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Large infrequently operated river diversions for Mississippi delta restoration

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ABSTRACT

Currently the Mississippi delta stands as a highly degraded and threatened coastal ecosystem having lost about 25% of coastal wetlands during the 20th century. To address this problem, a $50 billion, 50-year restoration program is underway. A central component of this program is reintroduction of river water back into the deltaic plain to mimic natural functioning of the delta. However, opposition to diversions has developed based on a number of perceived threats. These include over-freshening of coastal estuaries, displacement of fisheries, perceived water quality problems, and assertions that nutrients in river water leads to wetland deterioration. In addition, growing climate impacts and increasing scarcity and cost of energy will make coastal restoration more challenging and limit restoration options. We address these issues in the context of an analysis of natural and artificial diversions, crevasse splays, and small sub-delta lobes. We suggest that episodic large diversions and crevasses (>5000 $m^3 s^{-1}$) can build land quickly while having transient impacts on the estuarine system. Small diversions (<200 $m^3 s^{-1}$) that are more or less continuously operated build land slowly and can lead to over-freshening and water level stress. We use land building rates for different sized diversions and impacts of large periodic inputs of river water to coastal systems in the Mississippi delta to conclude that high discharge diversions operated episodically will lead to rapid coastal restoration and alleviate concerns about diversions. Single diversion events have deposited sediments up to 40 cm in depth over areas up to 130–180 km^2. This approach should have broad applicability to deltas globally.

1.0. Introduction: historical perspective

Currently the Mississippi delta stands as a highly degraded and threatened coastal ecosystem. Before human activities impacted the delta, primarily in the 20th century, it was a healthy functioning ecosystem (Kolb and van Lopik, 1958; Condrey et al., 2014; Muth, 2014). In this paper we discuss how the delta was formed and sustained, the causes of deterioration, and the potential use of very large but episodic diversions for wetland creation while minimizing negative impacts that arise when diversions are operated continuously.

Since the stabilization of sea level approximately 5000 years ago and prior to massive human impact, mainly in the 20th century, the Mississippi River formed a vast deltaic wetland complex encompassing about 25,000 km^2 in the north central Gulf of Mexico (Roberts, 1997; Day et al., 2007, 2014). One need only look at the northern Gulf coast to recognize that riverine inputs formed the delta, which protrudes out into the Gulf more than a degree of latitude compared to coastlines east and west of the delta. The coastlines on either side of the delta tend to be coastal bays fronted by linear barrier islands. It is a truism that it was the river that built the delta, but this question bears looking into in more detail.

Condrey et al. (2014) used maps and journals of early European explorers to describe what they called the last natural delta of the Mississippi that existed just prior to European settlement. The delta

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was a vast seaward-advancing arc that occupied, through four distributaries, all of the five most recent delta complexes of the Mississippi River (Teche, St. Bernard, Lafourche, Modern, and Atchafalaya) and extended across the deltaic plain. It was characterized by plumes of fresh water that extended for more than 10 km into the GOM during the spring flood of the river and by a vast offshore oyster reef that functioned as both an impediment to navigation and an offshore harbor. Insofar as possible, restoration should attempt to replicate conditions that existed before massive human impact. Condrey et al. (2014) suggest that much of Louisiana's coast was advancing into the sea at the onset of European colonization, that colonial and post-colonial modification of the Mississippi resulted in the loss of much of this potential.

The natural delta described by Condrey et al. (2014) was formed and sustained by a hierarchical series of energetic forcings or events that occurred over a wide range of temporal and spatial scales. The delta formed as a series of overlapping delta lobes (Blum and Roberts, 2012). The energetic forcings included the shifting deltaic lobes, but also crevasse formation, great river floods, hurricanes, annual river floods, frontal passages, and tides (Roberts, 1997; Roberts et al., 2015; Boesch et al., 1994; Day et al., 1997, 2000, 2007; Vorosmarty et al., 2009). As the delta developed, it formed a skeletal framework of interconnected natural levee ridges and barrier islands that enhanced sediment trapping and served to protect the delta from storm surge and salinity intrusion (e.g., Day et al., 2007; Xu et al., 2016).

During the twentieth century, there was massive deterioration of the delta, with about 25%, or 4800 km^2, of coastal wetlands lost (Barras et al., 1994; Britsch and Dunbar, 1993; Couvillion et al., 2011). A variety of factors led to this wetland loss, including reduction of sediment input from the basin, pervasive alteration of the hydrology of the deltaic plain, enhanced subsidence due mainly to petroleum extraction, saltwater intrusion, creation of impoundments, and barrier island deterioration (Day et al., 2000; Nyman, 2014; Olea and Coleman, 2014; Kemp et al., 2014). However, the most important factor leading to deterioration of the delta have been the near complete elimination of river water and sediment input to the deltaic plain due to flood control levee construction and closure of distributaries that connected the river to the wetlands (Day et al., 2000, 2007), as well as the reduction in sediment flux from the Mississippi River basin (Meade and Moody, 2010), and increased rate of sea-level rise experienced during the last several decades (Blum and Roberts, 2012).

There is broad agreement that the river must be reconnected to the delta if restoration is to succeed (Allison and Meselhe, 2010; Day et al., 2007, 2012; DeLaune et al., 2013; Lopez et al., 2014; Morris et al., 2013a; Nittrouer et al., 2012; Paola et al., 2010; Shen et al., 2015; Twilley and Rivera-Monroy, 2009). The river provides fresh water to reduce salinity stress, iron to complex with sulfide and reduce sulfide toxicity, mineral sediments to promote accretion, and nutrients to stimulate wetland productivity, which leads to organic soil formation (Mendelssohn and Morris, 2000; Nyman, 2014; Morris et al., 2013a; Day et al., 2014). Combating coastal erosion and restoring coastal wetlands is now a main component of State and Federal policy (CPRA, 2012a), and the construction of river diversions to reintroduce Mississippi River water and sediments into coastal basins is planned for coming decades (Wang et al., 2014; CPRA, 2012a; Day et al., 2014). Understanding how historical floods and crevasses built land informs future restoration work on diversions as scientific research and engineering converge on the best approaches for coastal land building. The objective of this paper is to discuss the potential of using large but infrequently opened diversions for wetland creation and delta restoration while addressing issues related to fisheries and water quality as a result of over-freshening in the context of 21st century mega-trends.

2.0. Existing natural and artificial diversions as models

The State of Louisiana's Master Plan for restoration and flood protection of the Mississippi delta involves a suite of restoration activities including wetland creation using pumped dredged sediments, hydrologic restoration, barrier island restoration, and structural and non-structural flood protection (CPRA, 2012a). A central element of the plan is the reintroduction of river water back into the delta plain to create and sustain wetlands. River diversions involve the construction of water control structures along the river and hydraulic management is often needed to direct water flow after it enters the coastal wetland complex. Successful river diversions should be informed by the history of natural sub-deltas and crevasse-splay deposits. The design and operation of diversions should be based on an understanding of the history of natural and constructed projects where river water flows into coastal systems (i.e., Allison and Meselhe, 2010). Here we review a number natural and artificial crevasses, diversions, and sub-deltas.

Davis (1993) reported that between 1850 and 1927 there were more than a thousand crevasses along the lower Mississippi levee. These crevasses overlapped to form a continuous band of crevasse deposits essential to the formation and maintenance of both natural levees and coastal wetlands (Fig. 1; Saucier, 1963; Davis, 2000; Allison and Meselhe, 2010; Shen et al., 2015). Day et al. (2016) reported that an artificial crevasse opened at Caernarvon during the great flood of 1927 had a peak discharge of nearly 10,000 m^3 s^{-1} and deposited a crevasse splay of about 130 km^2 in about 3 months (Fig. 2) with sediment deposition was as high as 42 cm.

The river diversion at Caernarvon, the first of the modern era, began discharging during 1991 into Big Mar – a water body that resulted from a failed agricultural impoundment – before entering the upper Breton Sound estuary (Lane et al., 1999, 2006). A small new sub-delta of almost 250 ha has formed in Big Mar, with about 235 ha since Hurricane Katrina in 2005 (Fig. 3; Lopez et al., 2014). However, under historical conditions of prolonged high sediment yield discharge during a single flood event, such as occurred in 1927 in the same location as the modern diversion, the impact on land-building is much more dramatic, as discussed below.

The artificial 1927 crevasse at Caernarvon was similar in size and duration to naturally occurring historical crevasses. For example, the Davis Crevasse, which formed in 1884 and is located on the west bank of the river 32 km upriver of New Orleans, had an area of about 150 km^2 and is still clearly visible on photos of the area (Fig. 4). Davis (1993) reported that the crevasse was directly attributed to an old rice flume that was abandoned and removed a few months prior to the high water, although a muskrat hole may have contributed to the break. Davis reported that "the crevasse was by far the single most destructive crevasse in the history of overflows in Louisiana". It led to extensive flooding with water levels as high as 0.6–2.4 m over much of the affected area.

Just east of the historical Davis Crevasse, the Davis Pond river diversion was initiated in 2002. The insert in Fig. 4 shows the new sub-delta that is forming, which is similar in size to the Caernarvon sub-delta. The Caernarvon, Davis, and Bonnet Carré historical crevasse splays and the newly forming small delta lobes at Caernarvon and Davis Pond illustrate the land building capacities of vary large diversions (e.g., >5000 m^3 s^{-1}) and small diversions (mean discharge about 50 m^3 s^{-1}) (See Table 1). The crevasse splays were formed by one (Caernarvon and Davis) to several (Bonnet Carré) annual discharge events. In contrast the small river diversions at Caernarvon and Davis Pond have been in operation for 25 and 14 years, respectively. Thus, large crevasses can create up to two orders of magnitude more land in a few events than is created over several decades by small diversions.

The Bonnet Carré crevasse was active in the 2nd half of the 19th

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