# USING 15-MINUTE ACOUSTIC DATA TO ANALYZE SUSPENDED-SEDIMENT DYNAMICS IN THE RIO GRANDE IN THE BIG BEND REGION

**David J. Dean, Hydrologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center, Flagstaff, Arizona, djdean@usgs.gov; David J. Topping, Research Hydrologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center, Flagstaff, Arizona, dtopping@usgs.gov; Ronald Griffiths, Hydrologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center, Flagstaff, Arizona, rgriffiths@usgs.gov; Thomas A Sabol, Hydrologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center, Flagstaff, Arizona, tsabol@usgs.gov; John C. Schmidt, Professor, Utah State University, Logan, Utah, jack.schmidt@usu.edu; Jeffery Bennett, Physical Scientist/Hydrologist, National Park Service, Big Bend National Park, Texas, jeffery_bennett@nps.gov**

## INTRODUCTION

The Rio Grande in the Big Bend region is subject to rapid geomorphic change consisting of channel narrowing during years of low flow, and channel widening during rare, large, long duration floods. Since the 1940s, there have been large declines in mean and peak stream flow, and the channel has progressively narrowed. Large, channel widening floods are infrequent and have failed to widen the channel to widths measured prior to the onset of channel narrowing in the 1940s. Before the most recent channel-widening flood in September 2008, the Rio Grande in the Big Bend was more than 50 percent narrower than measured in the 1940s.

Channel narrowing results in increased flood frequency and flood magnitude due to the loss of channel capacity and flood conveyance (Dean and Schmidt, 2011). Channel narrowing also results in the loss of important aquatic habitats such as backwaters and side-channels, because these habitats accumulate sediment and are converted to floodplains. Environmental managers are attempting to construct an environmental flow program for the purposes of minimizing channel narrowing during low flow years such that channel capacity, flood conveyance, and important aquatic habitats are maintained. Effective mitigation of channel narrowing processes requires an in-depth understanding of the predominant sediment source areas, the quantity of sediment input from those source areas, the parts of the flow regime responsible for the greatest sediment deposition, and the effect of managed flows in ameliorating the sediment loading that occurs within the channel.

Here, we analyze data collected with acoustic instrumentation at high temporal resolution to quantify suspended-sediment transport during a variety of flood types. We also investigate the effect of long duration managed flows in promoting sediment export and minimizing channel narrowing.

## STUDY AREA AND BACKGROUND

The Rio Grande in the Big Bend region of the Chihuahuan Desert extends from the confluence with the Rio Conchos 490 km downstream to Amistad Reservoir (Figure 1), and is the international boundary between the United States and Mexico. Prior to the 1940s, the hydrology of the Rio Grande in the Big Bend region was comprised of a snowmelt flood pulse in late spring and early summer from the upper Rio Grande, followed by a much larger summer flood pulse from the Rio Conchos basin driven by rains of the North American Monsoon and dissipating tropical storms in northern Mexico (Dean and Schmidt, 2011; Dean et al., 2011, Dean and Schmidt, 2013). Dam construction and agricultural diversions on the upper Rio Grande completely eliminated the spring snowmelt pulse from the Rio Grande in the Big Bend by the 1940s (Dean and Schmidt, 2011). Dam construction and water development on the Rio Conchos also contributed to reductions in mean and peak flow on the Rio Grande in the Big Bend region, however, large floods driven by dissipating tropical storms in northern Mexico occasionally still occur on the Rio Conchos when reservoir capacity is exceeded (Dean and Schmidt, 2013).

The current flood hydrology of the Rio Grande is highly variable. The lowest flows occur during the winter and spring, and base flows are commonly less than 1.5 $m^3/s$. High flows usually begin in May and June and can be generated by localized, convective thunderstorms lasting a few hours or days, or can be caused by longer duration dam releases from Luis L. Leon Dam on the Rio Conchos. Flash floods associated with convective thunderstorms contribute large amounts of sediment to the Rio Grande. Dam release floods from Luis L. Leon Dam are generally of moderate magnitude (40 to 200 $m^3/s$) and usually last longer than 5 days. Channel reset floods have peak discharges greater than 1,000 $m^3/s$, and have durations of weeks to months. Floods of this magnitude were common in the early 1900s, but are now rare.

Geomorphic investigations show that the modern Rio Grande in the Big Bend region is a river in geomorphic disequilibrium (Dean and Schmidt, 2011; Dean et al., 2011, Dean and Schmidt, 2013). This disequilibrium is characterized by channel narrowing over decadal timescales, and episodic channel widening during large floods (i.e., channel reset events, >1,000 $m^3/s$) originating in the Rio Conchos basin. Between channel reset events, the Rio Grande rapidly narrows by oblique and vertical accretion of fine sediment on floodplains and formerly active channel bars. Between 1991 and 2008, the river narrowed between 36 and 52 percent through the accretion of sediment that exceeded three meters in thickness (Dean and Schmidt, 2011; Dean et al., 2011). The most recent channel resetting flood occurred in 2008 and the channel is in a new phase of narrowing (Dean and Schmidt, 2013). The rapid rates of channel narrowing and sediment accumulation in the Rio Grande indicate that the river presently resides in a state of sediment surplus. Although general patterns of sediment surplus have been described, sediment inputs, and sediment-transport processes associated with this surplus condition remain unquantified.

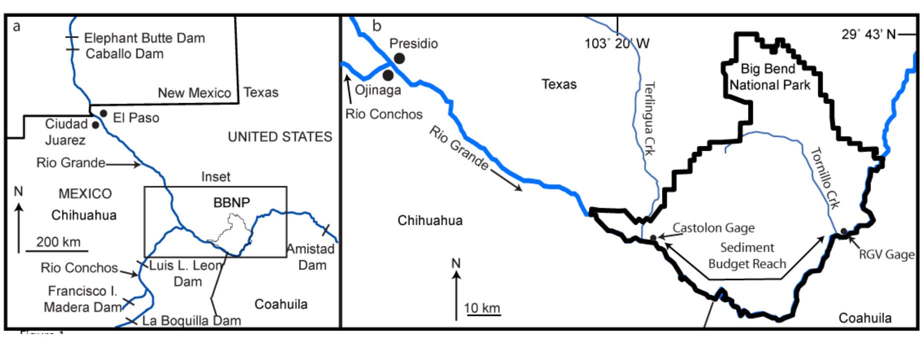


Figure 1 (a) Map of the Big Bend region. (b) Study Area

Little is known of the relative contributions of sediment from various source areas, the ranges in suspended-sediment concentrations and loads associated with different types of floods, the longitudinal trends and continuity of sediment transport along the river corridor, and whether all flood events or only a subset of floods contribute to the sediment surplus condition. We use 15-minute stream-flow and suspended-sediment transport data collected using acoustic instrumentation at discrete locations along the Rio Grande to begin to address these knowledge gaps. Using these data, we analyze suspended-sediment dynamics during two parts of the flood regime, (1) short-duration tributary-derived flash floods, and (2) longer-duration dam release floods from Luis L. Leon Dam on the Rio Conchos. We analyze the degree to which flash floods contribute to sediment accumulation within the channel, and examine the hypothesis that dam releases help to ameliorate sediment surplus conditions.

## METHODS

**Continuous Acoustic Suspended-Sediment Monitoring:** In rivers, the concentrations of some grain-size fractions of suspended sediment are typically controlled or regulated by changes in the upstream supply of those fractions. These supply-driven changes in suspended-sediment concentration can vary somewhat independently of the water discharge (Colby, 1963; Guy, 1970; Dinehart, 1982; Topping et al., 2000a, 2000b). The development of a progressive lag between suspended-sediment concentration and the kinematic discharge wave during a flood may result in poor correlation between water discharge and suspended-sediment concentration (Heidel, 1956; Dinehart, 1982). Increased form drag caused by bedform development during floods may also result in reduced suspended-sediment concentrations for the same discharges (Kleinhans et al., 2007). In the case of the Rio Grande in the Big Bend region, the upstream supplies of water and sediment are at times completely decoupled. Water during low flows is primarily supplied from the dam-regulated Rio Conchos and shallow aquifers, whereas water during high flows may be supplied from the Rio Conchos, any number of ephemeral tributaries within the region, and occasionally from the Rio Grande upstream from the Rio Conchos. Sediment is generally supplied by the Rio Conchos, local tributaries, and during higher discharge, may also be supplied by erosion of the floodplains that have developed in the formerly braided channels of the Rio Grande. Thus, at no time can stable relations between the discharge of water and suspended-sediment concentration be assumed.

Computation of accurate sediment loads in rivers where the transport of suspended sediment is, at least partially, regulated by changes in the upstream sediment supply requires high-resolution measurements of suspended-sediment concentration that are discharge-independent. To make these discharge-independent measurements of suspended-sediment concentration and grain size at high temporal resolution, we use a multi-frequency acoustic method that was developed and tested on the Colorado River in Grand Canyon National Park (Topping et al., 2004; Topping et al., 2007). This method utilizes 15-minute measurements of acoustic attenuation and backscatter using an array of 1 and 2 MHz side-looking acoustic-Doppler profilers (Topping et al., 2015). The basics of this method are as follows: (a) acoustic attenuation is used to calculate the velocity-weighted suspended-silt-and-clay concentration in the river cross section, (b) acoustic backscatter is used to calculate the apparent suspended-sand concentration at each frequency corrected for the backscatter produced by the silt and clay, (c) the apparent suspended-sand concentrations calculated at each acoustic frequency are then used in combination with theory to calculate an unbiased two-frequency measure of the velocity-weighted suspended-sand concentration and median grain size in the river cross section.

In November 2010, the USGS Grand Canyon Monitoring and Research Center (GCMRC), Utah State University (USU), and the National Park Service (NPS) installed two continuously operating suspended-sediment gaging stations on the Rio Grande near Castolon, Texas, and Rio Grande Village, Texas (Figure 1b). The Castolon sediment gage (Rio Grande above Castolon, Texas, 08374535) was established approximately 1.8 km upstream of the Castolon stream gage (Rio Grande near Castolon, Texas, 08374550), and the RGV sediment gage (Rio Grande above Rio Grande Village, Texas, 08375295) was established approximately 400 m upstream from RGV stream gage (Rio Grande at Rio Grande Village, Big Bend National Park, Texas, 08375300). Each sediment gage consists of a 1 MHz and 2 MHz side-looking acoustic-Doppler profiler, and an ISCO 6712 automatic pump sampler[1]. For ease of communication, the Castolon and RGV sediment and stream gages are referred to as the Castolon and RGV gages.

Acoustic attenuation and backscatter data were calibrated using physical suspended-sediment samples. At high flows, standard depth-integrated samples were collected using a US D-74 sampler (Edwards and Glysson, 1999) using the Equal-Width-Increment (EWI) method (Edwards and Glysson, 1999) at 10 equally spaced verticals across the channel using the additional transits recommended by Topping et al. (2011). At low flows, EWI measurements were made using a US DH-48 sampler and the same numbers of verticals and transits (Edwards and Glysson, 1999). During night-time hours, and when field crews were not available, suspended-sediment samples were collected automatically by the pump sampler. Samples collected by the pump sampler were calibrated to the cross section using paired EWI-pump measurements. These calibrations were developed for silt and clay and for multiple individual size classes of sand, as recommended by Edwards and Glysson (1999). The outcomes of the pump-sampler calibration are calibrated-pump measurements of the velocity weighted suspended-silt-and-clay concentration, suspended-sand concentration, and suspended-sand median grain size (albeit with larger error than the EWI measurements).

Sediment loads were calculated using the calibrated acoustic data, the EWI measurements, and the calibrated-pump measurements using the standard methods described by Porterfield (1972). Calibrated acoustic data at the two sediment gages were combined with discharges measured at the nearby Castolon and RGV stream gages to calculate instantaneous loads of suspended silt and clay and suspended sand. These instantaneous loads were then integrated over the hydrograph to calculate cumulative loads. Calibrated acoustic data include instantaneous concentrations of silt and clay, and sand, and the instantaneous median grain size of the suspended sand. All EWI and calibrated-pump and acoustic data are available on the USGS-GCMRC website, http://www.gcmrc.gov/discharge_qw_sediment/. This website also includes a sediment budget tool that calculates the change in sediment storage between the Castolon and RGV gages (i.e. the sediment budget reach) for any time period of interest. Uncertainty bands calculated using the sediment budget tool include biases in discharge calculations, uncertainty in the quantity of sand bedload (assumed to be 5% of total sand load), small biases in the

[1] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

suspended-sediment measurements, and uncertainty in the contribution of suspended sediment from ungaged tributaries.

## RESULTS

Here, we examine suspended-sediment transport dynamics during two parts of the Rio Grande flow regime. First, we analyze suspended-sediment transport during two periods when flash floods occurred in 2011 and 2013. The periods of flash floods are just two of many that have occurred since installation of the sediment gages, and are discussed here because they are representative of these types of events. Second, we analyze suspended-sediment transport during longer duration dam release floods that occurred in 2011, 2012, and 2013.

**Sediment Dynamics During Flash Floods:** Flash floods generally cause sediment deposition within the channel. Large suspended-sediment concentrations occur during flash floods, however, discharge and suspended-sediment concentration can attenuate rapidly downstream. This is clearly illustrated during the flash flood that occurred on 6/2/2011 as depicted in Figure 2a-d. This flood was sourced in the Rio Conchos basin and was nearly 200 $m^3$/s at the confluence of the Rio Conchos and the Rio Grande. At the Castolon gage, over 125 km downstream, discharge attenuated to 80 $m^3$/s, and was only approximately 20 $m^3$/s at the RGV gage (see Figure 1 for locations).

Sediment concentrations also significantly attenuated downstream. At the Castolon gage, the peak silt and clay concentration was 14,200 mg/L, and downstream, at the RGV gage, the peak silt and clay concentration was an order of magnitude less at 1,470 mg/L (Figure 2a). The peak sand concentration at the Castolon sediment gage was 260 mg/L, and was less than one mg/L at the RGV sediment gage (Figure 2b). The nearly complete attenuation of flow and sediment resulted in the deposition of more than 96 percent of the silt and clay load, and 100 percent of the sand load between the Castolon and RGV sediment gages during this flood.

For the same supply of sand on the bed, increases in flow will result in increases in the concentration and grain size of suspended sediment (Rubin and Topping, 2001). Thus, if increases in flow cause increases in suspended-sediment concentration and decreases in suspended-sediment grain size, changes in the sediment supply occurred (either from upstream or the floodplains). During the flash flood depicted in Figure 2a-d, silt and clay concentrations were higher on the falling limb of the flood (Figure 2a, c), resulting in a strong counterclockwise hysteresis loop for discharge and silt and clay concentration (Figure 2c). This indicates that a progressive lag developed between the kinematic discharge wave and the suspended silt and clay; the water and sediment both had the same tributary source, but the kinematic discharge wave “outran” the suspended sediment traveling at or below the velocity of the water. Sand concentrations however, was greatest during the largest discharges (Figure 2b), but the largest concentrations had the finest grain sizes (Figure 2d). Thus, silt and clay transport at both gages was primarily controlled by the upstream supply of sediment and the downstream rate of sediment transport relative to the flood wave, and not flow magnitude at the sediment gages. The negative relationship between suspended sand concentration and the grain size of suspended sand whereby the grain sizes of the suspended sand were finer for increasing concentration (Figure 2d) also indicate that sand transport at Castolon was controlled by the upstream supply.

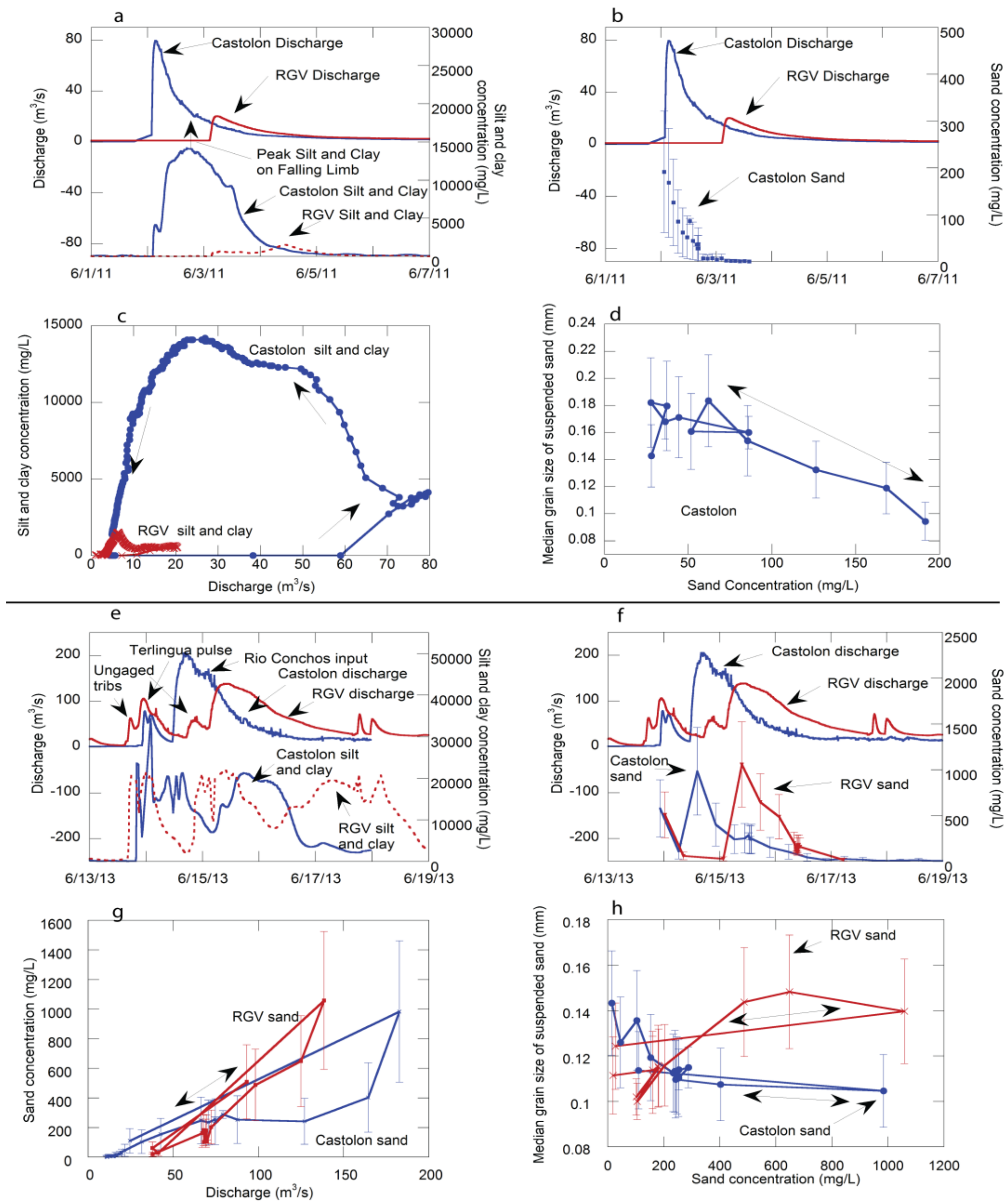


Figure 2 Suspended-sediment dynamics for flash flood between 6/2/2011 and 6/6/2011 (days 244-248)(a-d). Time series of discharge and sediment concentration are shown in (a) and (b). Counterclockwise hysteresis loop between discharge and silt and clay concentration shown in (c), and declines in sand grain size with increasing concentration show in (d). Suspended-sediment dynamics for flash flood event between 6/13/2013 and 6/19/2013 (days 986-992)(e-h). Time series of discharge and sediment concentration are shown in (e) and (f). Relations between discharge and sand concentration shown in (g), and relations between sand concentration and grain size shown in (h). Double-headed arrows show relations that are roughly linear in nature. Time-series are in days since 10/1/2010 because the start of the 2011 water year roughly corresponds to the installation date of the sediment gages. Data in b,d, and f-h show physical measurements only because some short-term biases existed in the acoustic data.

The second period of flash flooding shown here occurred between 6/13/2013 and 6/19/2013 (days 986-992, Figure 2e-h), and consisted of many flash floods from multiple source areas, including: ungaged tributaries both upstream and within the sediment budget reach, Terlingua Creek which is a large tributary approximately 9 km upstream from the Castolon gage, and a much larger pulse of water from the Rio Conchos. Peak flow magnitudes were more than twice as large as the previous flash-flood example.

Suspended-sediment dynamics were much more complex during the 2013 floods compared to in the 2011 flash flood example. The largest spikes in sediment concentration occurred at Castolon and were driven by the flash flood from Terlingua Creek. Silt and clay concentrations were over 34,000 mg/L, and sand concentrations were 877 mg/L at the Castolon sediment gage during this initial spike (Figures 2e-f).

With the exception of the initial flash from Terlingua Creek, concentrations of both silt and clay and sand during the remaining high flows were roughly equal at the two gages (Figure 2e-f). However, there was significant discharge attenuation between the Castolon and RGV gages, and thus, elevated sand concentrations occurred for a shorter period of time at the downstream RGV gage (Figure 2e-f). The attenuation of flow, and the shorter duration of elevated sediment concentrations at the downstream gage, resulted in the deposition of approximately 18,000 metric tons of sand, and over 110,000 metric tons of silt and clay.

Sand concentration at both sites increased relatively linearly with increasing discharge (Figure 2f-g). However, the suspended sand was finest at higher discharges at Castolon (Figure 2h), and the suspended sand was the coarsest at higher discharges at RGV. Thus, suspended-sand transport at Castolon was partially regulated by the upstream supply as evidenced by the fining of the suspended sand at the highest discharges, whereas sand transport was mostly regulated by flow at RGV, because larger discharges always transported more sand, and the median grain sizes of sand coarsened with increasing discharge. Higher sand concentrations, and coarser grain sizes with increasing discharge suggest that transport at RGV was primarily controlled by flow. Thus, sand transport at the two gages was controlled by different mechanisms (i.e. supply vs flow), and this is depicted in the different trends between sand concentration and the median grain size of sand in transport.

**Sediment Dynamics During Dam Release Floods:** Floods have been released annually from Luis L. Leon Dam since 2011. Here, we discuss some of the basic sediment-transport data from these releases. The first two dam release floods (2011 and 2012) were both of similar magnitude and duration; they were both between 50 and 70 $m^3$/s, and each lasted approximately 8-10 days (Figure 3a-b). The 2013 dam release flood (Figure 3c) consisted of three distinct pulses over the duration of approximately two and half months. The initial pulse was steady at approximately 180 $m^3$/s for approximately 15 days. The second pulse lasted approximately 10 days and peaked at 80 $m^3$/s, and the third pulse was steady at approximately 110 $m^3$/s for about 10 days. During each of the dam release floods, there were concurrent flash floods, indicated by the abrupt discharge spikes shown in Figure 3. These are not the same flash floods described in the previous section of this paper.

**Trends in Suspended-Sediment Concentration and Grain Size During Dam Release Floods:** Trends in sediment concentration and grain size for the three dam release floods provide insight into the relative supply of sediment near the sediment gages, and the evolution of the sediment supply over time. During the steady-state parts of each dam release, mean silt and clay concentrations were larger downstream at RGV compared to concentrations at Castolon (Figure 4a). The largest mean silt and clay concentrations occurred in 2012, and this was likely a result of the frequent 2012 flash flood activity that occurred before and during the dam release, thereby increasing the supply of silt and clay within the channel. The lowest mean silt and clay concentrations occurred during the largest and longest duration dam releases in 2013. The smaller silt and clay concentrations in 2013 indicate that the supply of readily-transportable silt and clay within the channel had been depleted over the longer duration of these dam releases.

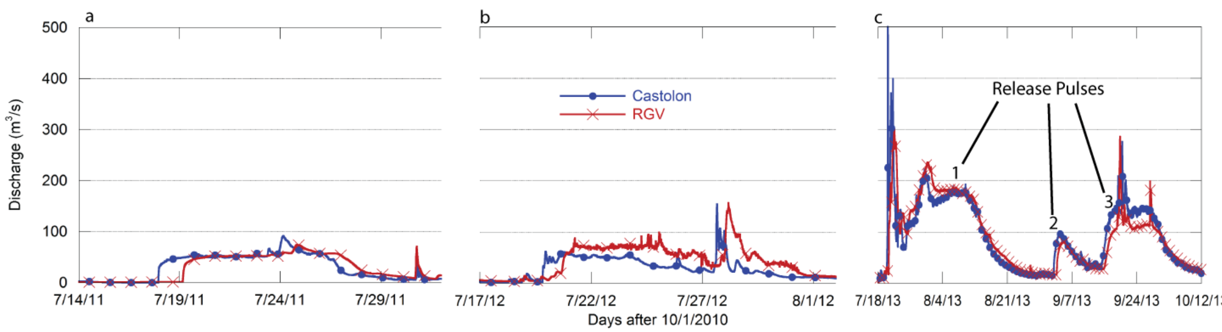


Figure 3 Luis L. Leon Dam releases in 2011 (a), 2012 (b), and 2013 (c).

The trends of sand transport during the dam releases were different than the trends in silt and clay transport. In 2011 and 2012, sand concentrations during the steady-state parts of the releases at the Castolon sediment gage were roughly twice as large as concentrations measured at the RGV sediment gage (Figure 4a). In 2011, the mean sand concentrations were approximately 60 mg/L at the Castolon gage, and 34 mg/L at the RGV gage. In 2012, mean sand concentrations were approximately 230 mg/L at the Castolon sediment gage and 125 mg/L at the RGV sediment gage.

Unlike during the 2011 and 2012 releases, mean sand concentrations during the 2013 release were higher at the RGV gage than at the Castolon gage (Figure 4a). During the steady-state part of pulse 1, mean sand concentrations at the Castolon sediment gage were approximately 550 mg/L, and mean sand concentrations were 650 mg/L at the RGV sediment gage. During pulse 2, mean sand concentrations were 160 mg/L at the Castolon sediment gage, and 175 mg/L at the RGV sediment gage (Figure 4a), and during pulse 3, mean sand concentrations were 257 mg/L at the Castolon sediment gage, and 475 at the RGV sediment gage. Although the error bars overlap in 2011, 2012, and pulses 1 and 2 of 2013, the general shift from higher upstream sand concentrations in 2011 and 2012 to higher downstream sand concentrations in 2013 is important because it provides insight into the evolution of the sand supply near each gage.

The average median grain sizes of suspended sand were generally much coarser at Castolon than at RGV (Figure 4b). Median grain sizes at the two sites were only similar during the 2012 dam release, and during pulse 3 of the 2013 dam release (Figure 4b). The finer median grain sizes at

Castolon in 2012, and during pulse 3 of 2013 may have been influenced by the flash flood activity that occurred coincidently with the releases. Thus, the channel was likely enriched with respect to the finer fractions of sand antecedent to these releases.

In 2011 and 2012, the larger concentrations of sand at Castolon indicate that there was a greater sand supply upstream of the sediment budget reach, and that sand supply was also generally coarser than the sand at the RGV gage (Figure 4). The increase in concentration over time at the RGV sediment gage indicates that the sand supply in the downstream portion of the budget reach became enriched with respect to the sand supply that existed in 2011 and 2012. The increase in downstream sand supply was likely caused by the frequent flash flood activity that occurred between the 2012 and 2013 releases, which would have loaded the channel with sediment prior to the 2013 release.

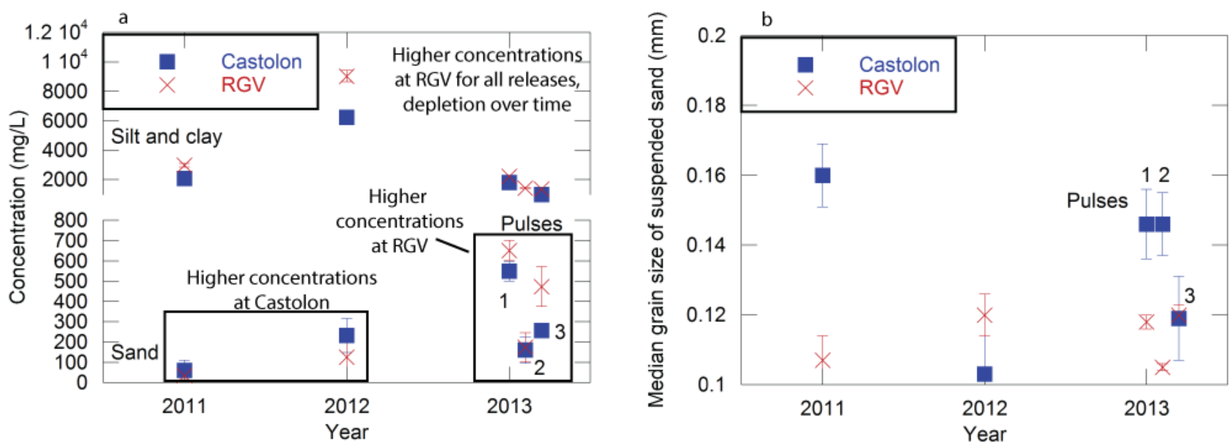


Figure 4 Mean sand concentrations (a) and median sand grain sizes (b) during the steady-state parts of the three dam release floods. Error bars represent 95 percent confidence intervals around the mean. For clarity, mean concentrations and median grain sizes were calculated without including the spikes in concentration during concurrent short-duration flash floods.

The long duration of the 2013 dam releases appears to have resulted in the partial depletion of transportable sand above the Castolon sediment gage. During the second and third pulses of the 2013 release, sand concentrations at the Castolon gage were much lower than concentrations during pulse one, which indicates that the sand supply was becoming depleted above/at the Castolon sediment gage, and erosion was occurring throughout the duration of the release. Sand concentrations during pulse 3 at RGV, however, were nearly as high as pulse 1 which indicates that erosion from upstream reaches was resulting in the enrichment of sand in the downstream parts of the budget reach.

**Analyses of the Change in Sediment Storage During Managed Flows:** Dam release floods have the potential to export sediment from the budget reach. The amount of export is controlled by the magnitude and duration of the releases, and the amount of sediment supplied from ephemeral tributaries. Analyses of the change in storage during the dam release floods show differing results over the three years; the central estimate of the silt and clay budget in 2011 was negative, while the central estimates of the silt and clay budgets in 2012 and 2013 were positive.

The central estimate of the change in storage for the silt and clay budget in 2011 indicates that 11,000 ± 25,000 metric tons of silt and clay were eroded from the budget reach (Figure 5a). A series of flash floods during the second half of the flood offset some of the export that occurred during the first half, and the uncertainty bands indicate that the silt and clay budget in 2011 was indeterminate (Figure 5a). During the steady-state part of the dam release flood, however, the silt and clay budget was clearly negative, which indicates that erosion was occurring throughout the duration of the release (Figure 5a). The central estimates of the change in the storage of silt and clay for the 2012 and 2013 dam release floods were both positive, yet the uncertainty bands indicate that the silt and clay budgets in these years were also indeterminate. Approximately 56,000 ± 244,000 metric tons of silt and clay accumulated during the 2012 release, and 250,000 ± 850,000 metric tons of silt and clay accumulated during the 2013 releases. Similar to the 2011 release, the estimate of the change in storage during the 'steady-state' parts of these releases do show that silt and clay was being eroded (Figures 5c, e). Flash flood activity during these floods, however, offset these negative changes in the budgets.

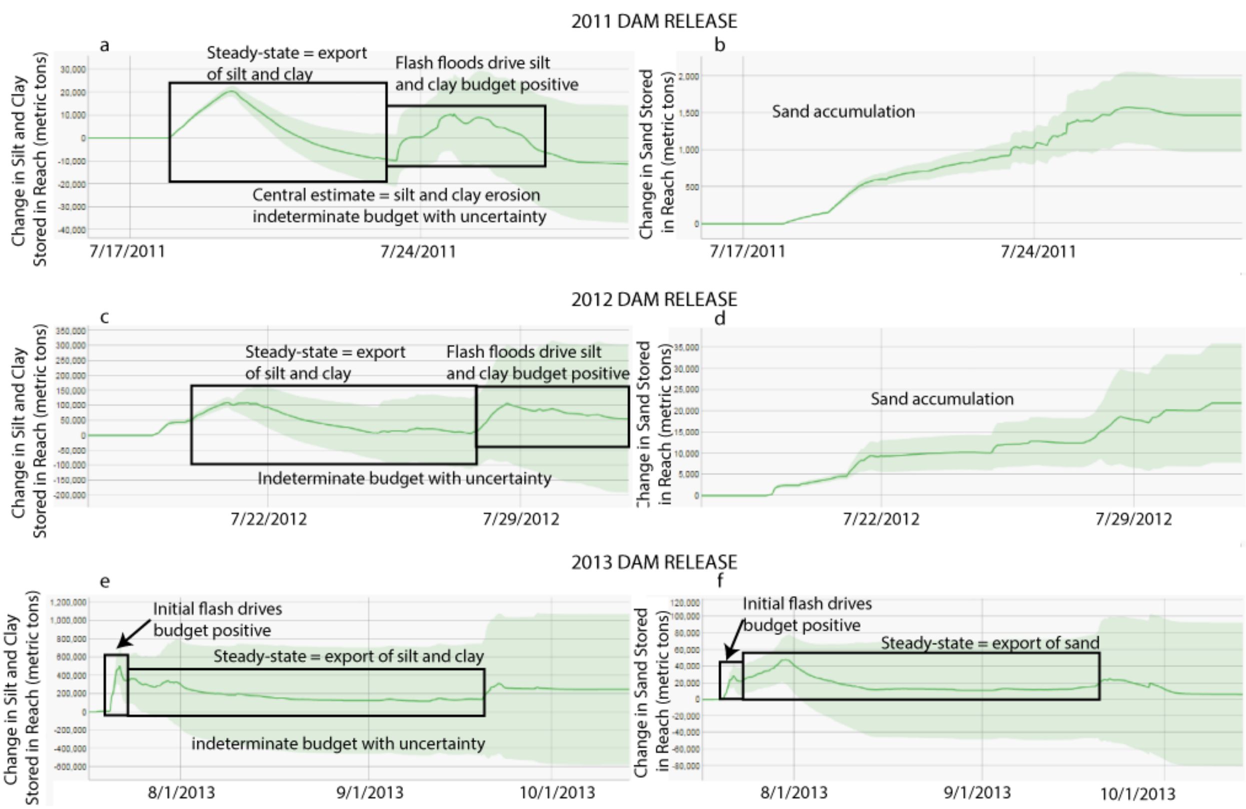


Figure 5 Changes in sediment storage for the 2011(a-b), 2012 (c-d), and 2013 (e-f) dam release floods.

Positive changes in the storage of sand occurred during the 2011 and 2012 dam release floods. In 2011, the budget reach accumulated 1,500 ± 500 metric tons of sand, and in 2012, the budget reach accumulated 21,000 ± 14,000 metric tons of sand. These changes were primarily driven by the much larger suspended-sand concentrations upstream at the Castolon sediment gage, thereby resulting in more sediment being transported into the budget reach than was exported. In 2013, the larger downstream sand supply, and the larger suspended-sand concentrations at RGV relative to Castolon resulted in a sediment budget that was much less positive compared to 2011 and 2012 (6,400 ± 86,600 metric tons), and the 2013 sand budget was indeterminate. Although many of the sediment-budget predictions were indeterminate during the dam release floods, general trends in the central estimate of the change in storage offer important insights into the erosion and deposition patterns during these releases. Additionally, specific trends in concentration and median grain size obtained from the acoustic data help corroborate these trends.

## CONCLUSIONS

The Rio Grande in the Big Bend region is in a stage of channel contraction following the 2008 channel resetting flood. Channel contraction occurs through the accumulation of sediment within the channel, and on bars and floodplains. The sediment responsible for this contraction is largely supplied by tributary-derived flash floods during the summer thunderstorm season. Continuous suspended-sediment monitoring at two sites on the Rio Grande has provided the ability to constrain the sediment contributions during tributary floods, and evaluate the impacts of long-duration dam release floods in alleviating the degree of tributary-sourced sediment loading that occurs.

Although the general sediment conditions on the Rio Grande consist of sediment surplus, periods of sand supply limitation can persist in downstream reaches after channel reset floods until the tributary sediment supply overwhelms the enlarged channel. Sand supply limitation was observed during the dam release floods in 2011 and 2012 whereby sand concentrations were much higher upstream at the Castolon sediment gage compared to the RGV gage downstream. Frequent summer storm activity, and associated flash floods, resulted in increases in the downstream sand supply by 2013. This increase in the downstream sand supply was apparent during the 2013 dam release because suspended-sand concentrations were larger in downstream reaches compared to upstream reaches for the same discharges. Continuous 15-minute sediment transport measurements provided the means for identifying these temporal changes in supply.

Analyses of suspended-sediment transport during long-duration dam releases shows that during the steady-state parts of these releases, sediment is evacuated from the sediment budget reach. This is corroborated by the decrease in sand concentration at the upstream gage for the same discharges during the 2013 dam release, the negative changes in the storage of silt and clay during the steady-state parts of the dam releases, and the decline in suspended sediment concentrations throughout the duration of the 2013 dam release. However, the amount of sediment evacuated during steady-state dam releases may be completely offset by sediment contributions from just a few flash floods. Therefore, larger or longer duration dam releases than those observed during the 2010-2013 period of this study are likely required to result in net sediment evacuation, channel enlargement, and habitat maintenance.

## ACKNOWLEDGEMENTS

This study was funded by the NPS, USGS, and the Commission of Environmental Cooperation. Thanks to Joe Sirotnak, Phil Wilson, Billie Brauch, David Larson, Keith Sauter and the NPS

River Rangers at Big Bend National Park. Special thanks to Hunter Edwards, Jeff Kelsch, Jeff Renfrow, Kelon Crawford, Dana Milani, and Trevor Bryan for their endless days in the field.

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