MEASURING BEDLOAD TRANSPORT ON THE MISSOURI RIVER USING TIME SEQUENCED BATHYMETRIC DATA

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Abstract Bedload transport on the Missouri River was computed using the ISSDOTv2 method. This method uses difference plots of time sequenced bathymetric data for the computation of bedload transport. Bathymetric data were collected at Washington and Kansas City, Missouri in the summer and fall of 2009. At each site multiple bathymetric swaths, temporally sequential and laterally adjacent across the river, were surveyed. Each survey trip captured four or more time varying bathymetries for each swath. Multiple difference plots were created from these swaths and the ISSDOTv2 computational method was then applied. The output for a given difference plot is a bedload transport value for the swath in tons per day. The values for each swath can be summed to provide the total bedload transport at a section. The entire procedure was accomplished at several different flow rates. The results of the measurement campaign indicates that it is possible to capture not just the bedload transport at a given river section, but also to quantify to some degree its lateral variation. Also, initial results indicate that a bedload sediment rating curve (the first of its kind for a large sand bed river?) can be developed with these measurements. A bed load rating curve of this system will prove to be an invaluable resource for river mangers as they address issues such as maintenance dredging requirements, sand mining, and the availability of sand to maintain ecological habitat features of rivers such as islands and bars.

INTRODUCTION

The measurement of bedload transport in large sand bed rivers has been attempted and discussed by many researchers. They have used a combination of varying techniques including physical samplers, and analytic methods. It is not the intent of this paper to review the previous work on the subject matter but to present initial results of the new methodology. However, in the interest of completeness, and as a resource to readers, a list of some of the more relevant literature with respect to bedload transport is provided in the 'References' portion of this paper.

Regarding the present work, in the spring of 2009 the US Army Corps of Engineers (USACE) Kansas City District contacted the Engineering Research and Development Center, Coastal and Hydraulics Lab (ERDC-CHL) and requested that bedload measurements be taken on the Missouri River at two sites, and at several different flow rates. The method of measurement was to be the ISSDOTv2 (Integrated Section Surface Difference Over Time-version 2) method developed at ERDC-CHL. The method uses time sequenced bathymetric data to compute bedload transport and has been thoroughly described in Abraham (2009). Two sites on the Missouri River were selected at which the measurements were to be made, one just north of Kansas City, and the other at Washington, Missouri. The intent was to take measurements throughout the year at different flow rates in order to produce, if possible, a bedload rating curve. Six measurement trips were planned; currently 4 trips at each site have been completed. The methodology, ISSDOTv2, has been shown to give good results under controlled conditions in research flumes where an equilibrium bed load transport was established. Although some field data were presented in that document, the analysis was necessarily brief and limited. The following results presented represent the most extensive application of the method to date for field data.

METHOD

The survey boat used is shown in Figure 1. The bathymetry is mapped through the use of a 250 KHz Geoswath echo sounder. The boat is RTK GPS positioned and compensated for pitch, heave and roll. Horizontal accuracy is stated as +/- 2 cm and vertical resolution of bathymetric elevations is approximately 3 cm in 50 meter of water. This allows vertical bathymetric changes of more than 5 cm to be recorded and used in determining the elevation change between two profiles taken at two different times over the same spatial location.

Figure 1 Survey boat with Geoswath echo sounder.

Figure 2 shows an example 3-d profile of swath 13 in which the sand waves are clearly identified. It should be understood that this method is only applicable with the existence of bed form waves. If waves are not present then it is not possible to estimate a bed load transport with this methodology.

Another swath was obtained at the same location, as shown in Figure 2 one-hundred minutes later. The bathymetric elevations of the first plot were subtracted from those of the second plot to obtain the difference plot of Figure 3.

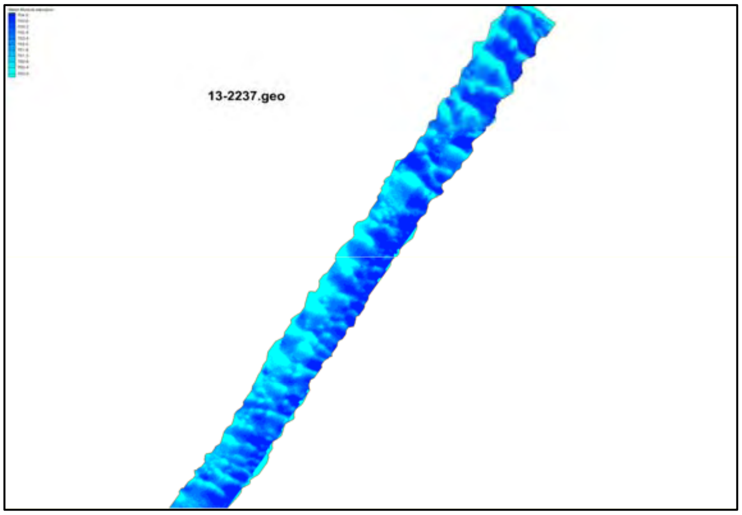

Figure 2 Swath of bathymetric data showing sand waves.

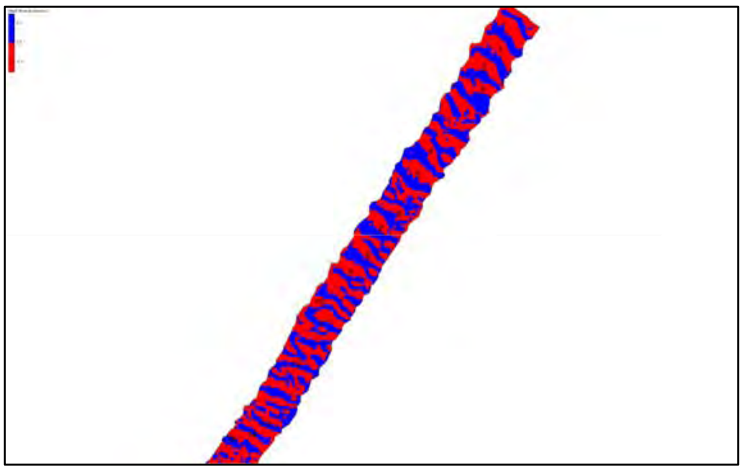

Figure 3 Difference plot showing scour and deposition of the sand waves.

The difference plot indicates areas of scour and deposition. All areas that are shaded red are locations in which scour has occurred on the upstream face of the sand waves and are contoured as negative values. Conversely, areas shaded in blue are depositional and contoured as positive values. For the ISSDOTv2 method only the area of scour, or the backside of the wave, is used for the bedload computations. The volume of scour and its spatial extant can be immediately determined by plots of the difference files as shown in figure 3. From such plots, bedload transport can be calculated for individual waves throughout any section of the river for which time sequenced bathymetric swaths were obtained.

The site where multiple swaths were taken is shown in Figure 4. It is located on the Missouri River just upstream of the confluence with the Kansas River. As can be seen, training structures extend out into the channel for a considerable distance. They affect flow and thus bedload transport as well. In general, once the area between the structures has filled in with sediment, the amount of bedload transport occurring in that portion of the channel is very small in comparison with the portion of the channel not obstructed by the dikes. In this work, the section of the channel not obstructed by structures is identified as the *active bedload-transporting portion* of the channel.

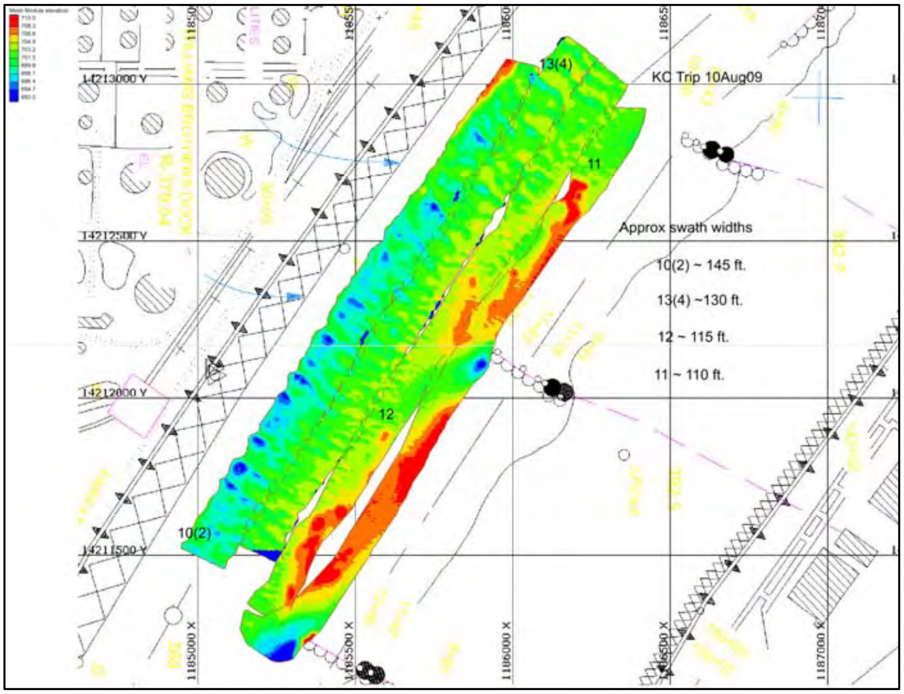

Figure 4 Bathymetric swaths superimposed on a schematic of the river.

Figure 4 shows the four bathymetric swaths for which data were obtained and their superposition over a schematic of the channel and structures. The influence of the structures is clearly evident from the bathymetry. Note the deep scour holes at the downstream end of each dike, and also the small size and/or absence of the sand waves in the swath(s) closest to the structures. The flow is top-right to bottom-left with the deepest water on the right descending bank (left side of the figure). The active bedload-transporting portion of the channel should be that portion of the cross-section that is covered by the four swaths.

For each swath four data sets were obtained at time intervals which varied from 18 to 34 minutes. This allowed computations to be made for plots whose time-difference varied from about 18 to 100 minutes. For each plot the scour volume of selected waves was computed and the bedload transport in that wave recorded in units of lbs/second-ft and tons/day-ft. The average of the waves was then taken as the transport in that swath for that time period. It was then multiplied by the average width of the swath to obtain a value being transported past any point in the swath at any given time. For example swath 10(2) and for data file 2-2032-2014; nine tons per day per foot of swath width was computed. By multiplying this value by the swath width of 145 feet, a transport value of 1303 tons per day could be determined for this part of the channel, as shown in the first line of data in Table 1. Similar computations were made for swaths 13(4), 12, and 11.

RESULTS

The results of the above methodology for the Kansas City site trip 4 are shown in Table 1.

Table 1 ISSDOTv2 computed results in four bathymetric swaths, Kansas City site, trip 4.

Diff File	Dt min	Transport lbs/s-ft	scour/depth ratio	Transport Tons/day per ft	Swath Width (ft)	Transport Tons/day	Swath#
2-2032-2014	18	0.21	1.13	9.0	145	1302.912	10(2)
2-2051-2032	19	0.28	1.15	12.1	145	1753.92	10(2)
10-2231-2200	31	0.25	1	10.9	145	1584.792	10(2)
2-2014-1932	42	0.23	1.01	9.9	145	1440.72	10(2)
2-2051-2014	37	0.24	1.08	10.4	145	1503.36	10(2)
2-2032-1932	60	0.22	1.01	9.4	145	1365.552	10(2)
2-2051-1952	59	0.20	0.96	8.6	145	1240.272	10(2)
					Avg	1455.933	
4-1939-1917	22	0.18	1.03	7.8	130	1010.88	13(4)
4-2004-1939	25	0.24	1.06	10.4	130	1347.84	13(4)
4-2021-2004	17	0.22	0.97	9.5	130	1235.52	13(4)
4-2042-2021	21	0.24	1.19	10.4	130	1347.84	13(4)
13-2141-2057	44	0.27	1.09	11.7	130	1516.32	13(4)
13-2204-2141	23	0.26	1.07	11.2	130	1460.16	13(4)
13-2237-2204	33	0.18	1.01	7.8	130	1010.88	13(4)
4-2004-1917	47	0.21	1.04	9.1	130	1179.36	13(4)
13-2204-2057	67	0.25	1.08	11.0	130	1426.464	13(4)
4-2021-1917	64	0.20	1.03	8.6	130	1111.968	13(4)
13-2237-2057	100	0.22	1.1	9.3	130	1207.44	13(4)
					Avg	1259.516	
12-2214-2153	21	0.10	1.03	4.2	115	486.864	12
12-2247-2214	33	0.08	1.13	3.5	115	407.376	12
12-2247-2153	54	0.11	0.98	4.5	115	521.64	12
					Avg	471.96	
11-2209-2146	23	0.05	1.05	2.3	110	251.856	11
11-2243-2209	34	0.07	1.18	3.1	110	337.392	11
11-2243-2146	57	0.06	1.06	2.4	110	261.36	11
					Avg	283.536	

The average transport of the combined four swaths is 3,470 tons per day. This is the sand transport in the active bedload-transporting portion of the river. It is interesting to note that about 78 percent of the transport occurs in swaths 10(2) and 13(4) which are up against the right descending bank. This is also the deepest part of the channel on the outside of a mild bend and would represent the thalweg. These swaths represent about 55 percent of the active bedload-transporting portion of the channel. The other two swaths represent about 45 percent of the active bedload-transporting portion of the channel, but move only 22 percent of the bedload. Of these later two swaths, the one nearest the structures, number 11, has the fewest and smallest waves, and transports about one-half the material of swath 12. From the table, it is clear that the methodology captures the lateral spatial variation of transport as well as the total value in the overall active bedload-transporting portion of the channel.

As evidence that the method is independent of the time-difference between the measured swaths, the transport values were plotted versus time between measurements as shown in Figure 5.

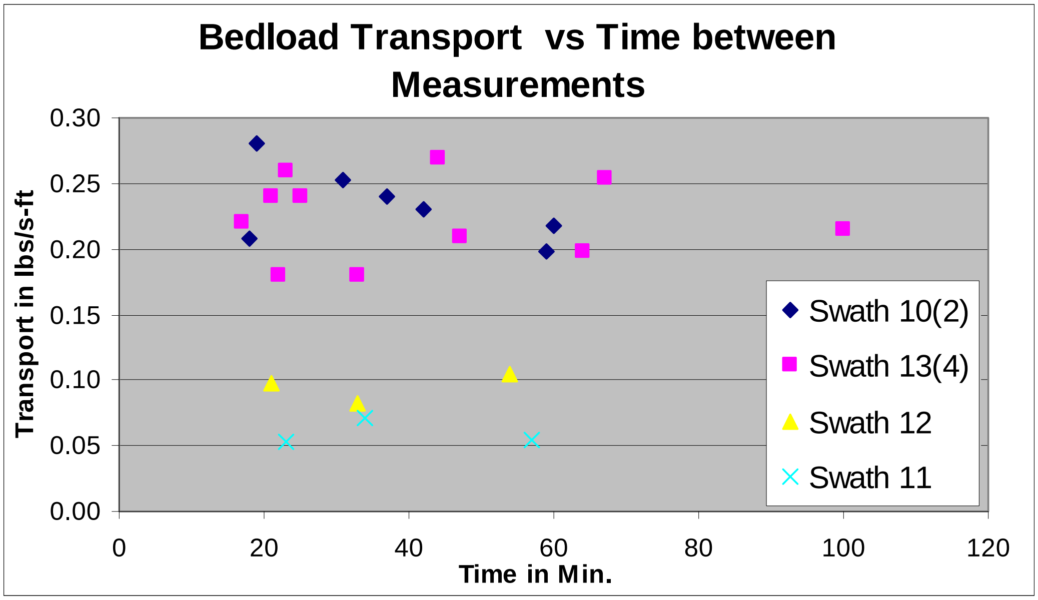

Figure 5 Plot to show that transport is independent of time between measurements.

The selection of the time difference is important. If the time difference between measurements (shown as 'Time in Min.' on the plot) is to short then the user encounters problems with instrument resolution in that there is not enough detectable scour that has occurred for a proper measurement to be taken. Likewise if the time difference is too long then there is uncertainty if the same waves are being captured for a proper difference file. Therefore, it is ideal to survey each swath multiple times on a set interval such that the surveys can be used to produce varying time differences as shown in Table 2. Multiple differences allow many more files to be produced

Table 2 Difference files configuration.

Swath 1						
Survey Time	Survey #	1st Diff	2nd Diff	3rd Diff	4th Diff	5th Diff
0	1	1-2	1-3	1-4	1-5	1-6
30	2	2-3	2-4	2-5	2-6	
60	3	3-4	3-5	3-6		
90	4	4-5	4-6			
120	5	5-6				
150	6					

which in turn increase the number of data sets that can be analyzed. This is important in applying the methodology to field data as it allows a better sensitivity analysis of the selection of time differences and the effect of equilibrium transport. This last item will be discussed in more detail in future papers.

Table 1 shows only the data collected at the Kansas City site for Trip 4. Data were also taken for trips 1, 2 and 3 at the Kansas City site, and trips 1-4 at the Washington site. Preliminary results indicate increasing bedload transport with increase in flow rate. Thus the initial basis for a bedload rating curve has been established. However, data analysis is not complete at this time and has not been presented to the District. Therefore information and findings regarding bedload rating curves will be published at a later date.

SUMMARY AND APPLICATION

Multiple data sets from two Missouri River sites were collected over varying temporal and spatial domains and analyzed using the ISSDOTv2 method for computing bedload transport. Results for Kansas City Trip 4 are shown in Table 2 and Figure 5 and clearly show the method's ability to define the lateral variability of the bedload transport and the independence of the method to varying time steps within certain limits. Additionally, the initial computations for 7 data sets show that the method captures the variance of bedload transport rate with changing flow rate, which should allow the development of bedload rating curves as more field data is obtained and processed.

With increasing dredging costs and environmental concerns in the management of sediment, river managers must continually re-evaluate their systems in light of new and improved measurement methods. ISSDOTv2 allows for a systematic approach to measuring bedload sediments, thus providing previously unobtainable information that river managers can use for further understanding the complex nature of bedload transport in large sand bed rivers.

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