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Evaluating trade-offs of a large, infrequent sediment diversion for restoration of a forested wetland in the Mississippi delta

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A B S T R A C T

Flood control levees cut off the supply of sediment to Mississippi delta coastal wetlands, and contribute to putting much of the delta on a trajectory for continued submergence in the 21st century. River sediment diversions have been proposed as a method to provide a sustainable supply of sediment to the delta, but the frequency and magnitude of these diversions needs further assessment. Previous studies suggested operating river sediment diversions based on the size and frequency of natural crevasse events, which were large (>5000 m^3/s) and infrequent (active < once a year) in the last naturally active delta. This study builds on these previous works by quantitatively assessing tradeoffs for a large, infrequent diversion into the forested wetlands of the Maurepas swamp. Land building was estimated for several diversion sizes and years inactive using a delta progradation model. A benefit-cost analysis (BCA) combined model land building results with an ecosystem service valuation and estimated costs. Results demonstrated that land building is proportional to diversion size and inversely proportional to years inactive. Because benefits were assumed to scale linearly with land gain, and costs increase with diversion size, there are disadvantages to operating large diversions less often, compared to smaller diversions more often for the immediate project area. Literature suggests that infrequent operation would provide additional gains (through increased benefits and reduced ecosystem service costs) to the broader Lake Maurepas-Pontchartrain-Borgne ecosystem. Future research should incorporate these additional effects into this type of BCA, to see if this changes the outcome for large, infrequent diversions.

1. Introduction

During the 20th century, Louisiana lost about 25%, or 4800 km^2, of coastal wetlands, due mainly to the effects of human activities (Couvillion et al., 2011). One of the major causes is leveeing of the Mississippi River (MR) and its distributaries, which has isolated deltaic wetlands from the MR, preventing overbank flooding and crevasse formation (Day et al., 2000, 2007, 2016a). Engineered sediment diversions, which divert sediment and nutrient laden freshwater from the MR to adjacent wetlands, have been identified as a critical tool in restoring the Mississippi river delta plain (MRDP) (Day et al., 2007, 2016a; Kim et al., 2009; Allison and Meselhe, 2010; Paola et al., 2011; CPRA, 2012, 2017a; Dean et al., 2014; Wang et al., 2014). Three operational river diversions were constructed for the purpose of restoration: the Caernarvon and Davis Pond diversions (99 and 302 m^3/s, respectively) control salinity intrusion, and the West Bay diversion (566 m^3/s) is designed to divert sediment to create and nourish wetlands near the mouth of the river. The Bonnet Carré spillway (operated at 3000–9000 m^3/s, several weeks

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to 2 months at a time every five to seven years on average), although intended for flood control rather than restoration, has led to a highly sustainable forested wetland adjacent to Lake Pontchartrain (Day et al., 2012).

If the MRDP's historic functioning is used as a blueprint for restoration, much bolder action is required (Condrey et al., 2014; Day et al., 2016a). Saucier (1963) and Davis (1993, 2000) documented numerous crevasses along the lower MR prior to major anthropogenic alteration. For example, the Bonnet Carré crevasse functioned intermittently in the second half of the 19th century with discharge ranging from 2000 to 6500 m^3/s and built a crevasse splay of about 70 km^2 as well as filling in parts of western Lake Pontchartrain with up to 2 m of sediment (Saucier, 1963; Davis, 1993) (a "crevasse splay" is defined as a fan-shaped deposit of sediment formed when a river spills water and sediment over or through a break in the river levee). Also, the 1927 artificial crevasse at Caernarvon resulted in a crevasse splay of about 130 km^2 with sediment deposition as high as 40 cm in only three months (Day et al., 2016b). Day et al. (2016a) presented the concept of large (>5000 m^3/s) and infrequent (active < once a year) diversions that would replicate the size and frequency of historic river crevasses. They hypothesized that, compared to an annually operated diversion, an infrequently operated diversion would still provide ample sediment for land building but with substantially lower impacts on water levels, salinity, nutrient load, and fisheries – controversial effects that have impeded implementation of diversions (Caffey and Schexnayder, 2002; Day et al., 2016a).

Maintaining land in the MRDP's lower reaches is becoming increasingly difficult, due to both a reduced sediment load in the MR (from dams and land use change in the upper basin), and accelerating eustatic sea-level rise (SLR) (Pfeffer et al., 2008; Blum and Roberts, 2009; Horowitz, 2010; Meade and Moody, 2010; Parris et al., 2012; Giosan et al., 2014). Also, given that subsidence generally decreases moving from the delta terminus upriver (Zou et al., 2015), land building should be more sustainable in the upper, more inland reaches of the delta. One potential location for a sediment diversion in the MRDP upper reaches is the Maurepas swamp, a 57,000 ha baldcypress-water tupelo (*Taxodium distichum* - *Nyssa aquatica*) forested wetland system located in the western Lake Pontchartrain Basin between Baton Rouge and New Orleans, Louisiana. The swamp is currently on a trajectory towards open water and the causes are numerous but well known; the dominant issue is that sediment and freshwater inputs from the MR that nourished the wetlands during seasonal flooding events in the past are now prevented by flood control levees (Shaffer et al., 2003, 2009, 2016; Keddy et al., 2007; Day et al., 2012).

Modelling of sediment diversions is important to understand performance and trade-offs of different operation approaches. The simplest models predict land gain based on mass balance and a uniform geometry (e.g. Parker et al., 1998; Dean et al., 2012, 2014), whereas more complex models simulate the physics of fluid flow and sediment transport based on basin hydrology and bathymetry (e.g. Edmonds and Slingerland, 2007). Predicting future scenarios with such modelling tools is useful in combination with benefit-cost analysis (BCA), where the economic benefits of different project options are compared to the economic costs, traditionally in monetary terms. For example, Kenney et al. (2013) combined a land building model with a cost model to assess trade-offs of cost, land building, and water usage for portfolios of sediment diversion projects. They used a physical unit (area of land built) to express benefits, where in other studies benefits are sometimes expressed in ecological terms, such as habitat suitability indices (Bartoldus, 1999; CPRA, 2012, 2017a). However, for policymakers and politicians, who are used to making decisions with dollars, such biophysical units are less intuitive.

The "ecosystem services" framework has recently gained traction as a means for communicating the benefits of natural systems. Especially in the management of coastal systems, which provide a rich array of benefits under increasing strain from human development (Turner and Schaafsma, 2015). Ecosystem service valuation (ESV) offers a means to capture, in monetary terms, these benefits. ESV is especially useful in BCA, where benefits and costs can be expressed with a common unit, but there exist methodological challenges which make its application difficult. In the 2012 Comprehensive Master Plan (CMP), for example, the Coastal Protection and Restoration Authority (CPRA) avoided representation of ecosystem services in monetary terms, stating that "we did not include this economic aspect of ecosystem services in the master plan analysis [because] [m]odels to analyze this aspect were not readily available, and we did not have time to develop them ourselves" (the same approach is taken in the 2017 CMP). Recent examples of combined modelling and ESV exercises applied to ecosystem restoration exist in the MRDP and Florida Everglades (Mather Economics, 2010; Caffey et al., 2014; REC & EE, 2016).

This study explored a large, infrequent sediment diversion, of the sort described by Day et al. (2016a), into the Maurepas swamp (Fig. 1) (unless otherwise stated, by "diversion" we mean "sediment diversion", a diversion intended to build land, versus a "freshwater diversion" which is intended to control salinity). Day et al. (2016a) suggested that large diversions operated infrequently are advantageous to small diversions operated continuously, but lack a quantitative assessment of the drawbacks of infrequent operation. In particular, what are the drawbacks of "curtailing" sediment delivery for one year or more compared to continuous operation? This paper addressed this question. By parameterizing a delta progradation model for the Maurepas swamp we were able to estimate land building for a number of diversion sizes, operation strategies (years inactive between operations), and SLR scenarios. First, we analyzed the relationship between years inactive, size, and land building in general, and assessed the potential to sustain land building. Second, we used the land building estimates to further assess large, infrequent diversions by performing a BCA, where ESV is applied to capture, in monetary terms, the benefits provided by the Maurepas swamp restoration. Based on the applied model, our estimates of ecosystem service benefits were limited to those

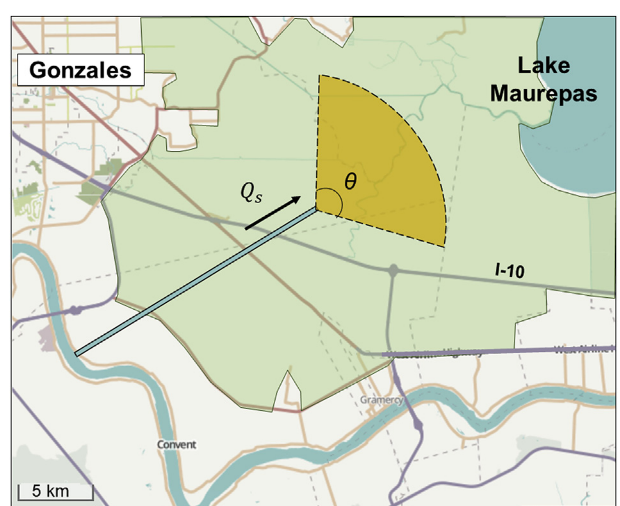

Fig. 1. Conceptual diagram of a sediment diversion into the Maurepas swamp (top view) with sand discharge, Q_s, and fan spreading angle, θ. Light green areas are wetland, and light grey areas are developed. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)