ARTICLE IN PRESS

Estuarine, Coastal and Shelf Science xxx (2016) 1–10

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Enhancing mud supply from the Lower Missouri River to the Mississippi River Delta USA: Dam bypassing and coastal restoration

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A R T I C L E I N F O

Article history:
Received 5 April 2016
Received in revised form
14 July 2016
Accepted 16 July 2016
Available online xxx

Keywords:
USA
Louisiana
Mississippi River Delta
Missouri River Basin
Delta Restoration
Dam bypassing
Sea level rise

A B S T R A C T

Sand transport to the Mississippi River Delta (MRD) remains sufficient to build wetlands in shallow, sheltered coastal bays fed by engineered diversions on the Mississippi River (MR) and its Atchafalaya River (AR) distributary. But suspended mud (silt & clay) flux to the coast has dropped from a mean of 390 Mt y^{-1} in the early 1950s, to 100 Mt y^{-1} since 1970. This fine-grained sediment travels deeper into receiving estuarine basins and plays a critical role in sustaining existing marshes. Virtually all of the 300 Mt y^{-1} of missing mud once flowed from the Missouri River (MOR) Basin before nearly 100 dams were built as part of the Pick-Sloan water development project. About 100 Mt y^{-1} is now intercepted by main-stem Upper MOR dams closed in 1953. But the remaining 200 Mt y^{-1} is trapped by impoundments built on tributaries to the Lower MOR in the 1950s and 1960s. Sediment flux during the post-dam high MOR discharge years of 1973, 1993 and 2011 approached pre-dam levels when tributaries to the Lower MOR, including the Platte and Kansas Rivers, contributed to flood flows. West bank tributaries drain a vast, arid part of the Great Plains, while those entering from the east bank traverse the lowlands of the MOR floodplain. Both provinces are dominated by highly erodible loess soils. Staunching the continued decline in MR fine-grained sediment flux has assumed greater importance now that engineered diversions are being built to reconnect the Lowermost MR to the MRD. Tributary dam bypassing in the Lower MOR basin could increase mud supply to the MRD by 100–200 Mt y^{-1} within 1–2 decades. Such emergency measures to save the MRD are compatible with objectives of the Missouri River Restoration and Platte River Recovery Programs to restore MOR riparian habitat for endangered species. Rapid mobilization to shunt fine-grained sediments past as many as 50 Lower MOR tributary dams in several U.S. states will undoubtedly require as much regional coordination and funding in the 21st century as the monumental effort it took to build the dams in the last century.

1. Introduction

Syvitski et al. (2009) found that dam and reservoir construction since the 1950s has caused an average 44% decline in sediment supply to 33 of the world's major deltas. Anthropogenic reductions in sediment loads coupled with rising sea level are affecting sustainability of deltaic ecosystems worldwide (Giosan et al., 2014; Syvitski and Kettner, 2011; Syvitski and Milliman, 2007). An ambitious initiative to staunch the loss of deltaic wetlands in the Mississippi River Delta (MRD), 25% since 1932 (4900 km^2), is now underway in Louisiana (Couvillion et al., 2011). The MRD restoration "Master Plan" calls for at least two large (Q_{max}>2100 m^3 s^{-1}), controllable sediment diversions on the Lowermost Mississippi River (MR) downstream of New Orleans (Fig. 1). These will be gated channels passing through the banks and flood control levees to reintroduce water and sediment to adjacent, sinking wetland basins (Coastal Protection and Restoration Authority, 2012).

These projects are being sited and designed to divert suspended sand (>62.5 μm) at a concentration at least equivalent to that in the main stream. This is done to minimize downstream deposition in

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http://dx.doi.org/10.1016/j.ecss.2016.07.008
0272-7714/

dredged reaches of the deep-draft MR navigation channel (Meselhe et al., 2012). By maximizing sand capture, diversion designers ensure that diverted silt and clay (mud<62.5 μm) will also be proportional.

Sand and mud passed through artificial outlets will serve different restoration purposes. The sand will build new deltaic platforms in shallow, open water near the diversion outlet (Coleman et al., 1998; Roberts et al., 2003), while the mud will travel farther into the receiving basin. There, newly introduced mud can be deposited and resuspended by waves until a portion is retained on vegetated surfaces during high astronomical and wind tides (Perez et al., 2000; Day et al., 2011; Twilley et al., 2016). Relatively minor additions of inorganic sediment neutralize toxic sulfides and stimulate build-up of a largely organic soil that can rapidly aggrade the marsh surface to keep up with relative sea-level rise (RSLR). RSLR is the combined displacement caused by eustatic rise and local subsidence (DeLaune et al., 2016). The effectiveness of diversions to build new land and save existing wetlands from submergence depends on the volume of sand and mud conveyed to the MRD from the interior of the continent (Fig. 1), and on its subsequent distribution throughout the MRD (Allison and Meselhe, 2010).

Allison et al. (2012) constructed an MRD sediment budget for both the mainstem MR and the Atchafalaya River (AR) distributary channel for three high-discharge years (2008–2010). The AR leaves the main MR course upstream of Baton Rouge at Old River at the upstream apex of the MRD (Fig. 1). It receives all of the Red River (RR) discharge, along with 20–25% of the water and sediment load carried by the MR from Natchez. Since 1963, the U.S. Army Corps of Engineers (USACE) has regulated this distribution daily to stop the progressive capture of MR mainstem flow by the shorter AR distributary (Reuss, 2004). The USACE manipulates flow through gated dams constituting the Old River Control Structure (ORCS) complex to maintain a latitudinal 70:30 split between the MR and AR/RR.

Allison et al. (2012) found that 44% of the average suspended sediment load entering the MRD (Mean $Q_{sed} = 228$ million metric tons per year, Mt y^{-1}) from the MR (193 Mt y^{-1}) and RR (35 Mt y^{-1}), was sequestered in overbank storage and channel bed aggradation inside the flood control levees. This sediment, 100 Mt y^{-1}, including 75 Mt y^{-1} of sand, found accommodation space in the interior of the sinking delta rather than on its periphery. So, only 56% of Q_{sed} during these high-discharge years could have been distributed to coastal wetlands outside the flood protection system, had the planned diversions been in operation. It might be inferred that a Q_{sed} of 100 Mt y^{-1} is the volume required just to maintain the alluvial portion of the MRD upstream of Baton Rouge and in the Atchafalaya Basin above Morgan City (Fig. 1).

The AR carried 62% of the 78 Mt y^{-1} of suspended sediment that, on average, reached the mouths of the two MR branches in the 2008–2010 water years (October 1-September 30). This sediment was conveyed by only 31% of the combined MR and RR mean water discharge (Q_{water}) of 745 km^3 y^{-1}. The sediment that reaches Atchafalaya Bay on the western side of the MRD has built two sand-dominant subaerial delta splays since first emergence in 1973. These now cover 200 km^2 of former bay bottom (van Heerden and Roberts, 1980; Roberts et al., 2003). Moreover, introduction of fine-grained sediment by the AR has created a submerged clay pro-delta deposit that extends many kilometers onto the inner continental shelf (Roberts et al., 2003).

Mud input from the AR has also prevented loss of an estimated 1400 km^2 of wetlands around Atchafalaya Bay over the past 80

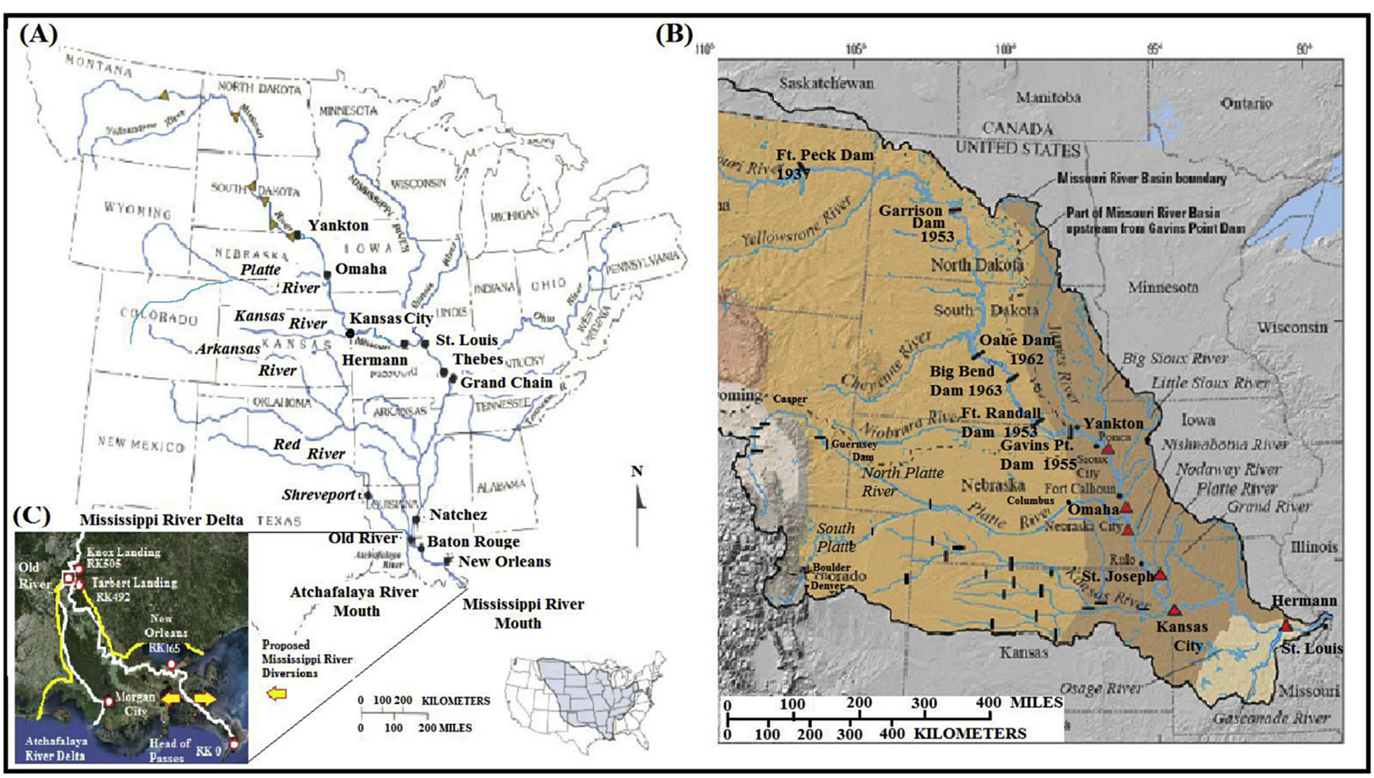

Fig. 1. (A) Mississippi River watershed with suspended sediment sampling stations, modified from Meade and Moody (2010). (B) Missouri River Basin showing some of the larger dams and USGS sediment sampling stations (red triangles), modified from Alexander et al. (2013). (C) MR Delta Plain (yellow line) and proposed large river diversion sites on the Lowermost MR (Coastal Protection and Restoration Authority, 2012). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Please cite this article in press as: Kemp, G.P., et al., Enhancing mud supply from the Lower Missouri River to the Mississippi River Delta USA: Dam bypassing and coastal restoration, Estuarine, Coastal and Shelf Science (2016), http://dx.doi.org/10.1016/j.ecss.2016.07.008