Journal of Environmental Management 393 (2025) 127117

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Systemic analysis of the tradeoffs associated with management strategies for natural and built Mississippi River outlets

Laura Manuel [a,*], Ehab Meselhe [a], Kelin Hu [a], Denise J. Reed [b]

[a] Department of River Coastal Science and Engineering, Tulane University, New Orleans, LA, USA
[b] Department of Earth and Environmental Sciences, University of New Orleans, New Orleans, USA

1. Introduction

Natural resource management in coastal regions is a challenging task often requiring actions which impact both the natural and built environments within the coastal regions. The interests of coastal industry, community, and environment are unique, yet commonly vested in the decisions made concerning the natural resources of coastal ecosystems which provide freshwater and habitat (Seitz et al., 2014), storm surge protection (Dasgupta et al., 2019), commerce and recreation(Littles et al., 2018), etc. Environmental management decisions made in coastal regions are inherently accompanied by tradeoffs associated with the natural environment's reaction to interventions. For example, dam construction in large river systems around the world result in tradeoffs where flood risk is reduced, agriculture needs are better met while sediment starvation in the downstream reaches is induced (e.g. the Mekong Delta (Li et al., 2017), Yangtze River (Yang et al., 2007), and Mississippi Delta (Meade and Moody, 2010). The tradeoffs of constructing levee systems, such as in the Lower Yellow River (Walling, 2011) and Mississippi Rivers (Coleman et al., 1998), are that levees protect communities from flooding, but funnel sediments offshore and prevent natural crevassing and nourishment to adjacent wetland areas. Levees may induce channel alteration through aggragation that reduces channel capacity and stresses levee infrastructure, as seen in the Indus River (Mahmood et al., 2022). This study investigates tradeoffs associated with the environmental management of the Lower Mississippi River to support ecosystems restoration and mitigate flooding, through the diversion of river waters into adjacent estuaries, and other uses of the river and coastal system.

River diversions reroute a portion of a river's flow into an adjoining basin. Diversions occur naturally or are manmade. River diversions for ecosystem restoration seek to reconnect the river to nearby wetlands by periodically rerouting floodwaters laden with sediment and nutrients from the river (Gagliano et al., 1981) (Amer et al., 2017). River diversions have the potential to support large scale coastal restoration through long term land building with temporary impacts to the environmental system (Day et al., 2018). The existing engineered diversions along the Lower Mississippi River are used to manage flood risk by reducing stress on river levees, build land, and/or mitigate salinity intrusion. Sensitivity of fish, shellfish and marine mammals to diversion-caused salinity changes in receiving estuarine basins must be considered in optimizing land-building strategies (De Mutsert et al., 2017; Garrison et al., 2020) (Khalifa, 2023; Peyronnin et al., 2017a). Further, diversions must be designed and managed to accommodate and adapt to ongoing climate change (Wang et al., 2017; White et al., 2019).

Achieving the balance between flood control and maintaining/rebuilding deltaic wetlands, and unnecessary over-freshening due to operation is a challenging task for diversion managers. Although the largest existing diversions that were built for flood control purposes have been in service for over 90 years, there has been no significant change to operation plans since their construction, namely the Morganza Spillway and Bonnet Carré Spillway (BCS). Yet, it is evident from the range of impassioned responses, both positive and negative, after each diversion operation or avoidance thereof, both the differing needs of resource users and the growing importance of investigation in the management plans for diversions (USACE (2023)). Publications and literature documenting the effects of BCS openings, specifically the severe damage to commercial fishing and oyster industry production for neighboring state, have been realized and exemplified in the 2019 event (McAnally and Nail, 1995; Mishra and Mishra, 2010; Mize and Demcheck, 2009; S. M. Parra et al., 2020; Turner, 2006).

What if the Mississippi river flood risk management features were operated differently? How will new diversions affect the already highly managed ecosystem? With consideration of these questions, the goal of this study is to analyze the collection of diversions and natural outlets on the Lower Mississippi River from a systemwide perspective and examine different operational tactics of diversions to quantify what tradeoffs emerge. This study is conducted via the development and application of numerical modeling tools on scales necessary for such a complex

* Corresponding author.
E-mail addresses: manuellaura97@gmail.com (L. Manuel), emeselhe@tulane.edu (E. Meselhe), khu1@tulane.edu (K. Hu), djreed@uno.edu (D.J. Reed).

https://doi.org/10.1016/j.jenvman.2025.127117
Received 18 March 2024; Received in revised form 20 August 2025; Accepted 22 August 2025
Available online 25 August 2025

environmental assessment. A focus of this study is the impact of annual changes in hydrological conditions on the basin changes due to the diversion operations. Existing diversions and proposed diversions by the state of Louisiana's Master plan (CPRA, 2023) are considered, as these diversions would be the most probable candidates to join the landscape in the future. Scenarios were designed to place diversions or lower pass closures fully on or fully off the landscape to bracket the possibilities of basin response. The translation of modeling output into meaningful metrics for decision-making is a vital component of this science support to decision making. This study aggregates and revises metrics from previous diversion studies (refer to Table 1.) to provide a holistic group of criteria to evaluate diversion tradeoffs. The metrics include both physical processes (water and sediment), ecological processes (marsh vegetation, oysters, and marine mammals), and highly relevant socio-economic interests of navigation and oyster suitability. This study establishes a framework that can be used for deltaic systems globally where ecosystem services intersect with socioeconomic interests requiring the pursuit of compromise for all stakeholders.

2. Study area

The Northern Gulf of Mexico (NGOM) includes the region from Galveston, TX to Panama, FL and Tarbert Landing, MS to the Gulf of Mexico. Though located in the state of Louisiana along the Mississippi river, existing large diversions, such as the BCS, have a historical record of propagating effects across multiple state coastal zones (Armstrong et al., 2021). This spatial domain allows the extent of influence to be captured without interference from the model boundary conditions. The South Louisiana estuarine basins within this study's analysis exhibit a natural salinity gradient from the most inland areas to the open gulf ranging from fresh to intermediate to brackish to salt water. These basins are relatively shallow, providing a generally well-mixed regime. Mississippi River diversions considered in this study were considered from the Old River Control Structure and including all diversions downstream to the Gulf of Mexico (See Fig. 1). This study did not include the Atchafalaya River Floodway, which leaves the main channel through floodgates just upstream of the northern limit of the study area at Old River.

2.1. East bank lower passes

Downstream of the levee system, a less regulated series of lower passes exists on the Mississippi River. These passes refer to all natural outlets on the river from Mardi Gras Pass to the end of the Birdsfoot Delta (See Fig. S4 in Supplemental Material). Some passes are maintained via dredging for navigation purposes and others via closure from an emergency management perspective, using rock closures or partial closures to restrict flow from entering a crevasse. The remaining passes naturally evolve with intermittent monitoring by researcher groups or government agencies to assess if they do pose any threat to industrial functions or the natural system. These natural diversions have created highly productive deltaic habitats in receiving bays, reversing decades of wetland loss. Sporadic deposition downstream of Venice due both to reduced flow in the Lower Mississippi and to maintaining an increased depth in the navigation channel has led to additional dredging and costs. This has drawn attention to the management of these lower passes (Allison et al., 2023). Impacts of lower pass flows on navigation raise other concerns. For example, the recent natural expansion of the Neptune pass (USACE et al., 2022) evolved rapidly and began to divert upward of 16 % of the flow from the Mississippi River, causing a significant tow on shipping traffic in the Mississippi River. The extensive time and resources required to address this natural diversion emphasizes the need to evaluate natural pass management protocol prior to an emergency response.

Table 1
Eight operation scenarios for evaluation that illustrate an envelope of options for diversion management with either present day infrastructure or including future infrastructure.

Operation Scenarios	Bonnet Carré			Lower Passes	Base Case
	Morganza	2023	Existing Infrastructure	Closures	A
				No Closures	B
		Future	Mid Barataria + Mid Breton	Closures	C
				No Closures	D
			Union + Ama	Closures	E
				No Closures	F
			Mid Barataria + Mid Breton + Union + Ama	Closures	G
				No Closures	H

3. Methods

To examine the influence of diversions in this large-scale estuarine system, a numerical model was developed, calibrated, and validated to simulate a suite of scenarios across various hydrologic conditions. The Delft3D Flexible Mesh (Deltares, 2011) modeling suite was used for this study. This process-based modeling suite allows for the inclusion of wind, rainfall, temperature, and salinity, which previous studies indicate is necessary to appropriately capture the response of the NGOM to diversion impacts in coastal regions (Kelin Hu et al., 2023a,b; S. Parra et al., 2020). Furthermore, the original two-dimensional hydrodynamic model was augmented to a fully three-dimensional version based on previous modeling in the coastal zone of Louisiana by Hu et al., 2023a,b, which verified the necessity of three dimensionality to capture salinity and temperature setup in the near shore region.

3.1. Model setup

The model developed for this analysis built upon previous modeling efforts by Meselhe et al., 2019 (Meselhe et al., 2019), which have investigated this domain using the Delft3D 4 Suite (Lesser et al., 2004). The modeling effort described in this study utilizes the Delft3D Flexible Mesh (Deltares, 2011) (Delft3D FM) modeling suite which provides the option to utilize a flexible triangular mesh. The mesh ranges from ~17 km near the coastal boundary to ~90m in the inland areas and contains over 4.3 million elements. The hydrodynamics are modeled beginning at the Mississippi River near Tarbert Landing discharge range 13 km downstream of the Old River Control Structures (Atchafalaya Floodway outlet) through the entire river channel and the natural outlets. This results in the model capturing the natural behavior of flow passing in and out of natural openings without predefined fluxes.

The model grid was combined with topo bathymetric data from the United States Geological Survey (USGS) National Land Cover Database, USACE river bathymetric surveys, and CPRA. River discharge daily time series, provided by the USGS or USACE, were applied for the following rivers: Mississippi, Atchafalaya, Neches, Sabine, Calcasieu Amite, Tickfaw, Tangipahoa, Teche, Pearl, Mobile, Wolf, Pascagoula, and Biloxi. Additionally, daily discharge timeseries from the USGS were prescribed for the following diversions: Bonnet Carre, Davis Pond, Naomi, and Caernarvon. A water level tidal boundary condition was applied along 50 points across the gulf boundary. These 50 water level time series were provided by a larger Gulf-Atlantic model (Meselhe et al., 2019) simulated for the same year. This model features a spatial resolution ranging from 6 km near the Louisiana coast to 40 km in the Atlantic Ocean. From a tidal constituent database (Mukai et al., 2002), seven dominant constituents (O1, K1, Q1, M2, N2, S2 and K2) are considered to determine tidal levels at the open-sea boundary across the Atlantic Ocean.

Atmospheric forcing in the form of gridded wind velocity at 10m, surface air pressure, precipitation, air temperature, humidity, and cloud

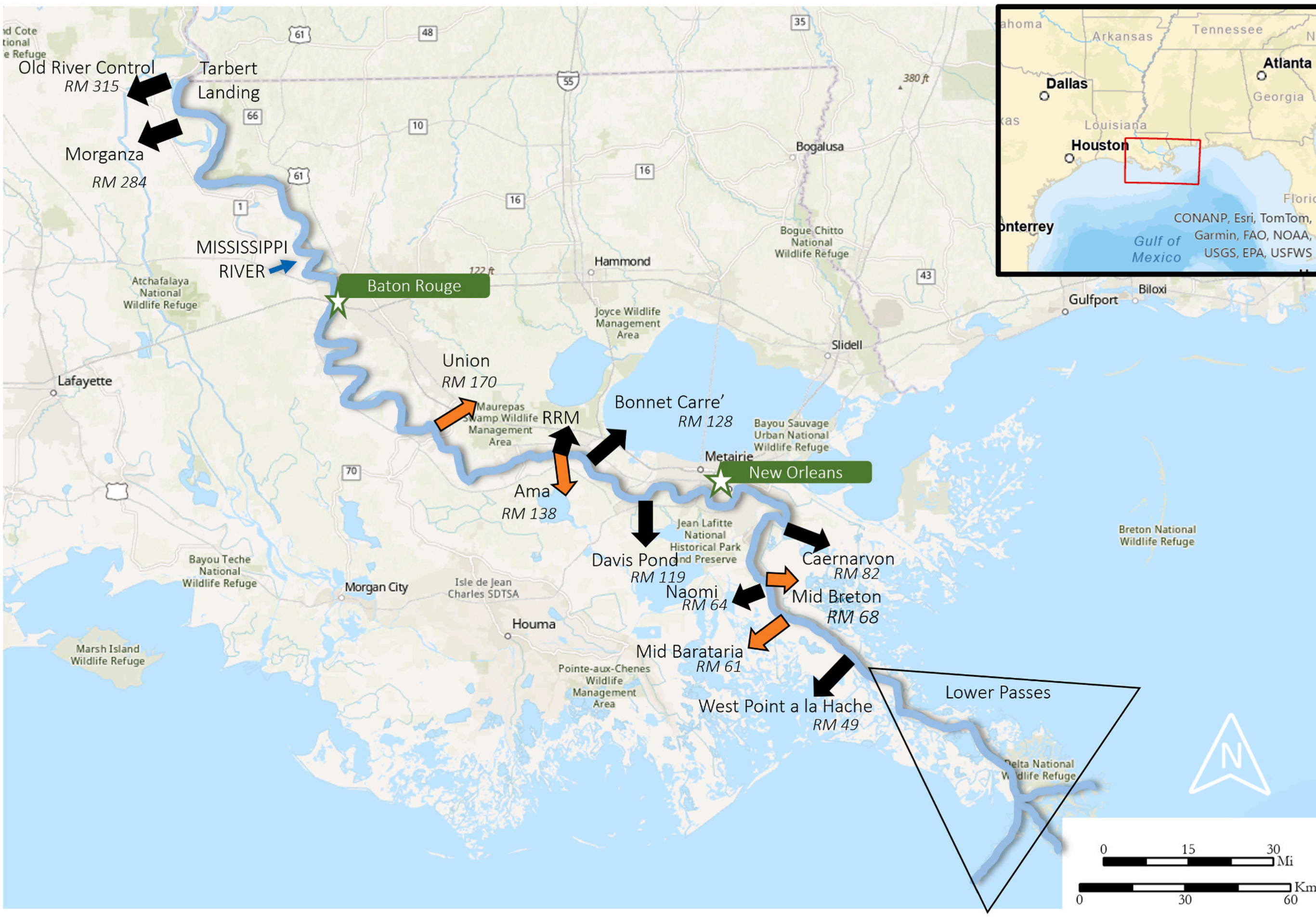

Fig. 1. Mississippi River existing (black arrows) and proposed (orange arrows) diversions located in South Louisiana from the Old River Control structure to the Gulf of Mexico. More details about the lower passes are shown in Fig. S4 in supplemental material.

coverage were applied at a 6-h timestep, provided by the Global Forecasting System's National Center for Environmental Prediction forecast model (GFS-NCEP). A spatially variable roughness was built into the model with discharge variable calibration scaling factors applied to the Mississippi river and floodplains. These scaling factors provide a means of calibrating the model to represent the following physical behavior: 1) floodplains provide a larger degree of resistance to the flow than the river bed (Aberle and Järvelä, 2013; Rowiński et al., 2018), and they interact with the Mississippi River only in the reaches north of Baton Rouge where the floodplains are connected to the river inside of the levee system, and 2) that as discharge in the Mississippi River increases, the degree of influence of the bed roughness decreases (Kopecki et al., 2017). Roughness scaling factors were calibrated for the 6 zones along the Mississippi River's length. The 3D model simulations feature 7 sigma layers and were utilized for final hydrodynamic, temperature, and salinity analysis. The progression of the model to a 3D is a direct result of previous modeling in the coastal zone of Louisiana by Hu et al., 2023a,b, which verified the necessity of 3 dimensionality to capture salinity and temperature in the near shore region (K Hu et al., 2023a,b).

3.2. Model calibration and validation

This model was calibrated for hydrodynamics, salinity, and temperature with data from the year 2018 and validated for the year 2019. The Mississippi River and its adjacent basins, specifically Barataria, Breton, Mississippi Sound, Maurepas, Lake Borgne, and Lake Pontchartrain, were calibrated to refine the study to the basins nearest to the diversion outfalls. Water level and discharge measurements were compared for river channel calibration using daily measurements from the USACE across 17 locations (see Fig. S7 in the Supplementary Material). Additionally, the Mississippi River is directly connected to the gulf below the levee system via several outlets, and these lower passes were calibrated using discrete measurements from the USACE.

The model performance in the basins was compared with recorded observations of water level, salinity, and temperature at +180 locations in the model domain from stations maintained by the National Oceanic and Atmospheric Administration (NOAA), USGS, or Coastwide Reference Monitoring System (CRMS). The interested reader may visit the webpage referred to in the Supplementary Material to review the hydrodynamic calibration and validation results. In addition to visual comparison, statistical analysis confirmed the model agreement using standard metrics and thresholds for performance (Meselhe et al., 2015). Specifically, the root mean square error, bias, and Pearson product-moment correlation coefficient were compared for all stations to indicate the model had reasonable agreement with the observations. Table S1–S3 in the Supplementary Material documents the overall statistical performance of the model.

One important behavior that the model identified was the difficulty to capture salinity representation (particularly over freshening by 5–10 ppt) in some areas of the model, particularly in the outer Breton basin. This trend was noted in both 2018 and 2019 results comparison and previous modeling efforts. Model diffusivity sensitivity analysis for over 30 model setups were run for two-to-four-week simulated periods to identify settings necessary to tune the model settings to appropriately capture salinity behavior on the west side of the Mississippi River. Variations of model diffusivity values (0.1, 1, 10, 20, 50, 100, 500, and

1000 m2/s) were tested in combination with Smagorinsky model application variations (Smagorinsky, 1963). This diffusivity analysis resulted in the development of a spatially varied diffusivity map applied in the model setup.

3.3. Operation scenarios and river hydrographs

A set of eight scenarios were designed to analyze the system of diversions on the Lower Mississippi River using the model. The scenarios Table 1 include present day structures, (as of 2023) future proposed structures, and considered the option of closing lower river outlets. The model scenarios provide a plausible envelope of management plans with a system wide perspective of river and basin interaction.

The proposed rules for the operation of each structure were not necessarily the optimum way to collectively operate the group of engineered features and crevasses. Rather, it was a suggested strategy to illustrate the benefit of conducting a scenario-based approach to evaluating trade-offs.

1. Morganza: The capacity of this structure is 16,990 cms (600K cfs). The structure would operate when the Mississippi River exceeds 35,396 cms (1.25 million cfs) at Tarbert Landing, MS about 6 km upstream of the Red River Landing gage and the stage at the spillway exceeds 15.85 m (52 ft) NAVD 88. This represents the water level that would overtop a low ridge to begin to flood the forebay and fill the forebay area, making operation feasible.
2. Bonnet Carre': The capacity of this structure is 7079 cms (250K cfs). The structure would operate when the Mississippi River exceeds 35,396 cms (1.25 million cfs) and the stage at the Carrollton exceeds 4.93m (16.18 ft) NAVD 88. The flow through the structure would be capped at 2832 cms (100K cfs).
3. Davis Pond: The capacity of this structure is 283 cms (10K cfs). It will operate based on its historical performance, except in the case of a flood event. When the Mississippi river exceeds 35,396 cms (1.25 million cfs) the diversion would be closed.
4. Caernarvon: The capacity of this structure is 212 cms (7.5K cfs). It would operate based on its historical performance, except in the case of a flood event. When the Mississippi river exceeds 35,396 cms (1.25 million cfs), the diversion would be closed.
5. Naomi: The capacity of this structure is 56.6 cms (2K cfs). It would operate based on its historical performance, except in the case of a flood event. When the Mississippi river exceeds 35,396 cms (1.25 million cfs), the diversion would be closed.
6. West Point a la Hache: The capacity of this structure is 56.6 cms (2K cfs). It would operate based on its historical performance, except in the case of a flood event. When the Mississippi river exceeds 35,396 cms (1.25 million cfs), the diversion would be closed.
7. River Reintroduction to Maurepas: The capacity of this structure is 56.6 cms (2K cfs). This structure would operate as described in (CPRA, 2014).
8. Union: The capacity of this structure is 708 cms (25K cfs). The structure would operate from 0 to 708cms from the Mississippi River near Union from 5663 to 28,317 cms (200K- 1million cfs).
9. Ama: The capacity of this structure is 708 cms (25K cfs). The structure would operate from 0 to 708cms from the Mississippi River near Ama from 5663 to 28,317 cms (200K- 1million cfs).
10. Mid Breton: The capacity of this structure is 1416 cms (50K cfs). The structure would operate from 0 to 1416 cms from the Mississippi River near Mid Breton from 12,743 to 28,317 cms (450K-1million cfs).
11. Mid Barataria: The capacity of this structure is 2124 cms (75K cfs). The structure would operate from 0 to 2124 cms from the Mississippi River near Mid Barataria from 12,743 to 28,317 cms (450K- 1million cfs).
12. Lower Passes: For scenarios where the passes were prescribed "open", the outlets were functioning per their historical capacities (verified by calibration model results compared to discrete measurements from the USACE). For the scenarios where the passes were prescribed "closed", the lower outlets were closed by a simulated barrier (See figure in Supplemental Material) to represent a structural closure that could be implemented for management purposes. Closure of the lower passes leads to a constriction of flow to the main channel with the potential to assist navigable discharge in the Mississippi river (specifically Southwest Pass navigation channel) to offset diversion discharge release upstream in some scenarios. Mississippi River discharge <11,327 cms (400K cfs) at Empire is considered low flow for navigation in the lower river, leading to management action (Peyronnin et al., 2017b). The lower passes in this group include Mardi Gras Pass down to Fort St. Phillip Pass.

The eight operational scenarios depicted in Table 1 were modeled under three Mississippi River hydrograph conditions: high/wet, average/typical, and low/drought. The most recent water years at the time of this study that represented these conditions were used for this analysis. Refer to the Supplemental Material to see the figure depicting the annual volume of water passing the Mississippi River at Tarbert Landing, MS, below Old River Control Structure over the last 50 years. The 5, 25, 50, 75, and 95 percentile lines were plotted against the data. The year 2022 served as the most recent drought year, below the 25 % annual volume line. Similarly, the years 2021 and 2019 served as the typical (average) and wet years, respectively. The hydrograph conditions of the Mississisippi River do not necessarily reflect local delta conditions, rather they represent river flow influenced by continental climate conditions.

The diversion operations were implemented in the model using a source-sink discharge time series at the intake/outfall of each structure using a simplified and conservative method. Each timeseries was determined by applying the operation criteria in conjunction with the Mississippi river discharge upstream of the diversion. Using the river hydrographs for the years 2019, 2021, and 2022 with the eight operational scenarios, 24 scenarios were simulated using the model. Boundary condition time series hydrographs of each operational scenario can be found in the Supplementary Material. This study utilizes the Morganza spillway structure as an alternative structure to the Bonnet Carre spillway. Therefore, for the 2019 flood analysis, the historical time series release through BCS was applied directly to the Morganza structure.

3.4. Scoring approach

Following the model simulations, scoring of each scenario was completed via scorecard metrics. These scorecards provide a means of evaluating operational scenarios consistently and holistically from a management standpoint using the following six metrics: flooding communities, marsh inundation, oyster suitability, marine mammal suitability, sediment delivery, and navigation. The metrics were chosen such that they 1) reflect unique aspects of diversion purpose (i.e. flood management, land building, and salinity control/ecosystem health) without extensive overlap and 2) the metrics were consistent with previous studies of diversion effects in the Northern Gulf of Mexico. References to precedented studies supporting the methodology of each metric are recorded in Table 2 and in the Supplementary Material. This study seeks to combine the metrics as a tool for basin response evaluation of diversion operation plans. Criteria considerations for each metric in the scorecards are as follows.

The metrics in Table 2 were calculated for 5 separate basins, with each basin comprising of combined ecoregion sections from precedented CMP efforts (CPRA, 2023). Using the scoring metrics, the model output was evaluated for each metric as it approaches or deviates from the Target Value. See equation (1):

Table 2
Scorecard Metrics to evaluate the operational scenarios.

Metric	Define Criteria Considerations	Target Value
Flooding communities (days) See Supplementary Material for location coordinates and aerial view.	Considered flooded day if water depth exceeds zero at access points (ex. Road, levee, driveway, etc.) to select vulnerable location per basin: o Venice Marina o Lower Lafitte Playground o University of New Orleans research facility o Amite diversion canal neighborhood o Delacroix	Zero days flood.
Marsh inundation (acreage) (CPRA, 2017, 2023; Gough and Grace, 1998; Mossa, 1996; Peyronnin et al., 2017b; Snedden et al., 2015)	Unstressed marsh is any cell that has an Annual Inundation Depth < the Inundation Threshold Depth (based on the mean annual salinity)	Acreage of available unstressed marsh in base conditions.
Sediment Delivery (tons/year)(Allison and Meselhe, 2010; Snedden et al., 2007) See Supplementary Material for rating curve information.	Sediment delivery in tons per year is calculated as the daily discharge through the diversion multiplied by the Mississippi River sediment concentration at the diversion location to produce the sediment load delivery. Sediment concentrations were based on the sediment rating curves from the Baton Rouge and Belle Chasse gaging stations.	Maximum delivery assumes that the only diversions open are those entering the basin of interest.
Eastern Oyster Suitability (acreage)(CPRA, 2012, 2017, 2023; Wang et al., 2017) See Supplementary Material for HSI information.	Coastal Master Plan 2023 Habitat Suitability Index formula.	Acreage with >0.5 HSI in base conditions within the Louisiana Department of Health designated oyster harvest areas.
Marine Mammal Suitability (acreage)(Garrison et al., 2020; McClain et al., 2020; Meselhe et al., 2019; White et al., 2018) See Supplementary Material for HSI information.	Meselhe et al. (2019) 'longest streak' formula applied to Bottle Nose Dolphins (compatible with the Environmental Impact Study for the Mid Barataria Sediment Diversion)	Acreage with <45 days salinity streak in base conditions
Navigation (metric ton/year) (Allison et al., 2012c; Nittrouer et al., 2008; Ramirez and Allison, 2013) See Supplementary Material for background information.	Bedform Transport Rate analysis $y = 146.3e^{1.77E-4*x}$	Bedform transport rate equivalent to base condition

$$\frac{Actual\ Value}{Target\ Value} * 100\% = \%Target_{scenariox} \quad (1)$$

OR.

The metrics were investigated as they deviated from the base condition toward or away from the target value. See equation (2):

$$\%Target_{scenariox} - \%Target_{Base} = \%from\ Base \quad (2)$$

Applying the scorecard approach to each of the 24 model scenarios synthesizes the model output into a form that could be used for decision support for freshwater allocation management and evaluating associated tradeoffs.

4. Results

The full set of scenario results can be found in the Supplementary Material. The most diagnostic results are included here as a subset including the wet and dry year output for Barataria, Breton, and Mississippi Sound.

4.1. Barataria basin

Scenarios A and B did not impact Barataria basin with any significant trends. The only exception was the decrease in MM suitability by 14 % in scenario A for a wet year. For all years, scenarios C, D, E, F, G, and H increased sediment delivery compared to the base case. Ama and Mid Barataria delivered approximately 2 tons and 8 tons per wet year, respectively. For the typical year, Ama and Mid Barataria delivered approximately 1 and 4 tons per year, respectively. For the dry year, Ama and Mid Barataria delivered approximately 1 and 3 tons per year, respectively. All simulations with diversions opening into Barataria produced a decrease from the base case in oyster suitability acreage within the harvest zones with an average of 23 % for the wet year, 17 % for the typical year, and 15 % for the dry year. MM suitability decreased whenever diversions were opened into Barataria by 17–56 % for the wet year, 13–22 % for the typical year, and 17–28 % for the dry year. Flooding to the access point for the selected location (Lower Lafitte Playground) was increased most notably from the base case in the wet year by anywhere from 7 % in scenario E to 24 % in scenario G. Marsh acreage above the inundation threshold increased slightly for all scenarios with diversions within 0–9 %. The results for the wet and dry scenarios are shown in Fig. 2.

4.2. Breton basin

Scenarios B and F did not impact Breton basin with any significant trends. The only exception was the increase in unstressed marsh acreage by 12 % in scenario F for a dry year. For all years, scenarios C, D, G, and H increased sediment delivery compared to the base case. In terms of sediment delivery, Mid Breton yielded approximately 5 tons per wet year, 2 tons per typical and dry year. Scenarios A and E increase oyster acreage by an average of 86 %, 74 %, and 39 % for wet, typical, and dry years, respectively. Scenarios C and G increase the oyster acreage by roughly 8 % for wet and dry years and roughly 17 % for a typical year. Scenarios D and H show decreasing oyster acreage by approximately 20 % for a dry year. Scenarios A and E increase MM acreage by an average of 240 %, 134 %, and 83 % for wet, typical, and dry years, respectively. Scenarios C and G increase the MM acreage by roughly 77 % for wet, 50 % for typical, and 27 % for dry years. Scenarios D and H show decreasing MM acreage by approximately 10 % for a dry year. Flooding the access point for the selected location (Delacroix) was increased marginally from the base case in scenarios with Mid Breton (C, D, G, and H). Marsh acreage above the inundation threshold decreased consistently for scenarios A, C, D, E, G, and H by an average of roughly 14 % for a wet year and 9 % for a typical year. Scenarios B and F did not show significant changes in marsh acreage for a wet or typical year. For a dry year, marsh acreage was increased by roughly 12 % for scenario F and decreased by roughly 11 % for scenario A. The results for the wet and dry year scenarios are shown in Fig. 3.

4.3. Mississippi Sound

Impacts to Mississippi Sound were most notable in the wet year scenario results. Compared to the base case, suitable oyster acreage is increased for scenarios A, B, C, D, E, F and G for the wet year. Scenarios with closures (A, C, E, and G) resulted in larger acreage increase in a wet year ranging from 40 % for scenario A to 20 % for scenario G. Scenarios

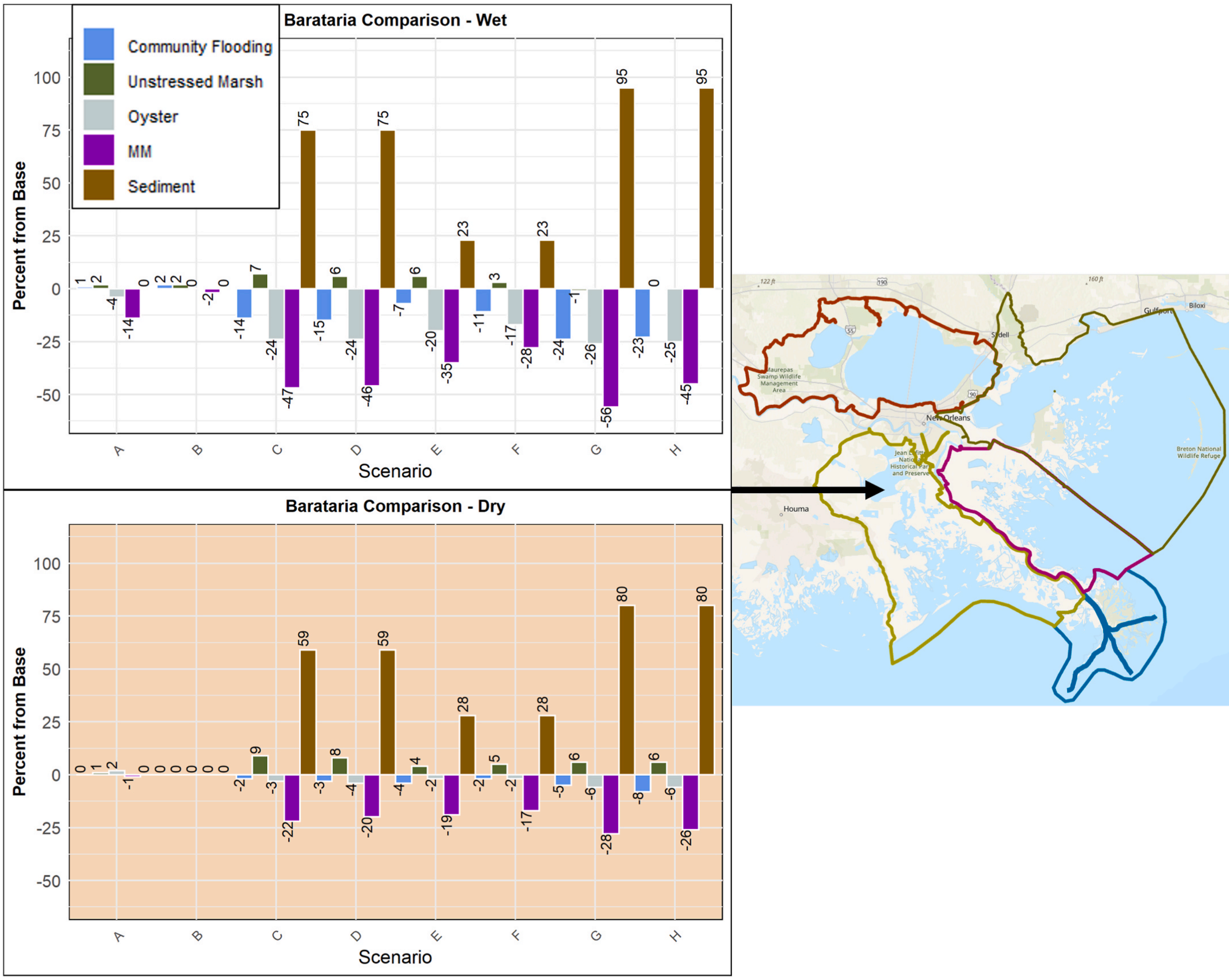

Fig. 2. Barataria Basin Metrics Percent deviation from Base for the Wet and Dry year analysis.

B, D, F, and H increased acreage during the wet year from 1 to 5 %. For the typical year, oyster acreage increased for scenarios A, C, and E on average of 11 % and decreased for scenarios D and H by roughly 5 %. Except for scenario E, all scenarios showed a decrease in oyster acreage from the base case by roughly 6 %. Compared to the base case, suitable MM acreage is increased for all scenarios in a wet year with a range of 10–48 %. For the typical and dry years, there is a much smaller degree of change with slight increases of approximately 1–4 % for scenarios A and C and slight decreases of approximately 1–6 % for scenarios D, F, G, and H. Flooding to the access point for the selected location (UNO Research Facility) was increased from the base an average of 5 % for the wet year. Marsh acreage above the inundation threshold decreased for scenarios A, C, and E by an average of roughly 4 % for a wet year. For a dry year, marsh acreage increased by an average of 4 % for scenarios E, F, G, and H. The results for the wet and dry year scenarios are shown in Fig. 4.

4.4. *Maurepas pontchartrain*

For all years, scenarios E, F, G, and H increased sediment delivery compared to the base case. In terms of sediment delivery, Mid Breton yielded approximately 2 tons per wet and typical year, and 1 ton per dry year. Flooding to the access point for the selected location (Amite diversion canal neighborhood) was negligible. Marsh acreage above the inundation threshold decreased for scenarios E, F, G, and H by an average of 9 %, 7 %, and 6 % for a wet, typical, and dry year, respectively. The Maurepas Pontchartrain result figures for the scenarios are included in the Supplementary Material.

4.5. *Mississippi River Delta*

For all years, scenarios A, C, and E increased sediment delivery compared to the base case by roughly 10 %, 3 %, and 8 %, respectively. Across all years, Scenarios D, F, G, and H resulted in an average sediment delivery decrease of 6 %, 4 %, 3 %, and 11 % respectively. Navigation criteria in terms of bedform transport rates were affected most notably during the wet year. In the wet year, transport rates increased by 12 % and 3 % for scenarios A and C, respectively and decreased by 3 % and 4 % for scenarios D and H, respectively. The marsh acreage and flooding to the access point for the selected location (Venice marina) was negligible. The Mississippi River Delta result figures for the scenarios are included in the Supplementary Material.

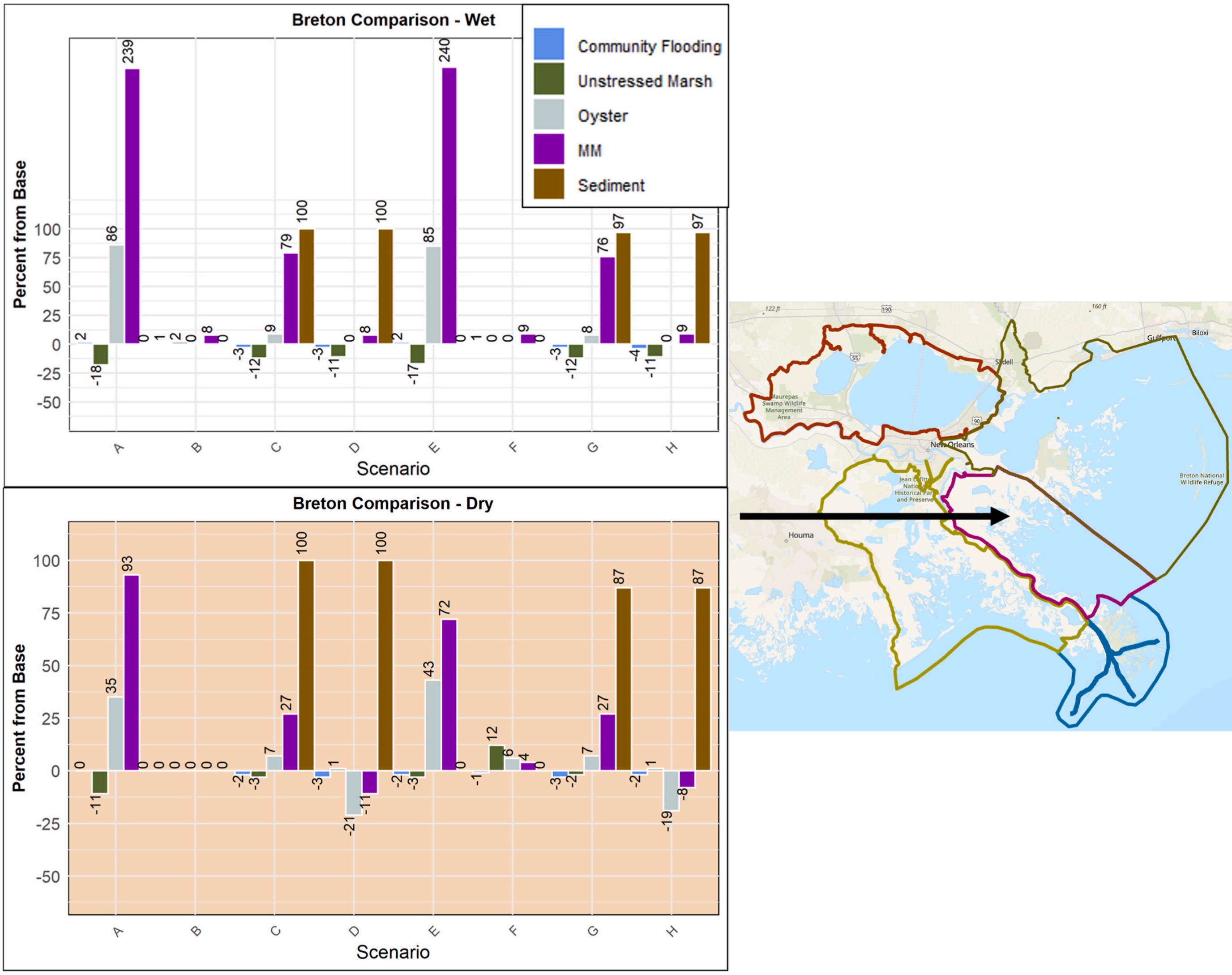

Fig. 3. Breton Basin Metrics Percent deviation from Base condition for the Wet and Dry year analysis.

5. Discussion

5.1. Flooding communities

The flooding metric is a simple representation of water depth based on a single point within the model domain. It does not represent the extent or magnitude of flooding, rather it is more reflective of how long water levels across the basin will be elevated from base condition due to each scenario. It is important to note that even if water levels do not exceed the elevation thresholds for communities, the sustained higher than base condition water levels in the basins may increase the vulnerability of communities, particularly in the event of hurricane events and storm surge. Additionally, diversions not designed for flood control have operation plans that require their closure during a storm event. More analysis of the potential for diversion enhanced flood risk at specific points of vulnerability is clearly needed. In general, this study highlights that sizing and locating diversions to provide beneficial delivery of riverine resources to ecosystems potentially increase the vulnerability (albeit not significantly in the scenarios modeled in this study) of adjacent communities. Furthermore, the flood risk to human life and property is a primary concern of the state and federal government, who then prioritize improving basin infrastructure to protect vulnerable communities like Lower Lafitte (see Supplemental Material location map). This prioritization is seen in projects like the Lafitte Ring Levee in the Coastal Master Plan (CPRA, 2023) and the Lower Lafitte Tidal Protection project (NOLA.com, 2023), which is under construction at the time of this study.

5.2. Marsh inundation

Marsh inundation was evaluated to examine potential stress to marsh areas in the receiving basins due to diversion operation. Excess inundation is interpreted in this study as a tradeoff that could partially offset the beneficial effects of introducing sediment, nutrients, and fresh water. Maurepas and Breton showed a slight decrease (~-10 % and −12 %, respectively) from healthy marsh area with the operation of Union and Mid Breton, particularly during the wet year scenarios. Conversely, Barataria showed an increase toward target acreage (~6 %) with diversion operations due to the freshening of the basin allowing for increased inundation tolerance. Generally, the simulations show that the diversion operations tested do not increase marsh inundation significantly beyond the inundation threshold developed for each marsh type based on base condition salinity regimes. Considering the relative coarse resolution of the model, this metric represents the ability of each basin to drain the diverted river flow gulfward.

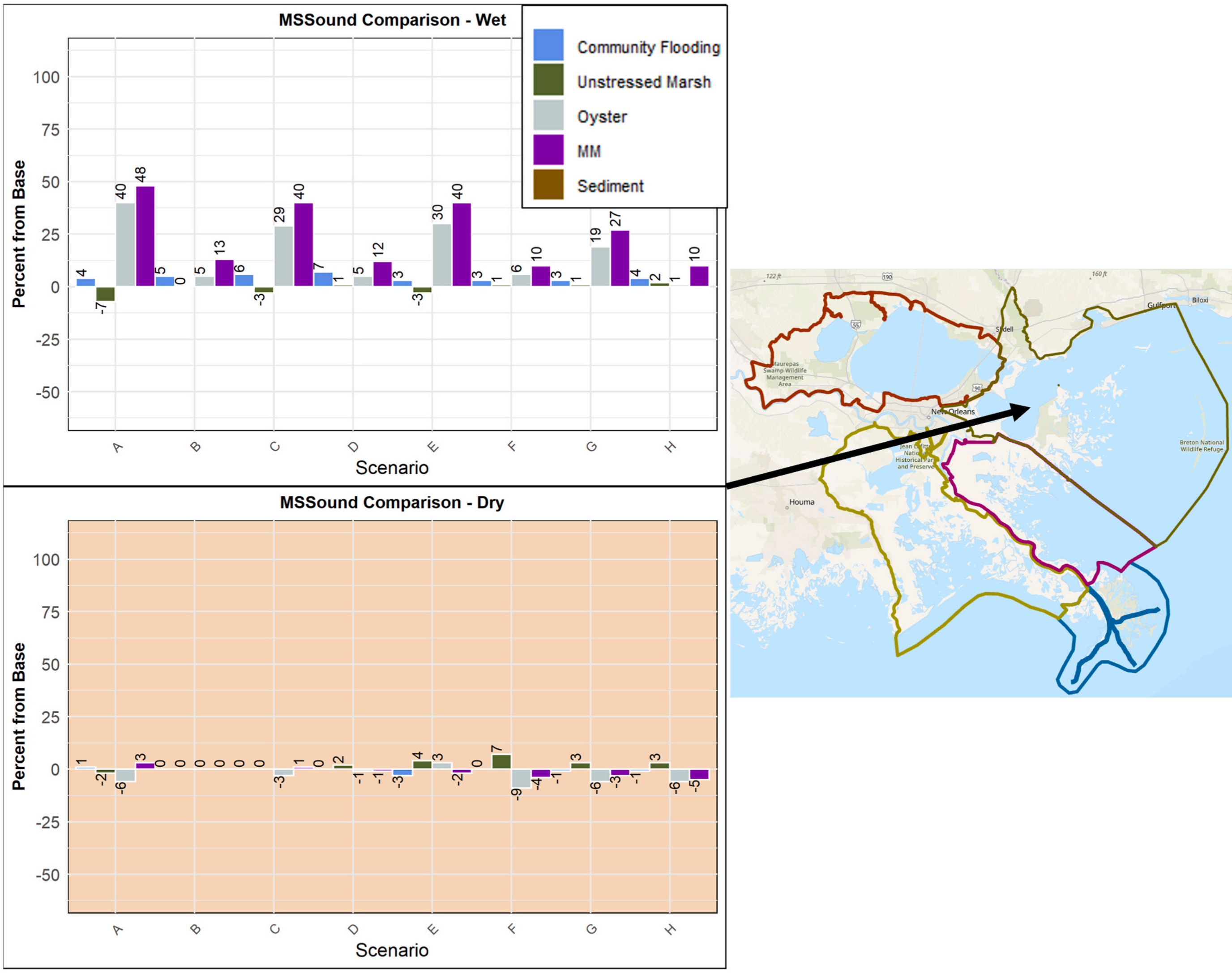

Fig. 4. Mississippi Sound Basin Metrics Percent deviation from Base for the Wet and Dry year analysis.

5.3. Marine mammals

The metric to evaluate marine mammal suitability zone is the area with less than a 45-day streak of salinities below 5 ppt, with gaps of 2 or fewer days allowed. The Supplementary Material shows the marine mammal suitability zone results in a map format. Due to its binary nature, the charts in the results section of this paper show the response of the basins to each scenario quite clearly. Barataria basin shows a general trend of decreasing marine mammal suitability with increasing diversion openings. Barataria has a slight negative response to the east side closures (scenarios A, C, E, and G), likely due to circulation caused by more discharge leaving the river through Southwest Pass instead of the natural outlets on the west side. Breton basin shows the strongest positive response (increase in suitable area) to lower pass closures, even with Mid Breton on the landscape. Both Breton and Barataria basins show similar behaviors across wet, typical, and dry year scenarios. The Mississippi Sound zone does not change significantly (±6 %) during the typical and dry year scenarios. For the wet year, however, conditions are improved across all scenarios from 10 to 48 %, primarily due to the use of Morganza instead of BCS, as well as the natural pass closures. There is the potential for a degree of contraction and expansion of the suitability zone within the receiving estuaries that are suitable for marine mammals.

5.4. Eastern Oysters

Included in Fig. 5 is the spatial distribution of the Eastern Oyster habitat suitability for the wet and dry year scenarios. Values reported in the results section of this study indicate the acreage of suitability >0.5 and within Louisiana Department of Health (LDH) delineated zones. Additionally, we can explore the dynamics of the HSI zones beyond the LDH zones, to examine the larger extent of the suitability ranges and how they behave across operation plans and hydrographic conditions.

Generally, the size and location of the favorable footprint is determined by the hydrologic conditions (wet, typical, dry). Barataria basin has a strong response to diversions opening. The favorable oyster zone shows a basin wide migration gulfward and decrease in size with the opening of Ama and/or Mid Barataria. Mid Barataria operates at triple the capacity of Ama and operates directly in the base zone of favorability. Results indicate Mid Barataria produces a decrease in suitability and a strong gulfward push. Ama still produces a strong response in Oyster HSI, showing the same gulfward migration and a squeezing or reshaping of the zone. Breton basin shows a strong response to the lower pass closures and the operation of Mid Breton. In general, the lower passes closures produce the largest increase in the suitability zone in this basin, specifically in scenarios A and E where Mid Breton is not on the landscape. The wet year analysis shows a similar footprint of HSI regardless of Mid Breton being opened or not. The effects of Mid Breton

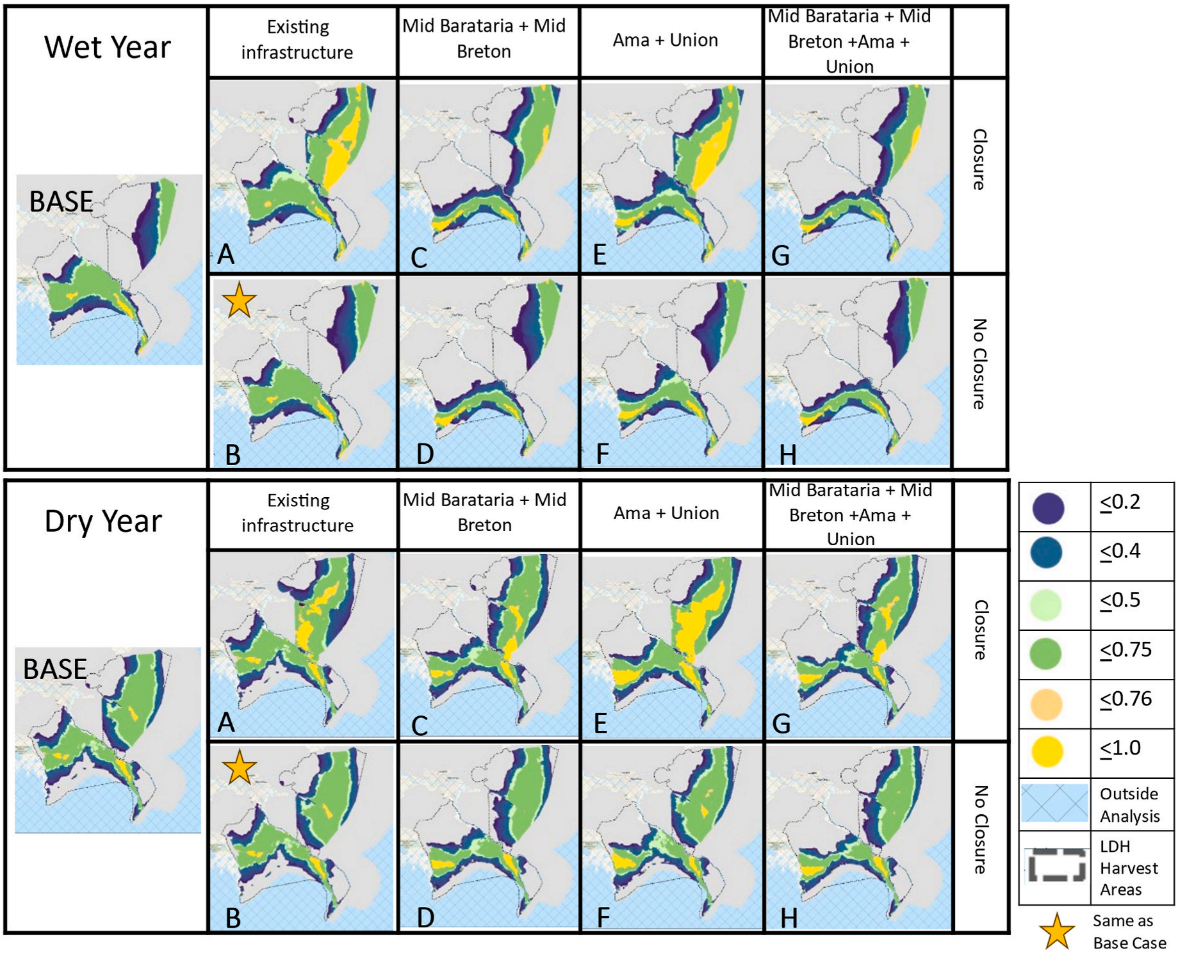

Fig. 5. Eastern Oyster Habitat Suitability Indices Results: Wet Year (Upper Panel) and Dry Year (Lower Panel). Lettering (ex. A, B, C, …) indicates operation scenario applied. Oyster Habitat Suitability Index ranges from 0 to 1. Areas in green and yellow are more suitable.

are more pronounced during the dry year analysis. Additionally, the response of the suitability zone is a gulfward migration in response to Mid Breton, where the favorable conditions are pushed further offshore. The freshening behavior and oyster suitability response compares to similar studies in this region (K. Hu et al., 2023a,b,c; Wang et al., 2017). The closure of lower passes produces a larger suitable footprint for Breton. Mississippi Sound oyster suitability responds to several management features: Bonnet Carre, Morganza, Union, lower pass closures, and potentially Mid Breton. In terms of the size of the suitability footprint and proximity to the harvest areas, Mississippi Sound favorability is improved by the lower pass closures and decreased by diversion operations.

The changes in oyster suitability within the Louisiana Department of Health (LDH) zones illustrates one tradeoff to large scale diversion operation for restoring wetlands. Essentially, the diversion operations change the size and shape of the favorable footprint and move the zone of suitability further offshore. This implies that the oyster industry and potentially other aquatic industries will need to adapt immediately in response to changes in river management. Alternative oyster farming techniques are being explored in South Louisiana, such as off-bottom oyster farming(Chapman, 2019; Leonhardt et al., 2017; Wang et al., 2017). Cage oyster farming can provide protection from blanketing of sediment from river diversions and changes in salinity, both of which induce oyster mortality in the Gulf of Mexico region(Chapman, 2019; Leonhardt et al., 2017). These adaptive strategies and the plan to subsidize their implementation are formally investigated in the design of proposed diversions, as seen in the Mid Barataria Sediment Diversion Environmental Impact Study (USACE, 2022). As alternative farming techniques continue to evolve, they may become a viable means of evolution for seafood industry in the gulf.

Sediment Delivery.

The sediment delivery component of this study was conducted via rating curves and volumetric analysis (Allison et al., 2012b). The study shows the positive correlation across all scenarios between diversion openings and sediment delivery to basins. Fig. 6 displays a downstream budget of total suspended sediment load for scenarios B and H, demonstrating open lower passes. Additional sediment budgets of scenarios A and G, demonstrating lower pass closures, are included in the Supplementary Material.

The benefits of riverine sediment diversions include the introduction of riverine nutrients (Bentley et al., 2014; Peyronnin et al., 2017b; PontchartrainConservancy, 2022), provision of sediment and river material to sustain marsh elevations (Day et al., 2016; Meselhe et al., 2016; Snedden et al., 2007; USACE, 2022), distributing organic material and sediment in a receiving basin, as well as providing new detritus and riverine sediment to support ecosystem health (Mann, 1988). The quantity of sediment delivered is directly dependent upon the incoming source suspended sediment concentration (Allison et al., 2012a), as well as the structures design capabilities to capture that portion of suspended sediment (Gaweesh and Meselhe, 2016). The sediment concentration of the Mississippi River is known to be highly variable and can fluctuate due to factors such as hysteretic behavior (Mossa, 1996), upstream bank material contribution, hydrographic conditions, overbank sediment storage (Allison et al., 2012b), and time of the year (Galler and Allison, 2008; Peyronnin et al., 2017b). For reference, hysteresis the behavior of suspended sediment concentrations in the river being different for the

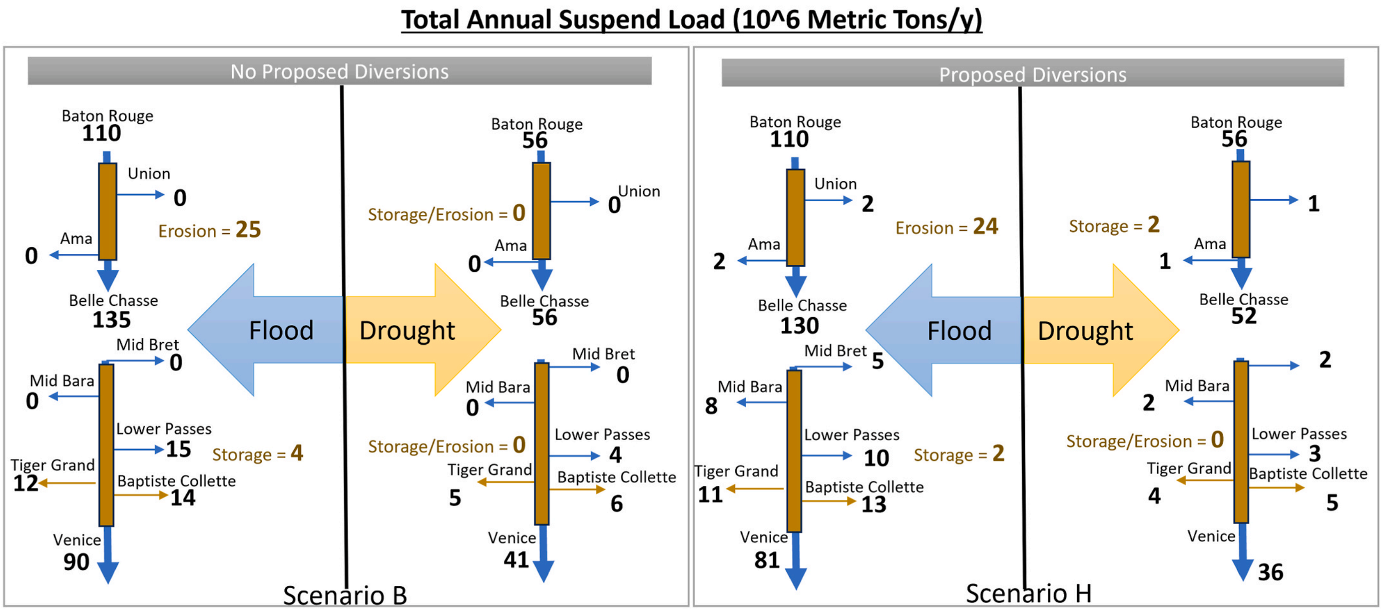

Fig. 6. Average annual total suspended sediment discharge (in 10ˆ6 tons/y) for the flood and drought years (2019 and 2022) scenarios A and G discussed in the present study for natural and man-made water exits from the Mississippi River below Baton Rouge, Louisiana. Also shown are annual channel storage rates (in 10ˆ66 tons/y) for two sub-reaches of the channel between Baton Rouge to Belle Chasse and Belle Chasse to Venice. Rates were calculated via rating curve application to discharge at respective outlets.

same discharge depending on whether stage is trending up or down. Regardless of the ability of the sediment diversions to build or sustain land, sediment delivery to adjacent basin marshes is considered a beneficial attribute of river diversions, except in the case of extensive blanketing of sediment over small seedlings immediately within the diversion's floodway(Gough and Grace, 1998; Levine and Stromberg, 2001) or over young oyster spat who might suffocate with sediment settling(Leonhardt et al., 2017).

5.5. Navigation

The bedform transport calculations are used here as a proxy indicator for maintaining uninterrupted navigation operations. Although there is uncertainty inherent in the bedform transport rate calculations, the results of this study do highlight some responses of the lower river to diversion operations and the impact of natural pass distribution on lower river hydrodynamics. Bedform transport rate reflects the potential for the deposition of sand in the navigation channel which may result in shoaling. The first key point is that the rules set to govern the lower discharge threshold of diversions prevent diversion operation from interfering with the navigation activities during low-flow (drought) events. The study showed no significant decrease in river stage or discharge during low flow, nor did the results show an extended duration of low flow conditions (below 400,000cfs at Venice, LA) beyond the base case. There is a relatively minor deviation in bedform transport (+/− <2000 MT/d) during a dry year, which supports this first point. A second, and perhaps more interesting point, is that the study shows that the operation of diversions during medium or high discharge events has the potential to decrease bedform transport capabilities in the lower river significantly, most pronounced in the scenarios which utilized all the diversions without lower pass closures. Bedform transport graphics may be found in the Supplemental Material. The most extreme case (scenario H) decreases the transport rate peak from the base condition by approximately 35 % and 26 % for the typical and wet hydrographic conditions, respectively. From a management perspective, it is important to consider that operation of diversions during a typical or wet year potentially prevents the river from "flushing" out the sand deposited in shoals in the lower river, leading to dredging concerns in the next low flow conditions. A third key finding of this study is the extensive impact of the natural passes in the lower river. In scenario G, with all proposed diversions operating and an entire closure of natural passes on the river's east side, the hydraulics conditions revert to the base-case conditions. This emphasizes the importance of monitoring, studying, and managing the river's natural outlets as more diversions come on to the landscape. They play a crucial role in maintaining the navigation activities in the lowermost reach of the Mississippi River.

Impacts to navigation of the Mississippi River may be thoroughly investigated via sediment transport modeling, as seen in the Mid Barataria Sediment Diversion Environmental Impact Study (USACE, 2022). In relation to this study, there are multiple scenarios and multiple diversions being added to the landscape with a lower pass system adding significant complexity to the situation. Therefore, the degree of uncertainty is too large to determine what the navigational implications would be for these scenarios without further modeling efforts. However, this effort serves as a viable screening tool to evaluate numerous scenarios to narrow down the plausible strategies for more detailed analysis.

5.6. Tradeoffs

While numerous permutations could be explored, this study's initial set of scenarios highlight tradeoffs related to diversion operation. Diversion operation during high flow events has the potential to maximize sediment delivery for land building and mitigate stress to levee systems, but it reduces the lower river's capacity to transport bed material in the navigational corridor. Diversion operation during low flow events offers less land building potential yet yields significant salinity gradient maintenance capabilities. Additionally, the impacts of using BCS could be mitigated by alternative measures, such as the use of the Morganza spillway. Morganza spillway provides a potential alternative to building new diversions that may cost multi-billions of dollars. The use of Morganza could provide ecological sustenance to an otherwise highly regulated freshwater basin that infrequently receives flood pulses that might reduce stagnation and sediment deposition in the basin (Hupp et al., 2008). Morganza spillway, as a surrogate structure to BCS, utilizes the river resources by flowing water, nutrients, and sediment through basins, rather than losing them to Lake Pontchartrain and the Gulf of Mexico. Located upstream of the vulnerable city of New Orleans, the upper river diversions have the potential to operate as flood management structures in addition to functioning for land building and ecosystem restoration objectives. When comparing the Mid Barataria and Ama diversions for Barataria basin benefits, Ama may offer a greater return on investment by distributing nutrients higher in the basin and providing a potential for flood management, which Mid Barataria diversion logistically could not accomplish. Similarly, Union diversion may supplement RRM and facilitate a longer more desirable path of diversion through wetlands to the Gulf of Mexico than BCS. This study shows that the effects of Union do not propagate significantly to the Mississippi Sound region, where excessive freshwater can inhibit fishing and aquaculture markets. Another tradeoff is the impact of the lower east side river outlets to basin salinity changes and lower river navigation. The natural passes are sighted in this study for the massive effect they have on these two criteria, particularly during high flow events. The use of natural outlets, even temporarily, may provide an additional management lever or an alternative strategy to building new diversions.

6. Conclusions

Coastal ecosystem management is challenging due to the interconnected natural and built environments, with unique socioeconomic and ecological interests often at odds. Therefore, the task of determining best management practices is often facilitated by extensive modeling efforts to reveal the most suitable choice of action to balance stakeholder interests. Evaluating multiple management strategies through the scoring approach in this study provides a concise and quantitative means to compare management alternatives across multidisciplinary criteria (ecological, industrial, and community perspectives). This approach synthesizes a highly detailed numerical analysis into succinct transdisciplinary performance metrics that are digestible to resource managers outside of the scientific modeling community. The approach facilitates the incorporation of new scientific information and relevant comparisons in decision-making by translating model output into a desired metric and directly comparing scenarios to one another. Results of this study bring a fuller, more "holistic", picture into focus of what various diversions and operational schedules can accomplish and processes the output more closely to the final product necessary to screen alternatives. Key findings include.

1. Natural hydrologic conditions have a greater influence on the conditions of the adjacent ecosystems than the quantity of diversions operating.
2. Continued monitoring of east side natural passes is crucial as they impact the salinity of Breton and MS Sound. Management of the natural passes can produce a basin side response that equals or exceeds the operation of diversions that drain into Breton and MS Sound.
3. The east side lower passes complex has a more pronounced effect on Breton than the Mid Breton diversion.
4. Inundation due to proposed diversions depends on the ability of a given basin to drain into larger water bodies. For example, proposed diversions in Barataria do not pose significant stress to through marsh inundation. Maurepas and Breton exhibit increased inundation.
5. Navigation criteria of stage and discharge are preserved across all scenarios examined in this study, meaning that stage is not decreased in the lower river due to any scenarios, nor is the low water discharge period extended. This is due to the combination of factors including a relatively small volume of water diverted compared to the main channel volume, the diversion rule to close during low flow, and the backwater condition prevailing in the tidally influenced lowermost reach of the river. As an alternative to an explicit (and computationally expensive) morphodynamic or sediment transport module, a simple indictor was used. This metric is based on a bedform transport formula. The analysis revealed a potential impact to navigation by demonstrating that increased diversion operation may attenuate flushing of bed material during a flood year. Consideration of the pulsed diversion idea could balance this impact. In scenario H, which represents the largest volume of water extracted from the Mississippi river through diversions or passes, the bedform transport rate is significantly decreased. The flood year analysis reveals that the bedform transport rates are reduced to nearly the equivalent rate of a typical or dry year (4000 metric ton/day). Such a reduction is plausible to result in navigational impacts either through interruptions or increased cost of dredging. A detailed sediment transport analysis should be considered. However, the bedform transport rate analysis can be used as an efficient screening tool.
6. On the east side, a similar basin-wide response occurs via completely different management strategies. For example, swapping BCS for Morganza and opening Mid Breton and Union can create very similar MS Sound conditions for a wet year.
7. Dry year diversion operation leads to more dramatic responses in basin salinity spatial distribution. During a flood year, the basins are largely fresh, regardless of operation scenarios.
8. Upper river diversions “soak the sponge” by nourishing their immediate receiving basins with minimal gulf influence. They are proposed to operate with a relatively small capacity but can provide sustenance for the basins from an interior location. This is a beneficial strategy that demonstrates the “in between” approach from the large flood control and sediment diversion structures.
9. This paper supports the formalization of adaptive and proactive management of diversion control structures and natural passes from a system wide perspective. This management should be informed by observational data of basin conditions and result in diversion operations that prioritize the safety of human life and management infrastructure, as well as the health of the basin ecosystems.

Suggestions for future research considering this study include the modeling of partial natural pass closure scenarios, modeling pulsed diversion strategies, and modeling varying diversion capacities. This research highlights the need for increased monitoring of natural riverine outlets and Breton estuary. Beyond this modeling effort, investigation of the adjacent Atchafalaya basin response to varying Morganza Spillway operational scenarios should be pursed as a primary next step.

The scoring approach developed in this study provides an evaluation framework covering physical, ecological and indirect socioeconomic metrics. The scoring approach allows for 1) physical value comparison (ex. Km^2/acres, m/ft, days, etc.), 2) comparison to target value (via percent of Target value calculations), and 3) comparison to base conditions (via percent deviation from base condition). Amid potentially overwhelming quantity of data produced by simulating several operational scenarios, the scoring approach facilitates the succinct communication of the efficacy of multiple management scenarios across a range of hydrologic conditions. This scoring framework can be applied to other systems requiring natural resource management around the world to explore viable strategies balancing ecosystem services with socioeconomic interests.

CRediT authorship contribution statement

Laura Manuel: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ehab Meselhe:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Kelin Hu:** Writing – review & editing, Validation, Supervision, Software, Methodology, Formal analysis, Data curation. **Denise J. Reed:** Writing – review & editing, Visualization, Validation, Methodology, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This paper is a result of research funded partially through a grant from the Environmental Defense Fund and by Tulane internal funding sources. In addition, this research was supported by use of high-performance computing (HPC) resources and services provided by both the Louisiana Optical Network Infrastructure (LONI) and the Technology Services at Tulane University. The research team is particularly grateful to Rachel Rhode, Natalie Peyronnin Snider, Alisha Renfro and the entire Mississippi River Delta group for their valuable discussions and feedback.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2025.127117.

Data availability

Data will be made available on request.

References

Aberle, J., Järvelä, J., 2013. Flow resistance of emergent rigid and flexible floodplain vegetation. J. Hydraul. Res. 51 (1), 33–45. https://doi.org/10.1080/00221686.2012.754795.

Allison, M., Demas, C., Ebersole, B., Kleiss, B., Little, C., Meselhe, E., Powell, N., Pratt, T., Vosburg, B., 2012a. A water and sediment budget for the lower Mississippi–Atchafalaya River in flood years 2008–2010: implications for sediment discharge to the oceans and coastal restoration in Louisiana. J. Hydrol. 432–433, 84–97. https://doi.org/10.1016/j.jhydrol.2012.02.020.

Allison, M., Demas, C., Ebersole, B., Kleiss, B., Little, C.D., Meselhe, E.A., Powell, N.J., Pratt, T.C., Vosburg, B.M., 2012b. A water and sediment budget for the lower Mississippi–Atchafalaya River in flood years 2008–2010: implications for sediment discharge to the oceans and coastal restoration in Louisiana. J. Hydrol. 432–433, 84–97. https://doi.org/10.1016/j.jhydrol.2012.02.020.

Allison, M., Demas, C., Ebersole, B., Kleiss, B.A., Little, C.D., Meselhe, E.A., Powell, N.J., Pratt, T.C., Vosburg, B.M., 2012c. A water and sediment budget for the lower Mississippi–Atchafalaya River in flood years 2008–2010: implications for sediment discharge to the oceans and coastal restoration in Louisiana. J. Hydrol. 432–433, 84–97. https://doi.org/10.1016/j.jhydrol.2012.02.020.

Allison, M., Meselhe, E., Kleiss, B., 2023. Impact of Water Loss on Sustainability of the Mississippi River Channel in its Deltaic Reach. Authorea. https://doi.org/10.22541/au.167929277.71582944/v1.

Allison, M.A., Meselhe, E.A., 2010. The use of large water and sediment diversions in the lower Mississippi River (Louisiana) for coastal restoration. J. Hydrol. 387 (3–4), 346–360. https://doi.org/10.1016/j.jhydrol.2010.04.001 [Review].

Amer, R., Kolker, A.S., Muscietta, A., 2017. Propensity for erosion and deposition in a deltaic wetland complex: implications for river management and coastal restoration. Remote Sens. Environ. 199, 39–50. https://doi.org/10.1016/j.rse.2017.06.030.

Armstrong, B.N., Cambazoglu, M.K., Wiggert, J.D., 2021. Modeling the Impact of the 2019 Bonnet Carré Spillway Opening and Local River Flooding on the Mississippi Sound. OCEANS 2021: San Diego – Porto.

Bentley, S.J., Freeman, A.M., Willson, C.S., Cable, J.E., Giosan, L., 2014. Using what we have: optimizing sediment management in Mississippi River Delta restoration to improve the economic viability of the nation. In: Day, J.W., Kemp, G.P., Freeman, A.M., Muth, D.P. (Eds.), Perspectives on the Restoration of the Mississippi Delta: the once and Future Delta. Springer, Netherlands, pp. 85–97. https://doi.org/10.1007/978-94-017-8733-8_6.

Chapman, E.L., 2019. Assessment of Off-Bottom Oyster (Crassostrea Virginica) Aquaculture Techniques on Biofouling in the Northern Gulf of Mexico. ProQuest Dissertations & Theses Global, United States – Louisiana (Publication Number 29114404) [M.Sc., Louisiana State University and Agricultural & Mechanical College]. http://libproxy.tulane.edu:2048/login?url=https://www.proquest.com/dissertations-theses/assessment-off-bottom-oyster-crassostrea/docview/2665133528/se-2?accountid=14437.

Coleman, J.M., Roberts, H.H., Gregory, W.S., 1998. Mississippi River Delta: an overview. J. Coast Res. 14 (3), 699–716. http://www.jstor.org/stable/4298830.

CPRA, 2012. Louisiana comprehensive master plan for a sustainable coast. Coastal Protection and Restoration Authority of Louisiana.

CPRA, 2017. Louisiana's Coastal Master Plan for a Sustainable Coast.

CPRA, 2023. Louisiana's Coastal Master Plan for a Sustainable Coast.

Dasgupta, S., Islam, M.S., Huq, M., Huque Khan, Z., Hasib, M.R., 2019. Quantifying the protective capacity of mangroves from storm surges in coastal Bangladesh. PLoS One 14 (3), e0214079. https://doi.org/10.1371/journal.pone.0214079.

Day, J.W., Lane, R.R., D'Elia, C.F., Wiegman, A.R.H., Rutherford, J.S., Shaffer, G.P., Brantley, C.G., Kemp, G.P., 2016. Large infrequently operated river diversions for Mississippi delta restoration. Estuar. Coast Shelf Sci. 183, 292–303. https://doi.org/10.1016/j.ecss.2016.05.001. Estuar. Coast. Shelf Sci. (Netherlands.

Day, J.W., Lane, R.R., D'Elia, C.F., Wiegman, A.R.H., Rutherford, J.S., Shaffer, G.P., Brantley, C.G., Paul Kemp, G., 2018. Large infrequently operated River Diversions for Mississippi delta restoration. In: Day, J.W., Erdman, J.A. (Eds.), Mississippi Delta Restoration: Pathways to a Sustainable Future. Springer International Publishing, pp. 113–133. https://doi.org/10.1007/978-3-319-65663-2_8.

De Mutsert, K., Lewis, K., Milroy, S., Buszowski, J., Steenbeek, J., 2017. Using ecosystem modeling to evaluate trade-offs in coastal management: effects of large-scale river diversions on fish and fisheries. Ecol. Model. 360, 14–26. https://doi.org/10.1016/j.ecolmodel.2017.06.029.

Deltares, 2011. In: *D-flow Flexible Mesh Computational Cores and User Interface User Manual* (SVN Revision: 76991, vol. 1. Deltares [User Manual].

Gagliano, S.M., Meyer-Arendt, K.J., Wicker, K.M., 1981. Land Loss in the Mississippi River Deltaic Plain.

Galler, J.J., Allison, M.A., 2008. Estuarine controls on fine-grained sediment storage in the Lower Mississippi and Atchafalaya Rivers. GSA Bulletin 120 (3–4), 386–398. https://doi.org/10.1130/B26060.1.

Garrison, L.P., Litz, J., Sinclair, C., 2020. Predicting the Effects of Low Salinity Associated with the MBSD Project on Resident Common Bottlenose Dolphins (Tursiops truncatus) in Barataria Bay, LA [Technical Memorandum], vol. 748. NOAA Technical Memorandum NMFS-SEFSC. https://doi.org/10.25923/53z9-nn54.

Gaweesh, A., Meselhe, E., 2016. Evaluation of sediment diversion design attributes and their impact on the capture efficiency. J. Hydraul. Eng. 142 (5), 04016002. https://doi.org/10.1061/(ASCE)HY.1943-7900.0001114.

Gough, L., Grace, J.B., 1998. Effects of flooding, salinity and herbivory on coastal plant communities, Louisiana, United States. Oecologia 117 (4), 527–535. https://doi.org/10.1007/s004420050689.

Hu, K., Meselhe, E., Reed, D.J., 2023a. Understanding drivers of salinity and temperature dynamics in Barataria estuary, Louisiana. J. Geophys. Res.: Oceans 128 (7), e2023JC019635. https://doi.org/10.1029/2023JC019635.

Hu, K., Reed, D., Meselhe, E., 2023b. Modeling Habitat Suitability for Common Bottlenose Dolphins (Tursiops truncatus) and Eastern Oyster (Crassostrea Virginica) in the Breton Sound and Pontchartrain-Chandeleur Basin with the Mid-Breton Sediment Diversion.

Hupp, C.R., Demas, C.R., Kroes, D.E., Day, R.H., Doyle, T.W., 2008. Recent sedimentation patterns within the central Atchafalaya Basin, Louisiana. Wetlands 28 (1), 125–140. https://doi.org/10.1672/06-132.1.

Khalifa, A.M., 2023. Development and Applications of Morphodynamic Model to Study Deltaic and Coastal Ecosystems. ProQuest Dissertations & Theses Global, United States – Louisiana (Publication Number 30528181) [Ph.D., Tulane University]. https://libproxy.tulane.edu:2048/login?url=https://www.proquest.com/dissertations-theses/development-applications-morphodynamic-model/docview/2849727387/se-2?accountid=14437.

Kopecki, I., Schneider, M., Tuhtan, J.A., 2017. Depth-dependent hydraulic roughness and its impact on the assessment of hydropeaking. Sci. Total Environ. 575, 1597–1605. https://doi.org/10.1016/j.scitotenv.2016.10.110.

Leonhardt, J.M., Casas, S., Supan, J.E., La Peyre, J.F., 2017. Stock assessment for eastern oyster seed production and field grow-out in Louisiana. Aquaculture 466, 9–19. https://doi.org/10.1016/j.aquaculture.2016.09.034.

Lesser, G.R., Roelvink, J.A., van Kester, J.A.T.M., Stelling, G.S., 2004. Development and validation of a three-dimensional morphological model. Coast. Eng. 51 (8), 883–915. https://doi.org/10.1016/j.coastaleng.2004.07.014.

Levine, C.M., Stromberg, J.C., 2001. Effects of flooding on native and exotic plant seedlings: implications for restoring south-western riparian forests by manipulating water and sediment flows. J. Arid Environ. 49 (1), 111–131. https://doi.org/10.1006/jare.2001.0837.

Li, X., Liu, J.P., Saito, Y., Nguyen, V.L., 2017. Recent evolution of the Mekong Delta and the impacts of dams. Earth Sci. Rev. 175, 1–17. https://doi.org/10.1016/j.earscirev.2017.10.008.

Littles, C.J., Jackson, C.A., DeWitt, T.H., Harwell, M.C., 2018. Linking people to coastal habitats: a meta-analysis of final ecosystem goods and services on the coast. Ocean Coast Manag. 165, 356–369. https://doi.org/10.1016/j.ocecoaman.2018.09.009.

Mahmood, A., Han, J.-C., Ijaz, M.W., Siyal, A.A., Ahmad, M., Yousaf, M., 2022. Impact of sediment deposition on flood carrying capacity of an alluvial channel: a case study of the lower Indus basin. Water 14 (20).

Mann, K.H., 1988. Production and use of detritus in various freshwater, estuarine, and coastal marine ecosystems. Limnol. Oceanogr. 33 (4part2), 910–930. https://doi.org/10.4319/lo.1988.33.4part2.0910.

McAnally, W.H., Nail, G.H., 1995. Freshwater diversion to reduce estuarine salinities. *International water resources engineering conference*. In: *Proceedings* Proceedings of the 1st International Conference on Water Resources. Part 1 (of 2), August 14, 1995 - August 18, 1995, San Antonio, TX, USA.

McClain, A., Daniels, R., Gomez, F., Ridgway, S., Takeshita, R., Jensen, E., Smith, C., 2020. Physiological effects of low salinity exposure on bottlenose dolphins (Tursiops truncatus). Journal of Zoological and Botanical Gardens 1. https://doi.org/10.3390/jzbg1010005.

Meade, R.H., Moody, J.A., 2010. Causes for the decline of suspended-sediment discharge in the Mississippi River system, 1940–2007. Hydrol. Process. 24 (1), 35–49. https://doi.org/10.1002/hyp.7477.

Meselhe, E., Costanza, K.E., Ainsworth, C., Chagaris, D., Addis, D., Simpson, E., Rodrigue, M., Hoonshin, J., Smits, J., 2015. Models Performance Assessment Metrics for the LCA Mississippi River Hydrodynamic and Delta Management Study.

Meselhe, E.A., Hu, K., Reed, D., 2019. Interaction of intr-basin ridge restoration with Mid-Barataria diverion Outflow. Report to the National Wildlife Federation, Issue.

Meselhe, E.A., Sadid, K.M., Allison, M.A., 2016. Riverside morphological response to pulsed sediment diversions. Geomorphology 270, 184–202. https://doi.org/10.1016/j.geomorph.2016.07.023.

Mishra, D.R., Mishra, S., 2010. Plume and bloom: effect of the Mississippi River diversion on the water quality of Lake Pontchartrain. Geocarto Int. 25 (7), 555–568. https://doi.org/10.1080/10106041003763394 (Geocarto Int. (UK)).

Mize, S.V., Demcheck, D.K., 2009. Water quality and phytoplankton communities in Lake Pontchartrain during and after the Bonnet Carré spillway opening, April to October 2008, in Louisiana, USA. Geo Mar. Lett. 29 (6), 431–440. https://doi.org/10.1007/s00367-009-0157-3 [Article].

Mossa, J., 1996. Sediment dynamics in the lowermost Mississippi River. Eng. Geol. 45 (1), 457–479. https://doi.org/10.1016/S0013-7952(96)00026-9.

Mukai, A.Y., Westerink, J.J., Luettich, R.A., 2002. Guidelines for Using Eastcoast 2001 Database of Tidal Constituents within Western North Atlantic Ocean, Gulf of Mexico and Caribbean Sea.

Nittrouer, J.A., Allison, M.A., Campanella, R., 2008. Bedform transport rates for the lowermost Mississippi River. J. Geophys. Res.: Earth Surf. 113 (F3). https://doi.org/10.1029/2007JF000795.

NOLA.com, 2023. Lafitte Breaks Ground on $14 Million Levee Project. We cannot afford to sit by. https://www.nola.com/news/jefferson_parish/lafitte-breaks-ground-on-14-million-levee-project/article_a832ca6c-4c16-11ee-8d7c-9b5377a0c51a.html.

Parra, S., Sanial, V., Boyette, A.D., Cambazoglu, M.K., Soto, I.M., Greer, A.T., Chiaverano, L.M., Hoover, A., Dinniman, M.S., 2020. Bonnet Carré Spillway freshwater transport and corresponding biochemical properties in the Mississippi Bight. Cont. Shelf Res. 199, 104114. https://doi.org/10.1016/j.csr.2020.104114.

Parra, S.M., Sanial, V., Boyette, A.D., Cambazoglu, M.K., Soto, I.M., Greer, A.T., Chiaverano, L.M., Hoover, A., Dinniman, M.S., 2020. Bonnet Carre Spillway freshwater transport and corresponding biochemical properties in the Mississippi Bight. Cont. Shelf Res. 199 (19). https://doi.org/10.1016/j.csr.2020.104114, 104114.

Peyronnin, N.S., Caffey, R.H., Cowan, J.H., Justic, D., Kolker, A.S., Laska, S.B., McCorquodale, A., Melancon, E., Nyman, J.A., Twilley, R.R., Visser, J.M., White, J.R., Wilkins, J.G., 2017a. Optimizing sediment diversion operations: working group recommendations for integrating complex ecological and social landscape interactions. Water 9 (6), 368. https://www.mdpi.com/2073-4441/9/6/368.

Peyronnin, N.S., Caffey, R.H., Cowan, J.H., Justic, D., Kolker, A.S., Laska, S.B., McCorquodale, A., Melancon, E., Nyman, J.A., Twilley, R.R., Visser, J.M., White, J.R., Wilkins, J.G., 2017b. Optimizing sediment diversion operations: working group recommendations for integrating complex ecological and social landscape interactions. Water 9 (6). https://doi.org/10.3390/w9060368.

PontchartrainConservancy, 2022. *Caernarvon Freshwater Diversion and Delta.* scienceforourcoast.Org/pc-Programs/coastal/coastal-Projects/archive-Caernarvon-Freshwater-Diversion-And-Delta.

Ramirez, M.T., Allison, M.A., 2013. Suspension of bed material over sand bars in the Lower Mississippi River and its implications for Mississippi delta environmental restoration. J. Geophys. Res.: Earth Surf. 118 (2), 1085–1104. https://doi.org/10.1002/jgrf.20075.

Rowiński, P.M., Västilä, K., Aberle, J., Järvelä, J., Kalinowska, M.B., 2018. How vegetation can aid in coping with river management challenges: a brief review. Ecohydrol. Hydrobiol. 18 (4), 345–354. https://doi.org/10.1016/j.ecohyd.2018.07.003.

Seitz, R.D., Wennhage, H., Bergström, U., Lipcius, R.N., Ysebaert, T., 2014. Ecological value of coastal habitats for commercially and ecologically important species. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 71 (3), 648–665. https://doi.org/10.1093/icesjms/fst152.

Smagorinsky, J., 1963. General circulation experiments with the primitive equations: I. The basic experiment. Mon. Weather Rev. 91 (3), 99–164. https://doi.org/10.1175/1520-0493(1963)091<0099:GCEWTP>2.3.CO;2.

Snedden, G.A., Cable, J.E., Swarzenski, C., Swenson, E., 2007. Sediment discharge into a subsiding Louisiana deltaic estuary through a Mississippi River diversion. Estuar. Coast Shelf Sci. 71 (1), 181–193. https://doi.org/10.1016/j.ecss.2006.06.035.

Snedden, G.A., Cretini, K., Patton, B., 2015. Inundation and salinity impacts to above- and belowground productivity in Spartina patens and Spartina alterniflora in the Mississippi River deltaic plain: implications for using river diversions as restoration tools. Ecol. Eng. 81, 133–139. https://doi.org/10.1016/j.ecoleng.2015.04.035.

Turner, R.E., 2006. Will lowering estuarine salinity increase Gulf of Mexico oyster landings? Estuaries Coasts 29 (3), 345–352. https://doi.org/10.1007/bf02784984 [Article].

USACE, 2022. Final Environmental Impact Statement for the proposed Mid-Barataria Sediment Diversion Project Plaquemines Parish, Louisiana. https://www.mvn.usace.army.mil/Missions/Regulatory/Permits/Mid-Barataria-Sediment-Diversion-EIS/.

USACE, 2023. Lower Mississippi river comprehensive management study. https://www.mvn.usace.army.mil/About/LMRComp/#:~:text=The%20Lower%20Mississippi%20River%20%28LMR%29%20Comprehensive%20Management%20Study,from%20Cape%20Girardeau%2C%20to%20the%20Gulf%20of%20Mexico.

USACE, Engineers, U. S. A. C. o., District, M. V. D. R. P. a. E. D. S. N. O., 2022. DRAFT ENVIRONMENTAL ASSESSMENT MISSISSIPPI RIVER, BATON ROUGE TO THE GULF OF MEXICO, LOUISIANA, NEPTUNE PASS ROCK CLOSURE, PLAQUEMINES PARISH, vol. 589. LOUISIANA EA #.

Walling, D.E., 2011. Human Impact on the Sediment Loads of Asian Rivers.

Wang, H., Chen, Q., La Peyre, M.K., Hu, K., La Peyre, J.F., 2017. Predicting the impacts of Mississippi River diversions and sea-level rise on spatial patterns of eastern oyster growth rate and production. Ecol. Model. 352, 40–53. https://doi.org/10.1016/j.ecolmodel.2017.02.028.

White, E., Messina, F., Moss, L., Meselhe, E., 2018. Salinity and marine mammal dynamics in Barataria basin: historic patterns and modeled diversion scenarios. Water 10. https://doi.org/10.3390/w10081015.

White, E.D., Meselhe, E., Reed, D., Renfro, A., Snider, N.P., Wang, Y., 2019. Mitigating the effects of sea-level rise on estuaries of the Mississippi delta plain using River Diversions. Water 11 (10).

Yang, S.L., Zhang, J., Dai, S.B., Li, M., Xu, X.J., 2007. Effect of deposition and erosion within the main river channel and large lakes on sediment delivery to the estuary of the Yangtze River. J. Geophys. Res.: Earth Surf. 112 (F2). https://doi.org/10.1029/2006JF000484.