Journal of Hydrology: Regional Studies 8 (2016) 10–25

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Long-term geomorphic response to flow regulation in a 10-km reach downstream of the Mississippi–Atchafalaya River diversion

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ARTICLE INFO

Keywords:
River diversion
Fluvial geomorphology
Channel morphology
Sand bars
Sediment transport
Lowermost Mississippi River

ABSTRACT

A recent study reported considerable sediment trapping by three large channel bars downstream 18–28 km of the Mississippi–Atchafalaya River diversion (commonly known as the Old River Control Structure, ORCS) during the 2011 Mississippi River flood. In this study, we analyzed 3-decadal morphological changes of the 10-km river channel and the three bars to elucidate the long-term effects of river engineering including diversion, revetment and dike constructions. Satellite images captured between 1985 and 2015 in approximate 5-year intervals were selected to estimate the change of channel morphology and bar surface area. The images were chosen based on river stage heights at the time when they were captured to exclude the temporal water height effect on channel and bar morphology. Using a set of the satellite images captured during the period of 1984–1986 and of 2013–2014, we developed rating curves of emerged bar surface area with the corresponding river stage height for determining the change in bar volume from 1985 to 2013. Two of the three bars have grown substantially in the past 30 years, while one bar has become braided and its surface area has shrunken. As a whole, there were a net gain of 4,107,000 m^2 in surface area and a net gain of 30,271,000 m^3 in volume, an equivalent of approximately 36 million metric tons of sediment assuming a bulk density of 1.2 t/m^3. Sediment trapping on the bars was prevalent during the spring floods, especially during the period of 1990–1995 and of 2007–2011 when large floods occurred. The results suggest that although revetments and dikes have largely changed the morphology of the channel and the bars, they seem to have a limited impact on the overwhelming trend of sediment deposition caused by the river diversion.

1. Introduction

The Louisiana Gulf coast in the USA has experienced one of the highest sea-level rises over the past century (Ivins et al., 2007). Concurrently, the Mississippi River Delta has undergone rapid land loss since the early 20th century (Britsch and Dunbar, 1993; Craig et al., 1979; Gagliano et al., 1981; Scaife et al., 1983). Since 1932 a total land loss of approximately 4900 km^2 has been reported for Louisiana's delta plain (Couvillion et al., 2011). A number of natural and human factors have been attributed to the problem including river engineering (Meade and Moody, 2010; Turner, 1997), accelerated

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http://dx.doi.org/10.1016/j.ejrh.2016.08.002

subsidence (Gagliano et al., 1981; Yuill et al., 2009), reduced riverine sediment supply (Kesel, 1988; Meade and Moody, 2010), disconnection of the river with its floodplains (Xu, 2014), coastal land erosion (Wilson, 2004), and relative sea level rise (Georgiou et al., 2005). Couvillion et al. (2013) projected that, if no actions were taken, at least another 2118 km^2 land of Louisiana's coast would be lost over the next 50 years. This land loss possesses a serious threat to the energy industry, river transportation, and commercial fisheries in this region, all of which have the level of national importance.

Currently, large sediment diversions are being proposed for restoring and protecting the sinking Louisiana's coast by diverting river water and sediment into the wetlands and estuaries surrounding the Lower Mississippi Rivers (LMR) (CPRA, 2012). Studies have been conducted extensively in the recent years on design and site selection of diversions (Gaweesh and Meselhe, 2016; Meselhe et al., 2012; Nittrouer et al., 2012), magnitude of diversion discharge (Wang et al., 2014), and operation strategy (Allison et al., 2014; Rosen and Xu, 2014). A few studies have also looked at potential impacts of river diversions on upstream and downstream sediment transport through modeling (Brown et al., 2013), short-term channel responses to opening of a large river spillway (Allison et al., 2013), wetland ecosystems (Couvillion et al., 2013), vegetation cover (Kearney et al., 2011), and physiochemical conditions of estuaries (Das et al., 2012; Lane et al., 2007). However, studies on long-term effects of large river diversions on nearby downstream channel morphology and sediment transport are scarce. Such information should be tightly associated with the design of proposed diversions because morphological response of the river reach may affect flood conveyance, channel stability and sediment supply to downstream reaches (Surian, 1999).

River diversions remove water from rivers and impose primary changes on flow and sediment transport (Church, 1995). To date, a number of studies have focused on the effects of diversions on downstream channel morphology and sediment deposition. For instance, for the rivers in montane environments, Baker et al. (2011) found that decreased flow velocity and fine sediment deposition downstream of diversions on 13 streams in the western America. Gaeuman et al. (2005) reported that water diversions eliminated moderate flood events which caused vegetation encroachment in the channel and corresponding channel narrowing. However, Ryan (1997) found subtle change in subalpine channels downstream of diversions. For alluvial rivers and reaches, Caskey et al. (2015) reported that channel simplifying and narrowing could occur because of diversion-induced flow alterations in single-thread, straight and meandering, alluvial channels on low to moderate gradient (<3%) valley segments. Wang et al. (2008) predicted that sediment deposition would develop along the whole reach in the long term downstream of the large water diversions in the Lower Yellow River. In general, these studies illustrate that the morphological responses of the downstream channels to the diversions are not only related to the changes in flow regimes and sediment availability, but also to the bed types and channel slope and geometry.

In the LMR, the extensive modifications have been undertaken since 1920s. Artificial cutoffs, levee and dike construction, bank revetment, and reservoir building along major tributaries have largely complicated the geomorphological response of the river reach (Harmar et al., 2005). The river engineering has forced channels to adjust, often resulting in the development of mid channel bars (Smith and Winkley, 1996). However, in his assessment on channel bars of the Lower Mississippi River, Kesel (2003) showed that the bar size and volume from 1880 to 1963 in the lowermost Mississippi River had little change. It has been debated whether this trend has remained in the past several decades. Therefore, studying historical changes of channel bars near diversions can help better understand possible geomorphic responses of a river reach to its proposed future diversion, The Mississippi–Atchafalaya River diversion at the Old River Control Structure (ORCS), with three shortly downstream large channel bars and nearby revetments and dikes, offer an excellent case to study the effects of these engineering practices on channel morphology and bar dynamics in the Lowermost Mississippi River. Little and Biedenharn (2014) recently completed an assessment on the riverbed from the ORCS to the mouth of Mississippi River outlets using single beam bathymetric data acquired in 1963, 1975, 1992, 2004 and 2012 (Little and Biedenharn, 2014). However, there was little information on bar emergence and sediment deposit because their work mainly focused on the bed elevation change. This, along with the relative coarse time resolution of the surveys, makes it difficult to discern the individual effects of the river engineering practices on bar and channel form changes

The purpose of this study is to examine morphological changes of the 10-km long river channel and the three emerged channel bars nearly downstream of the diversion during 1985–2015. Specially, we utilized satellite images and long-term hydrologic data to (1) examine the impacts of the diversion on flow regime, (2) interpret the morphological change of the river channel, and (3) quantitatively estimate variations of surface area and volume of three large channel bars located in the studied reach. The main goal of this study is to elucidate the effects of the large river diversion, revetments and dikes on the morphology of river channel and emerged channel bars. Such information can be helpful for the design of engineering projects in advance to reduce possible hazards in flood protection and navigation safety downstream of the proposed large sediment diversions in the LMR or elsewhere.

2. Study area

The lowermost Mississippi River is defined as the last 500-km long river reach from the Mississippi–Atchafalaya River diversion – the Old River Control Structure (ORCS) (31°04′36″N, 91°35′52″W) to the river's Gulf outlet (Fig. 1). The ORCS was built to prevent the majority of Mississippi River water from being captured by the Atchafalaya River (AR). The overbank structure, low sill structure and outflow channel were completed in 1963. An auxiliary inflow channel and a hydroelectric station were built in 1987 and 1991, respectively. Latitude flow is defined as water in the MR and AR flow across the latitude of Red River Landing (30° 56′20.4″) which is an important term in the diversion management. The often-quoted number of