MIDDLE MISSISSIPPI RIVER SEDIMENTATION ANALYSIS AT TRIBUTARY JUNCTIONS

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INTRODUCTION

The Mississippi River System (MRS) has a cumulative length of 6100 miles and connects 17 inland rivers. In 2012, MRS transported 1,402 million short tons of cargo through over 100 inland ports primarily through vessel traffic on federally-authorized navigation channels (U.S. Army Corps of Engineers (USACE), 2013). The Middle Mississippi River (MMR) is an integral piece of the MRS, beginning at the confluence of the Ohio River near Cario, IL and extending 300 miles upstream to just below Lock and Dam 22 as shown in Figure 1 (USACE, 2015).

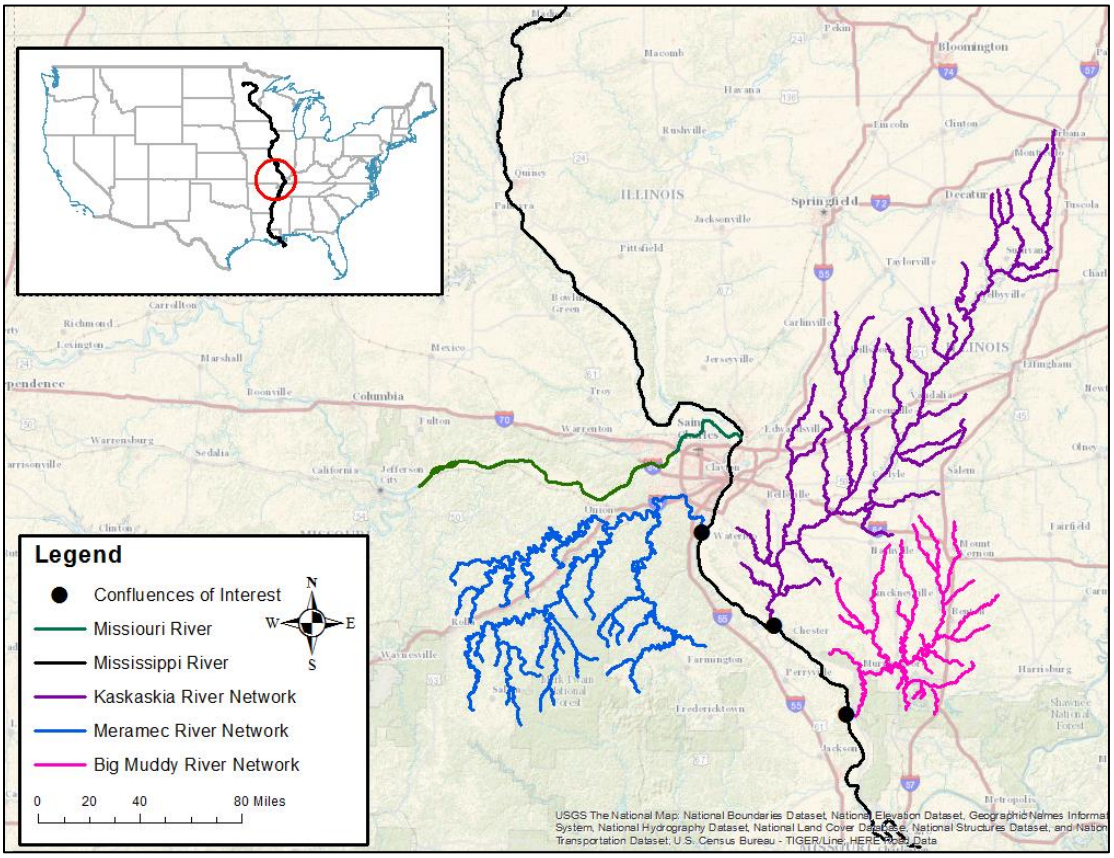

Figure 1 Middle Mississippi River study area

The MMR reach of the MRS marks a change in river management at the confluence of the Missouri River, where the Mississippi River transitions from an open river downstream to a slack-water navigation system upstream that continues through the Upper Mississippi River

(UMR). A slack-water navigation system requires construction of a series of Locks and Dams that create navigable pools to maintain channel depth. These operations may require routine maintenance dredging. The open river portion of the MMR maintains safe channel depths through routine maintenance dredging. Some characteristic descriptors of the open river portion of the MMR are crescent-shaped point bars, an atypically uniform width, and low to moderate sinuosity (Brauer et al., 2005).

Pinter et al. (2004) reviewed reported dredge volumes per river mile between 1964 and 1997, a 34-year record, of the UMR and MMR and noted that the open portion of the river had persistent sedimentation at tributary junctions. The MMR has four river confluences in the open channel reach, namely the Big Muddy River (BMR) confluence, Kaskaskia River (KR) confluence, Meramec River (MER) confluence, and Missouri River (MOR) confluence. Sedimentation rates and patterns described by Pinter et al. (2004) are briefly summarized here. Cumulative dredge volume near the BMR junction was 4.6 million cubic yards (mcy). Sedimentation occurred over a 3.1-mile reach of the MMR just downstream of the tributary junction. Dredge volumes and shoal formation size were along the downstream reach of the KR and not explicitly noted in the study; however, they were described as being a larger volume than both the MER and BMR. Pinter et al. (2004) also noted that sediment discharge from the KR is declining due to upstream Lock and Dam structures. Dredge volumes reported at MER totaled 4.8 mcy, occurring over a 4.1-mile distance of the MMR downstream of the junction. Dredge volumes reported at the MOR were an order of magnitude smaller (0.8 mcy covering 1.3 miles downstream of the junction). Pinter et al. (2004) speculated that the reduced sedimentation at the MOR was attributed to the upstream river training structures that may trap sediment. Due to the lack of similarity between MOR and BMR, KR and MER, the MOR was not included as part of this study.

The spatial distribution of cumulative dredge volumes per river mile provides essential insight into morphologic features of the MMR that continue to promote recurrent sedimentation and required routine maintenance to sustain navigable waters. An in-depth analysis of the temporal and spatial variability of these shoals as a function of the local hydraulic and sediment dynamics is needed to provide insight and yield innovative solutions to improve current dredge practices. Understanding the variability and physical mechanisms behind shoal development is a key step in developing science-based strategies that reduce routine dredge maintenance volumes.

There are two primary objectives of this study: (1) describe the temporal and spatial evolution of shoal formations downstream of tributary junctions using a collection of continuous hydrographic surveys of the navigation channel, and (2) examine the relationship between the morphologic evolution and variation in bulk hydrodynamic parameters.

CLASSICAL MODEL OF TRIBUTARY JUNCTION MORPHOLOGY

The classic morphologic model of asymmetric channel confluences has three main components: tributary mouth bars, a scour hole, and a sediment bar formed downstream of the junction (Best, 1986) (Figure 2). The tributary mouth bars develop at the entrance of one or both tributaries into the confluence. Tributary bars form primarily through bed load transport from the tributaries to the junction, and prograde and recede as a function of relative discharge of the tributaries (Biron,

1996). Presence of only one tributary bar is commonly observed when discharge from the main stream of the junction is highly dominant, typically due to a depth differential, i.e. discordant bed geometry, between both tributary mouths (Ashmore et al., 1983; Kennedy, 1984).

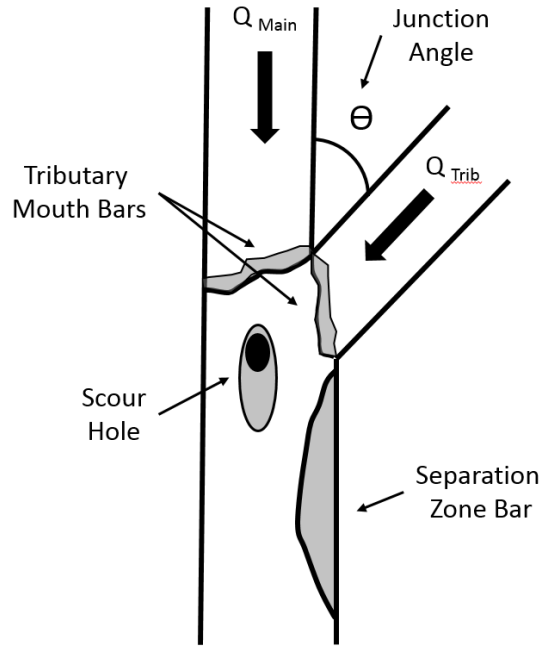

Figure 2 Asymmetrical confluence schematic

Scour holes form slightly downstream of the junction apex and typically bisect the junction angle where the two flows converge and there is downward directed momentum and increased turbulent kinetic energy from secondary circulation (Best, 1986; Rhoads and Kenworthy, 1998). Position of the scour hole can be inferred visually from the observed position of surficial flow convergence (Rhoads et al., 2009). However, in discordant systems such as the confluences of the MER, KR and BMR, scour hole morphology maybe not be easily observed (Biron et al., 1996; Biron et al., 1993; Bristow et al.,1993). One mechanism that could lead to the absence of a scour hole is a prograding tributary bar that has aggraded over the scour hole and essentially buried the hole.

A bank-attached sediment bar formation downstream of a tributary junction is often due to flow separation of the converging tributary flow around the downstream confluence junction. The confluence angle and its degree of confluence symmetry dictate the size and position of the downstream bar (Best, 1986). Confluence symmetry is defined by the confluence planform, where symmetric confluences are more "Y" shaped and asymmetrical confluences occur when the tributary channel joins the flow path of the main channel as shown in Figure 2 (Mosely, 1976). The bank-attached bar forms at the downstream junction corner of the tributary due to flow separation and is composed of fine sediment primarily from the tributary drainage network (Best, 1984; Best, 1986; Bristow et al., 1993). Bank-attached separation-zone bars increase in size when discharge of the tributary channel is comparable or greater than discharge of the main channel through creation a large low-flow, depositional zone and have the potential to deflect

flow from the main channel around the bar due to flow constriction around the bar (Best, 1986; Kenworth and Rhoads, 1995).

The tributary mouth bars, scour hole, and bank-attached tributary bar are dynamic in nature and migrate as a function of planform symmetry, junction angle (Figure 2), depth ratio, discharge ratio, and momentum flux ratio described in Equation 1 through Equation 3,

$$D_r = \frac{D_{Trib}}{D_{Main}} \tag{1}$$

$$Q_r = \frac{Q_{Trib}}{Q_{Main}} \tag{2}$$

$$M_r = \frac{\rho_{Trib} Q_{Trib} v_{Trib}}{\rho_{Trib} Q_{Trib} v_{Trib}} \tag{3}$$

where D_r is the dimensionless depth ratio; D_{main} and D_{trib} are the mean cross-sectional depths of the main and tributary channels [L]; Q_{main} and Q_{trib} are the discharges of the main and tributary channels [L^3T^{-1}]; ρ_{main} and ρ_{trib} are the density of the main and tributary channels [ML^{-3}]; and v_{main} and v_{trib} are the mean cross-sectional velocities of the main and tributary channels [LT^{-1}].

PRELIMINARY RESULTS AND SUMMARY

This study investigates the spatial and temporal variability of sedimentation downstream of the MER, KR and BMR confluences of the MMR. Preliminary results of sedimentation on the MMR downstream of the KR confluence are described in the following section. It is the intent of this effort to analyze a detailed record of hydrographic survey data for the BMR, KR, and MER to identify sedimentation near their confluences with the MMR. These efforts will be summarized in detail during the presentation. The presentation will also include an analysis of bulk hydraulic parameters in efforts to quantify the physical processes that yield sedimentation in these regions.

Preliminary Results – Kaskaskia River Confluence: The Kaskaskia River junction occurs at River Mile 161 along the MMR (Figure 1). Figure 3 compares a before and after dredge survey taken at the confluence (USACE, 2015). Both surveys were collected the USACE, Saint Louis District. Before-Dredge (BD) surveys are often conducted in regions that typically have recurrent sedimentation and are likely to require routine dredging to maintain navigation. The BD survey presented in Figure 3 was conducted on 5 August 2014. Qualitatively from the BD survey there appears to be notable sedimentation at two locations: (1) on the left bank (looking downstream) between the downstream junction corner of the KR and the first downstream weir, i.e. Weir 117.2(L), and (2) across the channel (right bank looking downstream) extending from Weir 117.5(R) downstream of Weir 117.1(R). Sedimentation occurring on the right bank appears to accumulate laterally into the navigation channel.

The After-Dredge (AD) survey was performed on 17 September 2014. AD surveys are used to ensure that after dredging occurs problematic sedimentation has been removed. From the AD

survey presented in Figure 3, it can be observed that the sediment accumulation on the right bank was removed and a wider channel was established. Sediment accumulation on the left bank downstream of the junction appears to have a slight accumulation, but does not appear to be impeding the navigation channel. The AD survey also shows sediment excavation from the KR channel allowing for deeper draft vessel traffic.

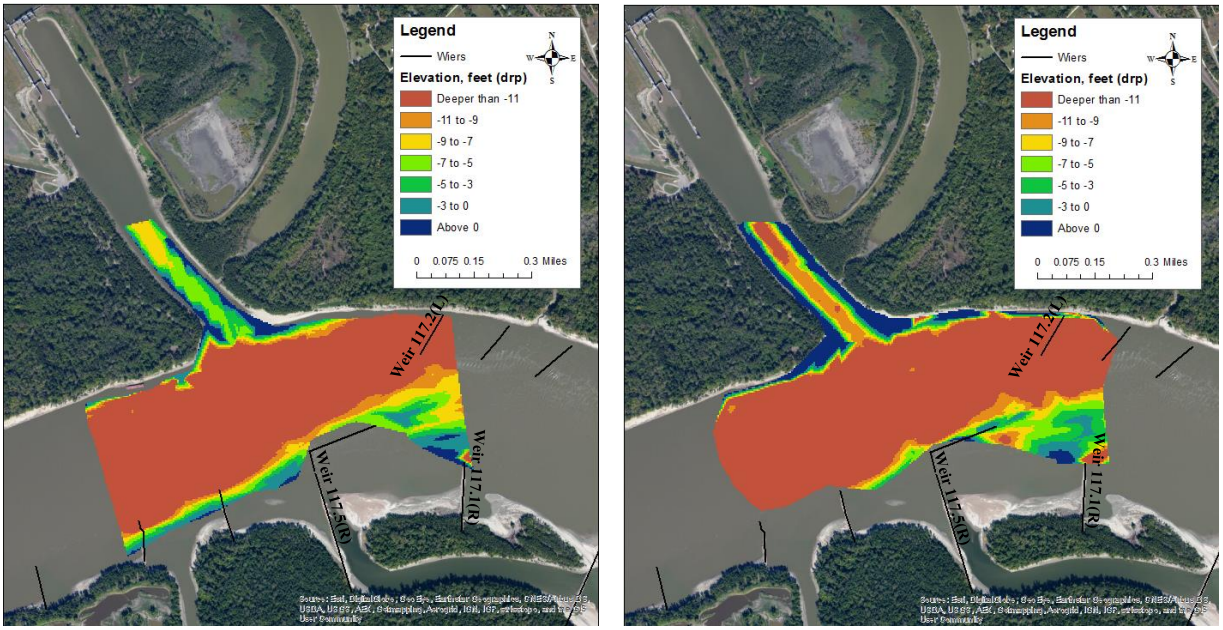

Figure 3 KR confluence showing a Before-Dredge Survey (left) and After-Dredge Survey (right)

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