Acoustic Measurements on a Shallow, Sand-Bed River: A Case Study from the Rio Grande

Jonathan AuBuchon, Regional Sediment Specialist, U.S. Army Corps of Engineers (USACE) - Albuquerque District, Albuquerque, NM, Jonathan.S.Aubuchon@usace.army.mil
David Abraham, Retired Research Hydraulic Engineer, formerly with USACE – Engineering Research and Development Center (ERDC), Vicksburg, MS
Ari Posner, Physical Scientist, U.S. Department of the Interior, Bureau of Reclamation (Reclamation) – Albuquerque Area Office, aposner@usbr.gov
Jeb Brown, U.S. Geological Survey, Hydrologist, New Mexico Science Center, Albuquerque, NM, jebbrown@usgs.gov
Tony Jackson, Research Scientist, USACE – ERDC, Vicksburg, MS, Anthony.R.Jackson@usace.army.mil
Ronald E. Griffiths, U.S. Geological Survey, Hydrologist, Grand Canyon Monitoring and Research Center (GCMRC), Flagstaff, AZ, rgriffiths@usgs.gov

Abstract

The Middle Rio Grande (MRG) is a dynamic and complex fluvial system where flow and sediment transported from the Upper Rio Grande and MRG tributaries influence the form of the river. How sediment is transported through the MRG is an important planning question as it addresses a wide range of concerns including flood control and river rehabilitation, thus continuous sediment measurements are needed to develop accurate sediment budgets.

Sediment measurement techniques have continued to improve and the advent of sediment surrogates, such as acoustic technology, has proven to be an effective option to obtain more complete spatial and temporal sediment data in larger fluvial systems. Measurements of sediment in shallow, sand bed rivers like the Rio Grande are more difficult because of the changing channel morphology and often limited water depth in which to install instrumentation. During the 2019 spring snowmelt runoff season, two acoustic techniques were employed and compared on the Rio Grande to evaluate sediment movement. Sediment movement near the bed was calculated by the Integrated Section Surface Difference Over Time version 2 (ISSDOTv2) using swath data collected from a multi-beam sonar. Measurements were made adjacent to U.S. Geological Survey (USGS) streamgaging stations where near simultaneous measurements were made by the USGS for streamflow, suspended-sediment concentration and gradation, and bed-material gradations. These measurements were conducted at two locations on the Rio Grande; one of the locations was co-located with two side-profiling suspended-sediment acoustic Doppler profilers that had been installed in the fall of 2016. Both a 1 MegaHertz (MHz) and 2 MHz side-profiling suspended-sediment acoustic Doppler instrument were installed on a fixed platform that was co-located with a USGS sediment gage.

The ISSDOTv2 method using multi-beam sonar and the side-profiling acoustic Doppler current profilers proved successful in collecting sediment information and compared well with the more traditional sediment measurements, providing insight into the sediment transport on the MRG because of the increase in spatial and temporal resolution. Overall, there are some limitations of these acoustical techniques, but the additional information gleaned is beneficial in understanding sediment transport in a shallow, sand-bed river, such as the Rio Grande.

Introduction

Sediment plays an important ecological function in water bodies throughout the United States. Too much or too little sediment can cause problems in fluvial systems that not only impair the riverine ecosystem, but also engineering systems, such as dams, reservoirs, water diversions, etc. For this reason, the transport of sediment in rivers is a critical question for managers concerned with river rehabilitation, irrigation and water diversion projects, water storage, water navigation, and water quality (Fripp et al., 2019; Kuhn et al., 2019; Travis et al., 2019). The collection and analysis of data help to better understand the relation between streamflow and sediment transport, facilitating better management of the fluvial system.

Background

Sediment transport can be classified in a variety of ways. The most common is by the transport mechanism (Julien, 2010). If the material is carried in suspension by the flowing water, it is referred to as suspended load. If the material moves along the bed of the river by saltation, rolling, sliding, etc., it is referred to as bedload. The combination of these two is referred to as the total load. Because the bed of the MRG predominantly moves as sand dunes, the term bedload herein refers to bedload moving as sand dunes, although it may also include the occasional gravel. The term sand total load is the sum of the bedload and the sand fraction of the suspended sediment. Since sand is found in the preponderance of material on the bed of the Rio Grande, hereinafter the sand total load is called the bed-material load. The 2019 sampling effort on the MRG focused on the bed-load and suspended-sediment loads and their combination (total load). During data analysis, the bed-material load was also evaluated. The sediment loads are discussed in terms of mass loading and particle-size composition.

Direct sampling methods have been developed over the decades to provide information related to the suspended-sediment load, the bedload, and the bed-material composition (Davis, 2005; Edwards and Glysson, 1998; Gray and O'Halloran, 2015; Gray and Simoes, 2008), but they lack the temporal and spatial resolution needed to accurately answer the questions related to how sediment moves within a fluvial system (Topping and Wright 2016). The limitations associated with direct sampling methods result in a knowledge gap that has historically been filled by using streamflow as a surrogate measurement for sediment transport and creating rating curves to estimate the sediment transport. This relation, however, is typically poorly correlated, with 1-3 orders of magnitude difference between a best fit rating curve and the collected samples (Mussetter Engineering, Inc. (MEI), 2002). Analytical methods (usually called 'transport functions') have also been developed to estimate the bed-load and/or total load by utilizing the flux of water and information on the bed material and/or measured sediment quantities, typically suspended-sediment information. On the MRG, the Bureau of Reclamation has utilized the Modified Einstein Procedure (Bureau of Reclamation Automated Modified Einstein Procedure or BORAMEP) (Holmquist-Johnson et al., 2009) to provide an estimate of the total and bed- load (primarily sand on the MRG).

With the advancement of acoustic collection devices, such as the multi-beam sonar, increased temporal and spatial resolution of datasets have become available. The higher resolution of these surfaces has provided an opportunity to assess real-time changes in the sediment moving near the bed of the river. Techniques such as Integrated Section Surface Difference Over Time version 2 (ISSDOTv2; Abraham et al., 2011; Abraham et al., 2017; Shelley et al., 2013; U.S. Army Corps of Engineers [USACE], 2018), have been developed to capture and estimate the amount of bed-load moving as dunes. The combination of bed-load assessments and parsing the measured suspended-sediment load by the sand fraction provides an opportunity to evaluate the bed-material load on the MRG without an unmeasured zone. Although the ISSDOTv2 method has been implemented on larger rivers, shallow river systems, such as the MRG, pose difficulties with the ability to successfully use a multi-beam system to collect the necessary data.

Sediment data collection has advanced to include increased temporal resolution by using surrogate measurements, such as light, sound, or density (Rasmussen et al., 2009; Landers et al., 2016; Brown et al., 2015). When these surrogate measurements are paired with the strategic collection of direct physical samples, more information is collected at a fraction of the cost of a similar physical sampling program (Gray, 2002), providing a greater understanding of sediment transport. This information leads to improved decisions regarding engineering design, reservoir life cycle estimates, ecosystem rehabilitation design, etc. (Wood and Teasdale, 2013). Field research in sound surrogates, specifically active acoustics, has shown considerable promise over the last decade using commercially available equipment. Commercial acoustical instrumentation was originally designed for velocity measurements, but devices that have strict internal power regulation, creating a constant acoustic source level regardless of battery voltage fluctuations, can also provide meaningful suspended-sediment information (Topping and Wright 2016). Active acoustic measurements have been successfully utilized for suspended-sediment measurements on larger fluvial systems (Wood and Teasdale, 2013; Topping et al., 2015; Topping and Wright, 2016) where the influences of the bed morphology are not as influential on the suspended-sediment concentrations. Testing on shallow, sand bed rivers (depth of 10 feet or less) however has been limited to areas where there is sufficient flow depth at various streamflow stages without the potential for sediment burial.

Study Area

Active acoustics were tested during the 2019 spring snowmelt runoff in two different locales (Figure 1). The chosen locations were co-located at or near existing USGS streamgaging stations to take advantage of other sediment data being collected by traditional sediment data collection methods (Edwards and Glysson, 1999). The two locations selected were the Rio Grande at Albuquerque, NM (USGS site number 08330000; referred to herein as Albuquerque) and the Rio Grande at San Acacia, NM (USGS site number 08354900; referred to herein as San Acacia) (U.S. Geological Survey, 2022). At both locations, suspended-sediment samples are collected from single point automatic pump samplers to provide a suspended-sediment concentration at regular intervals and during streamflow events during the spring snowmelt and monsoon seasons. In addition, the USGS collects cross-sectional suspended-sediment and bed-material samples using the Equal Width Increment (EWI) method.

Approach

In the summer of 2019, the ISSDOTv2 method was employed on the MRG near the USGS stations at Albuquerque and San Acacia. The method requires spatial coverage of the entire channel section where dunes are propagating downstream as well as rapid temporal resolution of the datasets to capture dune movement before the dune translates a full wavelength. The information was collected by the U.S. Army Corps of Engineers, Engineering Research and Development Center (ERDC) using a multi-beam sonar coupled with real-time kinematic (RTK), global positioning system (GPS) measurements.

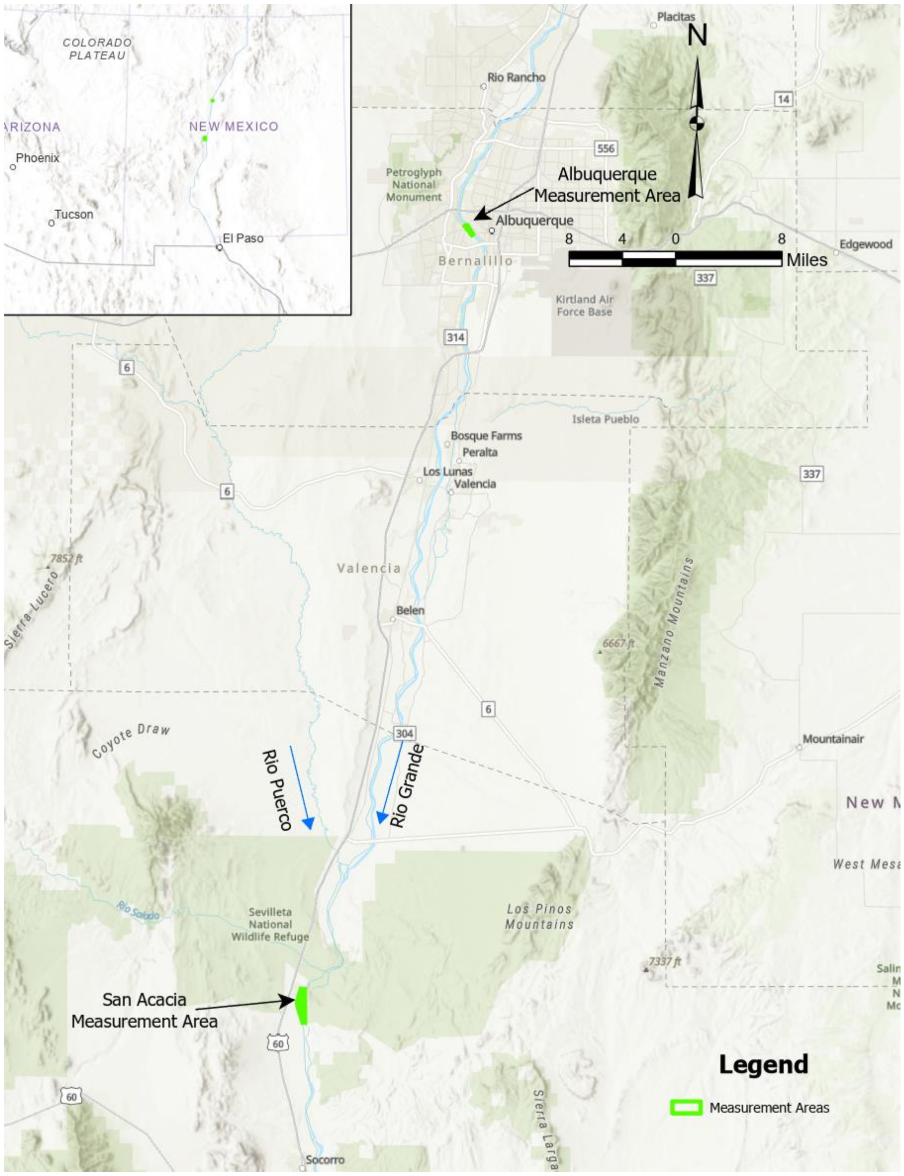

Figure 1. Measurement areas on the Middle Rio Grande. Background topography is from Esri accessed 21 March 2023.

Increased temporal resolution of the suspended sediment at San Acacia was achieved through active acoustics installed at the site since April 2016. Both a 1 MHz and 2 MHz active acoustic side profiler were deployed at this site. While ideally the acoustic instruments would be inundated throughout the year, this was thought to be problematic at this site because of potential burial or acoustic beam interference by the bed sediment which has been observed to change by as much as 5 feet over a season. Therefore, a special mounting setup, see Figure 2, was designed to situate the instruments near the channel thalweg at a set height above the observed baseflows (acoustic Doppler profilers inundated around a streamflow of 400 cubic feet per second [ft^3/s]). The acoustic Doppler profilers operated continuously through the 2019 spring snowmelt runoff season until early July 2019.

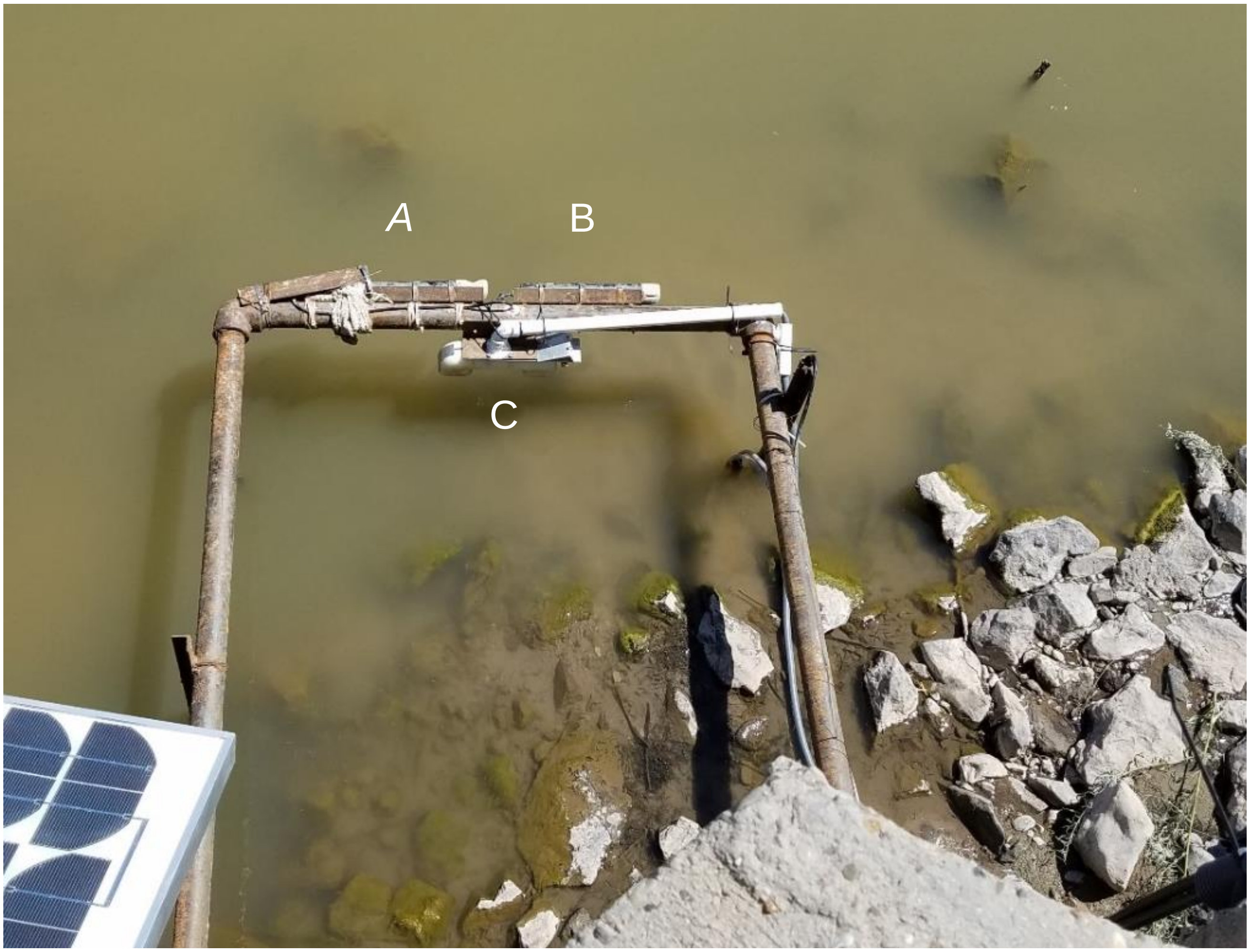

Figure 2. Active acoustic installations on the Rio Grande at San Acacia: A) 1 MHz and B) 2 MHz acoustic Doppler profilers. A third acoustic instrument (20 MHz, C) was also installed at this same location by the University of Mississippi National Center for Physical Acoustics (NCPA). Photograph taken by W. Carpenter (NCPA) on July 24, 2017.

Data Collection

The hydrograph from the 2019 spring snowmelt runoff is shown in Figure 3 for both Albuquerque and San Acacia. Streamflow and sediment data were retrieved from the National Water Information System (USGS, 2022). The runoff volume from 1 March through 31 July in 2019 was about 158% of the average daily streamflow based on an approximately 50-year period from 1 October 1970 through 30 September 2022 at the USGS streamgage station in Otowi, New Mexico (NM) (USGS site number 08313000). The acoustic Doppler profilers recorded data continuously through the beginning of June 2019. Streamflow at San Acacia is generally slightly less than at Albuquerque because of a combination of flow losses from irrigation diversions, groundwater loss due to perched channel conditions, and evapotranspiration.

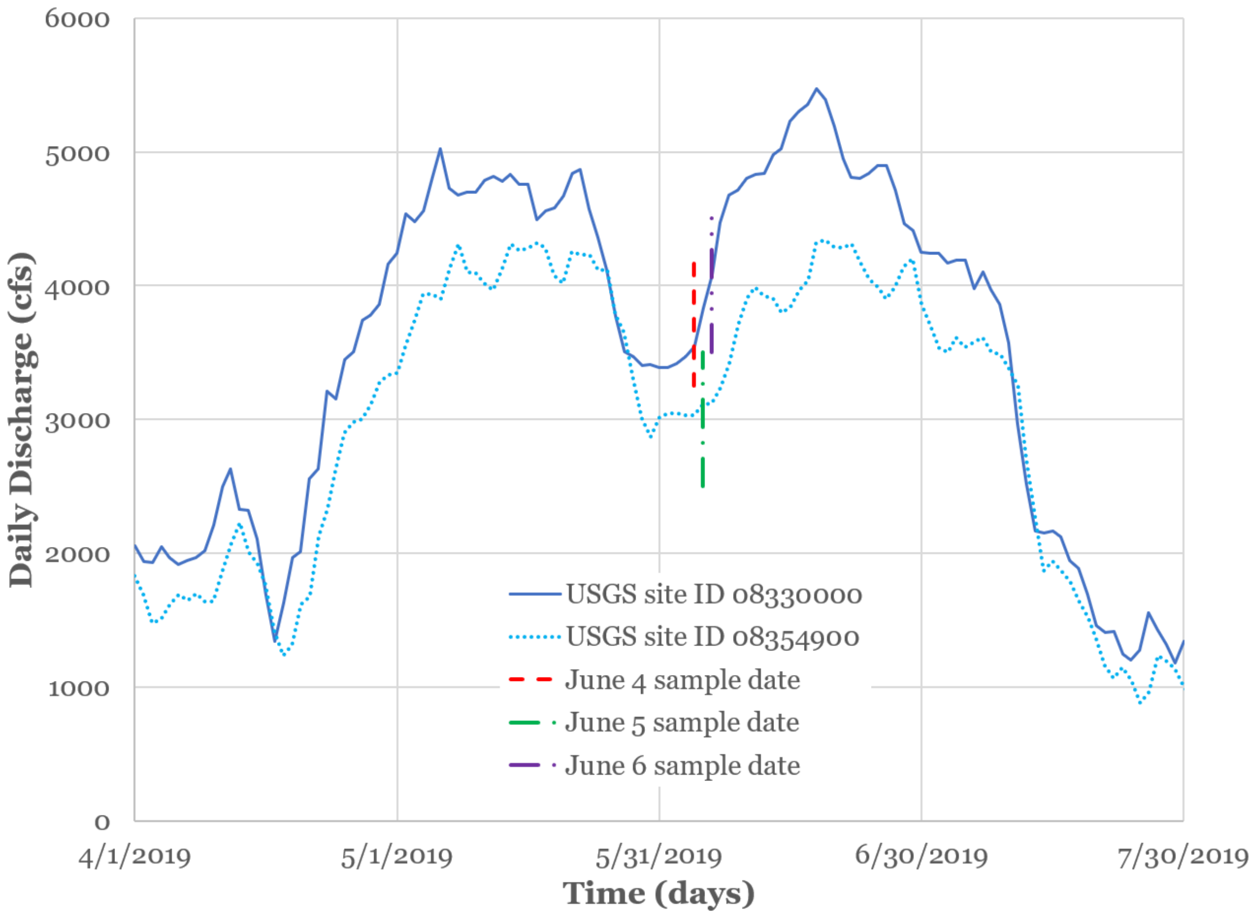

Figure 3. Daily streamflow hydrograph in cubic feet per second (ft^3/s) from Rio Grande at Albuquerque (USGS site number 08330000) and Rio Grande at San Acacia (USGS site number 08354900). The multi-beam and USGS EWI measurements were collected on June 4 and 6 at Albuquerque and June 5 at San Acacia.

To help with the calibration of the acoustic Doppler profilers as well as the semi-empirical estimation of a bed-load, physical sediment measurements (single point automatic pump samples and EWI samples) were collected at the two USGS stations. The acoustic Doppler profilers were installed in 2016 and the acoustic data through 2018 were coupled with the traditionally collected sediment data to calibrate the acoustic Doppler profilers. The acoustic Doppler profilers are configured such that they capture a horizontal slice of the river cross-section along two beams. In this way, a larger sample volume is collected that is calibrated to physical samples. These acoustical measurements provide a better temporal representation of the average suspended-sand concentration in the cross section than the relatively infrequently collected EWI or pump samples. The calibration was performed by the Grand Canyon Monitoring and Research Center using the more accurate EWI measurements for the sand calibration and the EWI and calibrated single point automatic pump samples for the silt and clay calibration. The calibration followed the general procedures listed by Topping and Wright (2016) and included performing ¼ phi gradation analyses using a laser diffraction instrument. The ¼ phi gradation laboratory analyses were necessary to calibrate the multi-frequency acoustic profiler pair to measure median-sand grain size and allow for the measurements of suspended-sand concentrations unbiased by changes in the suspended-sand grain size. A relatively large spring snow-pack runoff season in 2017 (133% of the average daily runoff from 1

October 1970 through 30 September 2022 at the USGS streamgaging station in Otowi, New Mexico) on the MRG provided a range in streamflow and suspended sediment sufficient for calibration of the acoustic Doppler profilers in advance of the 2019 spring snowmelt runoff season. During periods of data collection, the acoustic Doppler profilers measured sand concentrations, silt and clay concentrations, and sand grain size every 15-minutes. The accuracy of the acoustic Doppler profiler measurements in 2019 was assumed to be +/- 10% (Topping and Wright, 2016).

During the June 2019 ISSDOTv2 measurements, the USGS collected suspended-sediment samples near the station at Albuquerque and San Acacia. The suspended-sediment samples were collected using a depth integrated suspended-sediment sampler approved by the Federal Interagency Sedimentation Project (FISP) (Davis, 2005) following the EWI sampling method (Edwards and Glysson, 1998). A D-95 sampler was used at Albuquerque, and a DH-95 sampler was used at San Acacia. Ten sampling verticals along the river cross-section were utilized at Albuquerque and thirteen were employed at San Acacia. Two sample sets (A and B) were collected at each interval, according to guidance for minimizing the bias of the collected suspended-sediment samples (Gray and O'Halloran, 2015). The collected sample sets for each interval were visually inspected for consistency to ensure the sampler touched streambed properly and did not collect bed material sediments from a sand dune. A third sample set (C) was also collected at each of the sampling locations and composited at the laboratory to generate a suspended-sediment sample representative of the entire river cross-section.

The collected suspended-sediment samples analyzed at the USGS New Mexico Water Science Center Sediment Laboratory were processed for suspended-sediment concentrations (SSCs) and sediment-size gradations. The evaluation of the SSCs followed American Society for Testing and Materials (ASTM) D3977 Standard Test Methods for Determining Sediment Concentration in Water Samples (ASTM, 1997). The evaluation (Guy, 1969) of the sediment-size gradations (sand-fine split) included a wet sieving of the sample using a filter at the sand/fine boundary (.062 millimeters (mm). This process provided a percentage of the suspended-sediment sample that is composed of sands and fines. The sand fraction then underwent a gradation analysis using the visual-accumulation tube method (Colby and Christensen, 1956; Guy, 1969). If there were appreciable fines, a pipette analysis (Guy, 1969) was performed on a composite sample. The specific conductance of the water was also measured in the laboratory. Suspended-sediment concentrations, sand splits, and specific conductance were evaluated at both Albuquerque and San Acacia for all of the collected sample sets.

The USGS also collected bed material sediment samples at both Albuquerque and San Acacia. The bed material samples were collected using a FISP approved BMH-60 (Davis, 2005). Bed material samples were collected at the same locations as the SSC samples following methods described by Edwards and Glysson (1998). The collected bed material samples were analyzed at the USGS New Mexico Water Science Sediment Laboratory for evaluation of the sediment gradations according to ASTM D6913 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis (ASTM, 2017).

The ISSDOTv2 data were collected by ERDC using a boat with an RTK GPS receiver (Applanix Position and Orientation System (POS) for Marine Vessels (MV)) and Norbit wideband multibeam shallow water sonar system (see Figure 4). The swath width provided by the Norbit multi-beam system can be up to eight times the water depth per pass with a ranging accuracy of approximately 2.0 mm. The boat also utilized an inertial motion unit (Applanix POS MV inertial measurement unit (IMU)) and Hypack navigation and collection software. The Applanix POS MV is a high-performance GPS/IMU with the ability to receive real-time GPS/global navigation satellite systems (GNSS) satellite differential or RTK corrections providing post-processed centimeter level accuracy. Real-time RTK GPS corrections were supplied by a Trimble R8 GNSS receiver set over a known end point monument.

Figure 4. ERDC survey boat set up for the ISSDOTv2 data collection. The Applanix system is contained within the orange container on the boat. The Norbit multi-beam sonar is shown circled in green, while the Trimble R8 receiver is circled in orange. Note – the Norbit multi-beam sonar has not yet been placed under the water. Picture taken on the MRG, upstream of Central Avenue Bridge. Photograph by Jonathan AuBuchon, U.S. Army Corps of Engineers.

HYPACK positioning software was used to guide the vessel throughout the days of data collection. The crew used pre-loaded geo-referenced images for vessel navigation. The surveys were conducted from a 14-foot shallow draft boat equipped with a jet outboard. To process data using the ISSDOTv2 software, sonar data need to be collected over enough length of channel to capture multiple waveforms in a short period of time. The desire is to capture multiple snapshots of the dune movement prior to the waves translating an entire wavelength. It is also desirable to collect as much channel width as possible to capture the lateral variability of the bed forms. The subsequent resurveyed swaths must be run along the exact previous survey swath, in the same direction with the same vessel speed and conditions. This allows for a consistent time difference between swaths and provides increased accuracy of the resulting ISSDOTv2 calculations.

After the bathymetry survey was completed, all data files were moved to a computer for post-processing. The static GPS base station data files were sent to the National Geodetic Survey

Online Positioning User Service to verify base station coordinate accuracy. The Applanix POS MV data files created during collection were post-processed using the verified base station data files and the Applanix POSPAC Mobile Mapping Suite Software (Applanix, 2023). The resultant trajectory data were then exported and applied to the raw multi-beam data in HYPACK MBMAX processing software where outliers were removed, and point cloud files of the collected bathymetry were created.

Results

The following sections summarize results for the acoustical data collected in 2019.

USGS Data

Information about the total suspended sediment (concentration and gradations) and bed material (gradations) collected at Albuquerque and San Acacia is shown in Figure 5 (USGS, 2022). Variations across the cross-section were observed at both locations, with the larger percent sands in the suspended-sediment gradations tracking more closely with the high SSCs and larger bed-material sizes at Albuquerque than at San Acacia. The total suspended-sediment loads were estimated based on Equation 1 (Holmquist-Johnson et al., 2009), where Q_s is the suspended-sediment load (short tons/day), Q is the measured streamflow in cubic feet per second (ft^3/s) at the time of data collection, and C is the SSC (milligrams per Liter (mg/L) from the cross-section samples. The fraction of the total suspended-sediment load within the sand-size range, according to the Wentworth (1922) scale (62.5 microns to 2 mm), was calculated by multiplying the total suspended-sediment load by one minus the sand-fine split, expressed as a decimal.

$$Q_s = 0.0027QC \tag{1}$$

Acoustic Doppler Profiler Data

The acoustic Doppler profilers installed at San Acacia provided continuous measurement of the suspended-sediment load at San Acacia through most of the 2019 spring snowmelt runoff season. A comparison of the total and sand fraction of the SSC measured by the acoustic Doppler profilers to the recorded streamflow and measured SSCs (single point automatic pump samples and EWI) is shown in Figure 6. The measurements from the acoustic Doppler profilers follow a similar pattern to the measured SSCs. Figure 6 also shows that there is a threshold streamflow around 2,500 ft^3/s above which sand-sized particles compose a higher percentage of the suspended-sediment load compared with the fraction of particles smaller than 62.5 microns. Particles less than 62.5 microns in size (silt and clay particles) made up most of the suspended-sediment particles on the 2019 rising spring snowmelt hydrograph prior to reaching the streamflow threshold.

Another insight from the acoustic Doppler profiler data is the variation of the suspended-sediment peaks with the streamflow peaks. In general, the SSCs (total and sand-sized suspended-sediment particles) were observed to peak before the streamflow peaked (clockwise hysteresis). There is also more variability in the SSC during the rising and falling limbs of the hydrograph.

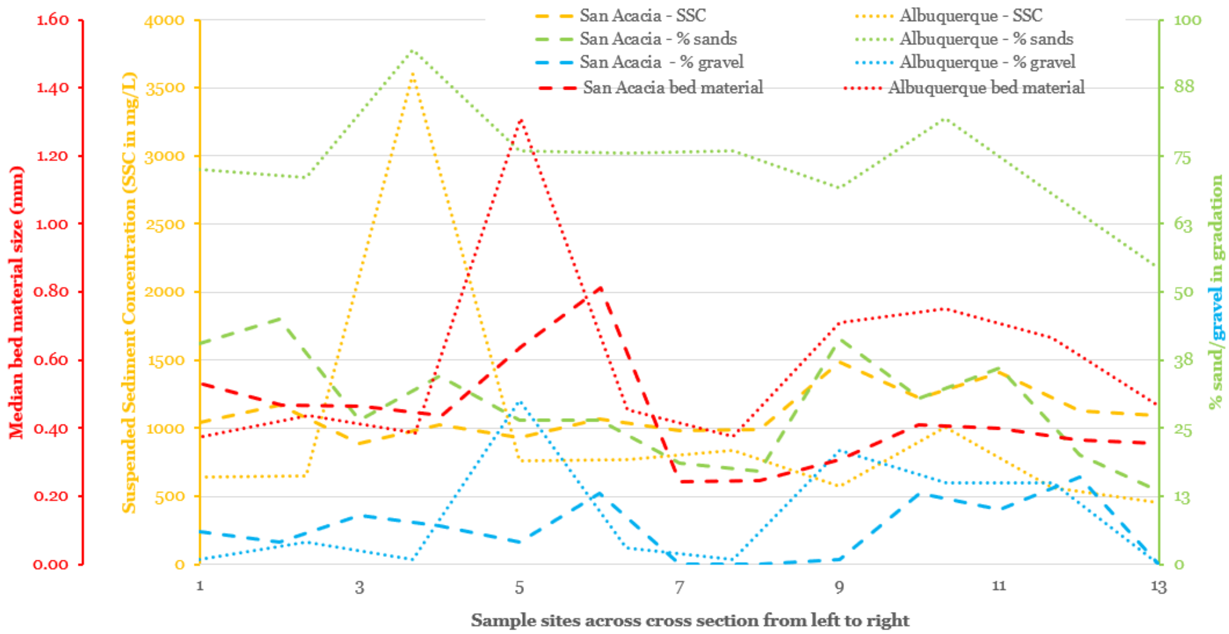

Figure 5. Cross-sectional variations of suspended-sediment concentration (SSC), % sand in the suspended sediment gradations, % gravel in the bed material gradations, and the median (d_{50}) bed material diameter (mm) at Albuquerque (USGS site number 08330000) and San Acacia (USGS site number 08354900). Note cross-sections are shown left to right. The sample sites at Albuquerque (10) were prorated to be spaced over the same length as the 13 sample sites at San Acacia.

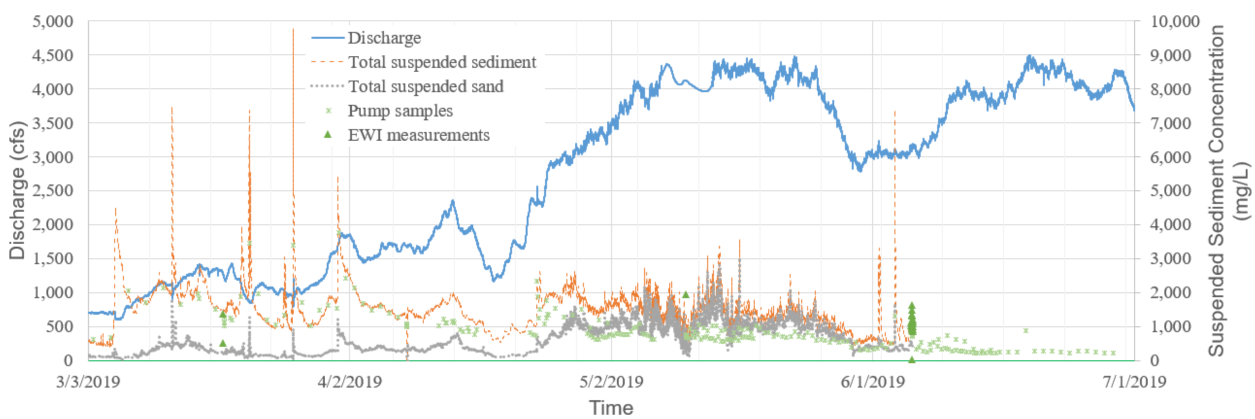

Figure 6. Water and suspended sediment at San Acacia (USGS gage site number 08354900) during 2019 spring snowmelt runoff. The acoustically collected suspended-sediment information is listed as total and sand concentrations. The collected physical suspended-sediment samples (single point automatic pump samples and EWI) are also shown (AuBuchon et al. 2020).

ISSDOTv2 Data

The bathymetric files collected by ERDC (an example of which is shown in Figure 7) were analyzed using the ISSDOTv2 method (Abraham et al., 2011; Abraham et al., 2018; Abraham et al., 2017; Shelley et al., 2013) to obtain a bedload transport value for each surveyed swath of river. The ISSDOTv2 method assumes that the river flows at a constant velocity and has a constant slope. While these assumptions are violated over large time increments, the assumptions remain viable over the smaller time intervals used in the collection of the multi-beam data. The ISSDOTv2 method also assumes that the dunes will keep their shape as they translate downstream. This is not always true in practice, but for most scenarios the shape is similar enough to provide meaningful results. A check is made within the ISSDOTv2 program to check this assumption and data are flagged if the ratio of the scour volume to the deposition volume is significantly different than unity (Shelley et al. 2013). The data collected on the MRG were verified to meet these assumptions. The bedload values obtained for each swath were then summed to obtain a total value for the cross section. The measured bedload for 4 June 2019 at Albuquerque was 2,300 short tons/day (2,100 metric tonnes/day). The measured bedload for 5 June 2019 at San Acacia was 1,900 short tons/day (1,700 metric tonnes/day). Adding the ISSDOTv2 measured bedload to the USGS measured suspended-sediment sand load provides an estimate of the bed-material load. For Albuquerque the bed-material load is 7,100 short tons/day (6,400 metric tonnes/day) and for San Acacia it is 4,600 short tons/day (4,200 metric tonnes/day).

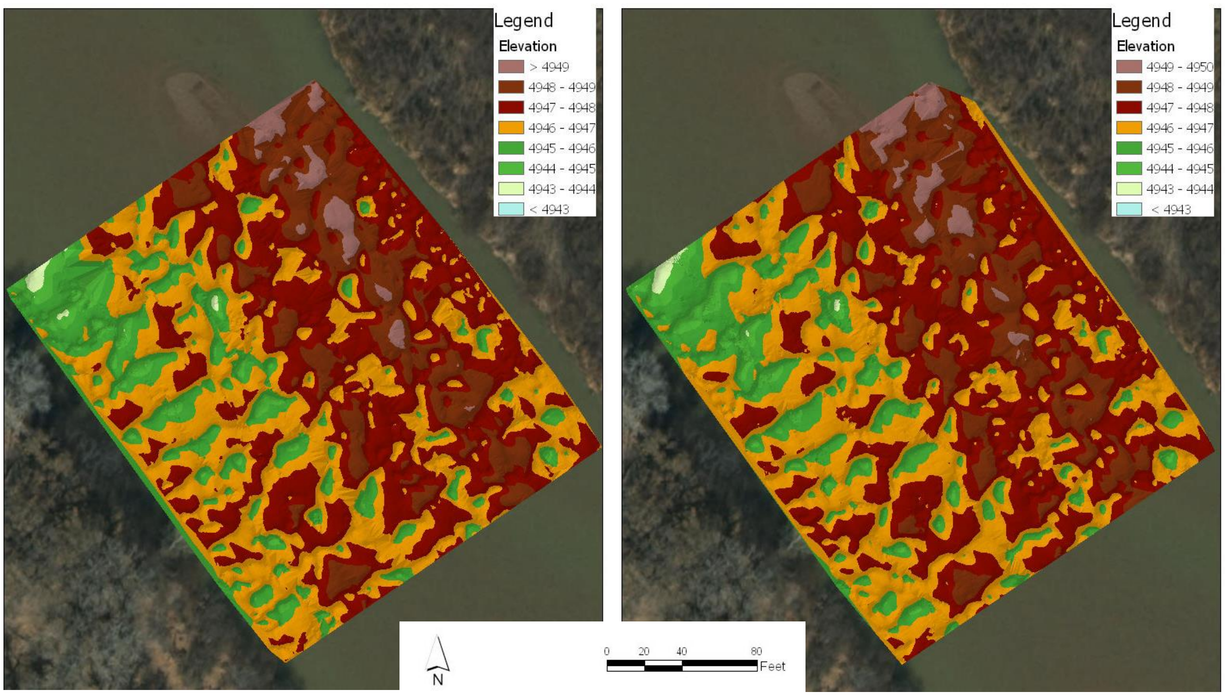

Figure 7. June 2019 collected multi-beam sonar data for the first and third pass at Albuquerque. Background is the 2018 MRG Council of Government's aerial photography from Esri's Basemap coverage (accessed 27 November 2022).

BORAMEP Calculations

The BORAMEP program provides both a suspended-sediment and total load estimate that can be separated by size clasts (greater than 62.5 microns) to obtain a bed-material load. The suspended-sediment load can be subtracted from the total load to obtain the bedload, assumed to represent the bedload moving as sand dunes. The bedload computed as part of the Modified Einstein Procedure through BORAMEP includes particles moving along the bed (sliding, rolling, saltating, etc.). To the extent that sediment particles are moving along the dune in this manner, the BORAMEP bedload will account for the bedload moving as sand dunes (Holmquist-Johnson et al., 2009). The BORAMEP derived values therefore can provide a direct comparison with the ISSDOTv2 measured bedload values. BORAMEP does not assume a bed form (e.g., dunes, antidunes, plane beds, etc.) of the bedload, but rather is a modification of the original Einstein procedure (Einstein, 1950) that includes the potential for bed-material particles to be transported regardless of the bed form (Yang, 1996). Thus, the Einstein sediment transport function and its modification, BORAMEP, can be applied to a variety of bed forms. At the time of data collection on the MRG, dunes were the primary bed form and thus the BORAMEP calculations reflect a bedload moving as sand dunes. The BORAMEP calculations also provide the ability to estimate the bed-material load. The BORAMEP calculation of the bedload resulted in 3,900 short tons/day (3,500 metric tonnes/day) at Albuquerque and 3,300 short tons/day (3,000 metric tonnes/day) at San Acacia. The bed-material load was calculated as 8,700 short tons/day (7,900 metric tonnes/day) for Albuquerque and 5,800 short tons/day (5300 metric tonnes/day) at San Acacia. The BORAMEP computed total load was 10,400 short tons/day (9,400 metric tonnes/day) at Albuquerque and 12,600 short tons/day (11,400 metric tonnes/day) at San Acacia.

Conclusions

Sediment plays an important role in the form and function of alluvial channels (Charlton, 2008; Julien, 2010). For this reason, the transport of sediment in rivers is critical to understand. From the collected sediment measurements made during the 2019 spring snowmelt runoff, a better understanding of the timing, magnitude, and duration of the suspended sediment in the MRG was developed.

From the collected acoustic Doppler profiler information at San Acacia, it was observed that more sand-sized particles are moving in suspension during the spring snowmelt runoff than at other time periods and that there is a streamflow threshold (~ 2500 ft^3/s) above which the suspended-sediment load is predominantly sand-sized particles. Once the sand is activated, the median suspended-sediment size is about 0.15 mm. Fine particles (silt- and clay-sized particles) tend to dominate the suspended-sediment record during the rest of the year and are also dominant on the rising and falling limb of the spring snowmelt runoff.

Based on the bedload and bed-material load estimates, along with the suspended-sediment samples, sand-sized particles are moving in suspension at both Albuquerque and San Acacia in early June 2019, with a decreasing amount of sand moving in suspension in the downstream direction. A wider variation in the suspended-sand concentration across the river channel was observed at Albuquerque than San Acacia. Although there was less measured bedload at San Acacia than at Albuquerque, the percentage of the bed-material load moving as bedload is greater at San Acacia than at Albuquerque (41 % versus 32%). The bedload at Albuquerque compared to San Acacia is about 21% greater, and the bed-material load is about 54% greater at Albuquerque than at San Acacia. The total load at San Acacia, however, is larger than at Albuquerque.

Our results suggest that the higher suspended-sand concentrations at Albuquerque than at San Acacia are able to be deposited in the downstream direction, likely in the edge zones where less suspended-sediment transport of sand was observed from the EWI measurements. The larger total load at San Acacia is a result of silt- and clay-sized clasts that have potentially been carried into the fluvial system by tributaries upstream from San Acacia but downstream from Albuquerque. A tributary upstream of San Acacia, the Rio Puerco, has large concentrations of suspended sediment in these size clasts when there is a rainfall runoff event (Brown et al., 2015; Griffin and Friedman, 2015).

The 2019 data collection effort showed that ISSDOTv2 can be effectively utilized on the MRG to assess measured bedload moving as dunes. Measurements could be made on the MRG in 2019 at a streamflow of around 3,500 ft^3/s at Albuquerque and 3,000 ft^3/s at San Acacia. This is likely a lower streamflow limit for effectively using the multi-beam instrument on the MRG. A comparison of the BORAMEP bed-material load estimates and the ISSDOTv2 plus the suspended-sand load from the USGS EWI measurement show that the BORAMEP bed material load estimates are about 25% higher, which is reasonably close (within an order of magnitude).

The acoustic Doppler side profilers installed at San Acacia indicate that acoustic technology developed on larger river systems is applicable to shallow, mobile bed systems like the MRG, provided a suitable mount can be constructed to avoid sediment burial. The drawback for the mounting at San Acacia was the inability to collect data when the water level was lower than the instruments. Even when the acoustic Doppler side profilers are submerged, however, no data may be collected if an insufficient horizontal distance is acquired prior to the outgoing acoustic signal reflecting off of the water surface, a depositional bed form, or accumulated debris. One of these reasons may be why the acoustic Doppler side profilers did not collect data during the falling limb of the 2019 spring snowmelt runoff season despite the water surface elevation being well above the mounting height of the instruments. For the acoustic Doppler profilers, additional exploration of why data were not collected when the instruments were covered with water would help to develop more robust data processing procedures.

The 2019 measurements were just a snapshot in time. Additional bedload measurements, especially if paired with continuous temporal measurements of suspended sediment, would provide additional understanding of fluvial sediment transport in the Rio Grande. Continued assessment of the bed material through methods such as paired data collections of the suspended sediment and bedload components could be useful for river managers and agencies attempting to understand fluvial sediment dynamics, especially if correlated to tributary sediment inputs. In the long term, more continuous acoustic datasets using the acoustic Doppler side profilers and accompanying physical samples can provide a better understanding of sediment transport in the MRG than by using only the discrete information currently acquired.

Acknowledgements

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