

Bed-load measurements on large, sand-bed rivers in the United States

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Abstract. The movement of bed forms (sand dunes) in large sand-bed rivers is being used to determine the transport rate of bed load. The ISSDOTv2 (Integrated Section Surface Difference Over Time version 2) methodology uses time sequenced differences of measured bathymetric surfaces to compute the bed-load transport rate. The method was verified using flume studies [1]. In general, the method provides very consistent and repeatable results, and also shows very good fidelity with most other measurement techniques. Over the last 7 years we have measured, computed and compiled what we believe to be the most extensive data set anywhere of bed-load measurements on large, sand bed rivers. Most of the measurements have been taken on the Mississippi, Missouri, Ohio and Snake Rivers in the United States. For cases where multiple measurements were made at varying flow rates, bed-load rating curves have been produced. This paper will provide references for the methodology, but is intended more to discuss the measurements, the resulting data sets, and current and potential uses for the bed-load data.

1. Introduction

While it is recognized that bed-load transport is an important process when considering river morphology, habitat restoration, and dredging requirements, the ability to measure bed-load transport has remained a challenge, especially on large, sand bed rivers. The ISSDOTv2 methodology uses surface differences of time sequenced bathymetric data to compute volume changes in moving sand waves to determine bed-load transport rates. The method consists of two basic components. The first is the data collection procedure and requirements. The second is the application of a computational code to operate on the processed data and compute a bed-load transport rate. The ISSDOTv2 method of measuring bed-load transport has been applied on several large river systems to create a database of over 125 bed-load transport measurements. This paper will provide a brief overview of the process and data collected to date as well as a discussion of the importance of these measurements.

2. Data collection

To use the ISSDOTv2 method for determining bed-load transport, three dimensional time sequenced bathymetric data are required. These must be good quality xyz data points that

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define the surface of the river bottom with a spatial and temporal resolution sufficient to accurately capture meaningful surface differences of the moving dunes (sand waves). At a given site, a survey boat using a multi-beam fathometer collects data points along parallel swaths in the longitudinal direction. The length of the swath should be sufficiently long enough to capture at least 7 to 10 of the largest sand waves. The width of each swath is dependent upon the water depth and the instrument beam angle. The number of swaths needed is in turn determined by the channel width. The intention is to cover as much of the cross section as possible. So in most of the sites measured to date anywhere from 3 to 10 swaths have been required to accurately map the active sand-transport (dune-covered) portion of the channel. Figure 1 shows an example of 11 combined swaths of data for a total coverage of approximately 840 m (longitudinal length) by 840 m (channel width) at a site on the Mississippi River at Vicksburg, MS. Each swath at the site was repeated (re-measured) multiple times with an interval of approximately 1 hour between each repeated measurement. Data collected in this manner provides multiple surfaces over varying time differences for use in the ISSDOTv2 computational procedure.

3. Bed-load computations

ISSDOTv2 computes bed-load transport in the following manner. The equation that is solved is:

$$g_{sb} = \frac{\rho(1-p)V}{1.8182\Delta t} \quad (1)$$

where g_{sb} is the bed-load transport rate, ρ is the density, p is the porosity, V is the scour volume and Δt is the time difference between multibeam measurements. The 1.8182 represents the fact that real world sand waves are not triangular in shape [2]. This equation has been proven to accurately relate bed-load mass transport rates to incremental scour (or deposition) rates [1]. It has the same units as the Simons and Richardson [3] equation,

$$g_{sb} = \frac{\rho(1-p)c\eta}{2} \quad (2)$$

where g_{sb} is the bed-load transport rate, ρ is the density, p is the porosity, c is the speed of the wave, and η is the wave height. Abraham et al [1] showed the two methods to be equivalent, with the ISSDOTv2 method being preferred due to the ease of directly computing scour volumes from the 3-d bathymetric data. The method has been shown to be repeatable and consistent. Research efforts are continuing to improve the method accuracy and to bound the uncertainty.

The ISSDOTv2 numerical code calculates the bed-load transport at user defined increments across the channel width (usually specified values between 0.25 meters and 1.5 meters). In these individual “subswaths” the bed-load transport is calculated in each wave individually and weighted appropriately to obtain a bed-load transport rate for each subswath. An example of the fidelity of the method is provided in Figure 1 which shows the bathymetry of the Mississippi River near Vicksburg, MS (top of the figure) where multiple sets of time sequenced data were obtained. The bed-load transport values computed using these data are shown in the graph at the bottom of Figure 1. This figure illustrates the lateral variability of the bed-load transport over the river section along with the method’s ability to capture this variation. The total bed-load transport for this section of the river is determined by integrating

(summing) the individual transport values of the subswaths over the 840 meter width of the measured section shown in the graph.

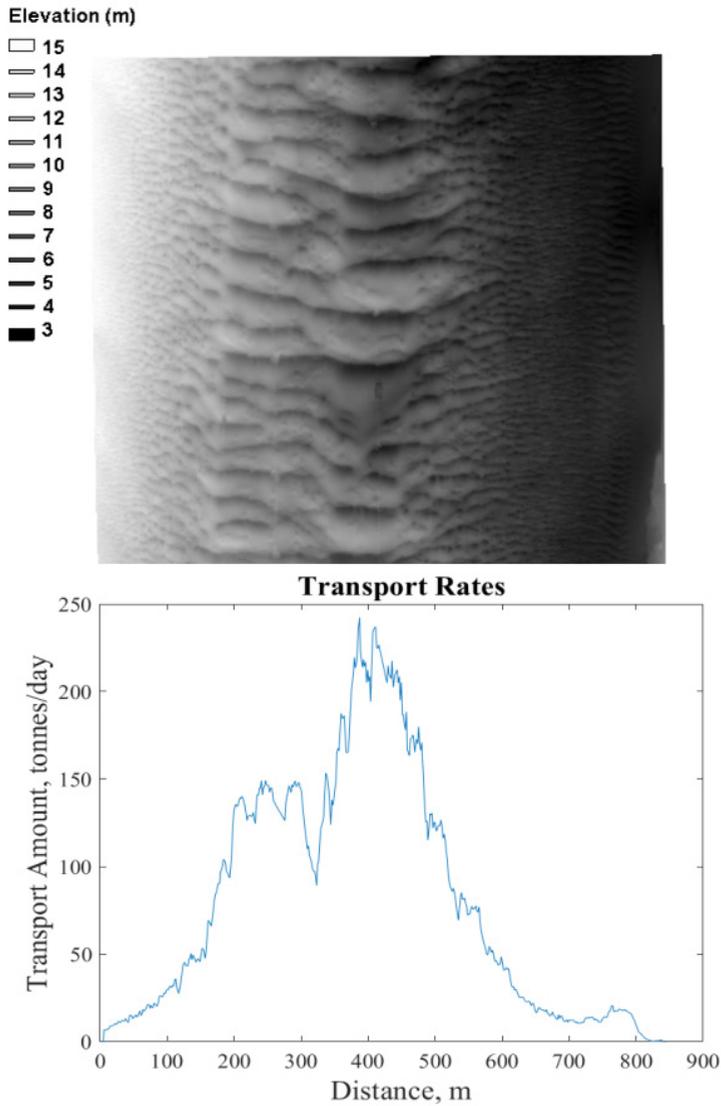


Figure 1. Bed-load transport variation across the river channel.

4. Acquired data sets

A database of bathymetry and computed bed load values has been created using measurements acquired in the above mentioned manner at numerous sites on 7 large sand

bed rivers in the United States. The sites and computed values are briefly discussed in section 4.1 and 4.2 respectively.

4.1. Sites and locations

The database includes measurements collected on the Atchafalaya, Clearwater, Mississippi, Missouri, Ohio, Red, Snake, and St. Clair Rivers in the United States. The number of locations and measurements on each river are shown in Table 1. In the Table the word ‘measurement’ means a group of time sequenced bathymetric sets (similar to Figure 1) sufficient to characterize bed-load transport at that site, and obtained during a period of relatively constant flow.

Table 1. Number of locations and measurements for each river

River	Locations	Measurements
Atchafalaya	6	21
Clearwater	1	3
Mississippi	13	47
Missouri	11	38
Ohio	2	2
Red	1	5
Snake	3	9
St. Clair	1	1

Locations of the measurement sites are shown in Figure 2. The Snake and Clearwater Rivers are shown together as one point, likewise the Atchafalaya and Red Rivers. This is because the measurements were collected near the confluence of these rivers. The Missouri and Mississippi Rivers have been a major focus of the bed-load measurements and their measurement locations extend over a larger portion of the rivers as shown in box 1 (Missouri) and box 2 (Mississippi). The Missouri River locations (box 1) cover 1020 kilometres (634 miles) of river and the Lower Mississippi River measurement sites span 700 kilometres (435 miles). An example of a bed-load transport rating curve developed for the Mississippi River is provided in Figure 3. This rating curve was developed using data obtained over the entire range of measurement locations on the lower Mississippi River (700 kilometres (435 miles)). This rating curve also includes measurements taken during the Flood of 2011 to provide values for the higher range of flows.

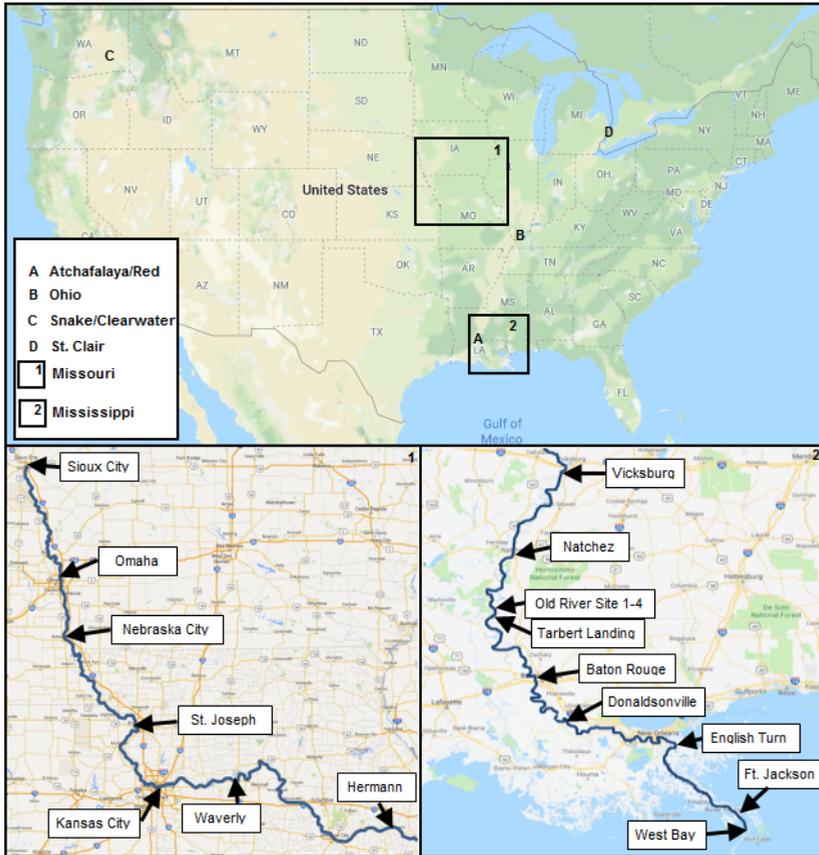


Figure 2. Map of measurement locations

4.2. Bed-load values

ISSDOTv2 bed-load measurements are often funded and collected as part of a larger study of a specific location or river of interest and documented in the respective reports. The Atchafalaya and Red River measurements can be found in the “Old River Control Complex Sedimentation Investigation” [4]. The Missouri River data was a part of the “Sediment and Hydraulic Measurements with Computed Bed Load on the Missouri River, Sioux City to Hermann, 2014” report [5]. When multiple measurements have been recorded at a specific location or on a certain river for varying flows, rating curves can be developed. An example rating curve of the Lower Mississippi River is shown in Figure 3.

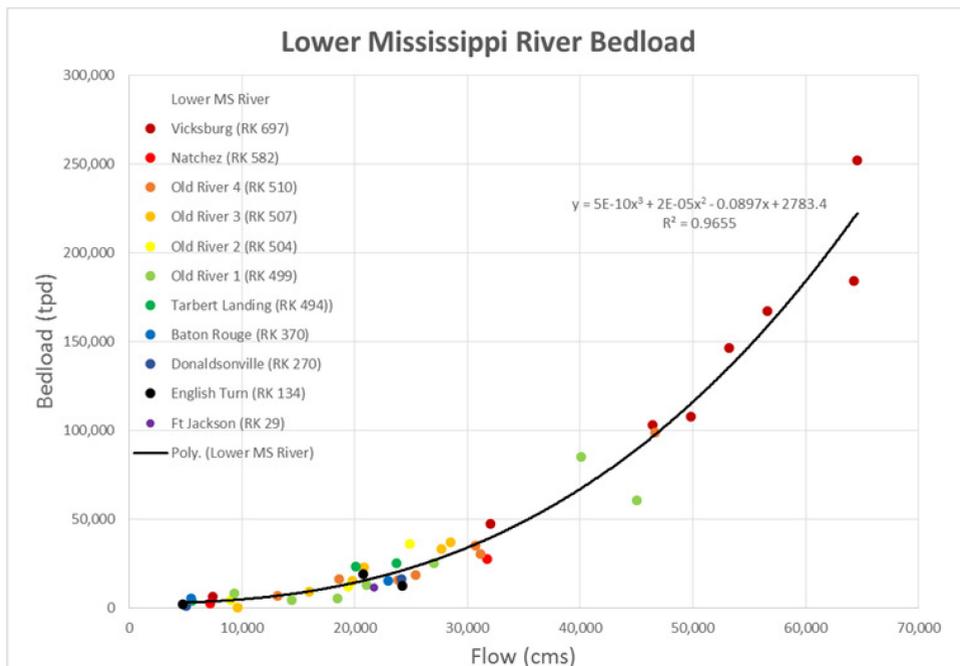


Figure 3. Lower Mississippi River Bed-load Rating Curve, in tonnes per day

5. Discussion of results and uses of the data

The ability to produce rating curves similar to the one shown in Figure 3 is important. Whether it is a small data set for a localized part of some river, or a large data set as in Figure 3, these curves can be useful indeed. Since a rating curve (like Figure 3) relates a given bed-load transport rate to a specific flowrate, it can be used with a flow hydrograph to create a bed-sedigraph, or a graph of bed-load transport rates plotted against the same time period as the hydrograph. If one integrates under that curve, it is possible to obtain the total amount of bed load delivered during the given hydrograph. This is a powerful tool for river managers, as it allows them to either hind-cast, or forecast bed sediment delivery at a location over the time period of any recorded or forecast hydrograph. Figure 4 shows an example where this method was used to calculate bed-load delivery on the Mississippi River over a nine year period. A combination of the Lower Mississippi rating curve (Figure 3) and flows from the Vicksburg gage were used to calculate yearly totals. These yearly totals are based on water years defined as October 1 to September 30. Thus river managers can obtain yearly or cumulative estimates of bed-load sediments using this procedure, which will in turn enable them to develop much more accurate and meaningful sediment budgets.

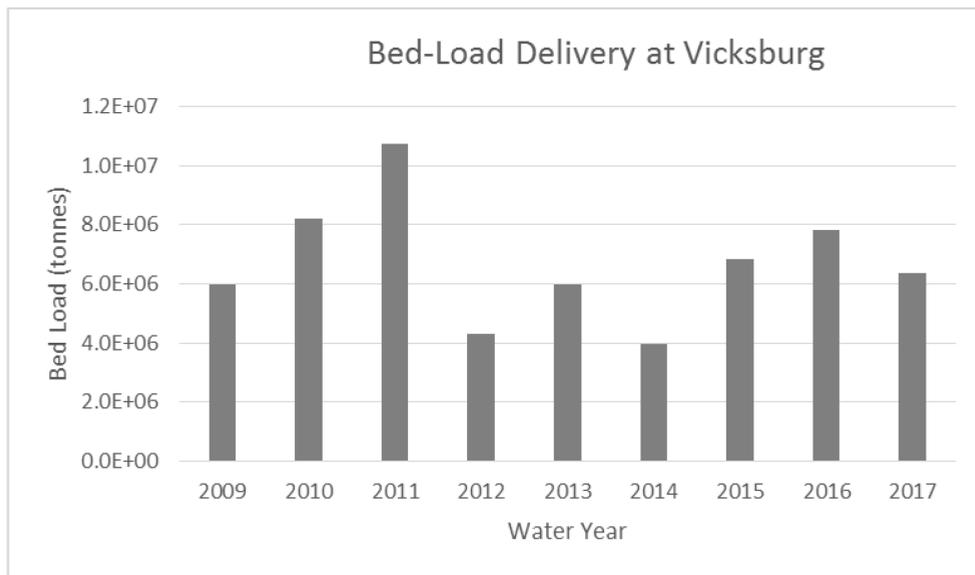


Figure 4. 2009 -2017 bed load delivery at Vicksburg, MS

Bed-load transport is a primary mechanism in fluvial geomorphology studies, assessments of habitat suitability and creation potential, and in determining dredging requirements. The ISSDOTv2 measurements have been obtained for a multitude of reasons ranging from the identification of suitable/unsuitable locations for endangered mussel habitat, to evaluating the effectiveness of training structures in diverting sediment [4], to utilization as a model validation tool [6]. Additionally, measurements on the Missouri River were shown to be in close agreement with the Einstein and Meyer-Peter Mueller bed-load transport functions [7]. These independent studies have over time resulted in the accumulation of a single large dataset of bed-load transport measurements across a number of locations and conditions. While separately these measurements have satisfied the immediate goals of the individual studies, they have resulted in the creation of a larger dataset that will be utilized in the future to further investigate other aspects of the bed-load transport process.

References

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