves are used to translate 15-minute stage 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 summer. 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 2009 field season and provide a third data set on bed material with which to track bed sediment 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 no fewer than 40 pebbles were sampled at each site for continuity with previous counts.

Ground Penetrating Radar (GPR) Survey

A pilot GPR survey was conducted in the Lulu City wetland on October 10, 2008 to test the effectiveness of the technology to: 1) detect the buried 2003 surface, 2) discern between multiple debris flow depositional events in the wetland, and 3) image the alluvial bedrock interface. An initial west-east oriented transect was completed at the head of the wetland with the 50 MHz frequency antennae to image to bedrock, and a follow-up survey was started with the 200 MHz frequency antennae to assess the top 5 meters of sediment in the wetland. The 200 MHz transect was not completed in October 2008 because of mechanical problems with the GPR trigger. At that time, a 65-cm deep pit was dug along the GPR transect to verify the GPR reflections with field evidence of buried vegetation, the water table, and any significant grain size changes. Preliminary results of the pilot survey were reported in the Final Report by Rathburn, dated 3/2/09.

Additional GPR transects were completed during summer 2009 as part of Z. Rubin's MS thesis to assess the aggradational history of the Lulu City wetland to establish a geomorphic context for channel restoration. Although the full results of that study are beyond the scope of this report, a 200 MHz frequency survey was completed at the head of the Lulu City wetland to satisfy the contractual agreement from 2008, with results reported herein.

Results

Data collected during the 2009 field season are presented first, and where necessary, as a compilation of all available data. In this way, the 2009 results can be viewed in the context of fluvial system recovery over the four years of data collection.

Flow Gauging

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 2004 and 2005, and again in 2008, with a smaller shift in 2009. A shift in the rating curve indicates aggradation of the channel bed, which, in the past has been observed and measured. This loss of channel capacity is expected 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 Lulu Creek (Figure 4) represents the second year of reliable data recording Ditch releases during snowmelt. Maximum daily flow in 2009 along Lulu Creek reached 1.2 m^3/s (42 ft^3/s), compared to 1.3 m^3/s (47 ft^3/s) in 2008.

Continuously recording stage measurements (Figure 5) show two prominent increases in stage from 6/13/09 to 6/25/09 and again from 8/15/09 to 9/19/09, when the Ditch was dry due to limits on capacity in Long Draw Reservoir when releases occurred down all tributaries, and during replacement of culverts along the Ditch, respectively. These periods represent a more natural flow regime, when Ditch regulation is at a minimum. Similar to 2008, pronounced fluctuations in stage occurred in 2009 during field work, and were corroborated by field observations of changes in depth from the staff plates.

Peak snowmelt discharge at the sample cross sections occurred on 6/24/09 and was recorded by all pressure transducers. This represents the first year peak discharge was directly measured with the pressure transducers, because it was the first time all equipment was available to be installed prior to snow melt. Peak discharge was recorded as 3.0 m^3/s (106 ft^3/s) at Gravel Beach, versus 2.5 m^3/s (88 ft^3/s) during 2008. The point measurements of cross sectional averages of flow measured in the field (symbols in Figure 5 and 6) correspond well with continuous measurements attained by the Leveloggers. In the past, calculations of peak discharge were made by indirect methods using field-based high water indicators.

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 2009 recorded at Lost Creek (4.6 m^3/s; 162 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 7), 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 7), the sample transect 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.

Interestingly, bedload transport of sand and larger-sized material is more strongly correlated with discharge (R^2 of 0.61-0.86), especially at the Gravel Beach cross section (Figure 8) than is suspended load. Bedload concentrations during 2009 were lower than over snow melt of 2008, with a maximum load of 96 g/s during 2009 versus 140 g/s passing Gravel Beach during 2008. As the most downstream 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 during high flows is larger than during low or receding flows. 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).

Results of the sieve analysis of bedload transported through the Crooked Tree cross section (Figure 9) indicate that sediment moving along the bed during summer 2009 ranged in median grain size (D_{50}) from very coarse sand to very fine gravel (1.2-2.3 mm). For two years, the grain sizes comprising bedload at Crooked Tree are comprised of finer sediments in transport during the first onset of snowmelt, when stored sediment is mobilized from the bed, compared to later in the hydrograph. The grain size then coarsens at peak flow (6/24/09), with an overall increase in grain size in transport over the 2009 field season resulting in a D_{50} of approximately 2 mm (very fine gravel). A temporal fining of grain size occurred at Gravel Beach however, over the 2008 and 2009 field seasons.

Pebble Counts

In a comparison of changes in the D_{50} of bed material grain size at the sample transects with distance downstream (Figure 10), it is evident that the most pronounced fining of bed sediment has occurred at Gravel Beach between 2004 (coarse gravel) and 2008 (fine gravel), with an increase in 2009 (medium gravel). The most pronounced coarsening, however, has occurred at Crooked Tree during both 2008 and 2009 (coarse gravel). Observations, measurements, and repeat photographs support both the increased deposition and coarsening of the bed material (Figures 10 and 11). Crooked Tree is located at a narrow portion of the Colorado River Valley, and the increased deposition and bed material grain size may be due to loss of sediment transport capacity at this choke point, or armouring of the channel bed leading to a more stable condition.

GPR
Results of the completed pilot GPR survey of the Lulu City wetland using the 200 MHz frequency antennae indicate that the 2003 deposit is a discrete, discernable deposit (Figure 12), and thins to the east until eventually pinching out beyond Pit 10. A strong radar reflection is evident on the image from the buried underlying vegetation surface, which is supported by a stratigraphic column constructed from the exposure in Backhoe Pit 11 (Figure 13), dug in September 2009, where roots of buried vegetation were identified at 75 cm. Thickness of the 2003 sediment is greatest near the current channel of the Colorado River, west of Pit 11, where sediment was deposited on a curved channel bed. Due to pit collapse during backhoe trenching, maximum thickness of 2003 sediment in this area was not determined. Based on the GPR results, however, maximum 2003 sediment thickness is greater than 1 m. Other GPR transects will be interpreted by Z. Rubin in his MS thesis to be completed spring 2010.

Discussion and Conclusions
Snowmelt runoff of 2009 was higher than during 2008, and represents the first time peak discharge was measured directly at all cross sections using the pressure transducers. The 15-minute continuous stage measurements of the Leveloggers provide excellent long-term records of changes in flow due to Ditch regulation, such as occurred when more normal discharges occurred twice during summer 2009. Based on field observations, flow regulation on the Ditch can increase or decrease stage in the Colorado River substantially in a short amount of time. This translates to erratic pulses of flow that entrain and mobilize sediment with every increase in discharge (as stream power). In addition, the installation of a pressure transducer and staff plate along Lulu Creek, upstream from the Ditch (Figure 1), provides new data on flows intercepted by Grand Ditch.

Bedload sediment measurements and grain size analyses indicate either a general fining or coarsening of sediment in transport occurred during 2009, depending on location in the valley, with an overall increase in load transported in the downstream direction over snow melt runoff. Gravel Beach is the most downstream cross section sampled, and the largest quantities of both suspended and bedload sediment were sampled at that location along the Colorado River relative to other sampling sites. Grain sizes in the coarse sand to fine gravel range are transported downstream, often resulting in bed aggradation at the sampling cross sections, which decrease channel conveyance of flow. In addition, local coarsening of both the bedload and the bed material at Crooked Tree may indicate the reach is on a trajectory toward stability, or that a local control on transport capacity exists at that point in the valley.

The pilot GPR survey of the Lulu City wetland shows promise in distinguishing sedimentary layers on the sub-meter scale. The 200 MHz frequency GPR survey along Cross Section 1 clearly delineates the 2003 sediment pinching out to the east, and correlates well to thicknesses of deposits exposed during backhoe trenching. Maximum thickness of 2003 debris flow sediment in this area is greater than 1 m in depth in the channel of the Colorado River. Additional data on the sedimentary architecture of the valley will be available in Z. Rubin's MS thesis, and will expand the knowledge base of valley evolution since deglaciation.

Recommendations

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 in 2010 is recommended. 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. A different sediment sampling technique, such as a bedload trap or a ground plate for the Helley-Smith (Bunte, 2005) may be required to collect meaningful bedload data along steep gradient reaches like Lulu Creek. External funding will be sought to support bedload sampling along Lulu Creek during summer 2010.

Continued discussion of site-wide restoration targets is recommended to facilitate a coherent channel restoration plan that supports riparian vegetation and aquatic ecological needs. Future uncertainties of climate change and forest cover predictions post bark beetle die-off should be incorporated into restoration planning where possible.

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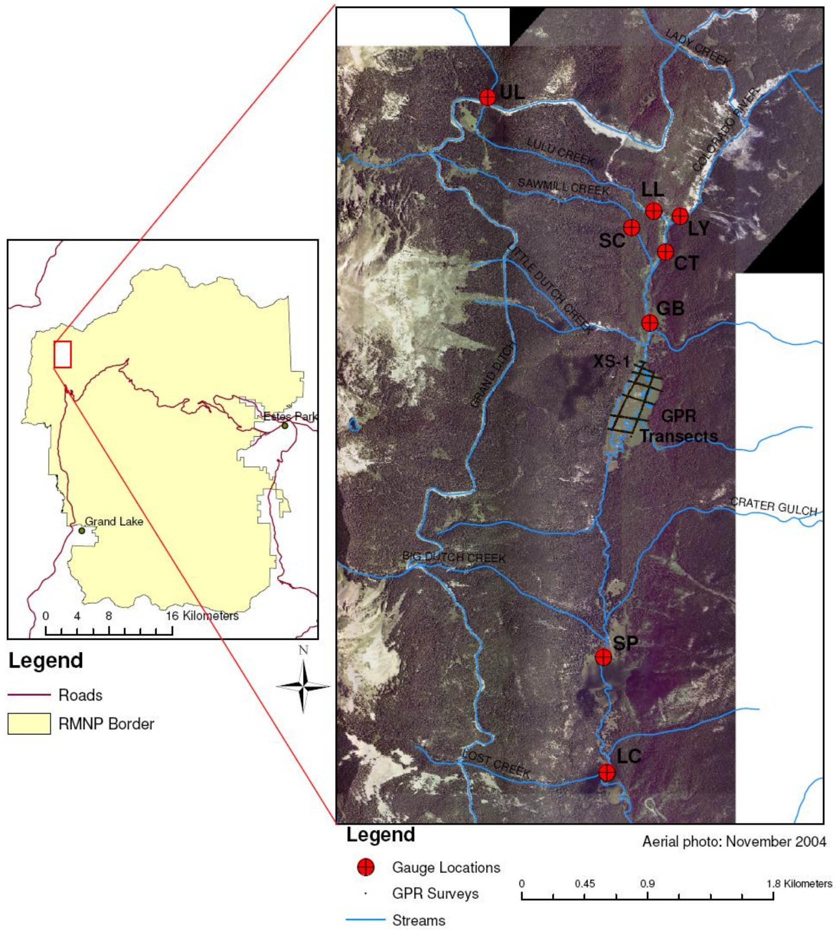

Figure 1. Aerial photograph showing locations of sampling cross sections (LL=Lower Lulu, LY=Little Yellowstone, CT=Crooked Tree, GB=Gravel Beach), reference reaches (UL=Upper Lulu, SC=Sawmill Creek, SP=Shipler Park, LC=Lost Creek), the GPR transects (black), with XS-1 (second cross section to the south) also shown in Figure 12. (Image modified from Rubin et al., 2009)

Figure 2. Staff plate mounted to PVC pipe housing pressure transducer, Sawmill Creek reference reach (6/4/09).

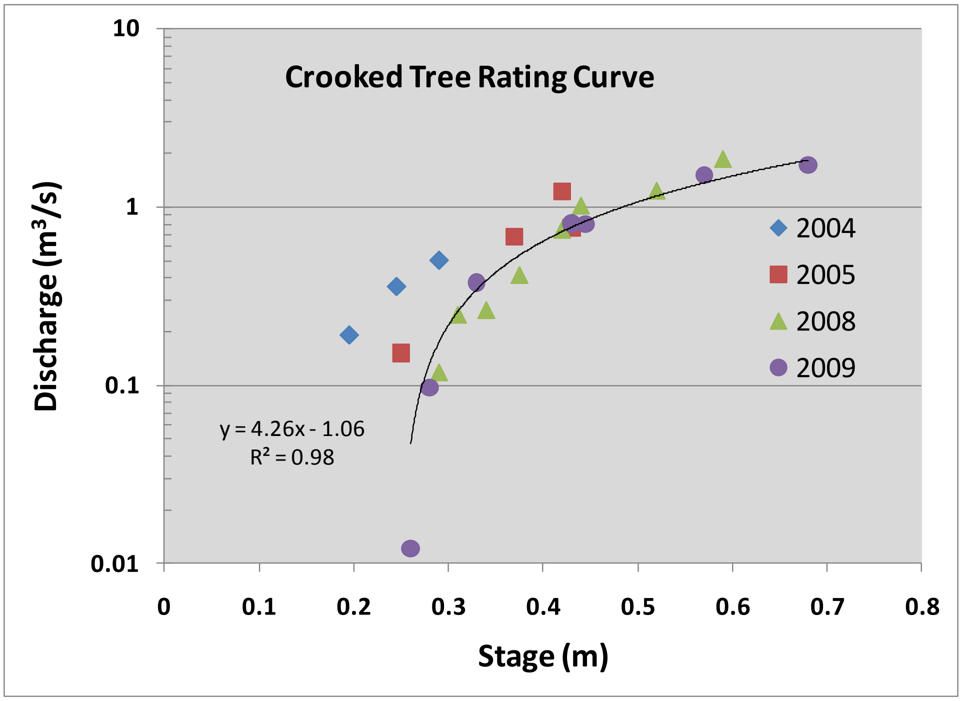

Figure 3. Rating curve for Crooked Tree on the Colorado River showing a shift over time in channel capacity due to aggradation of sediment on the channel bed.

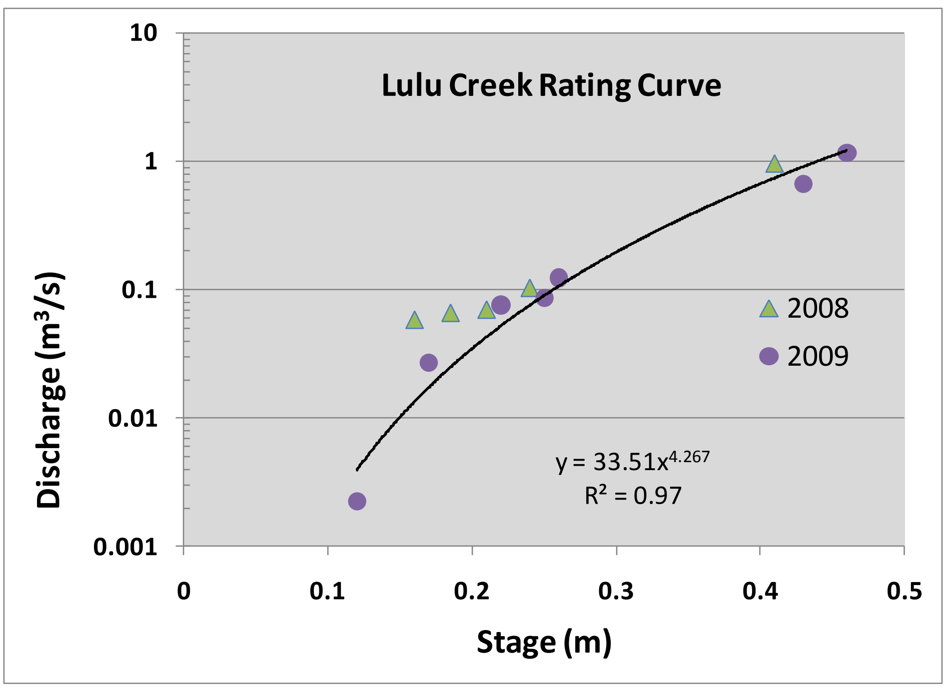

Figure 4. Rating curve for Lower Lulu Creek representing two years of reliable flow data on Lulu Creek that quantify Ditch releases.

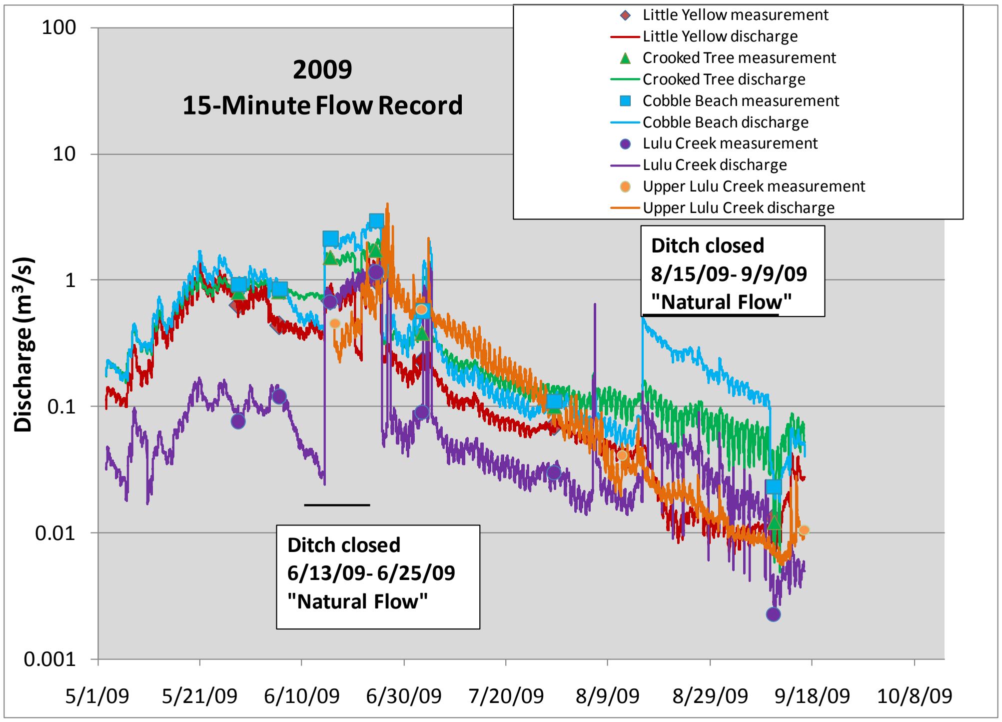

Figure 5. Stage recordings every 15 minutes by the Leveloggers at sample cross sections. The sawtooth pattern is due to diurnal fluctuations in stage, with the erratic stage fluctuations in June and August attributed to releases from Grand Ditch.

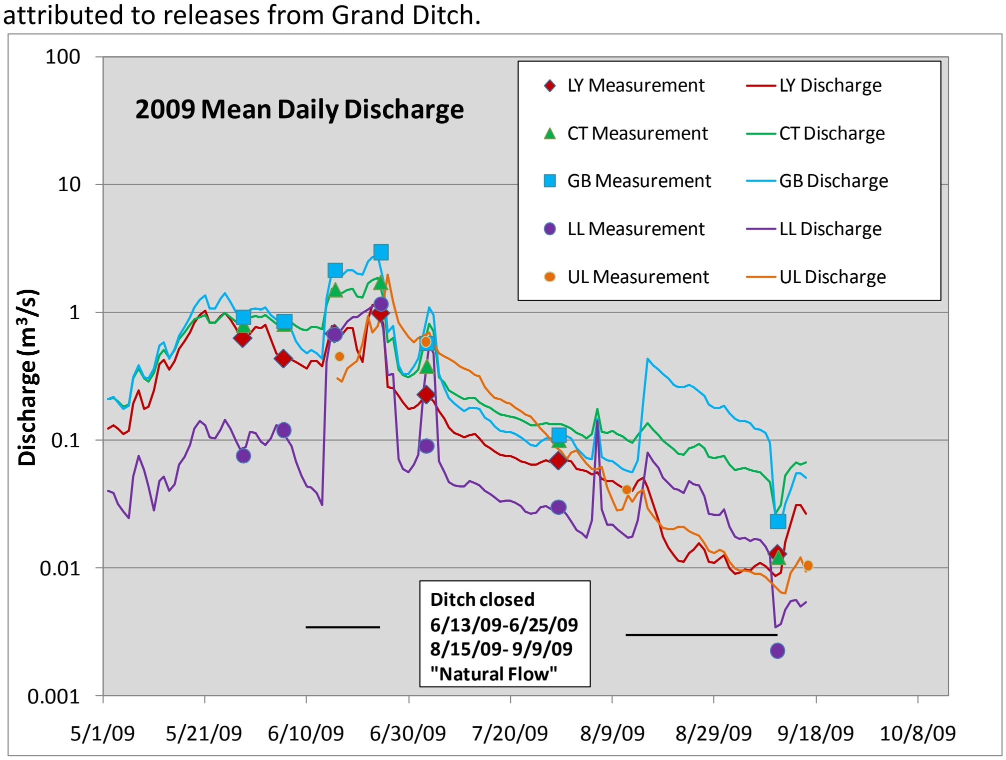

Figure 6. Hydrograph showing average daily flow at sample cross sections. Peak flow of 3.0 m^3/s occurred at Gravel Beach on 6/24/09 when Long Draw Reservoir was at capacity and water was released down all tributaries. Substantial releases occurred again in mid August with replacement of the culverts along Grand Ditch. (LY=Little Yellowstone, CT=Crooked Tree, GB=Gravel Beach, LL=Lower Lulu, UL=Upper Lulu as referenced in Figure 1).

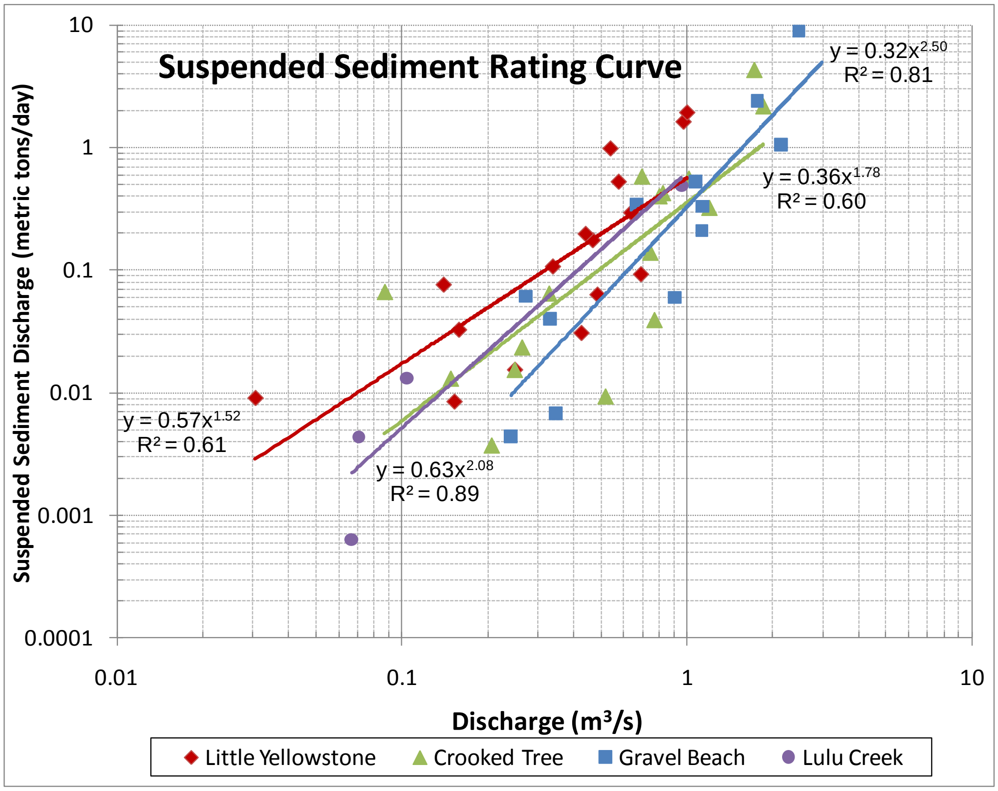

Figure 7. Suspended sediment transport versus water discharge for all four sampling cross sections. Suspended sediment was measured during 2004, 2005, 2008, and 2009 at all sites.

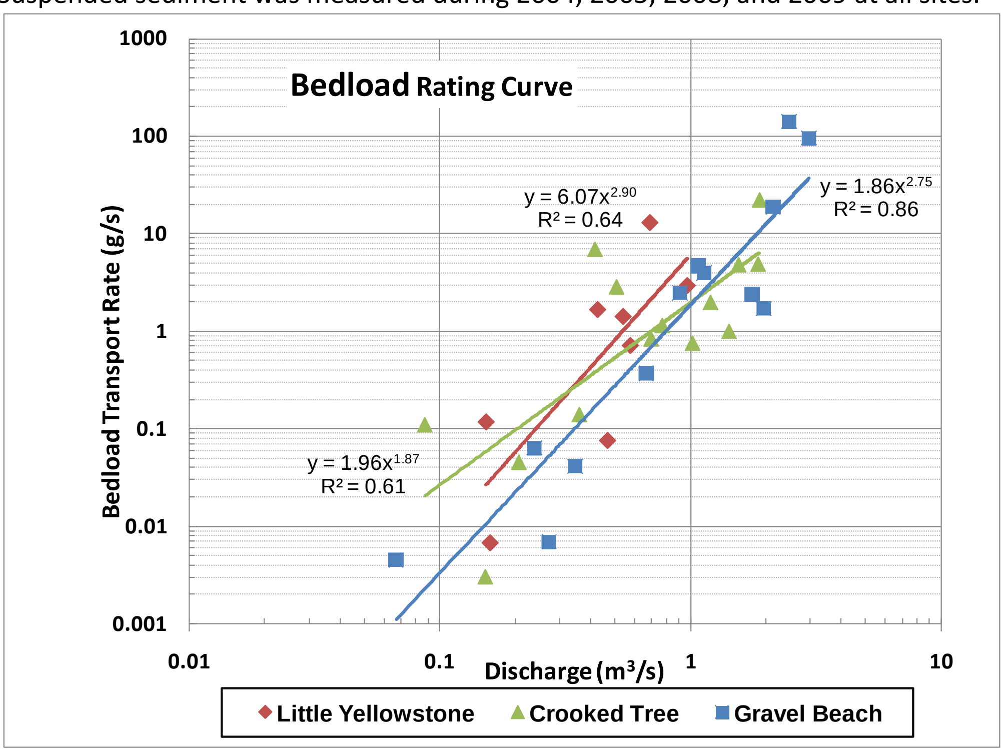

Figure 8. Bedload transport versus water discharge for three sampling cross sections. Data include bedload sediment measured during 2004, 2005, 2008, and 2009. Bedload transport was not measured along Lulu Creek because of the inability to use the Helley-Smith sampler in highly turbulent flow.

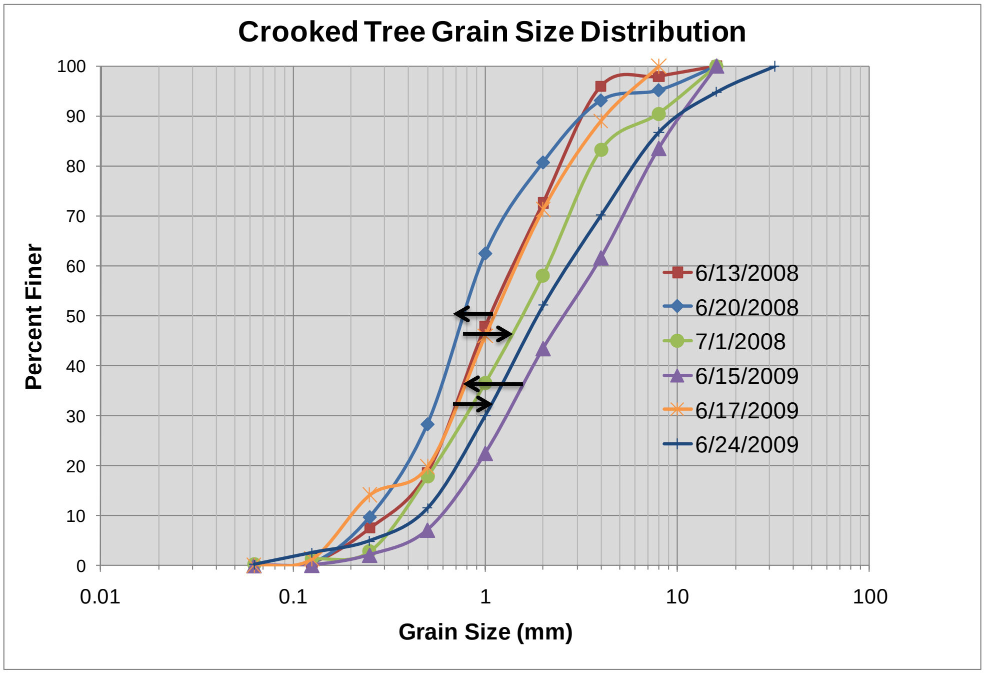

Figure 9. Cumulative frequency plot of bedload sediment in transport at the Crooked Tree cross section over the 2008 and 2009 field seasons. Fining of the bedload occurred at the onset of snow melt, with a coarsening occurring during peak flow (6/24/09), as indicated by the black arrows.

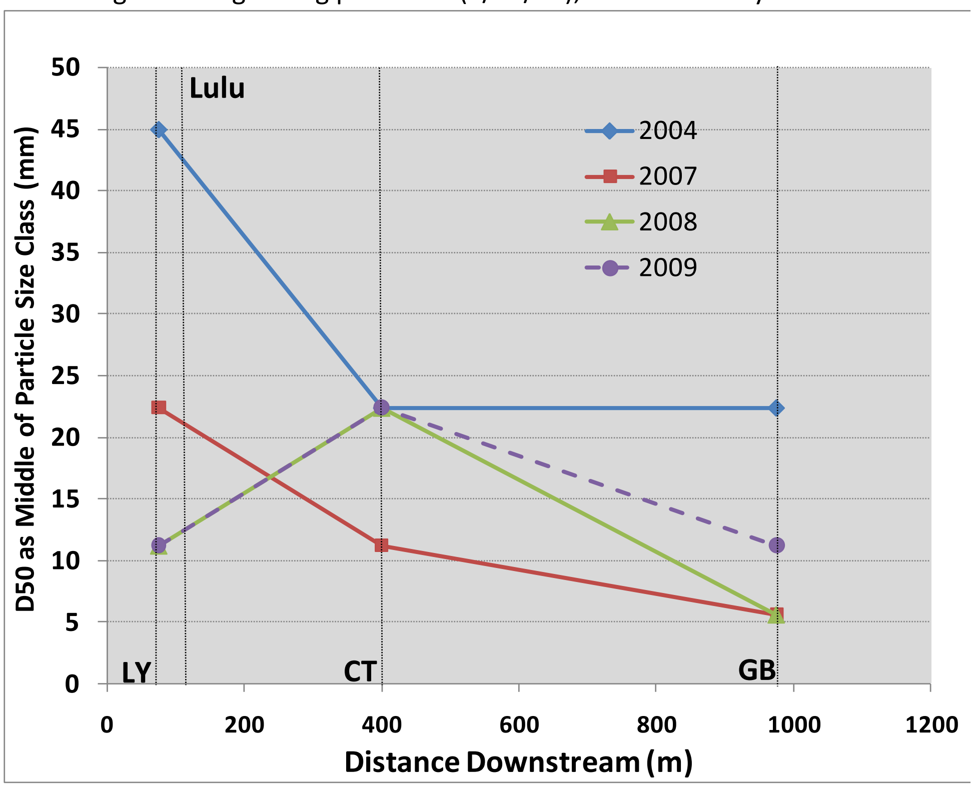

Figure 10. Bed material D_{50} changes with distance downstream, 2004-2009. A local coarsening of bed material at Crooked Tree (CT) for both 2008 and 2009 may be due to the narrow valley forming a choke point, or development of bed amour and increased channel stability. Vertical drop lines indicate locations of sample cross sections downstream from Little Yellowstone (LY).

Figure 11. Repeat photographs from Crooked Tree Cross Section on 8/31/08 (A), and 9/18/09 (B) showing growth of coarse bar beneath tree near right bank of channel. View is downstream. Coarsening of bed material is supported by bed material pebble counts depicted in Figure 10.

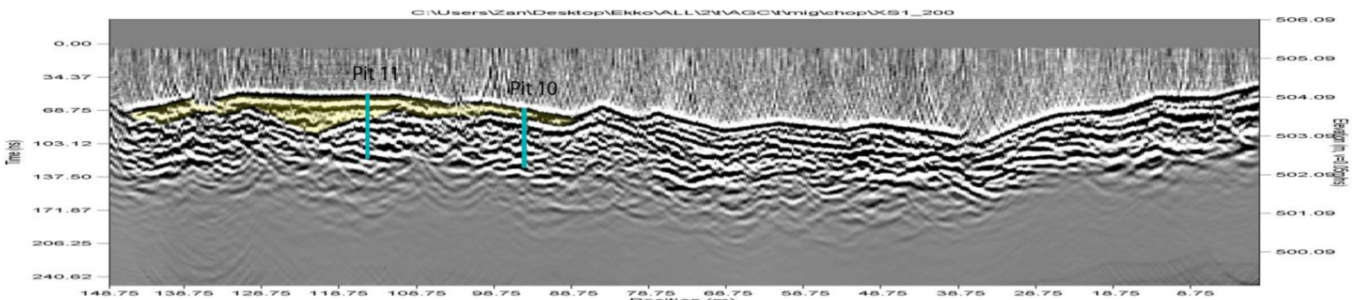

Figure 12. GPR reflections from Cross Section 1 (Figure 1) west to east across the head of the Lulu City wetland. Debris flow sediment from 2003 is highlighted in yellow, and clearly pinches out to the east of Pit 10. Backhoe pits are shown as vertical blue lines.

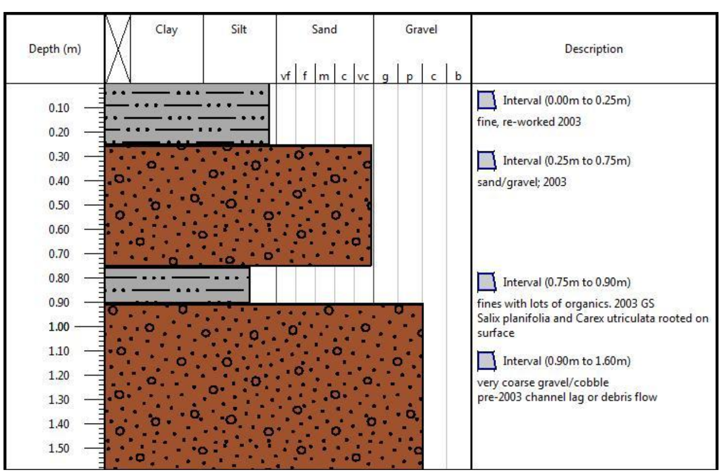

Figure 13. Stratigraphic column of sediment from Pit 11 along GPR Cross Section 1 within the Lulu City wetland, showing fine-grained, reworked 2003 fluvial sediment (gray), overlying coarse, 2003 sand and gravel debris flow sediment (brown). *Salix planifolia* and *Carex utriculata* at 75 cm were buried by the 2003 sediment and indicate ground surface at that time.