Bedform Analysis for select flows in the Mississippi River at Vicksburg, Mississippi

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Introduction

Quantification of sediment transport rates is necessary for river management but remains difficult due to large volumes of sediment in motion, heterogeneity in river conditions, and high personnel and equipment costs. Repeated measurements of river-bed topography, collected over the same reach with short time gaps, can be used to measure bed-load transport rates over river reaches. There are relatively few detailed descriptions of bedform morphometrics in large rivers due to the expense and difficulty in obtaining the measurements and to the time-consuming data analysis needed to extract bedform dimensions from the data. (Cisneros et al., 2020). Some examples of previous bedform studies in rivers include the River Waal (Zomer et al., 2021), the Rio Parana (Gutierrez et al., 2013), and the Missouri River (Holmes and Garcia, 2008).

The U.S. Army Corps of Engineers-Engineer Research and Development Center (USACE-ERDC) collected acoustic multi-beam topographic data in the Mississippi River near Vicksburg, MS, USA, to measure bed-load sediment transport rates during the unusually high flows that occurred during May and June of 2011. In addition, topography data from three other dates are included for comparison. Bed topography data were analyzed to quantify bedform dimensions and their response to changing flows during this extreme flow event. Results from this analysis improve upon our understanding of dynamic bed topography and bed-load transport for the MS River, which impacts riverine processes such as morphology, bed roughness, navigational clearance, dredging requirements, and habitat. Complete results from this study can be found in Wren et al. (2022).

Methods

The multi-beam sonar data was collected by the U.S. Army Engineer Research and Development Center (USACE-ERDC) for mapping river bathymetry and quantifying bed-load transport in the MS River near Vicksburg, MS, over a ~1 km^2 area. See Abraham et al. (2011) and McAlpin et al. (2022) for more information about using river bathymetry for bed-load transport measurements. The dates of data collection and discharge at Vicksburg are listed in Table 1, and the flow hydrographs are in Figure 1 (A-C). A detailed description of the data collection and methods is included in Ramirez et al. (2018). The study reach was near River Mile 432, about 3 km downstream of the U.S. Interstate Highway 20 bridge at Vicksburg, MS. The channel exhibits an asymmetric cross-sectional form throughout the study reach with a steeply sloped eastern side that is deeper than the western side. The channel width was between 1100 m at low flow and 1500 m when the flow was near bank full (Ramirez et al. 2018). Dates of data collection in 2011 were 5/15, 5/19, 5/26, 5/31, and 6/3. Note that Trips 1-5 were on different parts of the hydrograph generated by the 2011 flood (Figure 1C). The remaining three trips were in 2012, 2013 and 2016, including 2012 data that represents an unusually low discharge.

Table 1. Basic parameters for data collection. Measurements are from USGS station #07289000 at Vicksburg, Mississippi.

Trip	Discharge (m^3/s)	Date
1	64,600	05-15-2011
2	64,300	05-19-2011
3	56,700	05-26-2011
4	49,900	05-31-2011
5	46,500	06-03-2011
6	7,600	10-03-2012
7	31,600	04-29-2013
8	53,000	01-15-2016

The methods used to detect bedforms built on previous work by the authors, including Wren et al. (2016, 2020, 2021), along with other works that included wavelet analysis of bedforms, including Kumar and Foufoula-Georgiou (1994) and Gutierrez et al. (2013, 2014). The two-step process for obtaining bedform statistics began with wavelet decomposition of the signal to separate long and short bedforms, followed by the *findpeaks* algorithm in MATLAB for detecting peaks and troughs in the data (Mathworks, r2020b).

Results

Bedform characteristics are summarized in Figure 2; box sections are the 25th, 50th and 75th percentile values. Data within $\pm 2.7\sigma$ are indicated by the whiskers, where σ is the standard deviation of the data. The X-axis designations are T followed by trip number (see Figure 1 and Table 1), and the river section. Position in the cross-section had a strong effect on bedform length (A.) and height (B.), with lower heights and shorter lengths in the east section, higher and longer in the middle and intermediate in the west section. The east section had much lower heights and shorter lengths than the other two sections, with median amplitudes <2 m and most lengths <50 m. The effect of discharge for T1-T5 for the middle and west sections can be seen clearly. T1 and T2 data were collected near the peak of the 2011 flood, and median length was higher for T2, while amplitudes changed minimally for T1-T3. During the recession of the 2011 hydrograph, T3-T5 show gradually decreasing amplitudes and lengths. East section data from T6 shows bigger bedforms during historically low flows relative to the other trips. This may have been caused by extended periods of low flow that left coarser materials covered with a layer of sand. Data for T8 were collected near the peak of a hydrograph from December 2015. The lower flows from T6 and T7 produced lower heights and shorter bedform lengths. Low water levels prevented data collection in the west section during trip 6.

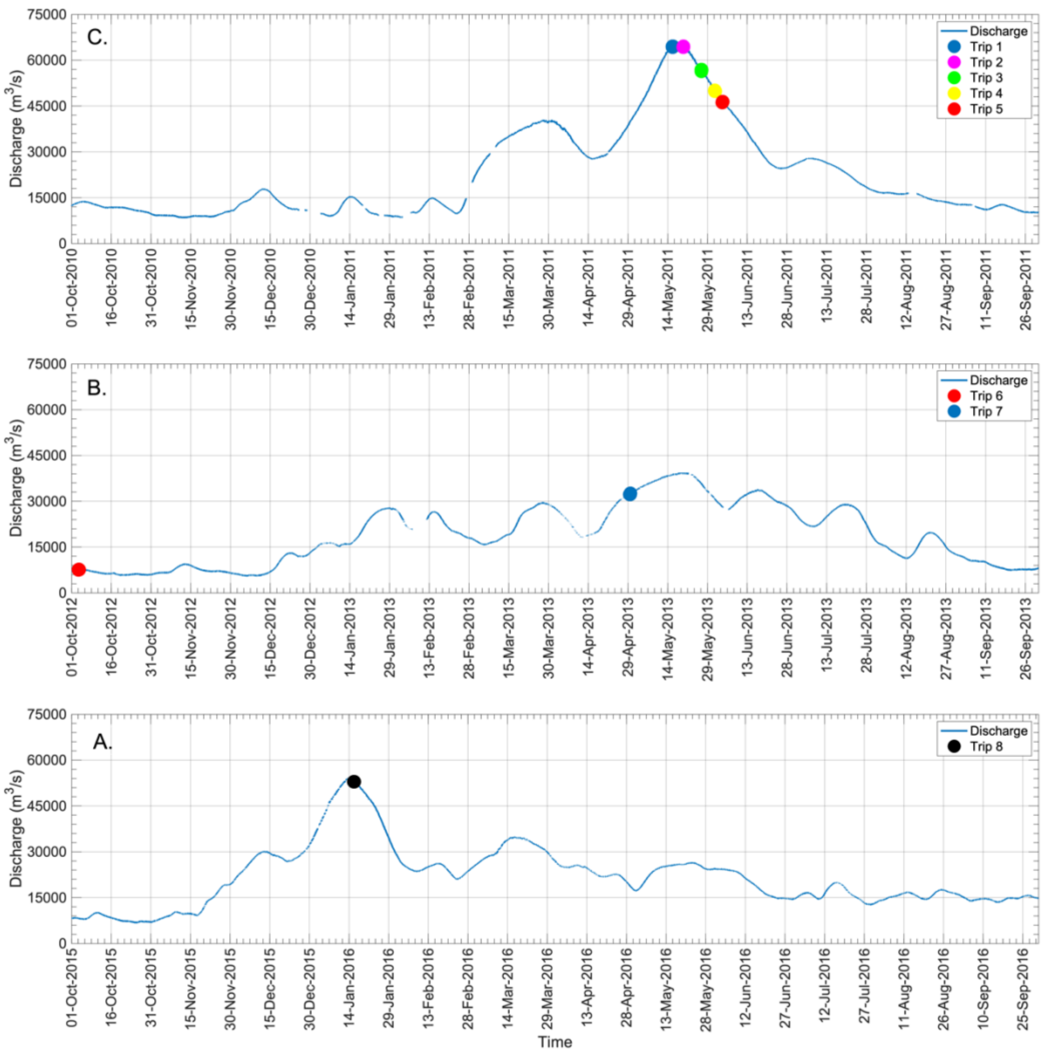

Figure 1. Mississippi River discharge hydrographs for (A.) Trips 8; (B.) trips 6 and 7; and (C.) trips 1-5.

Bedform length (Figure 3A) and amplitude (Figure 3B) predictions from Bradley and Venditti (2017), were compared with data from this study. The best fit relationships shown in Figure 3 were calculated with the MATLAB (Mathworks, r2020b) *fit* function. The slopes of the best fit for both amplitude and length are higher than that found by Bradley and Venditti (2017), which may be due to the collection of MS River data at different times relative to the peaks of flood hydrographs, resulting in measurements during evolving bed conditions. Nevertheless, the form of the equation from Bradley and Venditti (2017) is appropriate for the MS River data except for the east section. Bedforms at lower flows or depths may have topographic signatures left over from conditions near the peak flows for the hydrograph. Bedforms with higher depths were larger than predicted by Bradley and Venditti (2017), which may have been caused by differences in bed material size and specific flow conditions. The presence of coarser material in the east section also created local conditions that did not align well with the predictions. A relation based on transport stage, such as from Bradley and Venditti (2019), would likely provide improved predictions, but the range of shear velocity (U_*) to particle fall velocity (W_s) ratios is larger than the range used by Bradley and Venditti (2019) in their predictive relationships. In addition, only the average slope between gauges at Vicksburg and Natchez, MS, was available and is unlikely to match the slope of the study reach. One main conclusion of Bradley and Venditti (2019) was that, above a threshold value of U_*/W_s, the relationship between water depth and dune amplitude changes due to high transport rates. This conclusion is reasonable, but quantifying U_* and W_s for large rivers will require additional field measurements across a range of conditions and must include detailed measurements of bed topography.

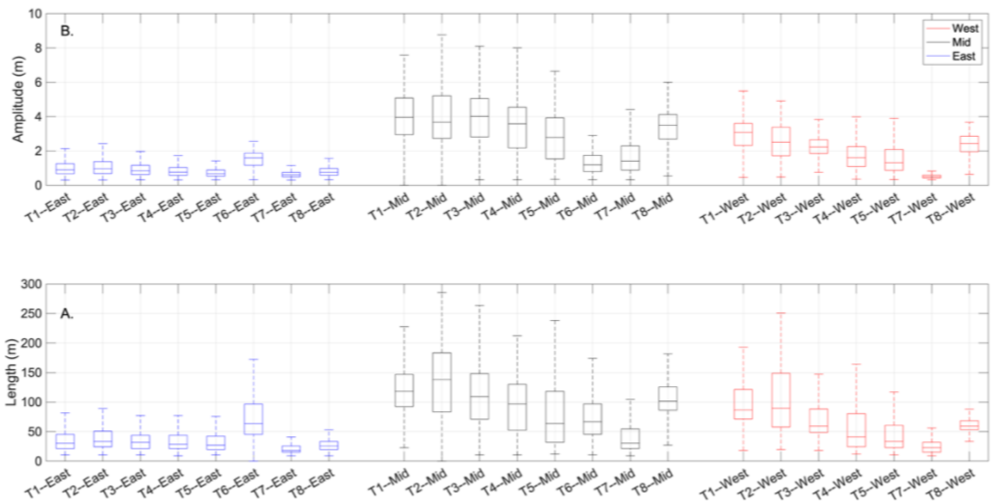

Figure 2. (A.) Length and (B.) Amplitude of bedforms measured in the Mississippi River near Vicksburg, MS, organized by location relative to cross-section and trip number, which can be seen in Table 1.

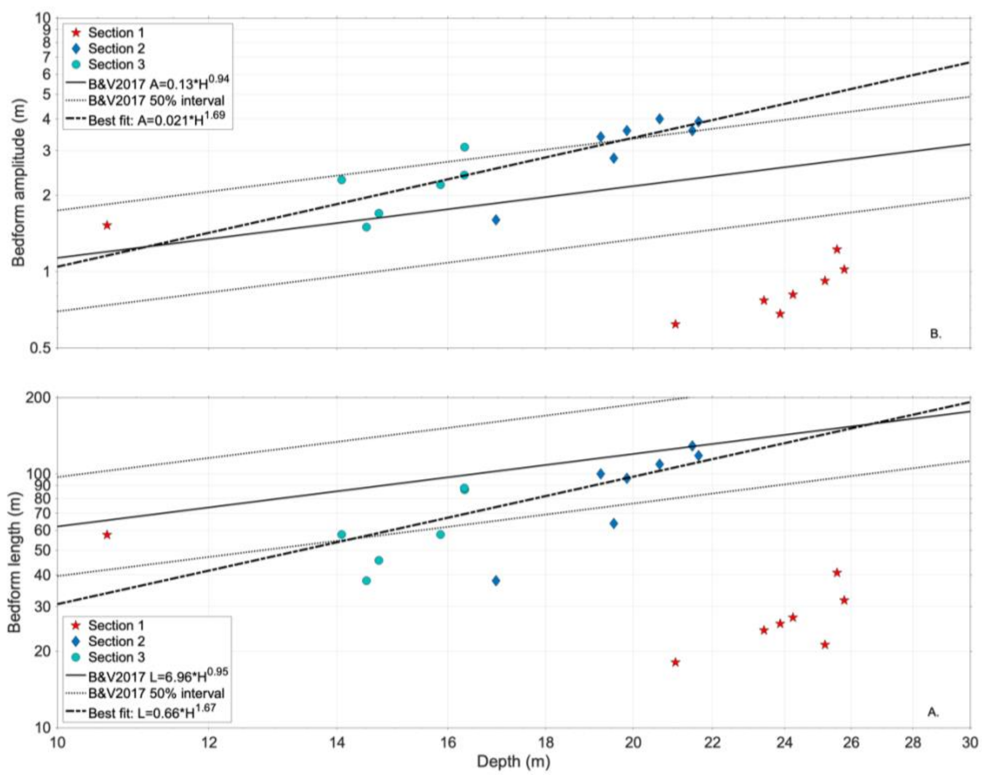

Figure 3. Bedform dimensions (A. length and B. amplitude) with predictive relationship from Bradley and Venditti (2017) and a best-fit line. A is bedform amplitude, H is flow depth, and L is bedform length.

Conclusions

Multi-beam acoustic measurements of bed topography in the MS River near Vicksburg, MS, USA, were analyzed to extract bedform characteristics. The data were collected by the U.S. Army Corps of Engineers-Engineer Research and Development Center to measure bed-load sediment transport. Wavelet filtering and peak-finding algorithms were used to identify individual bedforms from transects of bed elevation. Bedform characteristics varied strongly with relative position in the river cross-section, with the lowest amplitudes and shortest lengths near the east bank and the highest amplitudes and greatest lengths near the channel center. Bedform dimensions varied over hydrographs, yielding different values for similar flows from different parts of the hydrograph relative to peak flow. Other than the relatively short lengths and low heights of bedforms in the east section, dimensions generally increased with water depth. The east section may have been an outlier due to the coarse grain size distribution for the bed material at this location. These results demonstrate how bedforms in the MS River change with both flow depth and time relative to flow hydrograph peaks, which can be important for applications such as navigation, dredging, and flood related studies.

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