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Bed-Load Transport Measurements on the Chippewa River Using the ISSDOTv2 Method

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PURPOSE: This Regional Sediment Management (RSM) Technical Note (TN) provides information on bed-load measurements obtained on the Chippewa River, Wisconsin, in the spring of 2018. The ISSDOTv2 method was developed by the U.S. Army Corps of Engineers (USACE), Engineering Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), River and Estuarine Engineering Branch. The method uses time-sequenced bathymetric data to determine a bed-load transport rate. When transport rates are obtained with concurrent flow-rate data, it is possible to develop bed-load rating curves. Such rating curves are extremely valuable in forecasting or hindcasting bed-load sediment delivery for the location at which the data were obtained. This is very important for river managers in developing sediment budgets and in the planning of dredging operations.

In the present study, the USACE Mississippi Valley Division (MVD), St. Paul District (MVP), had contracted with the U.S. Geological Survey (USGS) for real-time monitoring of suspended-sediment concentrations (suspended sand load and bed-load sediment) on the lower Chippewa River, a major source and contributor of sand-sized sediment to the Upper Mississippi River (UMR). For the bed-load portion of measurements, a relatively new method proposed by the USGS was to be tested. Although physical bed-load sampling was planned, it was determined that the ISSDOTv2 method should also be used to provide a comparison to the proposed USGS real-time bed-load transport monitoring effort. The USACE National RSM Program provided funding for the ISSDOTv2 measurements. The bed-load values obtained using ISSDOTv2 are presented in this RSM TN.

INTRODUCTION: Sediment on the lower Chippewa River is a major source and contributor of sand-sized sediment to the UMR. In 2014, sediment deposition in the UMR navigation channel caused channel closures between Winona (River Mile [RM] 726) and Wabasha (RM 761), Minnesota, delaying commercial navigation for a period of 3 weeks. This event was costly (millions of dollars per day) to private industry and to the federal government. Additionally, the methods of dredging used in this emergency situation were met with great scrutiny and concern by federal and state natural resource agencies. Figure 1 shows the river reach where the Chippewa River enters the UMR in Lower Pool 4, with appropriate labels.

Real-time monitoring of bed material (sand) loads can facilitate channel maintenance by reducing the uncertainty associated with the timing and magnitude of sediments being transported into problem areas. If, for instance in the above scenario, it had been possible to predict when and how much sediment would be moved into the Mississippi River as a result of the high flows on the Chippewa, then the dredging preparation and response time could have been greatly reduced, meaning in turn that the river closure could have been much shorter.

It was for these reasons that MVP contracted with the USGS for real-time monitoring of suspended-sediment concentrations, suspended sand load, and bed-load sediment on the lower Chippewa River. The measured bed-load values provided by the ISSDOTv2 method have been shown to be very consistent and repeatable in numerous other studies (Abraham et al. 2018); thus, they can be used with confidence as mentioned above for comparison to other methods and/or for the development of a bed-load rating curve. The bed-load rating curve along with hydrograph predictions could provide the timing and quantity of bed-load sediments moving into the Mississippi River at its confluence with the Chippewa.

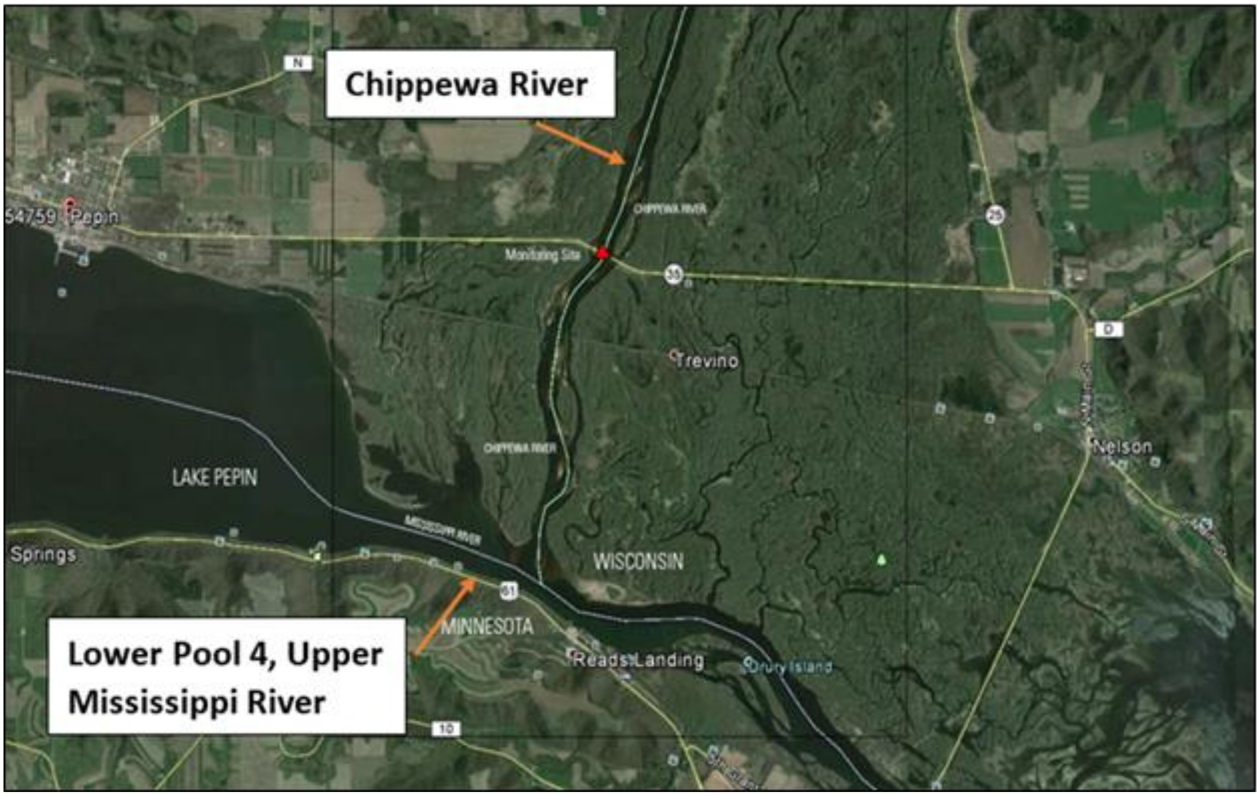

Figure 1. Project location.

Sufficient bathymetric measurements were obtained during the 2018 spring runoff on the Chippewa River to produce rating curves. These bathymetric measurements are the remaining subject of this RSM TN.

METHOD: ISSDOTv2 bed-load measurements were obtained at three locations on the Chippewa River. The locations are shown in Figure 2. The three site locations were selected for the following reasons. Site 1 could provide information on quantities of bed load actually moving into the Mississippi River as bed load. Site 2 was located at the same location as the USGS bed-load measurement site. Site 3 was located at a USGS streamflow gage where bed-load measurements could be taken from the bridge using a standard bed-load sampler and a new surrogate bed-load measurement method could be tested.

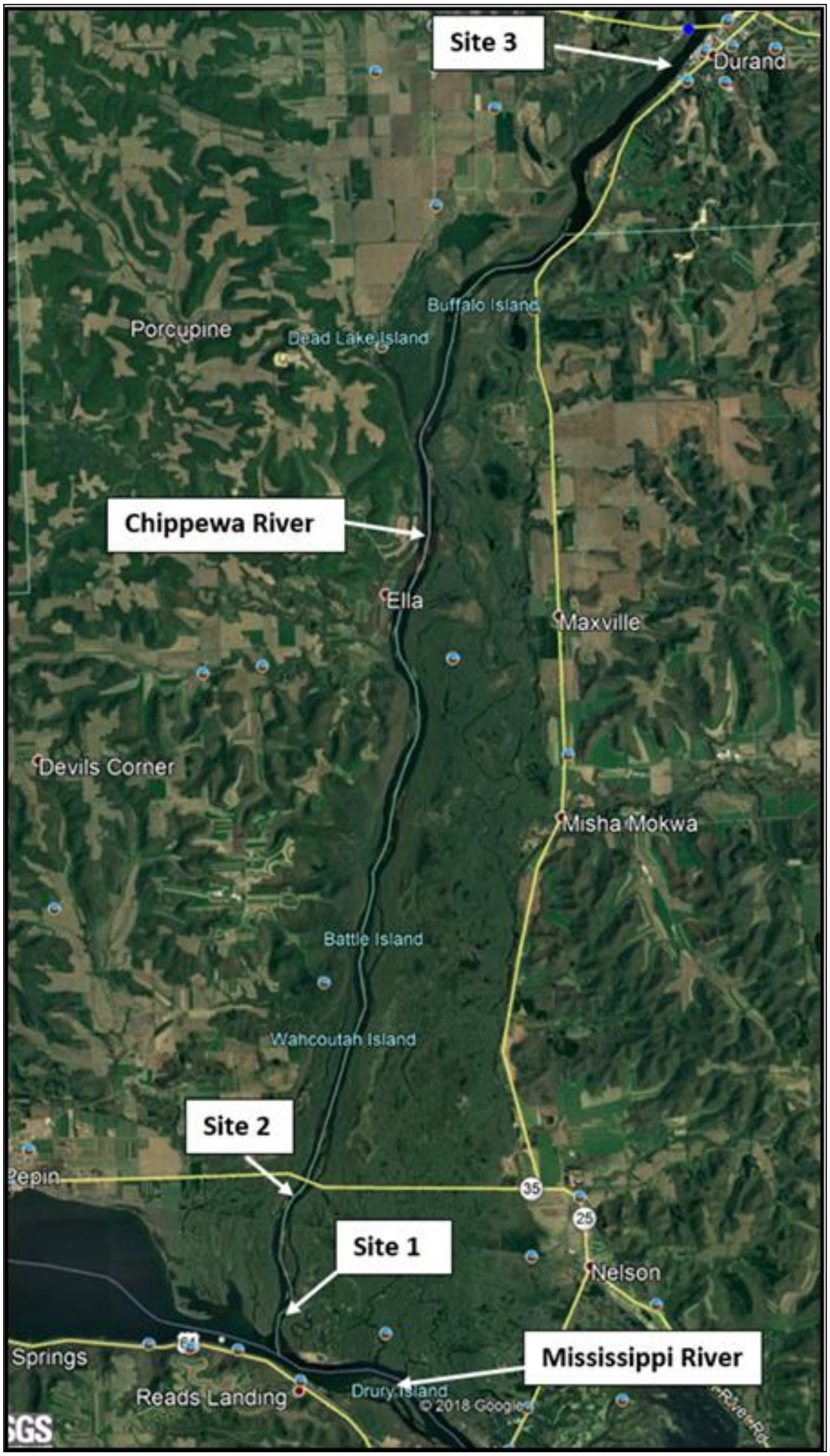

Figure 2. ISSDOTv2 measurement sites.

DATA COLLECTION: The bathymetric surveys were made from the research vessel *Garcia*, shown in Figure 3. The boat is equipped with an Inertial Motion Unit (IMU), Multi-beam fathometer, Accoustic Doppler Current Profiler (ADCP), and a Real-Time Kinematic Global Positioning System (GPS). All of these components are integrated into a complete hydrographic survey package. The multi-beam system is a 500 kilohertz Geoswath Plus Interferometric Multi-beam Sonar coupled with an Applanix PosMV IMU. Real-time GPS corrections are supplied by a Trimble R8 GNSS receiver and broadcast to the PosMV for positioning and crucial time tagging of all instruments. The swath width provided by this system is up to 12 times the water depth per pass with a ranging accuracy of approximately 2.0 millimeters.

Figure 3. Shallow-draft data collection vessel**.**

The data collected for use in the ISSDOTv2 methodology must be collected with attention to details not normally important during traditional multi-beam survey methods. The data need to be collected over a sufficient length of channel to capture multiple waveforms in a short period of time. 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 increased accuracy of the method.

The data were collected as described above and properly processed. They were then analyzed with the ISSDOTv2 method (Abraham et al. 2011; Shelley et al. 2013; Abraham 2018) to obtain a bed-load transport value for the surveyed section of river.

Data were collected for the three sites, as shown in Table 1, on the indicated dates and with the corresponding flow rates (discharge) in cubic feet per second (cfs).

Table 1. Dates ISSDOTv2 data were collected and corresponding flow rates; cubic feet per second (cfs).

	Site 1 – Mouth of the Chippewa	Site 2 – Hwy 35 Bridge	Site 3 – Durand S. of Hwy 10 Bridge
25 Apr	Local flow from ADCP (cfs) = 23,831		
26 Apr	Local flow from ADCP (cfs) = 22,351	Local flow from ADCP (cfs) – 28,970	
27 Apr		Local flow from ADCP (cfs) – 28,707	
28 Apr	Local frow fom ADCP (cfs) 19,304	Local flow from ADCP (cfs) – 27,683	
30 Apr		Local flow from ADCP (cfs) – 24,386	Local flow from ADCP (cfs) – 28,613
1 May	Local flow from ADCP (cfs) = 14,765	Local flow from ADCP (cfs) – 21,051	
2 May	Local flow from ADCP (cfs) 14,188	Local flow from ADCP (cfs) – 19,292	

RESULTS

Site 1. An example of the area covered by the bathymetric survey is given in Figure 4. Table 2 and the graph of Figure 5 show bed-load values in tons per day (tpd) versus flow rate in cubic feet per second (rating curve).

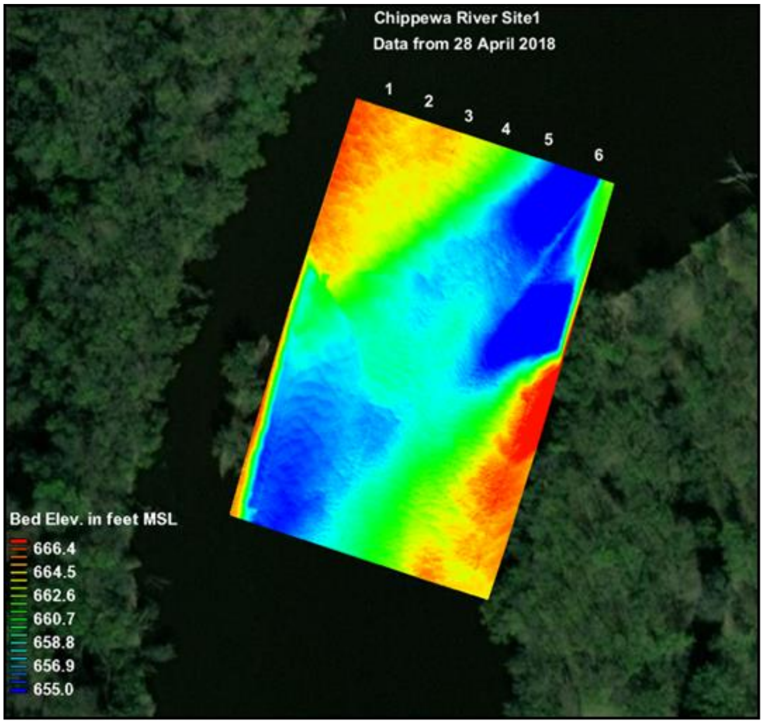

Figure 4. Site 1 bathymetry extent.

Table 2. Site 1 ISSDOTv2 measured bed-load values, tpd versus cfs.

Site 1		
Data points		
Near mouth of Chippewa		
	Bed load	Flow
	tpd	cfs
25 Apr	1,530	23,831
26 Apr	872	22,351
28 Apr	697	19,304
1 May	645	14,765
2 May	369	14,188

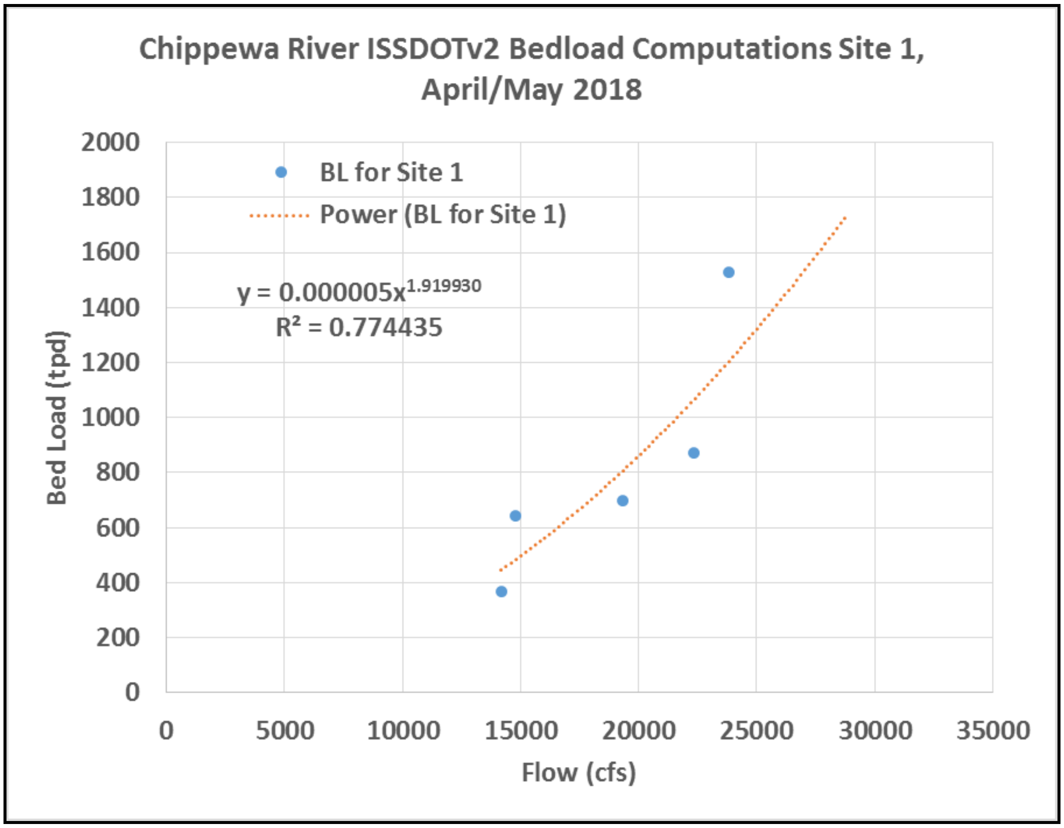

Figure 5. Site 1 ISSDOTv2 bed-load rating curve, tpd versus cfs.

Site 2. An example of the area covered by the bathymetric survey is given in Figure 6. Table 3 and the graph of Figure 7 show bed-load values versus flow rate (rating curve).

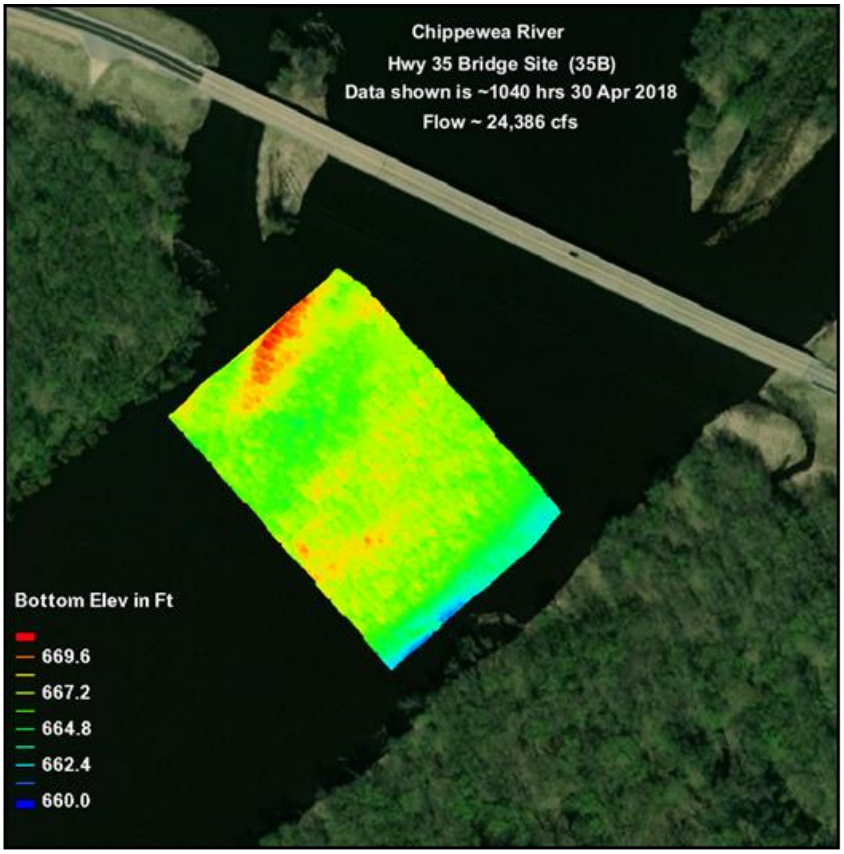

Figure 6. Site 2 bathymetry extent.

Table 3. Site 2 ISSDOTv2 measured bed-load values, tpd versus cfs.

Site 2		
Data points (Hwy 35 bridge)		
	Bed load	Flow
	tpd	cfs
26 Apr	3,567	28,970
27 Apr	3,263	28,707
28 Apr	3,050	27,683
30 Apr	1,419	24,386
1 May	796	21,051
2 May	531	19,292

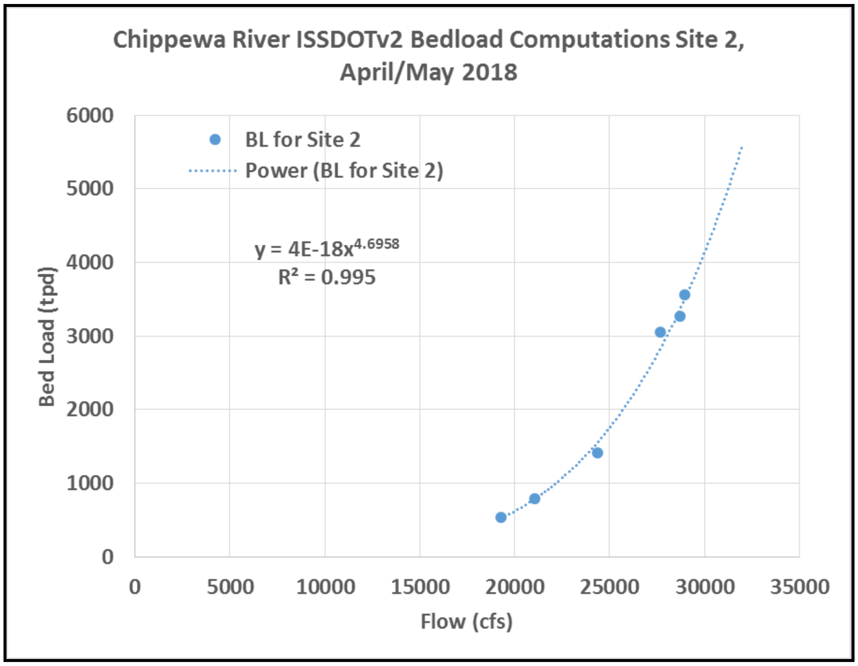

Figure 7. Site 2 bed-load rating curve, tpd versus cfs.

Site 3. An example of the area covered by the bathymetric survey is given in Figure 8. Table 4 shows bed-load values versus flow rate. There is no graph or rating curve for Site 3 because only one survey was made, and thus only one data point is available.

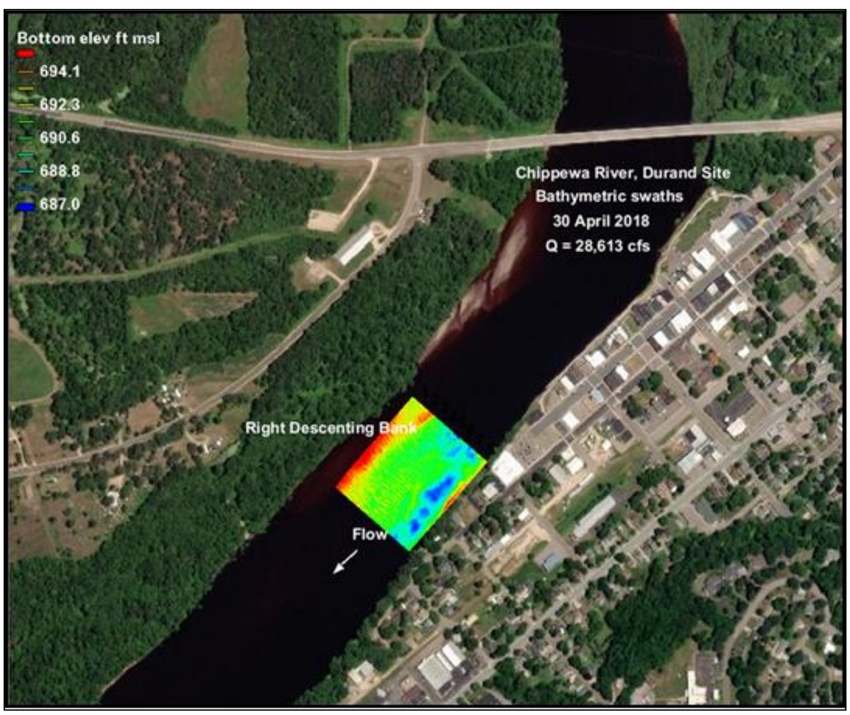

Figure 8. Site 3 bathymetry extent.

Table 4. Site 3 ISSDOTv2 measured bed-load value, tpd versus cfs.		
Site 3		
Data points		
South of Hwy 10 bridge at Durand		
	Bed load	Flow
	tpd	cfs
30 Apr	2,518	28,613

Sites 1, 2, and 3. The data points from all three sites were also combined as in Table 5 which shows bed-load values versus flow rate. Figure 9 shows the values of bed load for the three sites plotted on one graph, but each site being individually identifiable by differing colors and symbols.

Table 5. All sites where ISSDOTv2 measured bed-load values, tpd versus cfs.			
All Three Sites			
		Bed load	flow
		tpd	cfs
Site 1	25 Apr	1,530	23,831
Site 1	26 Apr	872	22,351
Site 1	28 Apr	697	19,304
Site 1	1 May	645	14,765
Site 1	2 May	369	14,188
Site 2	26 Apr	3,567	28,970
Site 2	27 Apr	3,263	28,707
Site 2	28 Apr	3,050	27,683
Site 2	30 Apr	1,419	24,386
Site 2	1 May	796	21,051
Site 2	2 May	531	19,292
Site 3	30 Apr	2,518	28,613

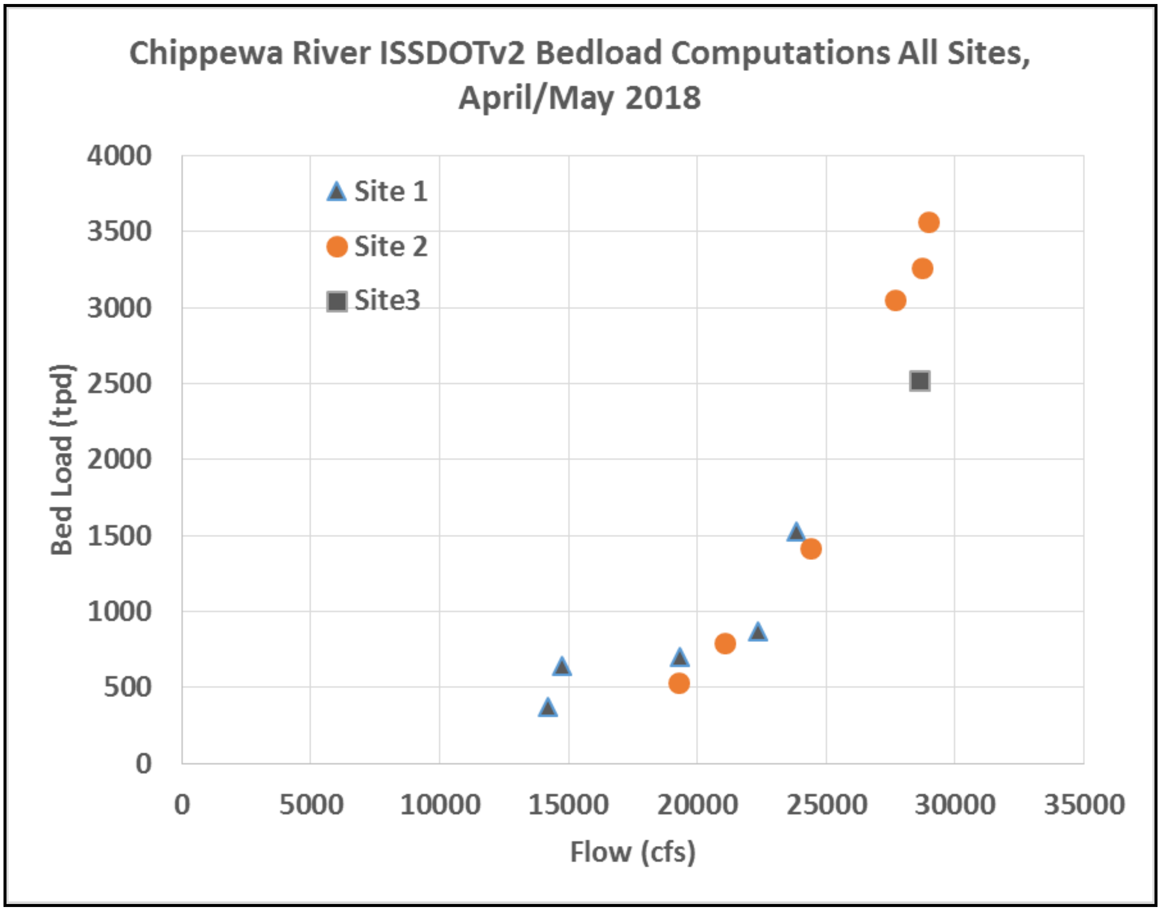

Figure 9. All sites where ISSDOTv2 measured bed-load values, tpd versus cfs.

As can be seen, there does not appear to be any major difference in the relationship of bed load to flow with regards to the site or location on the river. This would appear to justify using all the data points in producing a generalized rating curve for this portion of the Chippewa River. The plot in Figure 10 shows all data points plotted as a single series and a power curve fit through the points. The R-squared value is a statistical measure of how close the data are to the fitted regression line. In other terms, it is variously defined as "the percentage of the response variable variation that is explained by a linear model." The value of 0.85 indicates that the curve shown on the graph could be used with a relatively high expectation of providing representative values of bed load for given flow rates.

In the future, more measurements at higher flows would increase the range of bed-load values for such flows. Since the bed-load transport will usually continue to increase at higher flows, it is important to have data points at those flows as well. At some higher flow, the sediment regime will begin to transition to upper regime, but not knowing exactly what flow that would be implies that measurements should be made at higher flows until a leveling off, or even decrease, in bed-load transport becomes evident. That point would indicate the transition of bed load to suspended bed-material load. In this study, the data do not indicate that such a threshold has been reached.

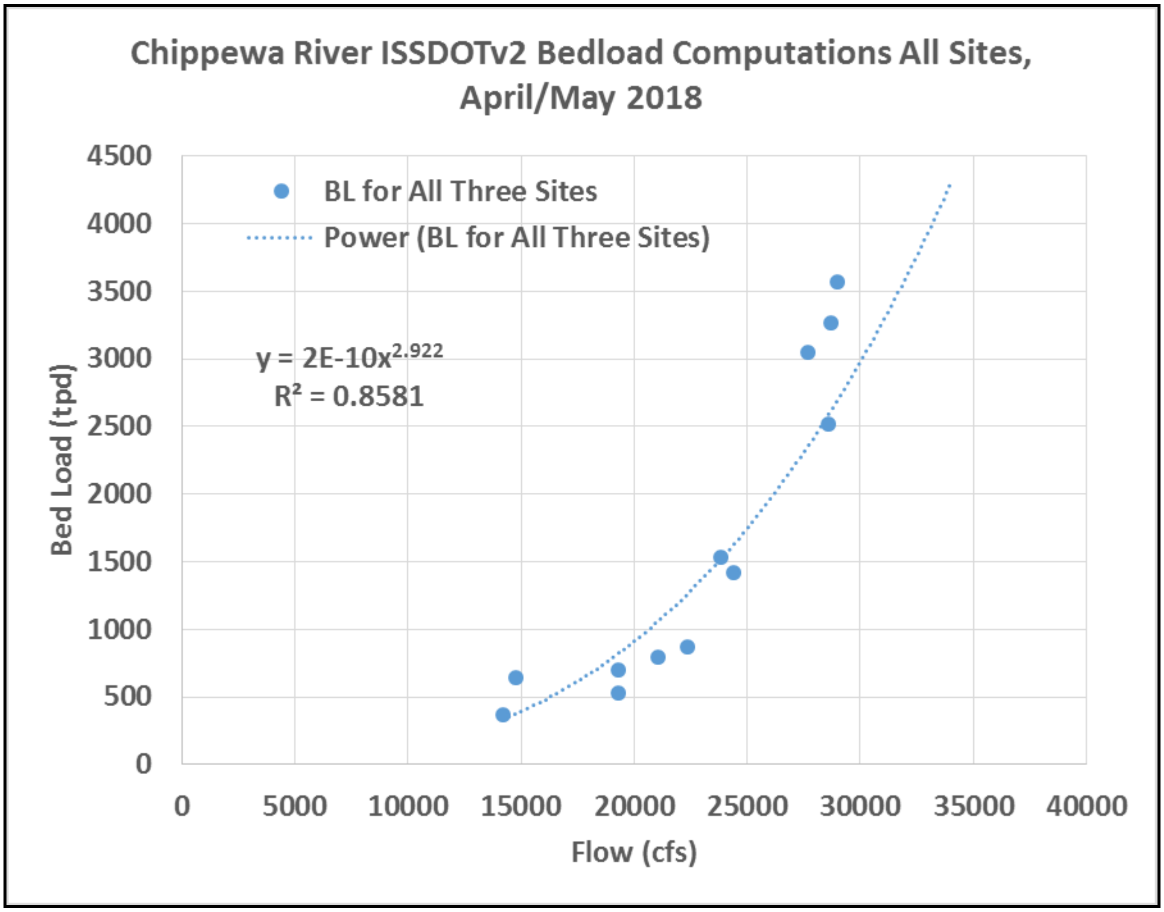

Figure 10. Bed-load rating curve for all sites measured on the Chippewa River, tpd versus cfs.

ADDITIONAL INFORMATION: This USACE RSM TN was prepared by Dr. David Abraham *david.d.abraham@erdc.dren.mil*, Keaton Jones *keaton.e.jones@erdc.dren.mil*, Anthony Jackson *anthony.r.jackson@erdc.dren.mil*, and Tate McAlpin *Tate.O.McAlpin@usace.army.mil*, ERDC CHL; and Jon Hendrickson *jon.s.hendrickson@usace.army.mil*, USACE MVD MVP. This study was conducted as an activity of the USACE National RSM Program, a Navigation Research, Development, and Technology portfolio program administered by Headquarters, USACE. Additional information pertaining to this RSM TN can be obtained from Dr. Abraham. For information pertaining to the USACE National RSM Program, please consult the RSM website (*http://rsm.usace.army.mil*) or contact the USACE National RSM Program Manager, Dr. Katherine Brutsché *Katherine.E.Brutsche@usace.army.mil*.

This RSM TN should be cited as follows:

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