Final Report
Flow and Sediment Monitoring along Lulu Creek and the Colorado River in Rocky Mountain National Park

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Introduction

Additional field work was completed during summers 2012 and 2013 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, and 2) to continue monitoring changes in bed sediment grain size. All activities were completed to provide critical data in support of restoration planning and design. A compilation 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 (Rubin et al., 2012; Rathburn et al., 2013). This report describes the 2012 and 2013 field work, results of the field work, interpretations, discussions, and recommendations related to future work along the Upper Colorado River.

Methods – Field Work and Data Analysis

2012

Field work began on April 22, 2012 with the installation of seven, automated pressure transducers at the Little Yellowstone, Lower Lulu Creek, Crooked Tree, Gravel Beach, Lower Sentinel, Shipler Park, and Lost Creek sites (Figure 1). A barometer (Barologger) was also installed near the Little Yellowstone cross section to provide barometric corrections for the pressure transducer data. A tree fell on the Sawmill Creek gauge between 2011 and 2012, preventing access to the gauge and cross section. New gauges were constructed at the Lower Lulu, Crooked Tree, and Gravel Beach sites on April 22, 2012 due to loss of theses gauges during high flow in 2011. The new gauges were constructed of similar equipment (electrical conduit attached to a fence post with hose clamps, and rubber cap on end of conduit) as the previous gauges, and were installed on the left bank of the Colorado River at or near the original cross sections to facilitate access and maintain data consistency. The pressure transducers at each gauge continuously measured water depth (stage) from April 22 until they were removed on August 8, 2012. In collaboration with the I& M effort in RMNP, water quality probes were installed downstream from both of the gauges at the two sentinel sites (Little Yellowstone, Lower Sentinel).

Nine single- or multi-day field outings were completed during summer and fall 2012, during which time the flow was gauged and sediment monitored. Suspended and bedload samples were collected on June 9 and June 16, 2012. At all other times, the discharge was too low for sediment transport samples to be collected. Finally, during the late summer and fall, pebble counts were completed at all sites, and a resurvey of step dimensions along Lulu Creek was completed.

2013

Field work began on May 7, 2013 with the installation of five pressure transducers and barometer at the Little Yellowstone, Lower Lulu Creek, Crooked Tree, Gravel Beach, and Lower Sentinel gauges (Figure 1). Pressure transducers were not installed at Shipler Park and Lost Creek because of the low snow pack and likely low runoff for 2013; sufficient low-flow data on these downstream reference reaches has been collected. River stage was recorded continuously from May 7 until June 11, 2013 when the memory within the data loggers of the pressure transducers filled and previous data did not overwrite (as was expected). As a result, the data loggers shut off on June 11 and no additional continuous stage data were collected. The pressure transducers were removed October 19, 2013.

Five single- or multi-day field outings were completed during summer and fall 2013 to gauge the flow and monitor sediment. Discharge was so low during summer 2013 that no sediment transport samples were collected. A resurvey of step dimensions on Lulu Creek was also completed during the summer field season.

Flow Gauging and Discharge Calculation

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 is recorded at each cross section and eventually calibrated to pressure transducer measurements recorded by the Levelogger. During flow data analysis for 2012, a rating curve and regressions equations were developed to translate 15-minute pressure transducer readings into discharge measurements.

Because of the filled memory within the data loggers, flows in 2013 were reconstructed from cross section data and field gauging measurements throughout the summer, rather than from the direct 15-minute pressure transducer recordings. The approach of reconstructing flows assumed that the August 2012 cross sectional channel geometry was representative of channel dimensions in May 2013. Once field work began in June 2013, the current channel geometry was used in discharge calculations. Given the extremely low discharges throughout the summer of 2013, the assumption of minimal channel geometry change is valid, especially early in the snow melt season when discharge is low.

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 three sampling cross sections during the 2012 field season and provide a fifth 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.

Pebble counts were not completed during the 2013 field season because of intense storms in September that caused substantial flooding and damage to roads accessing the field site. In addition, an unexpected government shutdown and Park closure in October also limited field access to complete pebble counts.

Results

Flow Gauging

Snowmelt 2012 and 2013 produced discharges that were well below bankfull conditions at all sites along Lulu Creek and the Colorado River. Rating curves were developed for all seven sampling cross sections, two of which are shown in Figure 3 and 4. Because replacement gauges were installed in 2012 at the new Crooked Tree and Gravel Beach sites (CT2 and GB2), previous rating curves are no longer applicable. Discharge at both gauges remained below 1 m^3/s in 2012, with accompanied stage changes spanning approximately 10 cm. The Gravel Beach 2 cross section changes less over time than the Crooked Tree 2 cross section, and hence the R^2 for the regression relation is larger (0.94 versus 0.57). Developing a rating curve over a range of discharges is important for identifying channel geometry changes, especially through shifts in the rating curve over time.

Mean daily discharge for 2012 is shown in Figure 5. The point measurements of cross sectional averages of flow measured in the field (symbols in Figure 5) correspond well with continuous measurements attained by the Leveloggers, except for the discharge measurement on 6/13/12 on Lost Creek (0.77m^3/s), which appears to be a good data point but may be due to measurement error. The hydrograph peaked on 7/30/12 (0.48 m^3/s) at the Shipler Park gauge, one of the two downstream reference sites on the Colorado River which receive substantial tributary inflow.

Mean daily discharge in 2013 is shown in Figure 6. A distinctive double-peaked pattern of discharge is shown, related to a mid- and late-May period of snow melt causing increasing discharges, separated by cold temperatures where discharge dropped distinctively. Of the five gauges installed in 2013, discharge at Gravel Beach was greatest, at slightly over 1 m^3/s on June 10, 2013. It is possible that peak flow was attained after June 10, given the loss of logged data due to memory filling. When field gauging began on June 13, discharges had already begun to drop on the receding limb of the hydrograph.

Sediment Transport

Suspended sediment transport of fine sand, silt and clay particles along the upper Colorado River was minimal during the 2012 and 2013 field seasons. The highest concentration of suspended sediment in 2012 was measured at the Lost Creek cross section (12.6 mg/L; 0.133 metric tons/day) on July 9, 2012. By comparison, a suspended sediment load of over 9 metric tons/day was measured at Gravel Beach in 2010, the highest concentration of fine sediment sampled during all monitoring. It is likely that suspended sediment loads were even greater in 2011, however the high, sustained flows made wading the river and sampling at cross sections infeasible.

Bedload transport of sand and larger-sized material was also minimal in 2012 and 2013 because of low discharge. On July 9, 2012 a bedload sample was collected at three of the seven cross sections (Little Yellowstone, Crooked Tree, and Lower Sentinel). At all other times during the 2012 field season and throughout the 2013 season, bedload transport was too low to measure. The greatest amount of bedload transport occurred at Little Yellowstone on July 9, 2012, with 22.5 g of sediment collected during the 2 minute sampling. Crooked Tree 2 and the Lower Sentinel sites had an order of magnitude lower quantity of bedload on that day.

Pebble Counts

The D_{50} of bed material grain size at the new Crooked Tree (CT2) site is coarser in 2012 than 2011, with a shift from medium to coarse gravel (Figure 7). It is important to remember that the new Crooked Tree cross section is approximately 5 m downstream from the original one where the 2004, 2009, 2010, and 2011 data were collected. Hence, changes in grain size from 2011 to 2012 do not reflect sediment transport processes in the way that repeat measurements at one site do. At Gravel Beach no change in bed material grain size was detected between 2011 and 2012, with coarse gravel comprising the median grain diameter (Figure 8).

Discussion and Conclusions

Snowmelt during the 2012 and 2013 field seasons produced discharges that were comparable to lower-than-normal snow melt runoff years of 2004 -2007. As a result of the minimal discharges, lower associated stream power transported minor amounts of suspended and bedload sediment in all of these years. Sediment was collected during only two of nine field outings in 2012, and not at all in 2013. Minor changes to the channel geometry and bed material grain sizes also occurred during the 2012 and 2013 field seasons. One major benefit of the 2012 field work was installation of new gauges at three locations that were damaged during 2011 high flows. The gauges on Lulu Creek, and at Crooked Tree and Gravel Beach on the Colorado River are now located on the left bank of the channel to facilitate easy access during high flows. Previously, crossing the river during peak flows to access the gauges was necessary.

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 continue until restoration commences. Pressure transducers have already been cleared of data and reset to ensure proper functioning for future use. 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) which will be important for post-restoration monitoring, substantial additional data on discharge and sediment transport are available with a minimum of field effort. Installing a new gauge near the original Sawmill Creek site for additional data on a reference step-pool channel is recommended. The Sawmill Creek data logger was not damaged during the tree fall, and therefore, could be installed at a new gauge in spring 2014.

References Cited

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Rubin, Z., Rathburn, S., Wohl, E., and Harry, D., 2012. Historic range of variability in geomorphic processes as a context for restoration: Rocky Mountain National Park, Colorado, *Earth Surface Processes and Landforms* 37:209-222, DOI:10.1002/esp.2249.

U.S. Geological Survey, 1999. Field Methods for Measurement of Fluvial Sediment: Techniques in Water Resources Investigations, Book 3, Applied Hydraulics, Ch. C2, 89 p.

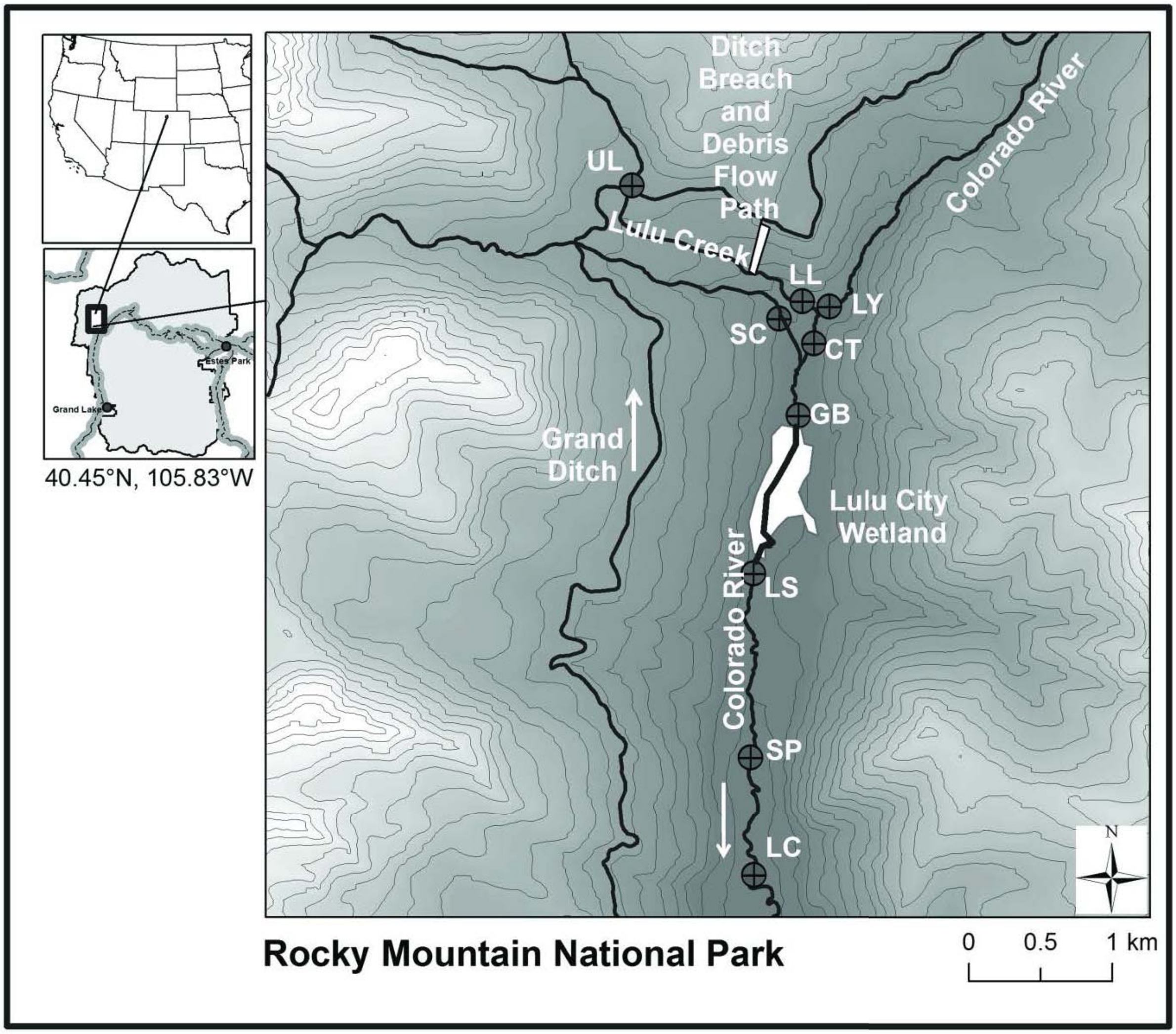

Figure 1. Location map of sampling cross sections (LL=Lower Lulu, LY=Little Yellowstone, Creek, CT=Crooked Tree, GB=Gravel Beach), reference reaches (UL=Upper Lulu, SC=Sawmill Creek, LS = Lower Sentinel, SP=Shipler Park, LC=Lost Creek). Figure from Rathburn et al., 2013.

Figure 2. New gauge installation on April 22, 2012 at A) Lower Lulu, B) Crooked Tree, and C) Gravel Beach (gauge is on left bank behind small tree). In image D) taken on May 7, 2013, a pressure transducer was placed in the Gravel Beach gauge prior to snowmelt. View in all images is downstream.

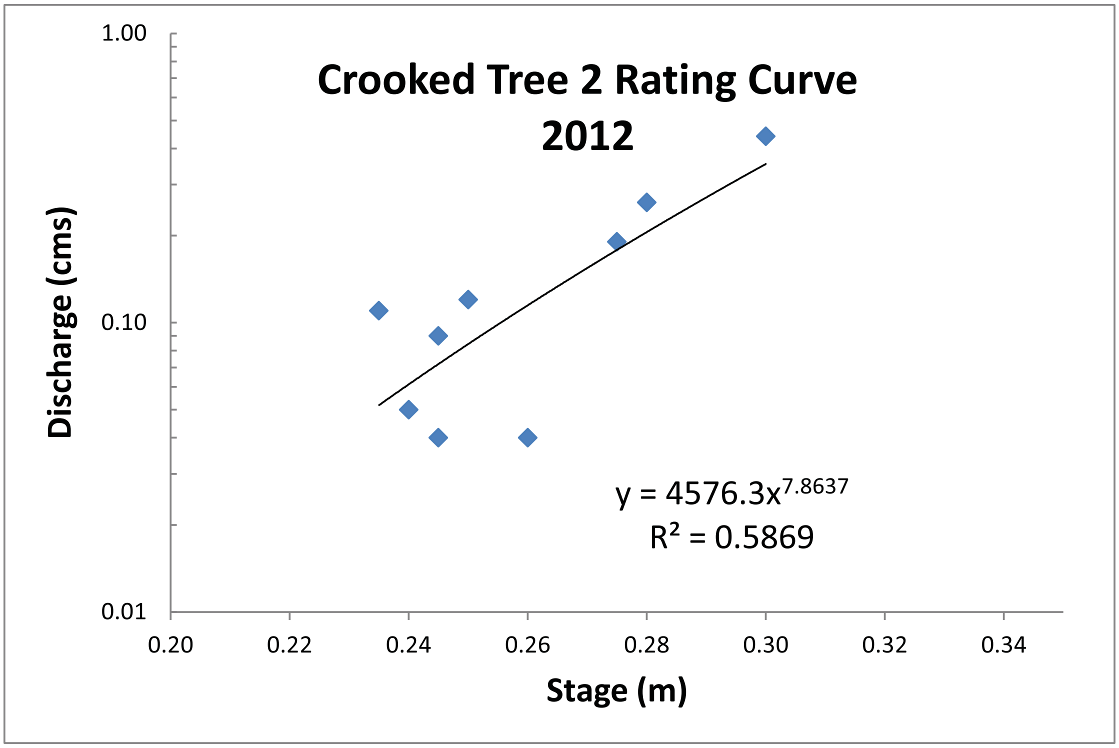

Figure 3. Rating curve for Crooked Tree 2 (the new gauge installed in 2012) on the Colorado River showing the regression equation fit to the 2012 data.

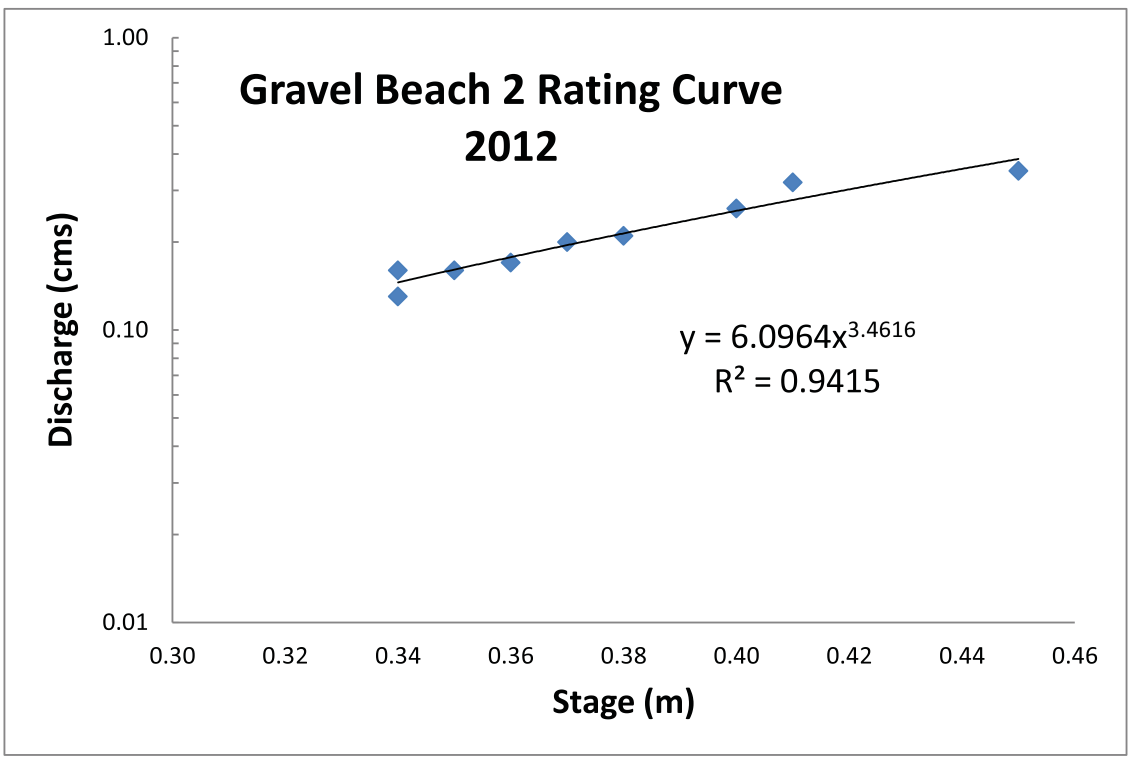

Figure 4. Rating curve for Gravel Beach 2 (the new gauge installed in 2012) on the Colorado River showing the regression data equation fit to the 2012 data.

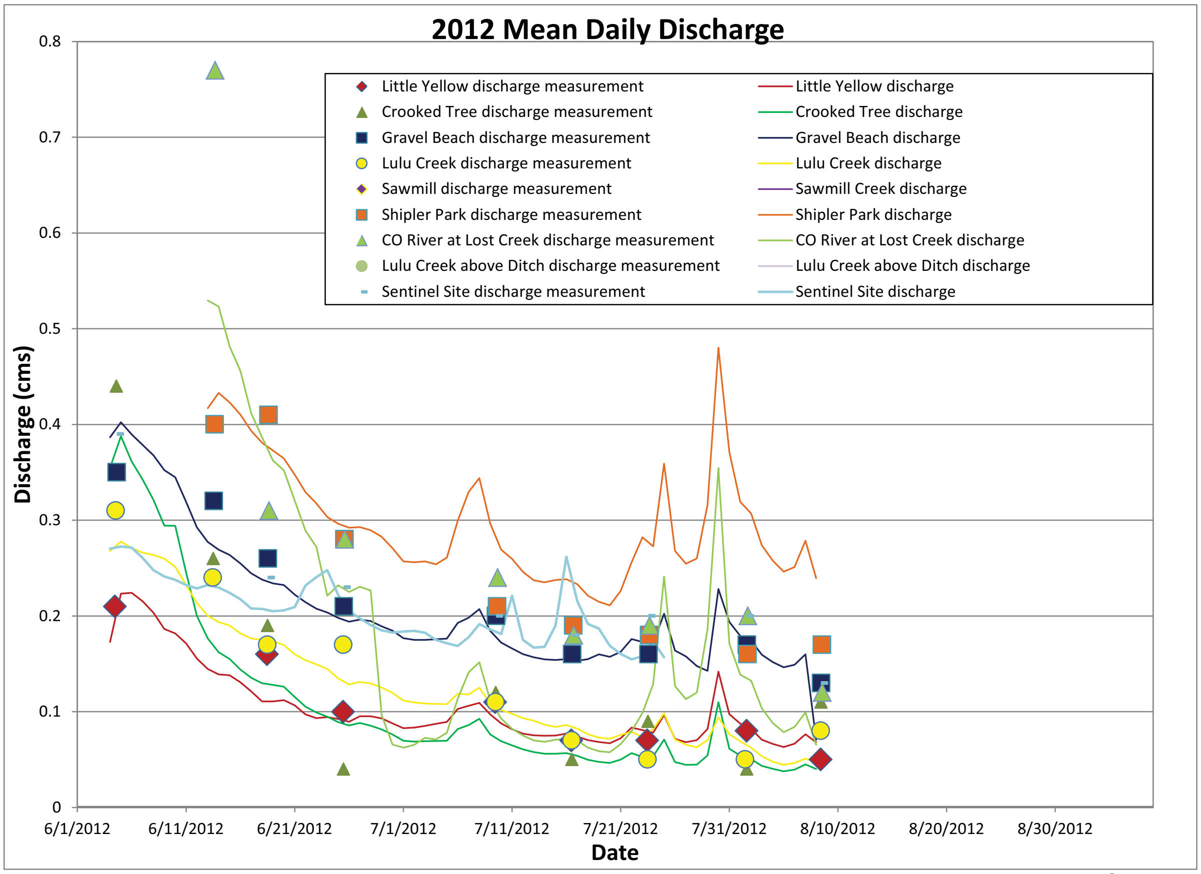

Figure 5. Hydrograph showing mean daily flow at sample cross sections. Peak flow of 0.48 m^3/s occurred at Shipler Park on 7/30/12. Locations of gauges shown in Figure 1.

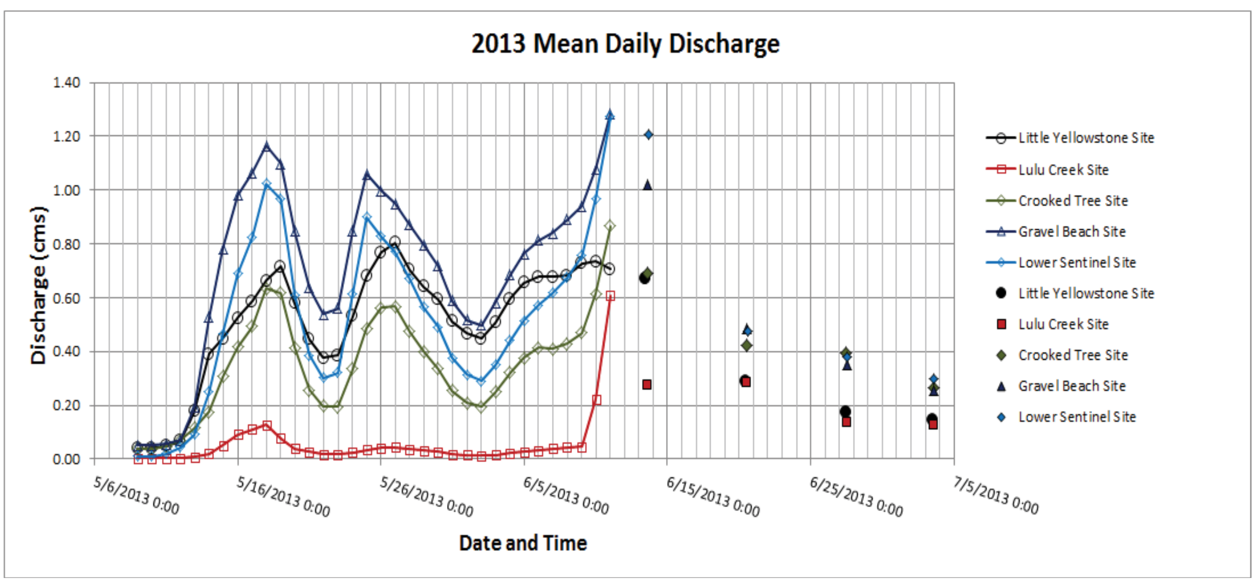

Figure 6. Hydrograph showing mean daily flow at the sample cross sections reconstructed from channel dimensions of 2012 from 5/7/13-6/11/13, shown as lines. After 6/11,13, when memory on the pressure transducers was filled, field gauging measurements of discharge are shown as solid symbols.

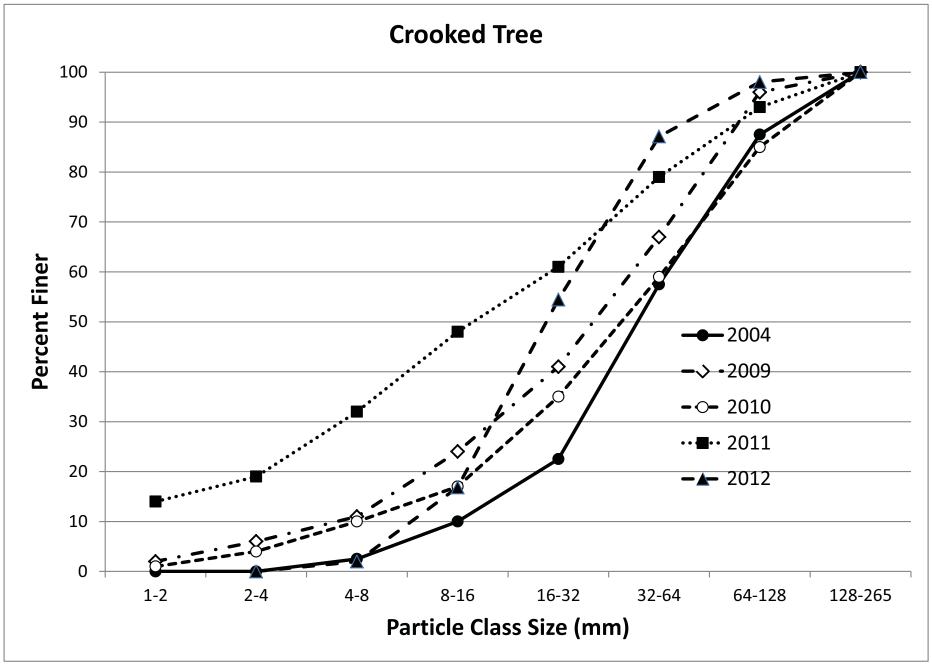

Figure 7. Cumulative frequency plot of bed material at the Crooked Tree cross section over five years of data. Note that i) 2004 data are for 40 clasts, whereas all other years are 100 clasts; and ii) the 2012 data were collected at the new cross section (Crooked Tree 2), slightly downstream from the original location. Pebble counts were not conducted in 2013 due to flooding that affected road access and the fall closure of RMNP.

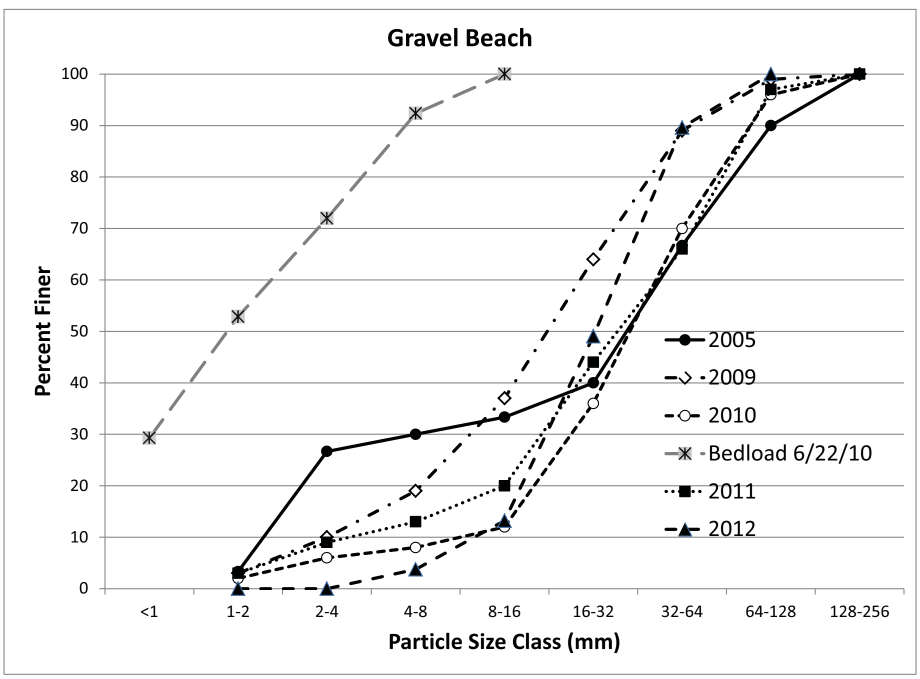

Figure 8. Cumulative frequency plot of bed material at the Gravel Beach cross section over five years of data. The bed load sample from 6/22/10 is shown to illustrate the sand-sized nature of the sediment in transport through the cross section, versus the coarser bed material (D50 is gravel and coarser). Note that 2005 data are for 30 clasts, whereas all other years are 100 clasts. Pebble counts were not conducted in 2013 due to flooding that affected road access and the fall closure of RMNP.