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Mississippi River channel response to the Bonnet Carré Spillway opening in the 2011 flood and its implications for the design and operation of river diversions

Mead A. Allison [a,*], Brian M. Vosburg [b], Michael T. Ramirez [a], Ehab A. Meselhe [c]

[a] University of Texas Institute for Geophysics, University of Texas, 10100 Burnet Road, (R2200) Austin, TX 78758-4445, USA
[b] Louisiana Coastal Protection and Restoration Authority, Baton Rouge, LA 70804-4027, USA
[c] The Water Institute of the Gulf, Baton Rouge, LA 70804, USA

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SUMMARY

The large Mississippi River flood in 2011 was notable in the lowermost Louisiana, USA reach for requiring operation of several flood control structures to reduce stress on artificial levees: the largest diversion went through the gated Bonnet Carré Spillway, which was opened for 42 days in May and June. The removal of approximately 20% of the total flood discharge from the river provided an opportunity to examine the impact of large water diversion on the sediment transport capacity of large rivers.

Boat-based, acoustic and water and bed sampling surveys were conducted in the Mississippi River channel adjacent to the Spillway immediately prior to the opening of the structure, at full capacity, and immediately following (June 2011) and 1 year after (June 2012) closure. The surveys were designed to examine (1) elevation change of the channel bed due to scour or aggradation of sediment, and (2) suspended and bedload transport variability upriver and downriver of the Spillway. The results indicate that approximately 9.1 million tons of sand were deposited on the channel bed immediately downriver of the water exit pathway and extending at least 13 km downriver at a rapidly and progressively reducing magnitude per river kilometer. The surficial deposit was of finer grain size than the lateral sand bars in the channel upriver of the structure. We argue the deposit was largely delivered from suspension derived from the observed deflation of lateral bars upstream of the diversion point, rather than from sand arriving from the drainage basin. Approximately 69% of the 2011 flood deposit was removed from the 13 km downstream reach between June 2011 and June 2012. We conclude that the source of the channel deposit was the reduction in stream power, and, thus, in the sediment transport capacity of the Mississippi, associated with the water withdrawal. The re-entrainment of this material in the following flood year indicates the system rapidly re-establishes an equilibrium to pre-opening conditions. Future diversions in the river for coastal restoration will have to address this issue to maintain a deep draft navigation channel in the Mississippi River.

1. Introduction

Management of large rivers has often included the use of water diversions for a variety of purposes. Such diversions can have potentially deleterious effects downstream of the diversion point, either directly, through the reduction in water discharge in the main channel, or indirectly, through a reduction in the sediment transport capacity. Rarely, however, have these effects been quantified. For example, water diversions have been utilized in the Ganges River in India (e.g., Farakka Barrage) to divert water up to 1100 cubic meters per second (cms) into the Hoogly River distributary channel at lower river stages to maintain navigability and to flush accumulating river bottom fine sediment from the Port of Calcutta. Studies attributed to Farakka noted that reductions in the water discharge in natural downstream distributary channels in adjacent Bangladesh have resulted in accelerating shoaling in these channels, and saline intrusion in adjacent deltaic wetlands (Mirza, 1998). In the Yellow (Huanghe) River in China, the diversion of water from the main channel in the lower drainage basin for irrigation to increase food production, has led to dry season water shortages further downstream in the basin (no-flow events) and channel shoaling ascribed to reduced transport capacity (Miao et al., 2011). In an extreme example, 85% of the flow of the Danube River was diverted into an artificial channel near the Hungarian–Slovakian border in 1996 to generate hydroelectric power, potentially impacting downstream wetlands and the drinking water supply (both surface and river-recharged groundwater aquifers (Smith et al., 2000)). Predicting the downstream impact of these structures prior to their construction, particularly on the sediment transport capacity of the system, is hindered by the limited availability of observational data to calibrate and validate numerical models of

* Corresponding author. Tel.: +1 512 471 8453; fax: +1 512 471 0348.
E-mail address: mallison@mail.utexas.edu (M.A. Allison).

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the impact of diversions on river hydrodynamics and sediment dynamics.

In the lowermost Mississippi River in Louisiana (Fig. 1), water diversions are utilized for two purposes. Several large diversions (>5000 cms) have been constructed over the last approximately 75 years for flood control, specifically to divert water from the main channel to relieve pressure on the downstream, channel-lining artificial levees that protect cities such as Baton Rouge and New Orleans from flooding. Smaller structures (<212 cms) are utilized to divert freshwater to limit saline intrusion in adjacent deltaic wetlands and coastal water bodies, and to use for drinking water and industrial purposes. In addition, the most recent management plan for the coastal restoration of the degrading deltaic wetlands of the Mississippi Delta in Louisiana (LACPRA, 2012), calls for the construction of larger water and sediment channel diversions (up to 7080 cms at higher river stages) that can be utilized for wetland creation and restoration.

The large flood in May–June 2011 provided an opportunity to test channel response to a large-scale diversion from the Mississippi River associated with the use of the flood control structures, which operate only during the most extreme flood events. The primary objective of the present study is to (1) examine how the channel below the diversion responded to the removal of up to 8000 cms of water, and (2) document the sediment transport regime above and below the diversion during the period when the structure was opened to capacity. This observational dataset can help test the ability of multi-dimensional numerical simulations of channel hydrodynamics and the sediment transport that can better predict the future Mississippi River response to planned large diversions for delta restoration.

2. Study area

The lower Mississippi River in Louisiana divides into two distributary channels immediately upstream of the Tarbert Landing monitoring station at the Old River Control Structures (Fig. 1). The Old River outflow channel merges further downstream with the Red River near Simmesport, LA to form the Atchafalaya River distributary (Fig. 1). The main Mississippi distributary channel below Old River passes through lowland floodplain/alluvial valley to flow downriver of Baton Rouge, LA, and then across the Holocene-age deltaic plain (Saucier, 1994) to the Gulf of Mexico (Fig. 1). Water movement through this lowermost Mississippi reach is coordinated by the U.S. Army Corps of Engineers through a flood control network that was designed to minimize the impact of large floods following the catastrophic 1927 Mississippi River flood. Within the Baton Rouge to New Orleans, LA reach that is the focus of this study, the river is lined with earthen levees located within 1 km of the channel banks and has stabilized banks (concrete mats in shallow water).

In large flood events when discharge at Red River Landing (e.g., below Old River Control immediately adjacent to the discharge measurement station at Tarbert Landing) reaches 1.25 million cfs (35,400 cms), additional water of up to the rated capacity of 250,000 cfs (7079 cms) is passed through the Bonnet Carré Spillway above New Orleans into Lake Pontchartrain (Fig. 1). Discharge above 1.5 million cfs (42,475 cms) is accommodated through the Morganza Spillway and West Atchafalaya Floodway upriver of Baton Rouge, and passing into the Atchafalaya Basin. The Bonnet Carré Spillway (RK 206; Fig. 1) was built between 1929 and 1936 as part of the post-1927 flood control system for the lower river. The structure is a 2134 m long concrete weir with 350 bays, each sealed with 20 timber "needles" that can be raised by a crane running along the weir top to allow river water to pass into an earthen leveled Spillway and flow into Lake Pontchartrain. Water only reaches the weir entrance bays at high discharges (>~24,900 cms), as the structure is fronted by a shallow forebay. Hence, it captures channel water from the uppermost water column. Opened on 10 occasions since 1937 (including 2011), detailed monitoring of water and suspended sediment discharge in the Spillway were conducted in the last three openings (1997, 2008, and 2011). The results of the first two events are compiled in Allison and Meselhe (2010). In 1997 when the structure was open for 23 days (maximum flow of 6600 cms), sampling was done at the Spillway, and at bridges crossing the Spillway 3.3 km and 8.8 km from the structure before the water enters Lake Pontchartrain. Allison and Meselhe (2010) demonstrated that a maximum of 340,000 tons/d (62% sand) of suspended sediment passed into the Spillway late in the rising limb of the flood (5985 cms diversion). Fallout of sediment (deposition in the Spillway) was rapid and weighted preferentially towards the more rapidly settling coarse fraction (sand). No river channel monitoring was conducted during either the 1997 or 2008 events.

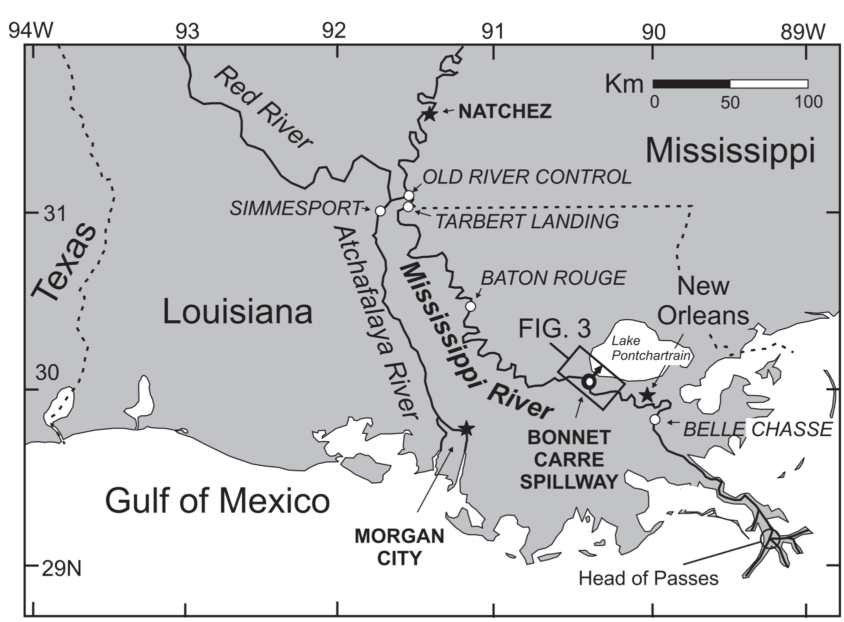

Fig. 1. Map of the study area showing the location of the Bonnet Carré Spillway and the limits of the larger map shown in Fig. 3.