DISSERTATION

SEDIMENT MANAGEMENT ALTERNATIVES ANALYSIS IN THE LOUISIANA DELTAIC PLAIN

Submitted by

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ABSTRACT

SEDIMENT MANAGEMENT ALTERNATIVES ANALYSIS IN THE LOUISIANA DELTAIC PLAIN

While coastal communities around the world are under threat from rising sea levels, those of Southeast Louisiana are some of the most threatened. Including subsidence, the region could potentially see rates of net sea level rise up to ten times the global mean.

There is no shortage of causes for how this situation has come to pass. A Systems Engineering solution needs to be multi-faceted, similar to how the problem was created:

- Climate change: like any coastal area, the region has to make hard decisions on how to handle a changing climate, but those choices have significant ramifications for the entire U.S. population, as significant commerce passes through the regional ports in the form of agriculture, oil/gas, petrochemicals, and the fishing industry.
- Engineered factors: by controlling the flow of the Mississippi River with the intent of flood protection through the use of levees, floodwalls, and spillways, humans have inhibited the natural processes that could rebuild the wetlands and natural protection barriers.
- River navigation: similarly, the locks and dams that allow maritime traffic have trapped the sediment that historically would have flowed down to the delta and built more land buffers against the sea.
- Industrial infrastructure: with thousands of miles of navigation channels and pipelines, the wetlands have been cut up into non-natural bodies of water, allowing hurricanes and saltwater intrusion unabated access to delicate ecosystems.

- Environmental damage: over 100 years of industrial development, combined with numerous environmental disasters, has compromised the health of the ecosystem.
- Invasive species: whether intentionally introduced or not, non-native species, both flora and fauna alike, have wreaked havoc on native populations and weakened deltaic processes.
- Stakeholder coordination: with dozens of local, state, and federal government agencies and nonprofit organizations, it is nearly impossible to make everyone happy.
- Limited resources: there is a funding gap between the budget needed to implement a successful strategy and what is expected to be available if the status quo is maintained.

While there are multiple methods employed to improve coastal resilience, a core strategy as defined by Louisiana's 2023 Coastal Master Plan is the introduction of sediment. The plan suggests two main alternatives of sediment management, that of the Major Diversions and Dredged Sediment. In this work, these two traditional alternatives are considered, and a new proposed approach is introduced, that of Micro Diversions, a concept developed in prior work by the author. All three approaches are described, analyzed, modeled, and compared against each other to determine which would be the most cost effective and appropriate for investment by coastal stakeholders.

The compared metric is Cost Benefit over a 50-year time horizon, calculated using the Life Cycle Cost and Net Benefit variables from each alternative. Inherent in the Systems Engineering approach is that the cost variables consider the time value of money.

The Major Diversion variables were taken from the stated goals in the Master Plan. The Dredged Sediment variables were forecasted from historical trends on recently completed and/or approved projects. The Micro Diversion variables were formulated from hydrologic software modeling of a limited system and expanded to compare in size to the other alternatives.

At a Cost Benefit of $61,773 per acre, the Major Diversion alternative was evaluated to be a better investment than Dredged Sediment or Micro Diversions ($67,300 and $88,206 respectively).

Because coastal conditions can change over time, and that the inputs to these alternatives can likewise change, it is suggested to view solutions with a systems-level approach, with the potential to implement complementary alternatives.

ACKNOWLEDGEMENTS

This research endeavor has been the most challenging as well as rewarding of my academic career, and of my professional career for that matter. I am extremely grateful to the numerous individuals who have provided input and expertise as I explored the various topics herein. I appreciate their engagement, and I hope that in return this dissertation is a valued contribution to coastal science and literature.

I want to thank my CSU graduate committee for their engagement. Special thanks to Dr. Young, the committee chair, for his patience and guidance for over a decade. I would like to thank Dan Zimmerle for his suggestions and feedback on statistical analysis, and to Dr. Grigg for his suggestions on the civil and environmental engineering aspects of my research. While Dr. Ross was a latecomer to the committee, I want to thank him for agreeing to be the outside department member.

Lastly but certainly not least, I want to thank my life partner, friends, and family for their support. They've had to put up with a stressed-out PhD candidate at times. Without their encouragement I might have abandoned the effort.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP	Above Head of Passes
CB	Cost Benefit
cfs	cubic feet per second
CPRA	Coastal Projection and Restoration Authority (Louisiana)
CWPPRA	Coastal Wetlands Planning, Protection, and Restoration Act
DS	Dredged Sediment
DSCB	Dredged Sediment Cost Benefit
USACE	United States Army Corps of Engineers
LCC	Life Cycle Cost
MR	Mississippi River
MBSD	Mid-Barataria Sediment Diversion
MBrSD	Mid-Breton Sediment Diversion
MRGO	Mississippi River Gulf Outlet
SELA	Southeast Louisiana
NB	Net Benefit
NPV	Net Present Value

1. Introduction

The global human population is under duress as rising seas due to climate change threaten existing man-made developments. With increases in mean sea level in the last 20 years of up to 6 to 8 inches (*Lindsey 2019, Slangen et al. 2017*) and forecast estimates ranging up to 10 feet by 2100 (*IPCC 2019*, *Strauss et al. 2015*), low-lying coastal communities will be especially impacted (*Fitzgerald et al. 2008*). While coastal flooding is dependent on multiple variables, many communities can expect to see a doubling of flood events over the next few decades (*Vitousek et al. 2017*), with the lowest-lying areas experiencing daily high-tide flooding (*Sweet et al. 2018*). One of the most vulnerable areas in the world susceptible to this issue is Southeast Louisiana (SELA), at the foot of the Mississippi River's bird foot delta.

1.1 Background

The greatest threat to the long-term viability of human habitation for SELA is land loss due to coastal erosion. Without a natural land barrier to protect it, the city of New Orleans as well as neighboring communities and industrial facilities will face increased danger from hurricanes and other natural forces emanating from the Gulf of Mexico (*Jones et al. 2016*). The coastline will constantly be changing and forcing the human population to adjust. From 1930 to 2010, Louisiana lost more than 1,800 square miles of land and from 2004 to 2008 alone lost more than 300 square miles due mainly to four major hurricanes (*Couvillion 2011*). As shown between the differences in Figure 1 and Figure 2, if efficient solutions are not implemented soon, thousands of acres of coastal land will continue to be lost to erosion every year, drastically altering the geography of the region and threatening the ability to maintain a healthy population for humans and native flora/fauna alike.

Projections to Year 2070 by the United States Army Corps of Engineers (USACE) forecasts significant land loss with negligible land gain (see Figure 3).

Figure 1: Current Coastline in Southeast Louisiana

(Source: NASA)

Figure 2: Projected Louisiana coastline in 2100 if status quo is maintained

(*Source: NASA*)

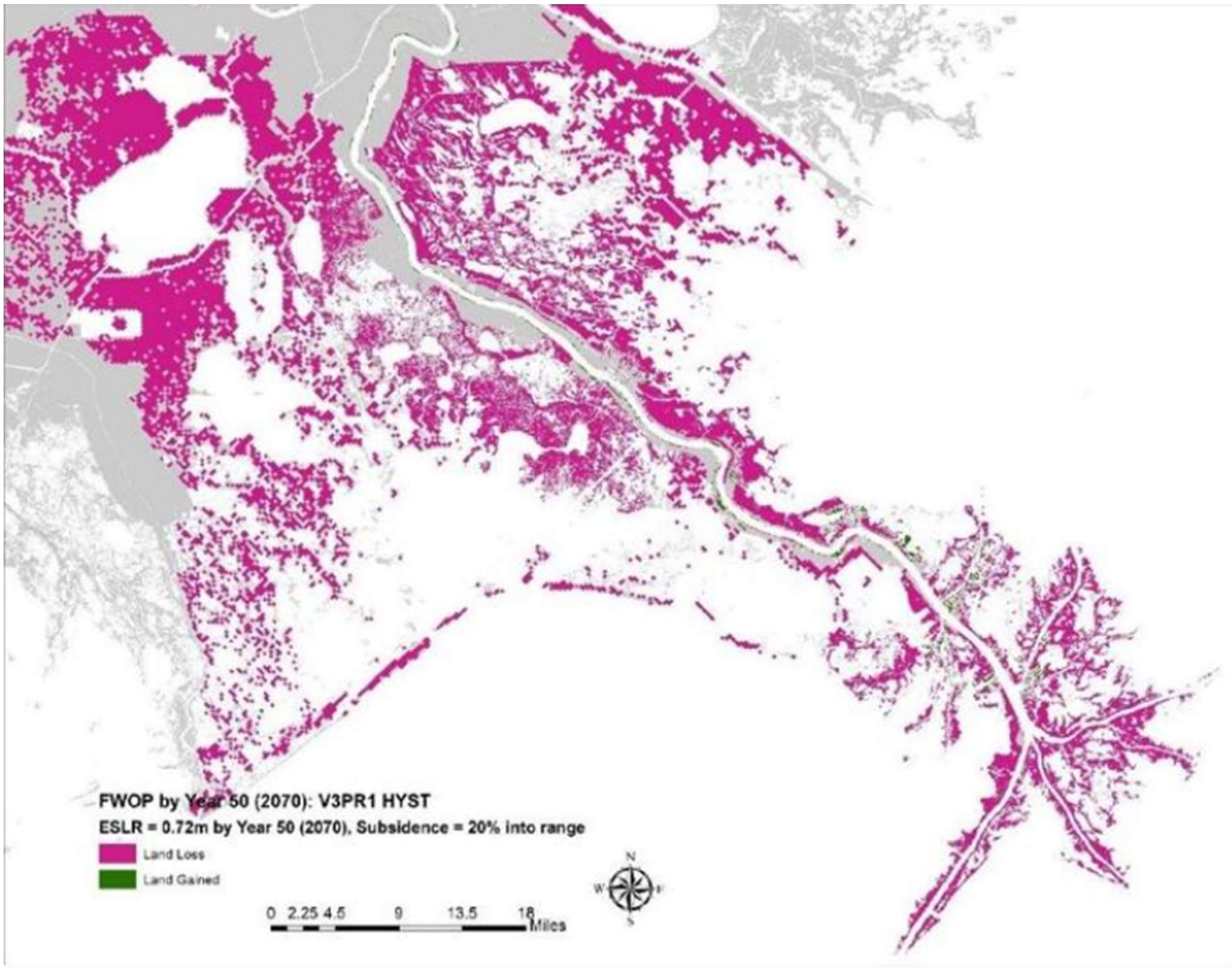

Figure 3: Projected wetland loss in Louisiana, to 2070

(*Source: USACE*)

1.2 Problem Identification

Due to subsidence, Louisiana has to deal with exacerbated relative sea level rise (RSLR), with rates up to a factor of 10 times global mean sea level rise (GMSLR) (*Jankowski et al. 2017, Frederick et al. 2018, Yi et al. 2015, Nienhaus et al. 2017*). For 7000 years the Mississippi River (MR) regularly overflowed its banks, depositing sediment that built up the coast and wetlands of the modern-day delta (*Day et al. 2007*). Over the last 200 years, manmade structures have restricted the sediment deposition by shifting the river dynamics (*Wang et al. 2017*). Both from dams up to 2,000 miles upriver that now only allow 50% of historical suspended sediment loads to pass downstream (*Blum and Roberts 2009*), to levees and floodwalls built with the purpose of flood control, the ability of the river to naturally rebuild land is inhibited, with the valuable sediment being swept off the continental shelf into the Gulf of Mexico (*Blum 2019*).

Multiple methods to restore damaged wetlands exist, including shoreline stabilization, oyster reef restoration, barrier island restoration, and ridge restoration. However, according to Louisiana's 2017 Coastal Master Plan, absolutely necessary will be sediment management solutions to get sediment from the Mississippi River to targeted habitats outside of the levees. There is no single sediment management method that has been suggested or implemented on a wide scale. Methods will invariably be considered largely on their respective funding requirements and returns on investment within limited stakeholder budgets.

1.3 Research Goals

Existing literature does not compare the cost benefits between sediment management alternatives. The goal of this research endeavor is to evaluate three alternatives, with two being traditional approaches and the third a new approach proposed by the author. Using objective analysis, the alternatives will be compared with the cost of each to implement based on similar acres of land created.

2. Deltaic System Influencing Factors

2.1 Climate Change

Given the reality of a rising sea, low-lying communities and habitats will be the most susceptible to increased damage. Increased costs can be expected in multiple facets of life, including mortality, agricultural yields, and direct property damage. By 2100 the U.S. Gulf Coast can expect to see double or triple the total climate change damages compared to the rest of the continental states (*Hsiang et al. 2017*). Increasing occurrences and severity of extreme weather events, such as flooding and hurricanes, will have significant impacts to the financing and insurance markets of these coastal communities, inhibiting their ability to recover and reconstruct (*Moody's 2017*). Figure 3 shows the estimated expected annual damage to infrastructure if the status quo is maintained.

While coastal loss is an immediate threat to the delta communities, a disappearing Louisiana coast has significant long term economic implications for the entire nation:

- Louisiana is home to 5 of the nation's 15 largest ports, handling a fifth of all U.S. port traffic.
- 60% of grain exported from the U.S. is shipped via the MR and passes through New Orleans, at an average annual value of over $80b. See Figure 4 for a small section of the MR showing the significant maritime traffic.
- Louisiana's 17 oil refineries account for a fifth of U.S. refining capacity.
- Oil, gas, and chemical infrastructure assets produce an average annual revenue of over $150b.
- South Louisiana is home to the U.S. Strategic Petroleum Reserve, which houses the country's emergency stockpile of oil reserves in underground salt caverns.

- Louisiana accounts for 30% of U.S. commercial fishing revenue, at an annual value of $2b.

(*Richardson and Scott 2004*)

Figure 4: Ship and barge traffic on the Mississippi River at the Port of New Orleans

(Source: Bob Nichols, USDA)

In addition to the loss and/or reduced annual revenues from operations disruptions, industrial facility owners/operators have trillions of dollars of assets at risk. Most industrial infrastructure cannot be sustainably operated in open water or near the sea at sea level. Even slight disruptions in industrial activity can have severe consequences on the global prices of oil, gas, chemicals, and grain (*EAP 2011*).

2.2 Engineered Factors

Humans have altered the geography of the deltaic plane in a myriad of ways, often with unintended consequences. Past river engineering had a focused goal of hemming in the

Mississippi River, for the benefits of flood control and river navigation, as the USACE is tasked with safeguarding the public and ensuring the Mississippi River is a navigable waterway. But these tasks are counterproductive to sustaining a healthy coastal ecosystem.

Levees and Floodwalls

After the Great Flood of 1927, which inundated much of Southeast Louisiana, the USACE implemented a flood protection strategy to protect coastal communities in and around New Orleans. The constructed levee and floodwall system has disrupted the delta's ability to naturally heal itself, with the sediment normally deposited in marsh and wetlands during high-river events now flowing straight out to the ocean (*Winer 2011*). The goal of protecting people and infrastructure has historically been at the expense of the natural system, but ultimately a compromised natural system will undermine the engineered solutions (*Twilley and Rivera-Monroy 2009*).

In the latest strategy iteration, the USACE has recommended that hurricane-levee systems and floodwalls be raised to standards to protect against storms with a 1% chance of occurring any single year, at a total cost of over $3b (*USACE 2019a, USACE 2019b*).

Spillways

In addition to levees and floodwalls, the USACE has constructed and implemented a system of flood control spillways, namely the Bonne Carré and the Morganza. Both are designed to be opened when the river reaches a critical flood stage, and save downstream settlements from inundation.

The Bonne Carré was completed in 1931 in response to the Great Flood in 1927 and is located 33 miles upriver from the river mouth. It was first utilized in 1937 and operated a total of 13 times. See Figure 5 for a view of the Bonne Carré being opened during the Spring flood event in 2011.

The Morganza was completed in 1954 and is located 280 miles upriver from the river mouth. It has only been opened twice, in 1973 and 2011.

An unfortunate reality of the spillways is that they release sediment into open water that historically would have overflowed the riverbanks into surrounding marshes. It's on this river sediment that the surrounding communities were built.

Figure 5: Bonne Carré Spillway in operation, 2011

(Source: USACE)

River Navigation

Since the mid-1800s dams and locks have been installed along the length of the river to assist with maritime traffic. The resulting effects to the coast are that sediment gets trapped by dams along the Mississippi, Ohio, and Missouri Rivers, with sediment loads over half of what they were 100 years ago before installation of the infrastructure (*Tweel and Turner 2012, Kemp et al. 2016)*. The Army Corps of Engineers has an annual budget in the millions of dollars appropriated to maintain the river at minimum depths for navigation (*USACE 2019a, USACE 2019b*).

<u>Industrial Infrastructure</u>

Thousands of miles of canals have been dug throughout the coastal wetlands by petrochemical companies, namely for the purposes of fluid pipelines and navigation. These industrial facilities inhibit the natural flow of coastal waters, and in severe storm events allow the sea a more direct, unabated path, for salt intrusion into delicate inland ecosystems. See Figure 6 for the unnatural rearrangement of coastal Louisiana wetlands. The same petrochemical industry has also extracted subterranean and/or subsea hydrocarbons, which increases the rate of fault-related subsidence (*Ko et al. 2004*).

Figure 6: Aerial view of pipeline canals cut through natural wetlands

(Source: USGS)

A case study on the Biloxi Marsh determined that decades of operation of the Mississippi River Gulf Outlet (MRGO), a canal dug in the 1960's to facilitate industrial logistics, was to blame for the degradation of coastal habitat in and around the marshes of Lake Borgne (*Day et al. 2019*). Figure 7 is a map of the MRGO, with its lengthy cut through the delta wetlands.

Figure 7: Map view of the MRGO

(Source: New York Times)

2.3 Environmental Damage

In addition to the effects of 100 years of industrial installations and operations throughout coastal Louisiana, the poor record of environmental stewardship has also hurt the natural landscape. There are several releases of various hydrocarbons and petrochemicals into coastal waters every year. The most noteworthy in recent history is that of the BP Horizon Oil Spill in the Gulf of Mexico in 2010, during which a safety system malfunction resulted in approximately 200 million gallons of crude oil to be released into the Gulf of Mexico over the course of 3 months, and which ultimately washed into and throughout coastal habitats through the Gulf

Coast Region. See Figure 8 for the magnitude of the incident and the emergency response. For several weeks oil was released, which blanketed reeds, cane, marsh grasses, and animals, tipping the scales of an already-compromised ecosystem which will take years if not decades to fully recover and the effects of which may never be fully quantified or understood (*Hester et al. 2017*).

Figure 8: BP Horizon oil disaster, 2010

(Source: Reuters)

2.4 Invasive Species

As any location in the world that has been touched by humans, Southeast Louisiana is no different regarding the negative effects brought on by invasive species. While the various species run the gamut from geckos to feral hogs, there are two species that are especially concerning with regards to the damage to coastal wetlands.

Nutria

Nutria is a semi-aquatic rodent, native to South America. They were first introduced into the U.S. in the late 1800's for the fur industry. Seen as a replacement for the over-hunted beaver and muskrat, the nutria quickly spread throughout the Southern U.S. by escaping during storms and possibly by poor industry management. With a temperate regional climate and high-water content of marshes and wetlands, nutria have proliferated throughout the Gulf Coast. They have a preference for root systems of aquatic plants, and even small populations can decimate a wetland aquatic ecosystem (*Jojola et al. 2005).*

Phragmites Scale

Scales are small insect parasites originating in Asia, that feed on the sap of plants. There lacks certainty how the Phragmites scale was introduced to Louisiana, but it is believed it was brought by migrating birds or in the ballast of ocean-going vessels. The name is derived from the plant it feeds on, the Phragmites australis, locally known as Roseau cane. Roseau cane is vitally important to the health of the Mississippi Delta ecosystem, as it is the organic anchor of the entire habitat, with a root system that binds the moist soil (*La. Sea Grant 2017*). The first indications of a problem were noticed in 2015, when local fisherman noticed large swaths of cane die-offs (*Schultz 2017*). Satellite imaging showed a widespread decline in the live cane biomass, with cumulatively thousands of acres of cane lost in the delta lobe between 2015 and 2018 (*Ramsey and Rangoonwaia 2017*). Compromised Roseau cane allows for increased damage from hurricanes compared to healthy habitats. There is currently no acceptable or efficient method to rid the region of this invader, without damaging the environment in the process such as burning or pesticides.

2.5 Stakeholder Coordination

Considering the severity of the coastal restoration problem, and given the economic risks, there are major obstacles in coordinating solutions among the various coastal stakeholders. With dozens of government agencies, environmental non-profits, and industry associations (Table 1), it is impossible to satisfy all involved with meeting the requirements needed to efficiently implement solutions. There are political, socioeconomic, and environmental conflicts throughout the coastal value chain, often pitting stakeholders against each other *(Lewis and Ernstson 2017).*

Table 1: Coastal Stakeholders

Federal Agencies	State and Local Agencies
U.S. Army Corps of Engineers	Coastal Protection and Restoration Authority
Environmental Protection Agency	Department of Natural Resources
National Oceanic and Atmospheric Admin.	Department of Transportation and Development
U.S. Geological Survey	Department of Environmental Quality
U.S. Fish and Wildlife Service	Department of Wildlife and Fisheries
Federal Energy Regulatory Commission	Department of Agriculture and Forestry
Department of Agriculture	Louisiana Public Service Commission
Department of Defense	Flood Protection Authority – East & West
Department of Energy	Mississippi Counties: Hancock, Harrison, Jackson
Department of Interior	Louisiana Parishes: Plaquemines, St. Bernard, Lafourche, Terrebonne, Jefferson, Orleans, St. Tammany, St. Charles, St. John, Tangipahoa
Department of Transportation	
Bureau of Ocean Energy Management	

Industry Organizations	Environmental Non-profits
The Water Institute of the Gulf	Coalition to Restore Coastal Louisiana
Port of New Orleans	Gulf Restoration Network
Port of South Louisiana	Lake Pontchartrain Basin Foundation
Big River Coalition	America's Wetland Foundation
Crescent River Port Pilots	National Audubon Society
New Orleans-Baton Rouge Steamship Pilots	National Wildlife Federation
Greater New Orleans Inc.	Sierra Club
Louisiana Shrimper Association	Gulf Coast Ecosystem Restoration Council
Louisiana Oysterman Association	Environmental Defense Fund
United Commercial Fisherman's Association	Coastal Guardians
Coastal Conservation Association	Save our Cypress
Gulf States Maritime Association	Levees.org
Louisiana Chemical Association	Restore the Mississippi River Delta Coalition
Louisiana Oil & Gas Association	Institute for Marine Mammal Studies

2.6 Limited Resources

The latest iteration of the State's Master Plan proposes $50b to be spent on coastal restoration projects over the next 50 years, with the funding sourced from environmental fines via the BP Oil Spill, offshore oil and gas royalties from federally-leased land for exploration, and possibly carbon offsets and/or wetland mitigation credits (*LCPRA 2017*). However, there remains a funding gap between the expected budget and funding sources. There is no easy answer to how this shortfall will be remedied.

3. Sediment Management Alternatives Descriptions

3.1 Major Diversions

The primary method suggested by CPRA in the 2023 Master Plan for sediment introduction is multiple large-scale diversions, also known as Major Diversions. These consist of controlled sediment and freshwater breaks on the banks of the MR, with thousands of cubic feet per second of water flowing into wetland basins through breaks or gates in the levee during high-river events.

There have been two Major Diversions proposed by the State and Federal Agencies:

- Mid-Breton Sediment Diversion (MBrSD), located on the East bank of the MR.
- Mid-Barataria Sediment Diversion (MBSD), located on the West bank of the MR.

See Figure 9 for a satellite view of the orientation of the two Major Diversions.

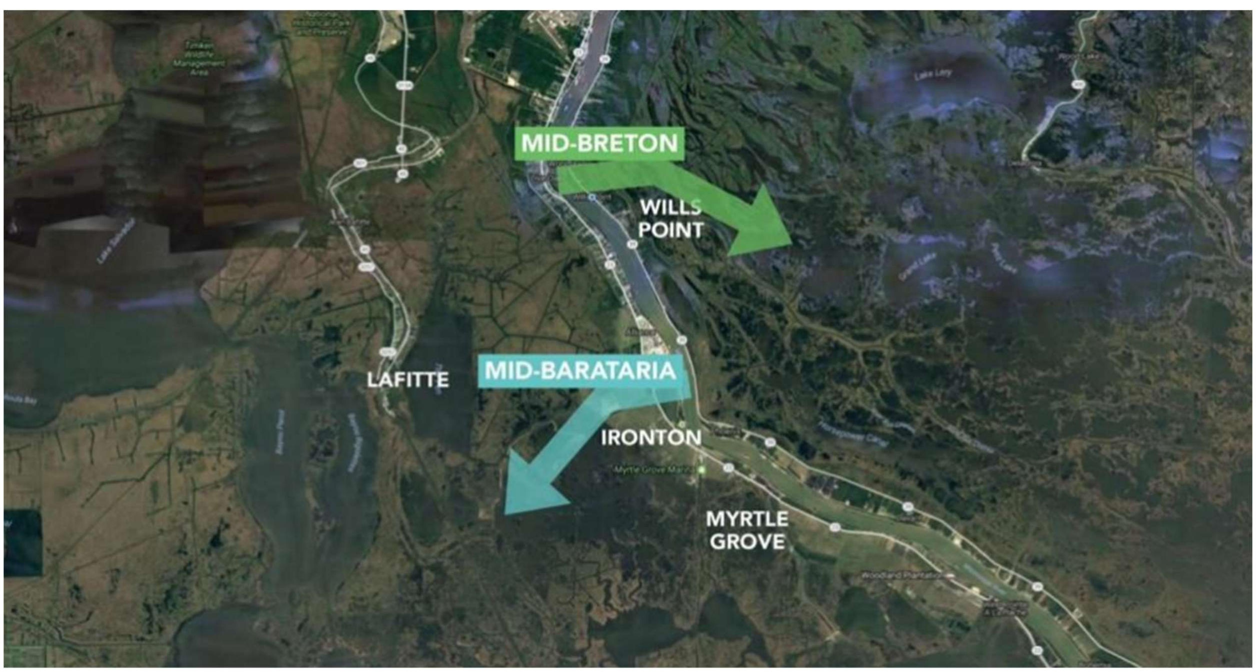

Figure 9: Satellite view of the two proposed Major Diversions

(Source: CPRA)

A potential side effect of this alternative is the threat of sediment accretion downstream from the diversion, which can affect maritime navigation. The various fisheries sectors also have concerns that an inundation of fresh water and sediment will hinder their ability to make a living (*Hyfield et al. 2008, Day et al. 2016, Allison and Meselhe 2010*).

Major Diversions positive aspect: High concentration of sediment via large flows.

Negative aspects:

- High initial cost and long timeline (more than 5 years) to construct.
- Difficult to modify after constructed.
- Threat of sediment accretion.

3.2 Dredged Sediment

Piping systems consist of dredges operated to relocate river sediment via pipes to target areas of subsidence. Large ships retrieve sediment from a water body floor, in many cases the Mississippi River itself, navigate as close as possible to the area needing restoration, and pump or dump the slurry mix to the desired location. See Figure 10 for a dredging operation that collects the sediment off the water body bottom and then pumps it to a target area.

While this method has proven results with sediment directed with high accuracy, it is expensive, as the ships require large amounts of fuel to operate. The large amounts of electricity to run the diversion pumps is not expected to be a cost-effective long-term strategy (*Wiegman et al. 2017*).   After a dredging project has been completed, the costs are not recoverable and there is no recurring return on investment (*Martin 2002*).

To date dredging projects either completed or planned in the Breton and Barataria basins to date have an estimate of 8,536 acres created at a total cost of just over $809 million.

Dredged Sediment positive aspect: Sediment can be deposited precisely where needed.

Negative aspect: Recurring annual costs to implement.

Figure 10: Dredging barge collecting sediment (L) and depositing outflow into target area (R)

(Source: USACE)

3.3 Micro Diversions

Given physical and economic constraints, new engineered methods will be needed to resolve this man-made problem, but ones that mimic and/or use nature to manage sediment versus methods that are energy-intensive and not sustainable long term (*Day et al. 2005*). An unexplored strategy is that of coordinated Micro Diversions, by implementing the piping method with permanent infrastructure.

Micro Diversions could function by diverting water and sediment from the MR via pipes running under or over the levee, to be deposited at an area outside of the levee. Multiple systems could be installed at various locations, with size and subsequent flow rates determined by the needs of the local habitat and stakeholders. Once installed, the flow rate of diverted water can be controlled by stakeholder personnel.

Multiple Micro Diversions could be orientated in various and flexible configurations. See Figures 11-13 for the multiple configurations.

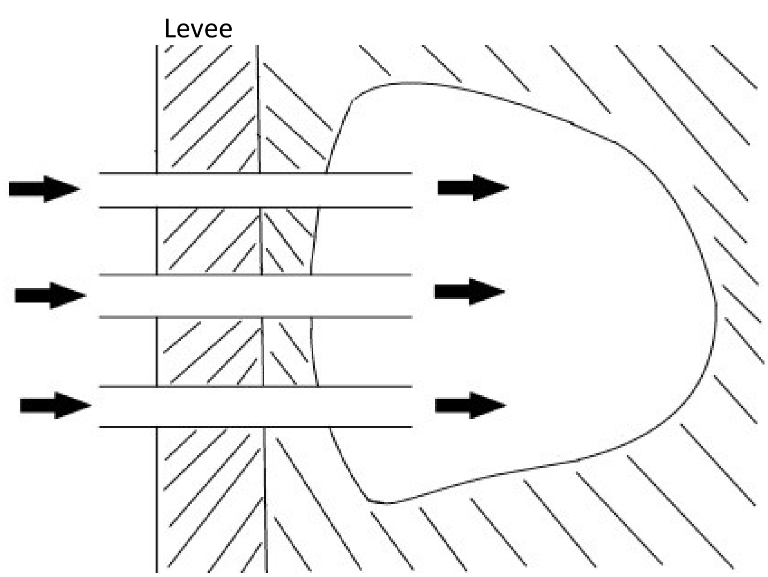

Figure 11: Coordinated Micro Diversion, point to point

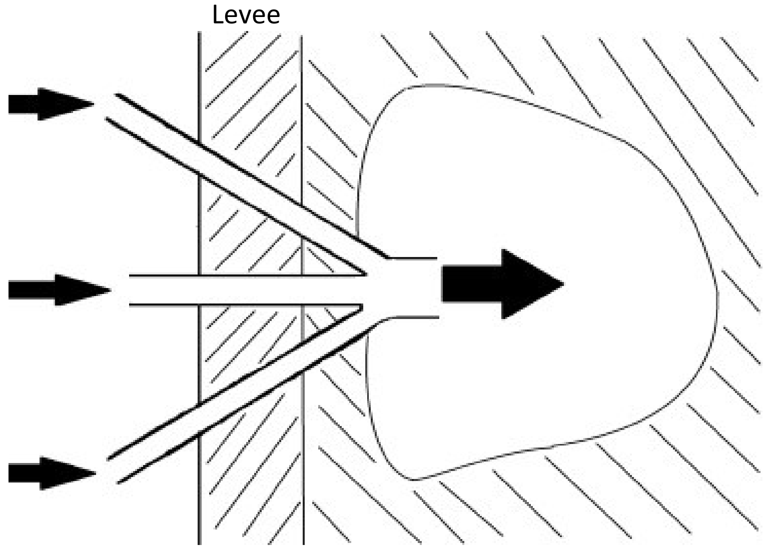

Figure 12: Coordinated Micro Diversion, converging points

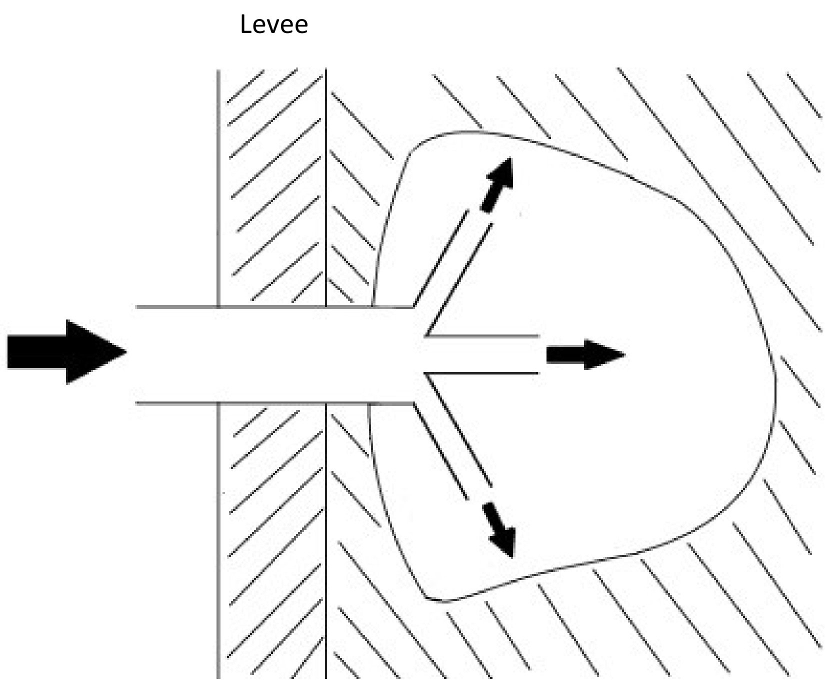

Figure 13: Coordinated Micro Diversion, diverging points

For a region-wide approach, the strategy would be to install hundreds of Micro Diversions along the MR. Compared to a Major Diversions, coordinated Micro Diversions would be the sprinkler approach versus a fire hose.

Positive aspects:

- Flexibility and scalability.
- Installed quickly (weeks or months).

Negative aspects:

- High initial costs to construct.
- Recurring cost to run pumps if needed.
- Additional costs to extend systems further into the wetlands.

4. Modeling Methodology

Each sediment diversion alternative was modeled with the goal of reaching a Cost Benefit (CB) metric to compare against each other. A lower CB signifies a better investment for coastal stakeholders.

CB is calculated by dividing the cost of the alternative by the acres of land created. CB is quantified as \$/acre.

$$\text{Cost Benefit} = \frac{\text{Cost}}{\text{Acres}} \tag{1}$$

The modeling timeline is based on 50 years (2020 to 2070), from the CPRA's 2023 Master Plan. While the benefits of the alternatives could possibly exist well beyond, the modeling was completed to year 2070.

A fundamental consideration of the systems engineering perspective is that funding mechanisms should consider the time value of money. Put simply, funds invested today are worth more than the same amount invested at some time in the future. One term of this concept is Net Present Value (NPV), which considers future cash flows and determines if an investment will be profitable over time. Since the systems in this analysis are intended to have costs but not revenue (i.e. no cash inflows), a version of NPV will be implemented called Life Cycle Cost (LCC).

LCC is the sum of all expenditures over the life of a project, discounted at an interest rate that considers the cost of capital investment.

$$\text{LCC} = \sum_{t=0}^{50} \frac{Cost_t}{(1+r)^t} \tag{2}$$

Where r is the discount rate, also known as the cost of capital or the available return on other investments. All sediment alternatives are compared using the same r value of 5%.

The term for acres of land created is Net Benefit (NB).

$$\text{Cost Benefit} = \frac{\text{LCC}}{\text{NB}} \tag{3}$$

For all three alternatives, the NB is 47,400 acres, from the combined Major Diversion model estimates of the CPRA 2023 Master Plan.

To determine the LCC for the respective alternatives:

Major Diversions - based on the MBSD and MBrSD estimated construction budgets from the 2023 Master Plan.

Dredged Sediment – forecast how many acres would need to be funded per year to reach the Major Diversion NB. Forecast the annual project costs based on historical cost trends of completed or ongoing projects.

Micro Diversion – using historical river gauge information as a baseline for sediment output, model hypothetical installations with Delft3D, a hydrodynamic and morphodynamic software platform, with estimates on construction costs, and forecasted over 50 years.

General model assumptions for all alternatives:

1. NB is the total acres of land that is created or reclaimed, including the fresh, brackish, and saline habitat restored, or maintained if no sediment alternative was implemented.
2. Fundamental to the LCC calculation is the value of r, also known as the discount rate or expected rate of return of an investment. For this analysis all alternatives are evaluated with r at 5%.
3. Only construction costs are considered for this analysis. Cost categories that would be common and estimated to be equal for all alternatives include planning and design, construction services, permitting, land acquisition, project monitoring, government agency engagement, and financial protocols.

General model limitations for all alternatives:

1. Potential variations in sea level rise due to climate change are not considered.
2. Future potential damage from natural disasters (i.e. hurricanes) or man-made disasters such as the BP Horizon Oil Spill are not considered.
3. Sponsoring government or non-profit agencies are not considered.

5. Modeling Analysis and Results

5.1 Major Diversions

The two planned major diversions are at different stages of the planning process.

MBSD, proposed location near Ironton (Mile 68 AHP), a Restoration Plan has been drafted in phases, with the latest phase published in September 2022[1]. Multiple State and Federal agencies have been involved in its creation, and it is now moving forward for engineering and permitting review, with approval by CPRA and the USACE.

The plan has proposed three alternatives (Table 2). The diversion will have a constant base flow of 5,000 cfs when the MR is below 450,000 cfs at the Belle Chasse gauge. Flows above 450,000 cfs will result in the structure fully opening with max flow reached above 1,000,000 cfs at Belle Chasse.

Table 2: CPRA proposed alternatives for the MBSD

Alternative	Max Flow through Diversion (cfs)	Estimated Construction Budget ($)	LCC over 50 years ($)	NB (acres)	CB ($/acre)
1	75,000	1,531,250,000	1,458,333,333	17,300	84,296
2	50,000	1,391,160,000	1,324,914,286	12,600	105,151
3	150,000	2,410,474,000	2,295,689,524	31,400	**73,111**

This analysis shows the best CB for MBSD is Alternative 3. See Appendix A for the LCC calculations. See Figure 14 for the aerial view of how the 31,400 acres of NB could be dispersed.

MBSD Alternative 3 Cost Benefit = **$73,111 / acre**

[1] Louisiana Trustee Implementation Group Final Phase II Restoration Plan #3.2: Mid-Barataria Sediment Diversion

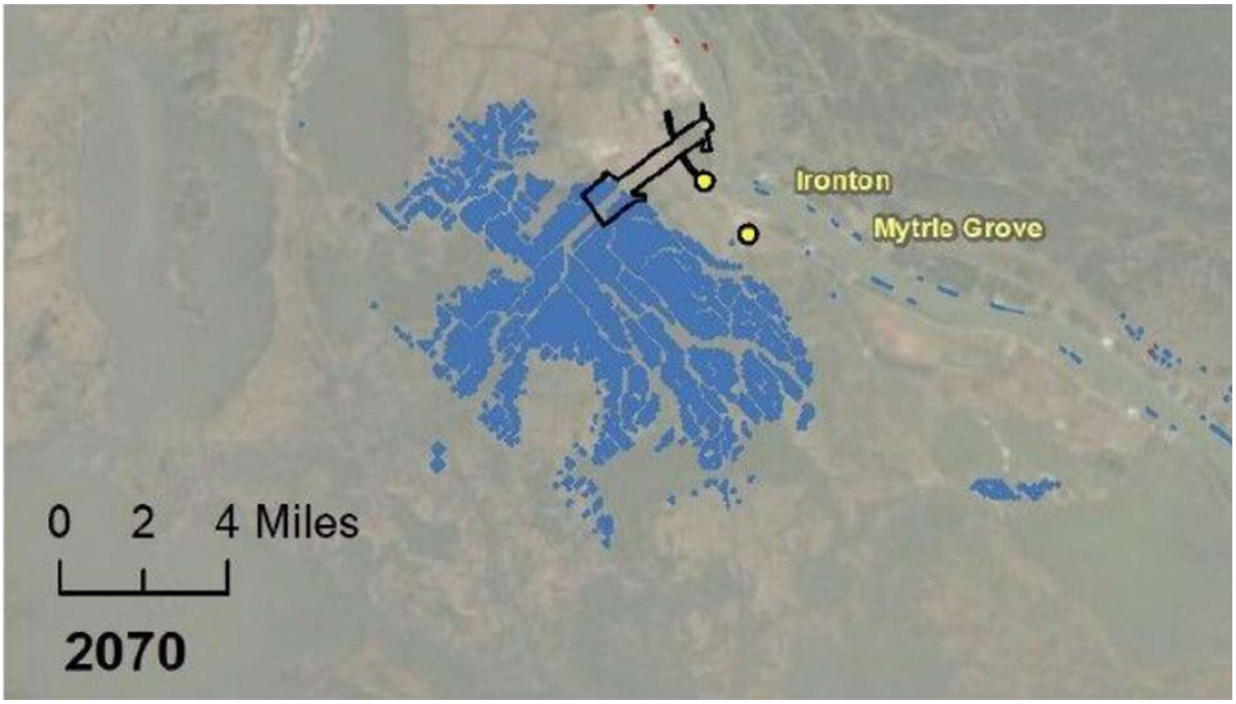

Figure 14: Mid-Barataria Diversion expected land gain by 2070 with Alternative 3 implemented

(Source: CPRA)

Based on the latest report for the Mid-Breton Sediment Diversion Assessment (MBrSD)[2], proposed location near Wills Point (Mile 70 AHP), the diversion has undergone multiple design changes, with the latest iteration a 75,000 cfs max flow diversion at a cost estimate of $800 million, with a target net benefit of 16,000 acres. The estimated budget is not bifurcated into construction cost, planning and design, monitoring, etc. In order to accurately weigh only the construction budget, the percentage was calculated using the average of the construction budget percentages from the three MBSD alternatives (see Table 3).

[2] Mid-Breton Sediment Diversion (MBrSD) Assessment – Final Report

Table 3: Construction Budget Percentage of Total Budget for Mid-Barataria Diversion

	Diversion cfs		Overall Budget	Construction Budget	Percentage of Total Budget %
Alternative 1	75,000		$1,874,910,000	$1,531,250,000	82%
Alternative 2	50,000		$1,716,503,000	$1,391,160,000	81%
Alternative 3	150,000		$2,804,463,000	$2,410,474,000	86%
				Average:	83%

MBrSD budget = $800m x .83 = $644m

MBrSD LCC over 50 years from Appendix A = $632,380,952

$$\text{MBrSD Cost Benefit} = \frac{LC}{\text{NB}} = \frac{\$632{,}380{,}952}{16{,}000} = \textbf{\$39,524 / acre}$$

To calculate the total CB of implementing both Major Diversions, the respective LCC's of the diversions are added, divided by the combined NB's of the diversions.

$$\text{Total Major Diversion Cost Benefit} = \frac{\text{M}BSD\ \text{L}C\ \ + MBrSD\ LCC}{\text{MBSD NB} + \text{MBrSD NB}} = \frac{\$2{,}295{,}689{,}524 + \$632{,}380{,}952}{31{,}400\text{ acres} + 16{,}000\text{ acres}}$$

Implementing both Major Diversions will result in a CB of **$61,773 /acre**.

This analysis assumes both Major Diversions are implemented concurrently. It should be noted that projects of this magnitude are difficult to design, permit, finance, and construct, as the respective locations could deal with unique obstacles. The calculated CB is assumed with both diversions implemented simultaneously under ideal time constraints.

A significant aspect this analysis does not consider are the potential damaging effects to wildlife and fisheries. Coastal researchers have raised concerns regarding the harm the Major Diversions would have on bottle-nosed dolphin populations, with estimated population decline of 34% in any given year within the first decade of operation of just the Mid-Barataria diversion (Garrison et al 2020).

The effects on fisheries have been difficult to model. The decrease in salinity levels will affect the habitats of both harvested and non-harvested species. Expected declines in oyster, shrimp, and certain finfish harvest will result in decreased economic output for commercial fisherman, while there are expected increases in catfish and alligator habitat. The changing economic landscape will likewise result in a forced relocation of commercial and residential infrastructure supporting the fisheries.

While the Master Plan estimates do include funding to alleviate these effects, they are hard to accurately model, as the total depth and breadth of effects are unknown. On the criteria of the changing economic landscape, it is unknown if the industry will relocate to a neighboring regional community or be permanently obsolete in location and activity.

5.2 Dredged Sediment

Future dredged sediment results were modeled using MS Excel, from the historical project performance and/or planning (*CWPPRA 2023*). Projects could be sorted through multiple criteria, including basin (Barataria or Breton). Total NB of future dredged sediment projects will total the combined NB of the MBrSD and MBSD Alternative 3 for a total 47,400 acres.

To analyze the CB of future projects, multiple steps were required to evaluate the independent variables of completed or approved projects. Variables included the budgetary figures of current estimates; planned net benefit; the year of approval (see Tables 4 and 5).

Table 4: Historical marsh creation projects in the Breton Basin

Number	Year Approved	Current Estimate ($)	NB (acres)
BS-43	2021	33,638,138	283
BS-44	2021	41,294,787	307
BS-41	2020	35,521,865	294
BS-42	2020	41,683,037	297
BS-37	2019	39,838,425	314
BS-38	2019	31,777,082	379
BS-32	2018	37,358,961	411
BS-24	2013	23,692,705	322

Table 5: Historical marsh creation projects in the Barataria Basin

Number	Year Approved	Current Estimate ($)	NB (acres)
BA-257	2022	42,657,227.00	302
BA-258	2022	37,207,763.00	343
	2019	41,795,419.00	297

BA-217			
BA-206	2018	37,524,056.00	536
BA-194	2016	35,066,972.00	205
BA-195	2016	23,838,905.00	226
BA-171	2014	50,943,676.00	379
BA-173	2014	29,937,575.00	237
BA-164	2013	14,727,482.52	118
BA-125	2012	33,664,671.00	432
BA-68	2009	34,649,280.78	370
BA-48	2007	37,002,781.40	186
BA-42	2006	34,858,395.76	447
BA-39	2003	23,870,606.89	326
BA-36	2002	16,286,153.00	605
BA-37	2002	29,516,673.14	713

Step 1: Calculate the Dredged Sediment Cost Benefit (DSCB) of historical projects, with NB in acres (see Table 6 for spreadsheet calculations).

$$\mathrm{DSCB} = \frac{\text{Current Estimate}}{\mathrm{NB}} \tag{4}$$

Table 6: DSCB of Historical Projects in the Barataria and Breton Basins

Basin	Acres	Current Estimate ($)	DSCB ($/acre)
Barataria	118	42,657,227	361,502
	186	37,207,763	200,042
	205	41,795,419	203,880
	207	37,524,056	181,276
	226	1,034,879	4,579
	237	35,066,972	147,962
	283	23,838,905	84,236

	294	50,943,676	173,278
	297	29,937,575	100,800
	297	14,727,483	49,587
	302	33,664,671	111,472
	307	34,649,281	112,864
	314	37,002,781	117,843
	322	34,858,396	108,256
	326	23,870,607	73,223
	343	16,286,153	47,481
	370	29,516,673	79,775
Breton	379	33,638,138	88,755
	379	41,294,787	108,957
	411	35,521,865	86,428
	432	41,683,037	96,489
	447	39,838,425	89,124
	536	31,777,082	59,286
	605	37,358,961	61,750
	713	23,692,705	33,230

Step 2: Perform a regression analysis of the DSCB over time. See Table 7 for the DSCB with corresponding year and Figure 15 for the scatter plot, trend line, and R^2 value of the regression analysis.

Table 7: DSCB of completed projects with the year approved

Basin	Year Approved	DSCB ($/acre)
Barataria	2022	141,249
	2022	108,477
	2019	140,725
	2018	70,008
	2016	4,999
	2016	171,058
	2016	105,482
	2014	134,416
	2014	126,319
	2013	124,809
	2012	77,927
	2009	93,647

	2007	198,940
	2006	77,983
	2003	73,223
	2002	26,919
	2002	41,398
Breton	2021	118,863
	2021	134,511
	2020	120,823
	2020	140,347
	2019	126,874
	2019	83,845
	2018	90,898
	2013	73,580

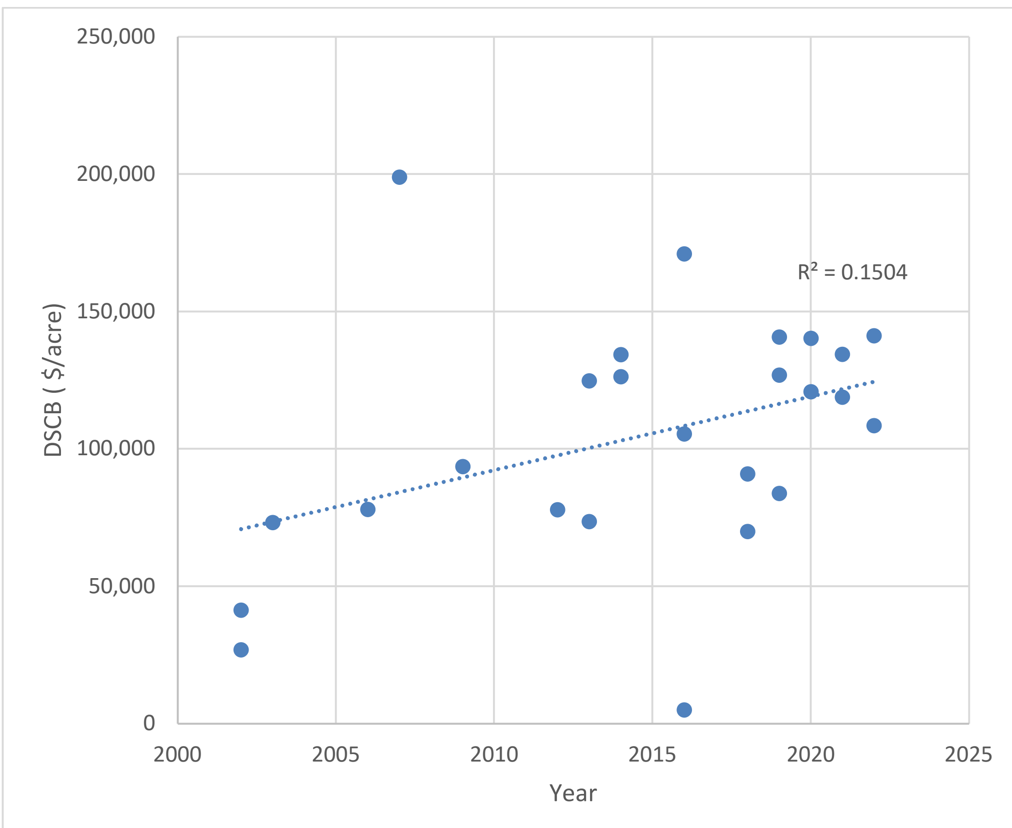

Figure 15: Scatter plot, trendline, and R^2 value for the DSCB over time of all completed or approved Breton and Barataria dredged sediment projects

In statistical modeling, R^2 value measures how correlated the data points are to the regression line. A higher R^2 value implies more correlation. Values above .5 imply high correlation, with values below .5 implying low correlation. In order to eliminate the influence of potential outlier data points, the regression analysis was performed again with a trimmed mean, with the highest and lowest DSCB values eliminated (198,940 and 4,999 respectively). The new regression returned an R2 value of nearly .5 (see Figure 16).

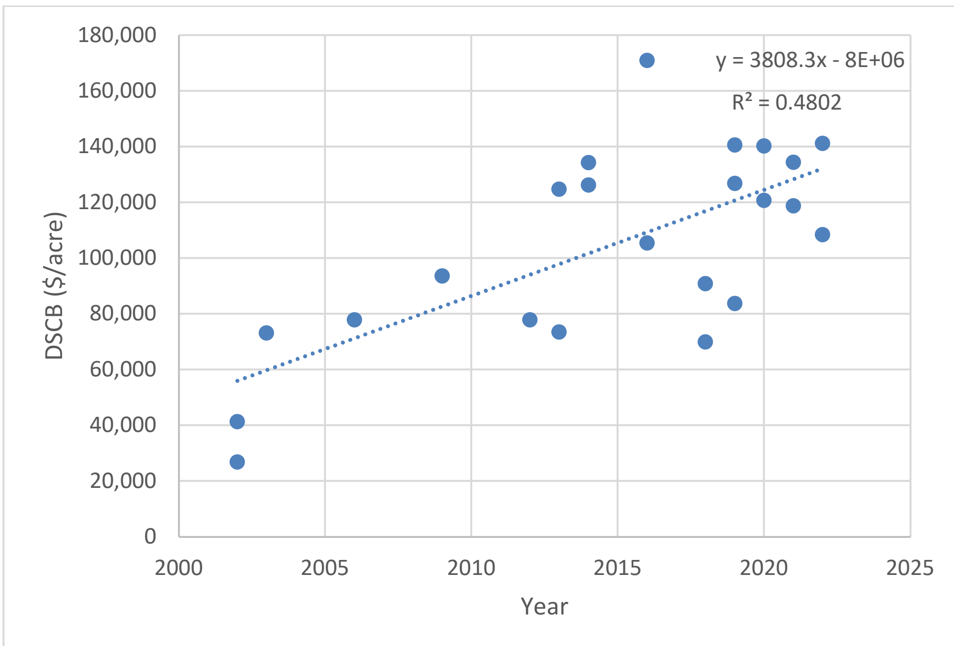

Figure 16: Scatter plot, trendline, slope formula, and R^2 value for the DSCB over time of all completed or approved Breton and Barataria dredged sediment projects, with highest and lowest DSCB values eliminated

Step 3: Calculate the DSCB for future years using the trendline equation and year for x value.

Slope (m) = 3808.3 Intercept = -7568230

$$\text{DSCB} = (3803.3\ x\ Year) - 7568230 \tag{5}$$

See Appendix B for yearly DSCB calculations.

See Figure 17 with all future years plotted. Future years should plot directly on the scatterplot trendline.

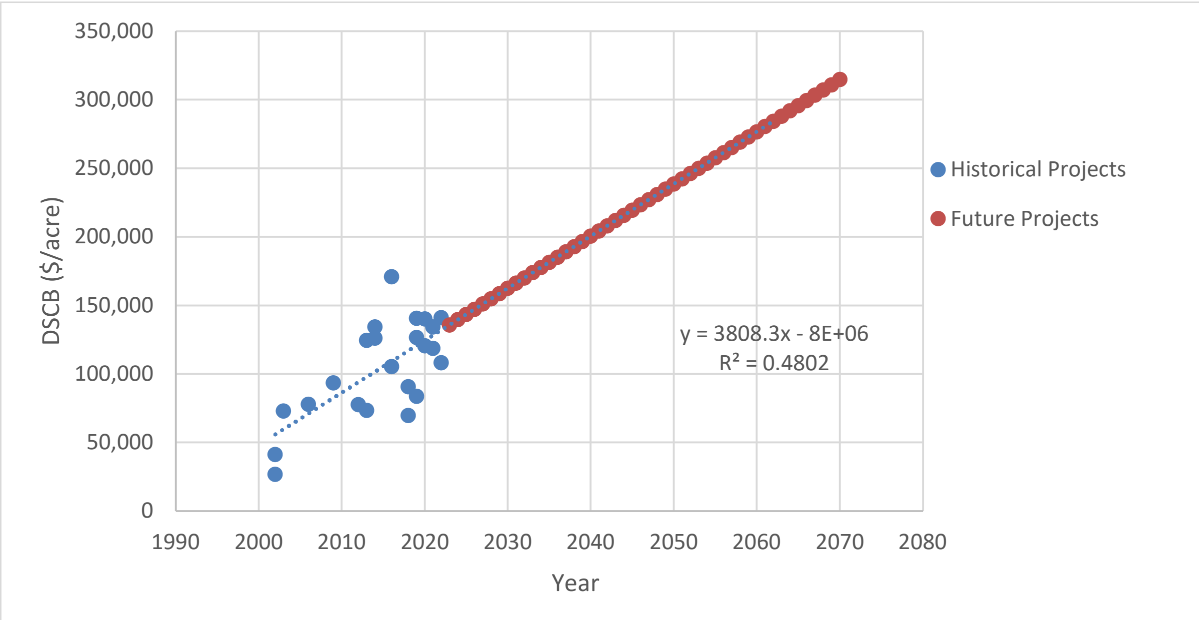

Figure 17: Scatter plot, trendline, slope formula, and R^2 value for the DSCB of historical and future projects

Step 5: Calculate the estimated annual NB of projects for future years, by dividing the combined Major Diversion NB by 50 years.

$$\text{DS Annual Net Benefit} = \frac{\text{Combined Major Diversion NB}}{\text{Total Evaluation Period}} = \frac{47400\ acres}{\text{50 years}}$$

$$= 950 \text{ acres/year}$$

Step 6: Calculate the Annual DS Project Cost

$$\text{Annual DS Project Cost} = \text{Annual DSCB x Annual DS Net Benefit}$$

(See Appendix B)

Step 7: Calculate the Total DS LCC (See Appendix B)

LCC = $3,190,046,880

Step 8: Calculate the Total DSCB $= \frac{\mathrm{L}CC}{\text{Total NB}} = \frac{\$3{,}190{,}046{,}880}{47{,}400 \text{ acres}} =$ **$67,300 / acre**

The Dredged Sediment CB is $67,300 /acre.

Similar to the assumptions made for the Major Diversion alternative, it is an assumption that the annual DS projects will always be 950 acres. The NB is assumed for this analysis, but in physical implementation would likely be higher or lower based on unique location specifics, such as permitting, design specifications, and environmental conditions.

5.3 Micro Diversions

After satellite and physical surveys of potential research locations, a site on the East Bank of the MR was selected for a Micro Diversion model, near the town of Davant, LA (AHP mile 55.3) in the Breton hydrologic basin. See Figure 18.

Figure 18: Satellite view showing the selected Micro Diversion location in relation to the city of New Orleans

(Source: Google Earth)

The existing Breton Basin was modeled in Delft3D. The software platform creates a hydrologic model based on publicly available data sets. See Figure 19 for the basic hydrologic model and Figure 20 for the refined model with added geographic inputs.

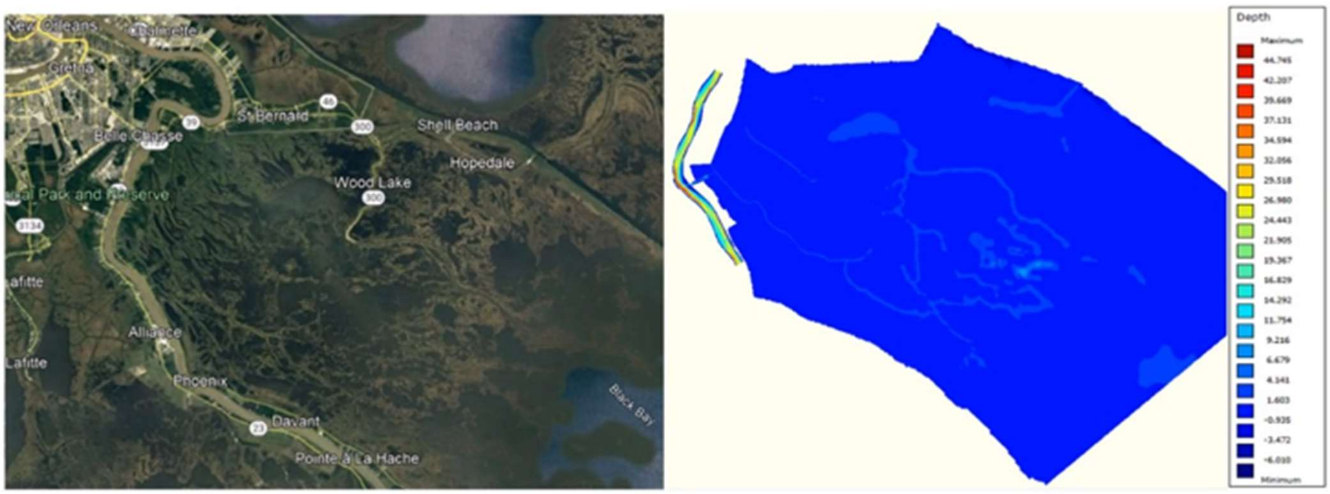

Figure 19: Google Earth view (L) and initial Delft3D model (R) of the Breton hydrologic basin

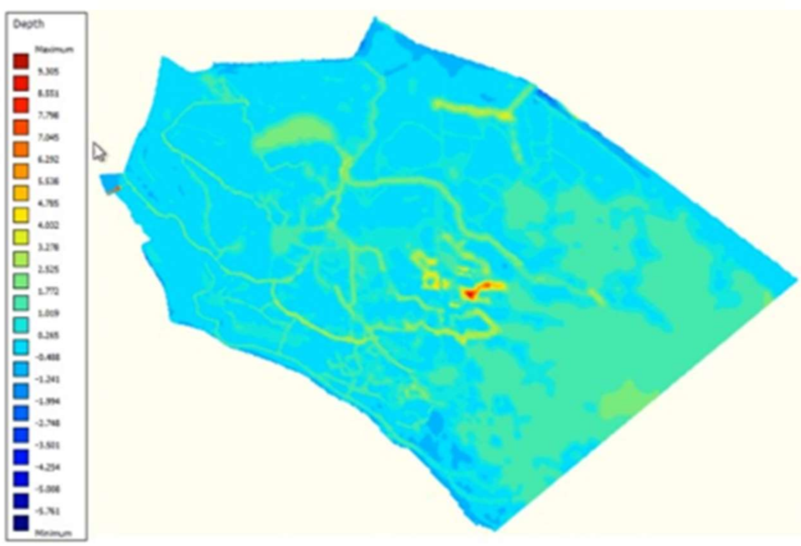

Figure 20: Refinement of the model with added inputs

Figure 21 shows the granularity of the model, with the software able to show hydrologic changes in data subsets with precision at 1000 square meters.

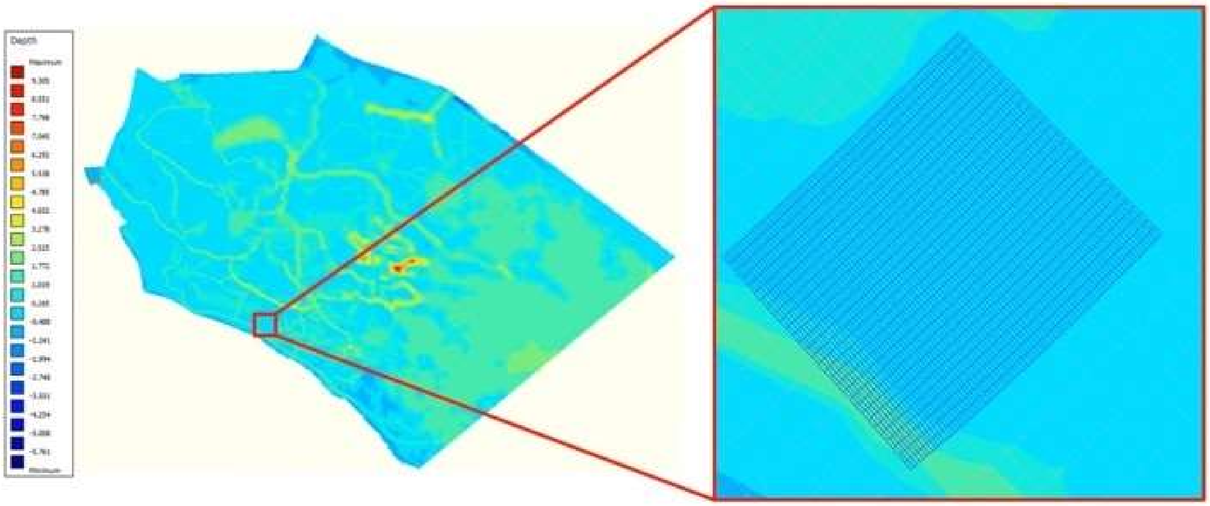

Figure 21: Precision at outfall area, with individual cells at 20m x 50m

Due to the computing requirements of the Delft3D platform, the Micro Diversion model was run for a single year with the following parameters: Single 48” pipe, horizontally directional drilled under the MR levee, with water and sediment flowing into the target area under the system’s self-sustaining pressure. Total length of pipe is 5000 ft. See Figure 22 for the system orientation.

Estimated total cost to construct this system is $10,000,000, with assumptions of piping material and installation cost of $1000 per linear foot and $2.5m each for the intake and outfall structures.

Total Cost = Piping (material and installation) + Intake structure + Outfall Structure

= \$1000/ft x 5000ft + \$2.5m + \$2.5m

= \$10,000,000

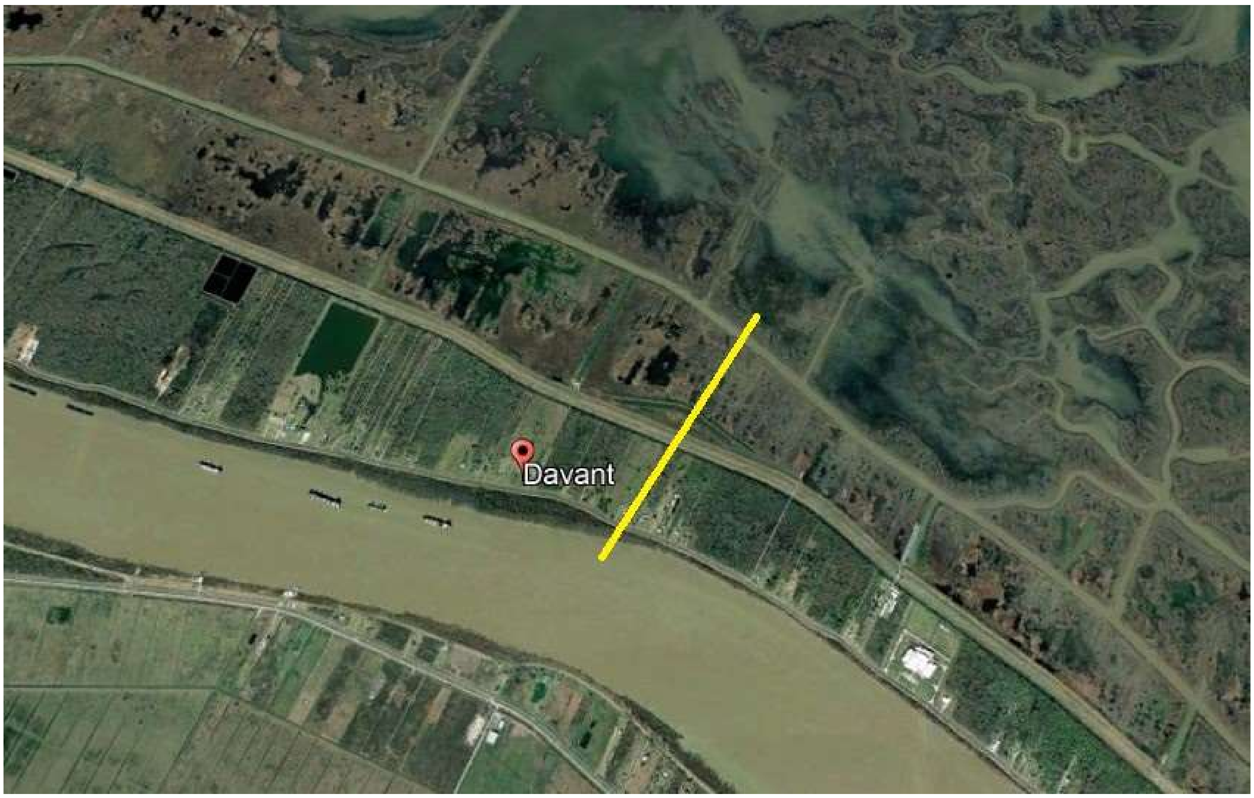

Figure 22: Orientation of single system micro diversion scenario

This diversion will generate flow due to the output point of the pipe with respect to the level of the river, with this delta defined as head (h). See Figure 23 for a graphic of the Micro Diversion basic principles.

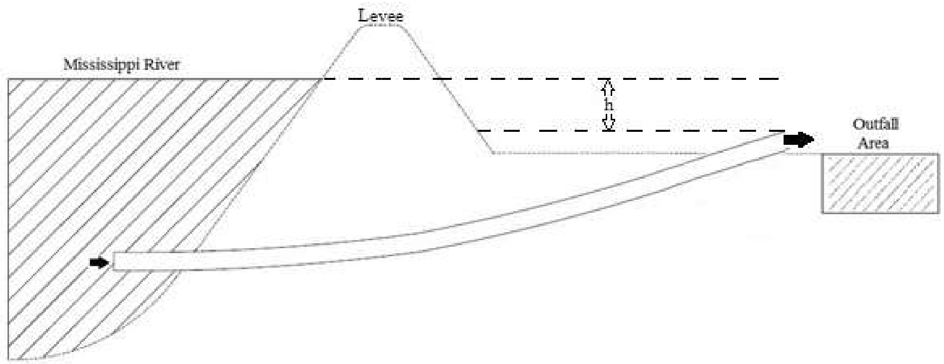

Figure 23: Micro Diversion orientation with respect to the MR, levee, and head measurement

The output point was set at 1ft elevation. The river level was determined using data inputs from the historical MR gauge logs of the USACE. Data was obtained for the calendar year January 1 to December 31, 2015, at the West Point a la Hache gauge (river mile 48.7). A gauge reading of 2' would signify the system being shut off due to lack of head to warrant operation.

Volumetric flow rate (Q) was calculated by the equation:

$$Q = \frac{\pi}{4} D^2 V \quad (6)$$

where $V(velocity) = \sqrt{2gh}$ and g = 32.2 ft/s^2

Note: friction loss along the length of pipe was not considered for any of the Micro Diversion analysis.

See Appendix C for gauge, velocity, and flow calculations and Figure 23 for the hydrograph output depicting the flow rate Q for 2015.

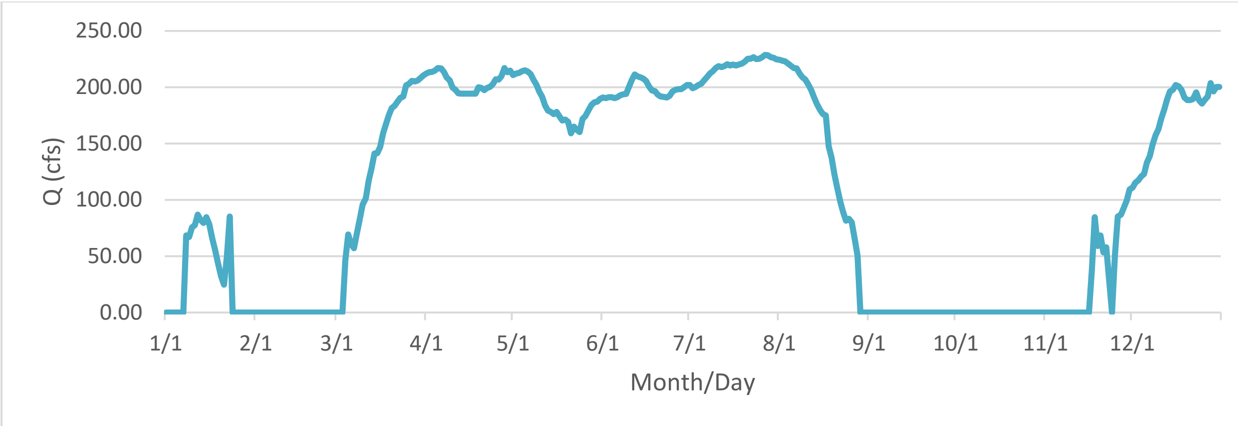

Figure 24: Hydrograph of a single 48” pipe for 2015

The hydrograph was inserted into the Delft3D model as an input with averaged sediment parameters. The output hydro model resulted in 3 ft of sedimentation at the output point, in an area approximately 100m x 100m (see Figure 24). All other sedimentation is negligible. Sediments are transported as far as 5 km away from the outfall point to the open boundary, possibly due to strong tidal currents.

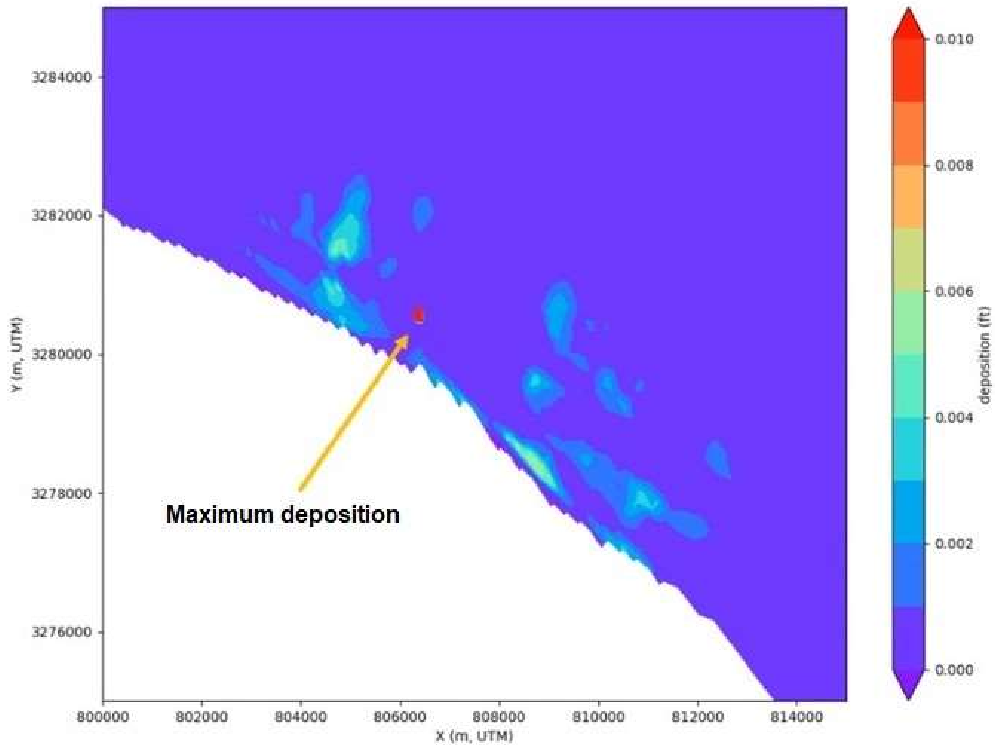

Figure 25: Scenario 1 hydro model output

Considering the output of a single 48” system configuration is not statistically or practically significant, a second system configuration was modeled with five 48” units, each operating year-round at full capacity with external power, to produce a constant 600 cfs, regardless of river level. Total volume discharge at the output was 3000 cfs. See Figure 25 for the 5-system orientation.

Figure 26: Orientation of a 5-unit system Micro Diversion scenario

The model was run again for the year 2015.   The output showed a 5000m x 5000m area with 50% coverage of .1 ft. (See Figure 26)

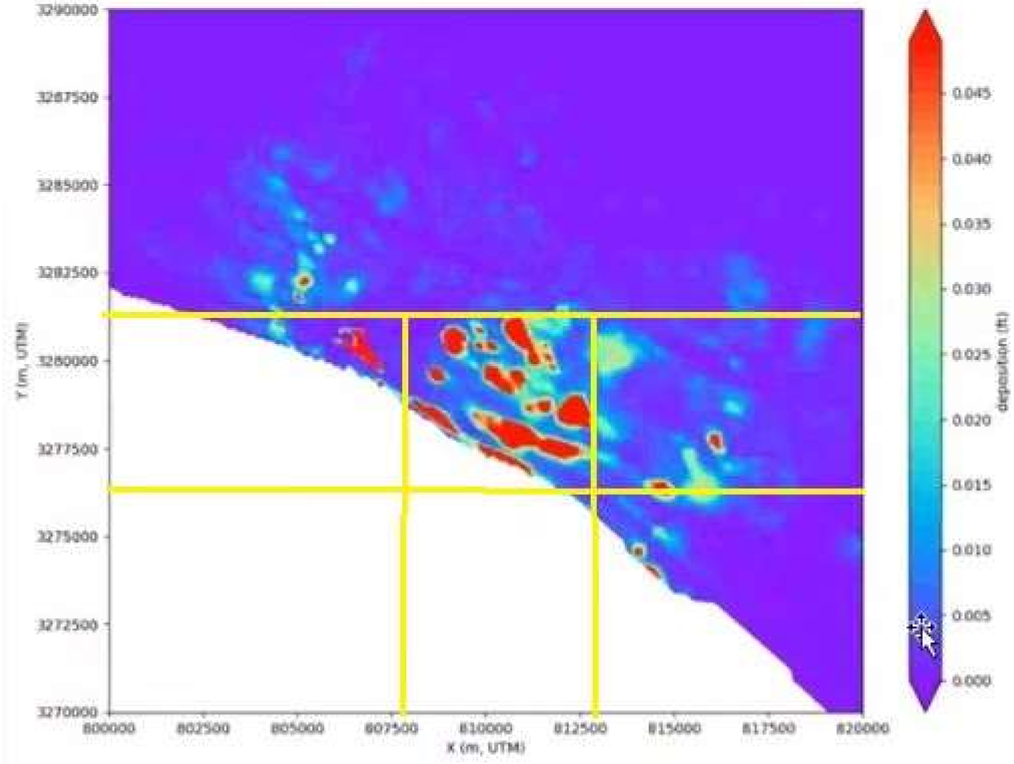

Figure 27: Scenario 2 hydro model output

While the sedimentation is significant, it is not enough for plant life to successfully root on a wide scale.

With an assumption that the system is run for 10 years with equal input characteristics and that sedimentation would physically overtop the previous year's, a .1ft sedimentation elevation needed for plant life to root could be achieved, with a NB of 2200 acres.

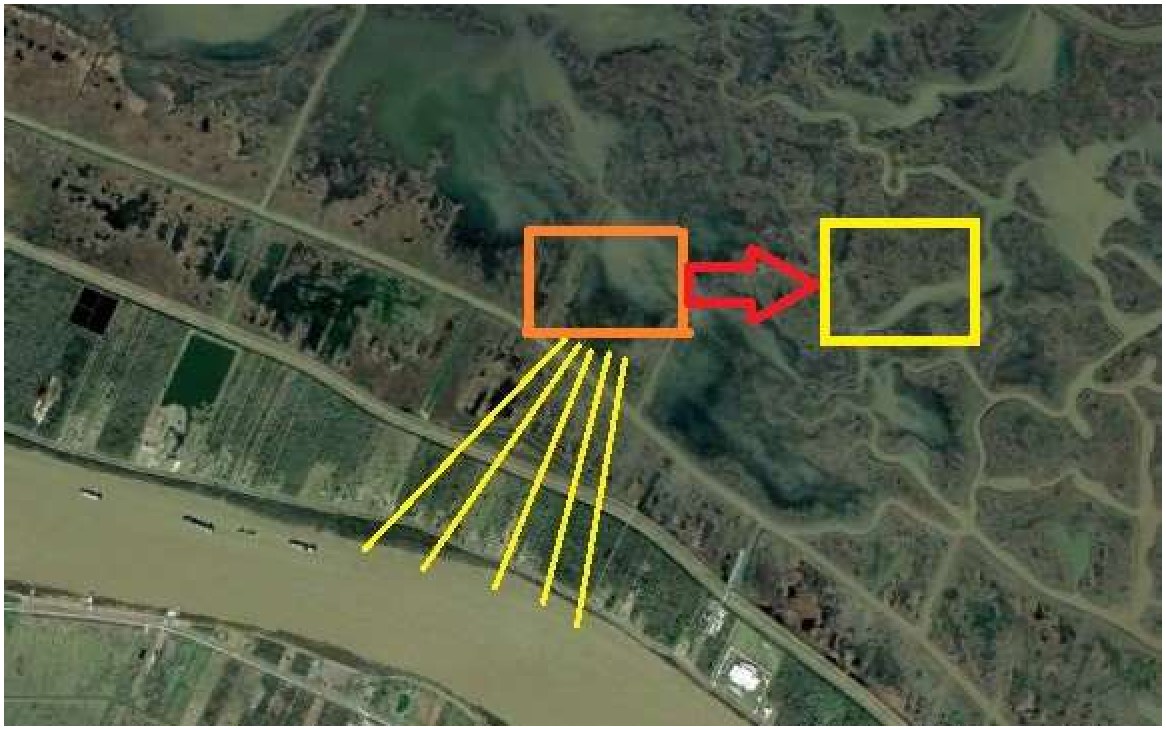

Figure 28: Period 2 relocation of target area

This assumed system can be repeated every 10 years with extension infrascturure to new target areas, but with the original intake system still in place. See Figure 27 as an example of how the system outfall could be relocated.

The 5-unit system would have a NB of 11,000 acres after 50 years of operation (2200 acres every 10 years)

The construction estimate is based on the following assumptions:

- From the initial system configuration, one piping unit including intake and outfall strcutures costs $10m, therefore 5 units will cost $50m total.

- To achieve a 3000 cfs flowrate, the requirement would be approximately 50MW of pumping capacity. The estimate for physical infrastructure and installation is $1m per MW, for a pump system cost of $50m.

Initial Construction Cost = Piping System + Pumping System

= $50m + $50m

= $100m

- $10m in additional construction costs every 10 years in order to extend the outfall piping 5000 ft.

Total Construction Cost = Initial Construction Cost + Period Construction Cost

= $100m + ($10m x 4 periods)

= $140m

Total Construction Cost for for the 5-unit system is $140,000,000

The operations estimate is based on the following assumptions:

- The pumping system is operated 24 hours per day, 365 days per year.

- No downtime for maintenance or requested shutdowns.

- Utility power rates of $.08/kwh.

Year 1 Utility Cost = Rated Power x (24 hrs/day) x 365 days x Utility Rate

= 50,000 kw x 24 hrs/day x 365 days x .08 $/kwh

= $35,040,000

- Additional $5m per year in operator and maintenance costs.

- Total operational costs in the first year (2020) would be approximately $40m.

- Forecasting potential increases in utility prices and spare parts, the operations cost will annualy increase 1% for the life of the system.

To calculate the LCC of the 5-unit system, the annnual construction costs are added to the annual operational costs. See Appendix D for the Micro Diversion LCC calculation.

Micro Diversion LCC = $970,276,242

Similar to the other alternatives, to calculate CB the LCC is divided by the NB.

$$\text{Cost Benefit} = \frac{LCC}{\text{NB}} = \frac{\$970{,}276{,}242}{11000 \text{ acres}} = \mathbf{\$88{,}206\ /\ acre}$$

To approximate the Major Diversion NB of 47,400 acres, 4 Micro Diversions would need to be implemented. See Table 8 for the four-year summation of LCC and NB.

Table 8: Micro Diversion Total Cost and NB to Operate Scenario 2 to 2070

System No.	System LCC ($)	Net Benefit (acres)
1	$970,276,242	11000
2	$970,276,242	11000
3	$970,276,242	11000
4	$970,276,242	11000
Totals:	$3,881,104,967	44000

$$\text{Total Micro Diversion Cost Benefit} = \frac{LC}{NB} = \frac{\$3{,}881{,}104{,}967}{44000 \text{ acres}}$$

= $88,206 / acre

An additional limitation of a Micro Diversion system is that the 10-year periodic extension of the outfall target area could have significant hurdles. Most wetland property is privately owned, so it's impossible to say that all landowners would sign onto a system-wide strategy.

It should be noted that the Micro Diversion concept involves an engineering concept that has never been attempted. While under-river crossings have been successfully completed (utility power lines and communications cables), these crossings have been under both levees, with both ends of the crossing above sea level. In contrast, a Micro Diversion would have an output above sea level, with an input below. This arrangement has never been attempted. While physically possible, there are numerous permitting processes and stakeholder concerns that would have to be addressed.

While the CB of this alternative is the least attractive, what this analysis did not include are the non-cost related benefits. Because of the flexibility advantage, the Micro Diversion concept has potential benefits to property owners who could be either be negatively affected by the Major Diversions, or perhaps who won't see the sediment flows reach their location.

This flexibility also has an advantage for environmental stakeholders, as a coordinated system of multiple Micro Diversions could manage salinity levels as well as sediment concentration levels. Sediment concentration could be increased via an agitator at the pipe input, and decreased with a filter or screen. Control could be instantaneous depending on environmental and/or community requirements.

6. Conclusions

Southeast Louisiana is experiencing a land loss crisis. While there will be numerous strategies employed to attempt to solve the problem, a fundamental component of stakeholder efforts is how to best manage introducing sediment into coastal wetlands.

There are many factors to consider in evaluating the best sediment management alternatives, including environmental effects to wildlife and fisheries, obstacles to river navigation, and balancing the interests of competing parties. Inherent to the Systems Engineering approach is to consider all the relevant factors, evaluate options, and suggest a path forward that is best for the entire system. Part of this process identifies which factors hold the most weight. Considering the realities of limited financial resources devoted to coastal management, the most important factor to consider is the return on investment of proposed coastal projects.

Taking into account the Net Benefits and Life Cycle Costs of three sediment management alternatives, a Cost Benefit for each was calculated.

The most attractive Cost Benefit is that which is the lowest. Comparing the three alternatives, if coastal decision makers were to select only one alternative, the most efficient expenditure of capital would be to construct both major diversions and operate them for 50 years (See Table 9 for the alternatives comparison).

Table 9: Sediment Management Alternative Comparison

Alternative	Life Cycle Cost ($)	Cost Benefit ($/acre)
Major Diversions	2,928,070,476	61,773
Dredged Sediment	3,190,046,880	67,300
Micro Diversion	3,881,104,968	88,206

While the Major Diversion alternative was determined to be the most efficient, it does not imply that it should be considered as the only alternative. A systems-level strategy could be employed, where multiple alternatives are combined and the strengths of each potentially contribute to a better outcome than considering each by itself.

In addition, with physical implementation what is considered the best alternative can change over time. Major Diversions take years to build and might take years or even decades before any visible benefit, whereas the benefits of Dredged Sediment projects are visible immediately.

Further complicating the alternative evaluation is that local environmental conditions can change, for better or worse. A significant component of the Life Cycle Cost calculation for the Micro Diversion alternative is the operation of the pumping mechanisms and associated utility power requirement. Should utility rates not increase as was input into the model, or perhaps a more efficient way to power the pumps is discovered, it would make the Micro Diversion Cost Benefit much more attractive.

For all alternatives, a changing landscape can hinder the ability to fully execute. Natural disasters, such as hurricanes, or human-caused events, such as the BP Horizon oil spill, can affect an alternative's competitiveness. The-50-year project timeline proposed by the Master Plans is a long time to account for unknown risks that can nullify a reality that existed when decisions were made or the introduction of a new parameter that changes the requirement dynamics.

7. Future Research

There are ample areas for further research into sediment management alternatives. The alternatives analyzed and discussed should not be mutually exclusive. For example, while the least efficient use of resources according to this analysis was Micro Diversions, it's possible some Micro Diversion units could complement areas where the Major Diversions are lacking. This is an area ripe for further research and modeling, with a systems approach.

More research is also required to account for the positive and negative effects of the sediment management alternatives, beyond simply the Cost Benefit. A weighted scoring system could be evaluated to give value to various criteria such as the damage to wildlife and fisheries, environmental pollution, and issues related to property rights, to name a few, with scores reflecting how each alternative meets the requirements.

Running similar models but with improved inputs, the accuracy of each alternative Cost Benefit calculation could be improved:

<u>Major Diversions</u>

With the Master Plan put out by CPRA every 5 years, the Major Diversions have been given a lion's share of the resources, both funding and expertise. While the models are complicated and consider numerous externalities, they should incorporate more inputs from potential hurricanes. With a warming ocean, storm events are forecast to be more frequent and catastrophic. Future Major Diversions model runs can introduce more powerful storm events.

Dredged Sediment

The DS alternative relies on standard practices of sediment collection. There has been substantial effort to increase the collections from appropriated USACE activity. The agency is tasked with maintaining the MR at a navigable depth. Much of the collected sediment is dumped off the continental shelf. Known as beneficial reuse, coastal projects would be using sediment that the USACE has already invested funds in collecting. It's a win-win for all stakeholders (*Suedel et al. 2021*). Future models could include cost share opportunities with the USACE, which would greatly reduce the LCC of DS.

Micro Diversions

While the Delft3D software is one of the best platforms for hydrologic modeling, it is computing intensive, requiring high-capacity mainframes and extended run timeframes. With more computing capacity, Micro Diversion system modeling could be improved by expanding the input parameters:

- Multiple-year timeframes, perhaps even decades, vs the single year used in this analysis.
- Added precision to the Life Cycle Cost, with more detailed estimates that can be tabulated to confirm or improve the assumptions made (i.e. pump and pipe infrastructure costs, etc.).
- Modeling various configurations in conjunction with Major Diversion models.
- Optimizing certain parameters according to stakeholder requirements.

Micro Diversion modeling could also employ Monte Carlo simulations, to account for uncertainties in the model assumptions. By predicting the probability of LCC and NB, a better estimate of Cost Benefit can be achieved.

References

2023 Master Plan, Louisiana's Comprehensive Master Plan for a Sustainable Coast, 4th Edition, released January 2023.

Allison, M.A., Meselhe, E.A., The use of large water and sediment diversions in the lower Mississippi River (Louisiana) for coastal restoration. *Journal of Hydrology*, 387 (2010) 346-360 https://doi.org/10.1016/j.jhydrol.2010.04.001

Blum, M., Roberts, H. Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. *Nature Geosci*ence **2,** 488–491 (2009) https://doi.org/10.1038/ngeo553

Blum, M. Organization and reorganization of drainage and sediment routing through time: the Mississippi River system. Geological Society, London, Special Publications, 488, 15-45, 30 July 2019. https://doi.org/10.1144/SP488-2018-166

Brown, G.L., McAplin, J.N., Pevey, K.C., Luong, P.V., Price, C.R., Kleiss, B.A. Mississippi River Hydrodynamic and Delta Management Study: Delta Managememt Modeling. U.S. Army Corps of Engineers. Engineer Research & Development Center. 2019. http://dx.doi.org/10.21079/11681/32446

CWPPRA Projects, https://lacoast.gov/new/projects/list.aspx

Day, J.W., Barras, J., Clairain, E., Johnston, J., Justic, D., Kemp, G.P., Ko, J., Lane, R., Mitsch, W.J., Steyer, G., Templet, P., Yañez-Arancibia, A. Implications of global climatic change and energy cost and availability for the restoration of the Mississippi delta, *Ecological Engineering*, Volume 24, Issue 4, 2005, Pages 253-265. https://doi.org/10.1016/j.ecoleng.2004.11.015

Day, J. W. Jr., Boesch, D.F., Clariain, E.J., Kemp, G.P., Laska, S.B., Mitsch, W.J., Orth, K., Mashriqui, H., Reed, D.J., Shabman, L., Simenstad, C.A., Streever, B.J., Twilley, R.R., Wastson, C.C., Wells, J.T., Whigham, D.F., Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita. *Science* **315**, 1679–1684 (2007). https://doi.org/10.1126/science.1137030

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., Large infrequently operated river diversions for Mississippi delta restoration. *Estuarine, Coastal and Shelf Science* 183 (2016) 292-303.

Day, J.W., Kemp, G.P, Lane, R.R., McDade, E.C., Dawers, N.H., Rudolf, W.B., New Information Supporting the Stabilization & Restoration of the Biloxi Marsh Complex, A Unique and Distinct Ecosystem. 2019.

Energy Assurance Plan. Recovery Act – Energy Assurance Planning – State of Louisiana. Louisiana Department of Natural Resources. Page 27. https://www.dnr.louisiana.gov/assets/TAD/reports/EnergyAssurancePlan_FINAL_TO_DOE.pdf

Fitzgerald, D.M., Fenster, M.S., Argow, B.A., Buynevich, I.V. Coastal Impacts Due to Sea-Level Rise. *Annual Review of Earth and Planetary Sciences,* 2008 36:1, 601-647.

Frederick, B.C., Blum, M., Fillon, R., Roberts, H. Resolving the contributing factors to Mississippi Delta subsidence: Past and Present. *Basin Research,* 2019; 31: 171– 190. https://doi.org/10.1111/bre.12314

Garrison, L.P, Litz, J. and 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. NOAA Technical Memorandum NOAA NMFS-SEFSC 748: 97 p.

Hester, M.W. Willis, J.M., Rouhani, S., Steinhoff, M.A., Baker, M.C. Impacts of the Deepwater Horizon oil spill on the salt marsh vegetation of Louisiana, *Environmental Pollution*, Volume 216, 2016, Pages 361-370. https://doi.org/10.1016/j.envpol.2016.05.065

Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., Rasmussen, D., Muir-Wood, R., Wilson, P., Oppenheimer, M., Larsen, K., Houser, T. (2017). Estimating economic damage from climate change in the United States. *Science*, 356. 1362-1369. https://doi.org/10.1126/science.aal4369.

Hyfield, E.C.G, Day, J.W, Cable, J.E, Justic, D., 2007, The impacts of re-introducing Mississippi River water on the hydrologic budget and nutrient inputs of a deltaic estuary, *Ecological Engineering*, Volume 32, Issue 4, 2008, Pages 347-359

IPCC 2019. Intergovernmental Panel on Climate Change. *The Ocean and Cryosphere in a Changing Climate*. September 24, 2019.

Jankowski, K., Tornqvist, T. & Fernandes, A. Vulnerability of Louisiana's coastal wetlands to present-day rates of relative sea-level rise. *Nature Communications,* **8,** 14792 (2017) https://doi.org/10.1038/ncomms14792

Jojola, Susan; Witmer, Gary W.; and Nolte, Dale, "Nutria: An Invasive Rodent Pest or Valued Resource?" (2005). *Wildlife Damage Management Conferences - Proceedings*. 110.

Jones, Cathleen & An, Karen & Blom, Ronald & Kent, Joshua & Ivins, Erik & Bekaert, David. (2016). Anthropogenic and geologic influences on subsidence in the vicinity of New Orleans, Louisiana. *Journal of Geophysical Research: Solid Earth*. 121. https://doi.org/10.1002/2015JB012636

Kemp, G.P, Day, J.W., Rogers, J.D., Giosa, L., Peyronnin, N. Enhancing mud supply from the Lower Missouri River to the Mississippi River Delta USA: Dam bypassing and coastal restoration. *Estuarine, Coastal and Shelf Science*,Volume 183, Part B, 2016, Pages 304-313, https://doi.org/10.1016/j.ecss.2016.07.008

Ko, J., Day, J., Barras, J., Morton, R., Johnston, J., Kemp, G., Clairain, E., Theriot, R. (2004). Impacts of Oil and Gas Activities on Coastal Wetland Loss in the Mississippi Delta.

LCPRA 2012. Louisiana Coastal Protection and Restoration Authority. *Louisiana's Comprehensive Master Plan for a Sustainable Coast* (2012).

LCPRA 2017. Louisiana Coastal Protection and Restoration Authority. *Louisiana's Comprehensive Master Plan for a Sustainable Coast* (2017). http://coastal.la.gov/our-plan/2017-coastal-master-plan/

Lewis, J.A., Ernstson, H. Contesting the coast: Ecosystems as infrastructure in the Mississippi River Delta, Progress in Planning, Volume 129, 2019, Pages 1-30, https://doi.org/10.1016/j.progress.2017.10.003

Lindsey, R., Climate Change Global Sea Level, 2009, retrieved on Nov 9, 2019 from climate.gov

Louisiana Sea Grant, Phragmites Scale Newest Coastal Threat. October 4, 2017. https://www.laseagrant.org/2017/phragmites-scale-newest-coastal-threat/

Martin, J.F., Emergy valuation of diversions of river water to marshes in the Mississippi River Delta, *Ecological Engineering*,Volume 18, Issue 3, 2002, Pages 265-286. https://doi.org/10.1016/S0925-8574(01)00082-9

Moody's Investor Service, Climate change is forecast to heighten US exposure to economic loss placing short- and long-term credit pressure on US states and local governments. 2017.

Nienhuis, J.H., Tornqvist, T.E., Jankowski, K.L., Fernandes, A.M., Keogh, M.E. A New Subsidence Map for Coastal Louisana. The Geological Society of America. *GSA Today*, posted June 14, 2017. https://doi.org/10.1130/GSATG337GW.1

Ramsey, E.W. III, and Rangoonwaia, A. 2017. Mapping the Change of Phragmites australis Live Biomass in the Lower Missisissippi River Delta Marshes: U.S. Geological Survey Open-File Report 2017-1098. https://doi.org/10.3133/ofr20171098

Schultz, B., Scale insect attacking coastal vegetation raises concerns, LSU AgCenter, 2017.

Suedel, B.C., McQueen, A.D., Wilkens, J.L., Saltus, C.L, Bourne, S.G., Gailani, J.Z., King, J.K., Corbino, J.M. Beneficial use of dredged sediment as a sustainable practice for restoring coastal marsh habitat. *Integrated Environmental Assessment and Management*. Volume 00, Number 00, page 7.

Slangen, A.B.A., F. Adloff, S. Jevrejeva, P.W. Leclercq, B. Marzeion, Y. Wada, and R. Winkelmann, 2017: A review of recent updates of sea-level projections at global and regional scales. *Survey Geophysics.*, **38**, no. 1, 385-406

Strauss, B.H., Kulp, S., Levermann, A. Carbon choices determine US cities committed to futures below sea level. *Proceedings of the National Academy of Sciences* Nov 2015, 112 (44) 13508-13513 https://doi.org/10.1073/pnas.1511186112

Sweet, W.V., Dusek, G., Obeysekera, J., Marra, J.J., Patterns and Projections of High Tide Flooding Along the U.S. Coastline Using Common Impact Threshold, NOAA Technical Report NOS CO-OPS 086. 2018

Turner R.E., McClenachan G (2018) Reversing wetland death from 35,000 cuts: Opportunities to restore Louisiana's dredged canals. PLoS ONE 13(12): e0207717. https://doi.org/10.1371/journal.pone.0207717

Tweel AW, Turner R.E. (2012), Watershed land use and river engineering drive wetland formation and loss in the Mississippi River birdfoot delta. *Limnology and Oceanography* 57 https://doi.org/10.4319/lo.2012.57.1.0018

Twilley, R.R., Rivera-Monroy, V. Sediment and Nutrient Tradeoffs in Restoring Mississippi River Delta: Restoration vs Eutrophication. *Journal of Contemporary Water Research and Education*. Vol 141, Issue 1, March 2009, pp. 39-44 https://doi.org/10.1111/j.1936-704X.2009.00035.x

USACE 2019a. Lake Pontchartrain & Vicinity, LA, General Re-Evaluation Report. U.S. Army Corps of Engineers, New Orleans District. 12/1/2019.

USACE 2019b. West Bank & Vicinity, Louisiana, General Re-Evaluation Report. U.S. Army Corps of Engineers, New Orleans District. 12/8/2019.

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

Wiegman, A.R.H., Day, J.W., D'Elia, C.F., Rutherford, J.S., Morris, J.T., Roy, E.D., Lane, R.R., Dismukes, D.E., Snyder, B.F. Modeling impacts of sea-level rise, oil price, and management strategy on the costs of sustaining Mississippi delta marshes with hydraulic dredging, *Science of The Total Environment*, Volume 618, 2018, Pages 1547-1559, https://doi.org/10.1016/j.scitotenv.2017.09.314

Winer, H.S. "Re-Engineering the Mississippi River as a Sediment Delivery System," *Journal of Coastal Research* 2011(10059), 229-234, (1 March 2011). https://doi.org/10.2112/SI59-024.1

Vitousek, S., Barnard, P. L., Fletcher, C. H., Frazer, N., Erikson, L, Storlazzi, C.D, "Doubling of coastal flooding frequency within decades due to sea-level rise". *Scientific Reports* **7,** 1399 (2017). https://doi.org/10.1038/s41598-017-01362-7

Yi, S., Sun, W., Heki, K., and Qian, A. (2015), An increase in the rate of global mean sea level rise since 2010. *Geophysical Research Letters*, 42, 3998– 4006 https://doi.org/10.1002/2015GL063902

APPENDIX A

LCC of Mid-Barataria and Mid-Breton Diversion Alternatives

Year	Mid-Barataria Diversion			Mid-Breton Diversion
	Alternative 1	Alternative 2	Alternative 3	
2020	$1,531,250,000	$1,391,160,000	$2,410,474,000	$664,000,000.00
2021	0	0	0	0
2022	0	0	0	0
2023	0	0	0	0
2024	0	0	0	0
2025	0	0	0	0
2026	0	0	0	0
2027	0	0	0	0
2028	0	0	0	0
2029	0	0	0	0
2030	0	0	0	0
2031	0	0	0	0
2032	0	0	0	0
2033	0	0	0	0
2034	0	0	0	0
2035	0	0	0	0
2036	0	0	0	0
2037	0	0	0	0
2038	0	0	0	0
2039	0	0	0	0
2040	0	0	0	0
2041	0	0	0	0
2042	0	0	0	0
2043	0	0	0	0
2044	0	0	0	0
2045	0	0	0	0
2046	0	0	0	0
2047	0	0	0	0
2048	0	0	0	0
2049	0	0	0	0
2050	0	0	0	0
2051	0	0	0	0
2052	0	0	0	0
2053	0	0	0	0
2054	0	0	0	0
2055	0	0	0	0

2056	0	0	0	0
2057	0	0	0	0
2058	0	0	0	0
2059	0	0	0	0
2060	0	0	0	0
2061	0	0	0	0
2062	0	0	0	0
2063	0	0	0	0
2064	0	0	0	0
2065	0	0	0	0
2066	0	0	0	0
2067	0	0	0	0
2068	0	0	0	0
2069	0	0	0	0
2070	0	0	0	0
LCC →	$1,458,333,333	$1,324,914,286	$2,295,689,524	$632,380,952

APPENDIX B

Dredged Sediment Future Project Costs and LCC

Year	DSCB ($/acre)	Net Benefit (acres)	Annual Project Cost ($)
2020	124,530	950	118,303,244
2021	128,338	950	121,921,126
2022	132,146	950	125,539,009
2023	135,955	950	129,156,891
2024	139,763	950	132,774,773
2025	143,571	950	136,392,656
2026	147,380	950	140,010,538
2027	151,188	950	143,628,420
2028	154,996	950	147,246,303
2029	158,804	950	150,864,185
2030	162,613	950	154,482,067
2031	166,421	950	158,099,950
2032	170,229	950	161,717,832
2033	174,038	950	165,335,715
2034	177,846	950	168,953,597
2035	181,654	950	172,571,479
2036	185,462	950	176,189,362
2037	189,271	950	179,807,244
2038	193,079	950	183,425,126
2039	196,887	950	187,043,009
2040	200,696	950	190,660,891
2041	204,504	950	194,278,773
2042	208,312	950	197,896,656
2043	212,121	950	201,514,538
2044	215,929	950	205,132,420
2045	219,737	950	208,750,303
2046	223,545	950	212,368,185
2047	227,354	950	215,986,068
2048	231,162	950	219,603,950
2049	234,970	950	223,221,832
2050	238,779	950	226,839,715
2051	242,587	950	230,457,597
2052	246,395	950	234,075,479
2053	250,204	950	237,693,362

2054	254,012	950	241,311,244
2055	257,820	950	244,929,126
2056	261,628	950	248,547,009
2057	265,437	950	252,164,891
2058	269,245	950	255,782,773
2059	273,053	950	259,400,656
2060	276,862	950	263,018,538
2061	280,670	950	266,636,420
2062	284,478	950	270,254,303
2063	288,287	950	273,872,185
2064	292,095	950	277,490,068
2065	295,903	950	281,107,950
2066	299,711	950	284,725,832
2067	303,520	950	288,343,715
2068	307,328	950	291,961,597
2069	311,136	950	295,579,479
2070	314,945	950	299,197,362

LCC → $3,190,046,880

APPENDIX C

Velocity and Flow Rate Calculations

Point ala Hache River Gauge - 2015

Date / Time	Stage (Ft)		h	V	CFS
1/1	1.23	2	0	0.00	0.00
1/2	1.22	2	0	0.00	0.00
1/3	1.21	2	0	0.00	0.00
1/4	1.38	2	0	0.00	0.00
1/5	1.44	2	0	0.00	0.00
1/6	1.63	2	0	0.00	0.00
1/7	1.98	2	0	0.00	0.00
1/8	2.46	2	0.46	5.45	68.47
1/9	2.44	2	0.44	5.33	66.96
1/10	2.56	2	0.56	6.01	75.54
1/11	2.59	2	0.59	6.17	77.54
1/12	2.74	2	0.74	6.91	86.84
1/13	2.66	2	0.66	6.53	82.01
1/14	2.62	2	0.62	6.33	79.49
1/15	2.7	2	0.7	6.72	84.46
1/16	2.6	2	0.6	6.23	78.20
1/17	2.43	2	0.43	5.27	66.20
1/18	2.29	2	0.29	4.33	54.36
1/19	2.18	2	0.18	3.41	42.83
1/20	2.1	2	0.1	2.54	31.92
1/21	2.06	2	0.06	1.97	24.73
1/22	2.24	2	0.24	3.94	49.46
1/23	2.71	2	0.71	6.77	85.06
1/24	2.01	2	0	0.00	0.00
1/25	1.78	2	0	0.00	0.00
1/26	1.45	2	0	0.00	0.00
1/27	1.37	2	0	0.00	0.00

1/28	1.22	2	0	0.00	0.00
1/29	1.23	2	0	0.00	0.00
1/30	1.23	2	0	0.00	0.00
1/31	1.23	2	0	0.00	0.00
2/1	1.22	2	0	0.00	0.00
2/2	1.23	2	0	0.00	0.00
2/3	1.25	2	0	0.00	0.00
2/4	1.23	2	0	0.00	0.00
2/5	1.35	2	0	0.00	0.00
2/6	1.23	2	0	0.00	0.00
2/7	1.24	2	0	0.00	0.00
2/8	1.22	2	0	0.00	0.00
2/9	1.22	2	0	0.00	0.00
2/10	1.22	2	0	0.00	0.00
2/11	1.21	2	0	0.00	0.00
2/12	0.97	2	0	0.00	0.00
2/13	0.98	2	0	0.00	0.00
2/14	0.97	2	0	0.00	0.00
2/15	0.98	2	0	0.00	0.00
2/16	0.96	2	0	0.00	0.00
2/17	0.98	2	0	0.00	0.00
2/18	0.98	2	0	0.00	0.00
2/19	0.98	2	0	0.00	0.00
2/20	0.98	2	0	0.00	0.00
2/21	1.35	2	0	0.00	0.00
2/22	1.16	2	0	0.00	0.00
2/23	1.15	2	0	0.00	0.00
2/24	0.99	2	0	0.00	0.00
2/25	1	2	0	0.00	0.00
2/26	0.98	2	0	0.00	0.00
2/27	0.99	2	0	0.00	0.00
2/28	1.09	2	0	0.00	0.00
3/1	1.23	2	0	0.00	0.00
3/2	1.5	2	0	0.00	0.00
3/3	1.87	2	0	0.00	0.00
3/4	2.21	2	0.21	3.68	46.26

3/5	2.47	2	0.47	5.51	69.21
3/6	2.36	2	0.36	4.82	60.57
3/7	2.32	2	0.32	4.55	57.11
3/8	2.48	2	0.48	5.57	69.94
3/9	2.67	2	0.67	6.58	82.63
3/10	2.9	2	0.9	7.62	95.77
3/11	3.01	2	1.01	8.08	101.45
3/12	3.34	2	1.34	9.30	116.86
3/13	3.61	2	1.61	10.20	128.09
3/14	3.95	2	1.95	11.22	140.97
3/15	3.96	2	1.96	11.25	141.33
3/16	4.12	2	2.12	11.70	146.99
3/17	4.48	2	2.48	12.66	158.98
3/18	4.74	2	2.74	13.30	167.10
3/19	5.01	2	3.01	13.94	175.14
3/20	5.23	2	3.23	14.44	181.43
3/21	5.3	2	3.3	14.60	183.38
3/22	5.44	2	3.44	14.91	187.23
3/23	5.56	2	3.56	15.16	190.47
3/24	5.6	2	3.6	15.25	191.54
3/25	5.99	2	3.99	16.05	201.65
3/26	6.05	2	4.05	16.17	203.16
3/27	6.15	2	4.15	16.37	205.65
3/28	6.13	2	4.13	16.33	205.15
3/29	6.16	2	4.16	16.39	205.90
3/30	6.25	2	4.25	16.57	208.11
3/31	6.35	2	4.35	16.76	210.55
4/1	6.42	2	4.42	16.90	212.24
4/2	6.46	2	4.46	16.97	213.19
4/3	6.47	2	4.47	16.99	213.43
4/4	6.52	2	4.52	17.09	214.62
4/5	6.62	2	4.62	17.28	216.98
4/6	6.61	2	4.61	17.26	216.75
4/7	6.47	2	4.47	16.99	213.43
4/8	6.26	2	4.26	16.59	208.36
4/9	6.17	2	4.17	16.41	206.15

4/10	5.91	2	3.91	15.89	199.62
4/11	5.83	2	3.83	15.73	197.56
4/12	5.71	2	3.71	15.48	194.44
4/13	5.7	2	3.7	15.46	194.18
4/14	M	2	3.7	15.46	194.18
4/15	M	2	3.7	15.46	194.18
4/16	M	2	3.7	15.46	194.18
4/17	M	2	3.7	15.46	194.18
4/18	M	2	3.7	15.46	194.18
4/19	5.92	2	3.92	15.91	199.87
4/20	M	2	3.9	15.87	199.36
4/21	5.82	2	3.82	15.71	197.30
4/22	5.9	2	3.9	15.87	199.36
4/23	5.93	2	3.93	15.93	200.13
4/24	6.03	2	4.03	16.13	202.66
4/25	6.21	2	4.21	16.49	207.13
4/26	6.19	2	4.19	16.45	206.64
4/27	6.32	2	4.32	16.71	209.82
4/28	6.62	2	4.62	17.28	216.98
4/29	6.46	2	4.46	16.97	213.19
4/30	6.52	2	4.52	17.09	214.62
5/1	6.36	2	4.36	16.78	210.79
5/2	6.41	2	4.41	16.88	211.99
5/3	6.44	2	4.44	16.94	212.71
5/4	6.5	2	4.5	17.05	214.15
5/5	6.54	2	4.54	17.13	215.10
5/6	6.49	2	4.49	17.03	213.91
5/7	6.39	2	4.39	16.84	211.51
5/8	6.18	2	4.18	16.43	206.39
5/9	6.01	2	4.01	16.09	202.15
5/10	5.77	2	3.77	15.61	196.01
5/11	5.59	2	3.59	15.23	191.27
5/12	5.31	2	3.31	14.62	183.66
5/13	5.15	2	3.15	14.26	179.17
5/14	5.11	2	3.11	14.17	178.03
5/15	5.04	2	3.04	14.01	176.01

5/16	5.11	2	3.11	14.17	178.03
5/17	4.97	2	2.97	13.85	173.97
5/18	4.85	2	2.85	13.57	170.42
5/19	4.88	2	2.88	13.64	171.32
5/20	4.81	2	2.81	13.47	169.22
5/21	4.48	2	2.48	12.66	158.98
5/22	4.67	2	2.67	13.13	164.95
5/23	4.58	2	2.58	12.91	162.15
5/24	4.52	2	2.52	12.76	160.25
5/25	4.9	2	2.9	13.69	171.91
5/26	4.98	2	2.98	13.87	174.27
5/27	5.15	2	3.15	14.26	179.17
5/28	5.33	2	3.33	14.67	184.22
5/29	5.41	2	3.41	14.84	186.42
5/30	5.44	2	3.44	14.91	187.23
5/31	5.53	2	3.53	15.10	189.67
6/1	5.57	2	3.57	15.19	190.74
6/2	5.55	2	3.55	15.14	190.20
6/3	5.58	2	3.58	15.21	191.01
6/4	5.58	2	3.58	15.21	191.01
6/5	5.55	2	3.55	15.14	190.20
6/6	5.58	2	3.58	15.21	191.01
6/7	5.65	2	3.65	15.36	192.86
6/8	5.68	2	3.68	15.42	193.66
6/9	5.69	2	3.69	15.44	193.92
6/10	5.93	2	3.93	15.93	200.13
6/11	6.18	2	4.18	16.43	206.39
6/12	6.38	2	4.38	16.82	211.27
6/13	6.31	2	4.31	16.69	209.58
6/14	6.28	2	4.28	16.63	208.85
6/15	6.23	2	4.23	16.53	207.62
6/16	6.14	2	4.14	16.35	205.40
6/17	5.94	2	3.94	15.95	200.38
6/18	5.81	2	3.81	15.69	197.05
6/19	5.79	2	3.79	15.65	196.53
6/20	5.67	2	3.67	15.40	193.39

6/21	5.61	2	3.61	15.27	191.80
6/22	5.59	2	3.59	15.23	191.27
6/23	5.57	2	3.57	15.19	190.74
6/24	5.63	2	3.63	15.31	192.34
6/25	5.78	2	3.78	15.63	196.27
6/26	5.83	2	3.83	15.73	197.56
6/27	5.86	2	3.86	15.79	198.34
6/28	5.86	2	3.86	15.79	198.34
6/29	5.92	2	3.92	15.91	199.87
6/30	6	2	4	16.07	201.90
7/1	6	2	4	16.07	201.90
7/2	5.89	2	3.89	15.85	199.10
7/3	5.93	2	3.93	15.93	200.13
7/4	6	2	4	16.07	201.90
7/5	6.04	2	4.04	16.15	202.91
7/6	6.17	2	4.17	16.41	206.15
7/7	6.29	2	4.29	16.65	209.09
7/8	6.42	2	4.42	16.90	212.24
7/9	6.5	2	4.5	17.05	214.15
7/10	6.62	2	4.62	17.28	216.98
7/11	6.69	2	4.69	17.41	218.62
7/12	6.66	2	4.66	17.35	217.92
7/13	6.69	2	4.69	17.41	218.62
7/14	6.77	2	4.77	17.55	220.48
7/15	6.72	2	4.72	17.46	219.32
7/16	6.75	2	4.75	17.52	220.02
7/17	6.72	2	4.72	17.46	219.32
7/18	6.75	2	4.75	17.52	220.02
7/19	6.79	2	4.79	17.59	220.94
7/20	6.86	2	4.86	17.72	222.55
7/21	6.97	2	4.97	17.92	225.05
7/22	6.97	2	4.97	17.92	225.05
7/23	7.04	2	5.04	18.04	226.63
7/24	6.96	2	4.96	17.90	224.83
7/25	6.97	2	4.97	17.92	225.05
7/26	7.04	2	5.04	18.04	226.63

7/27	7.14	2	5.14	18.22	228.87
7/28	7.11	2	5.11	18.17	228.20
7/29	7.04	2	5.04	18.04	226.63
7/30	7.01	2	5.01	17.99	225.96
7/31	6.95	2	4.95	17.88	224.60
8/1	6.94	2	4.94	17.86	224.37
8/2	6.9	2	4.9	17.79	223.46
8/3	6.87	2	4.87	17.74	222.78
8/4	6.79	2	4.79	17.59	220.94
8/5	6.7	2	4.7	17.42	218.85
8/6	6.62	2	4.62	17.28	216.98
8/7	6.61	2	4.61	17.26	216.75
8/8	6.41	2	4.41	16.88	211.99
8/9	6.28	2	4.28	16.63	208.85
8/10	6.19	2	4.19	16.45	206.64
8/11	6.02	2	4.02	16.11	202.40
8/12	5.83	2	3.83	15.73	197.56
8/13	5.58	2	3.58	15.21	191.01
8/14	5.36	2	3.36	14.73	185.04
8/15	5.17	2	3.17	14.31	179.74
8/16	5.04	2	3.04	14.01	176.01
8/17	M	2	3	13.92	174.85
8/18	4.13	2	2.13	11.73	147.33
8/19	3.85	2	1.85	10.93	137.31
8/20	3.47	2	1.47	9.74	122.40
8/21	3.19	2	1.19	8.77	110.12
8/22	2.95	2	0.95	7.83	98.39
8/23	2.78	2	0.78	7.10	89.16
8/24	2.65	2	0.65	6.48	81.39
8/25	2.68	2	0.68	6.63	83.25
8/26	2.63	2	0.63	6.38	80.13
8/27	2.42	2	0.42	5.21	65.42
8/28	2.25	2	0.25	4.02	50.47
8/29	2.03	2	0	0.00	0.00
8/30	1.76	2	0	0.00	0.00
8/31	1.59	2	0	0.00	0.00

9/1	1.58	2	0	0.00	0.00
9/2	1.6	2	0	0.00	0.00
9/3	1.73	2	0	0.00	0.00
9/4	1.77	2	0	0.00	0.00
9/5	1.68	2	0	0.00	0.00
9/6	1.64	2	0	0.00	0.00
9/7	1.78	2	0	0.00	0.00
9/8	1.77	2	0	0.00	0.00
9/9	1.73	2	0	0.00	0.00
9/10	1.36	2	0	0.00	0.00
9/11	1.35	2	0	0.00	0.00
9/12	1.36	2	0	0.00	0.00
9/13	1.37	2	0	0.00	0.00
9/14	1.36	2	0	0.00	0.00
9/15	1.36	2	0	0.00	0.00
9/16	1.36	2	0	0.00	0.00
9/17	1.41	2	0	0.00	0.00
9/18	1.61	2	0	0.00	0.00
9/19	1.5	2	0	0.00	0.00
9/20	1.53	2	0	0.00	0.00
9/21	1.54	2	0	0.00	0.00
9/22	2.05	2	0	0.00	0.00
9/23	1.98	2	0	0.00	0.00
9/24	2.13	2	0	0.00	0.00
9/25	1.94	2	0	0.00	0.00
9/26	1.83	2	0	0.00	0.00
9/27	1.82	2	0	0.00	0.00
9/28	2.2	2	0	0.00	0.00
9/29	1.81	2	0	0.00	0.00
9/30	1.59	2	0	0.00	0.00
10/1	1.84	2	0	0.00	0.00
10/2	1.82	2	0	0.00	0.00
10/3	1.76	2	0	0.00	0.00
10/4	1.51	2	0	0.00	0.00
10/5	1.49	2	0	0.00	0.00
10/6	1.5	2	0	0.00	0.00

10/7	1.51	2	0	0.00	0.00
10/8	1.5	2	0	0.00	0.00
10/9	1.59	2	0	0.00	0.00
10/10	1.49	2	0	0.00	0.00
10/11	1.52	2	0	0.00	0.00
10/12	1.5	2	0	0.00	0.00
10/13	1.5	2	0	0.00	0.00
10/14	1.45	2	0	0.00	0.00
10/15	1.16	2	0	0.00	0.00
10/16	1.27	2	0	0.00	0.00
10/17	1.58	2	0	0.00	0.00
10/18	2.01	2	0	0.00	0.00
10/19	1.84	2	0	0.00	0.00
10/20	2.08	2	0	0.00	0.00
10/21	1.98	2	0	0.00	0.00
10/22	2.02	2	0	0.00	0.00
10/23	1.73	2	0	0.00	0.00
10/24	1.76	2	0	0.00	0.00
10/25	1.86	2	0	0.00	0.00
10/26	2.15	2	0	0.00	0.00
10/27	1.88	2	0	0.00	0.00
10/28	1.59	2	0	0.00	0.00
10/29	1.43	2	0	0.00	0.00
10/30	1.31	2	0	0.00	0.00
10/31	1.89	2	0	0.00	0.00
11/1	2.09	2	0	0.00	0.00
11/2	2	2	0	0.00	0.00
11/3	1.79	2	0	0.00	0.00
11/4	1.75	2	0	0.00	0.00
11/5	1.64	2	0	0.00	0.00
11/6	1.56	2	0	0.00	0.00
11/7	1.42	2	0	0.00	0.00
11/8	2.77	2	0	0.00	0.00
11/9	1.84	2	0	0.00	0.00
11/10	1.45	2	0	0.00	0.00
11/11	1.21	2	0	0.00	0.00

11/12	1.28	2	0	0.00	0.00
11/13	1.66	2	0	0.00	0.00
11/14	2.01	2	0	0.00	0.00
11/15	1.66	2	0	0.00	0.00
11/16	1.88	2	0	0.00	0.00
11/17	2.14	2	0.14	3.01	37.77
11/18	2.7	2	0.7	6.72	84.46
11/19	2.34	2	0.34	4.69	58.86
11/20	2.46	2	0.46	5.45	68.47
11/21	2.28	2	0.28	4.25	53.42
11/22	2.33	2	0.33	4.62	57.99
11/23	2.08	2	0.08	2.27	28.55
11/24	1.87	2	0	0.00	0.00
11/25	2.25	2	0.25	4.02	50.47
11/26	2.71	2	0.71	6.77	85.06
11/27	2.74	2	0.74	6.91	86.84
11/28	2.85	2	0.85	7.41	93.07
11/29	2.97	2	0.97	7.92	99.42
11/30	3.17	2	1.17	8.69	109.19
12/1	3.2	2	1.2	8.80	110.59
12/2	3.3	2	1.3	9.16	115.10
12/3	3.35	2	1.35	9.34	117.29
12/4	3.43	2	1.43	9.61	120.72
12/5	3.48	2	1.48	9.78	122.81
12/6	3.74	2	1.74	10.60	133.16
12/7	3.89	2	1.89	11.05	138.78
12/8	4.19	2	2.19	11.89	149.39
12/9	4.43	2	2.43	12.53	157.37
12/10	4.6	2	2.6	12.96	162.78
12/11	4.91	2	2.91	13.71	172.21
12/12	5.18	2	3.18	14.33	180.02
12/13	5.51	2	3.51	15.06	189.13
12/14	5.78	2	3.78	15.63	196.27
12/15	5.83	2	3.83	15.73	197.56
12/16	6	2	4	16.07	201.90
12/17	5.95	2	3.95	15.97	200.63

12/18	5.83	2	3.83	15.73	197.56
12/19	5.57	2	3.57	15.19	190.74
12/20	5.49	2	3.49	15.02	188.59
12/21	5.49	2	3.49	15.02	188.59
12/22	5.52	2	3.52	15.08	189.40
12/23	5.74	2	3.74	15.54	195.23
12/24	5.48	2	3.48	14.99	188.32
12/25	5.37	2	3.37	14.75	185.32
12/26	5.5	2	3.5	15.04	188.86
12/27	5.61	2	3.61	15.27	191.80
12/28	6.07	2	4.07	16.21	203.66
12/29	5.78	2	3.78	15.63	196.27
12/30	5.93	2	3.93	15.93	200.13
12/31	5.93	2	3.93	15.93	200.13

APPENDIX D

Micro Diversion LCC calculation

Year	Construction Cost ($)	Operating Costs	Total Costs
2020	100,000,000	40,000,000	140,000,000
2021	0	40,400,000	40,400,000
2022	0	40,804,000	40,804,000
2023	0	41,212,040	41,212,040
2024	0	41,624,160	41,624,160
2025	0	42,040,402	42,040,402
2026	0	42,460,806	42,460,806
2027	0	42,885,414	42,885,414
2028	0	43,314,268	43,314,268
2029	0	43,747,411	43,747,411
2030	10,000,000	44,184,885	54,184,885
2031	0	44,626,734	44,626,734
2032	0	45,073,001	45,073,001
2033	0	45,523,731	45,523,731
2034	0	45,978,969	45,978,969
2035	0	46,438,758	46,438,758
2036	0	46,903,146	46,903,146
2037	0	47,372,177	47,372,177
2038	0	47,845,899	47,845,899
2039	0	48,324,358	48,324,358
2040	10,000,000	48,807,602	58,807,602

2041	0	49,295,678	49,295,678
2042	0	49,788,634	49,788,634
2043	0	50,286,521	50,286,521
2044	0	50,789,386	50,789,386
2045	0	51,297,280	51,297,280
2046	0	51,810,253	51,810,253
2047	0	52,328,355	52,328,355
2048	0	52,851,639	52,851,639
2049	0	53,380,155	53,380,155
2050	10,000,000	53,913,957	63,913,957
2051	0	54,453,096	54,453,096
2052	0	54,997,627	54,997,627
2053	0	55,547,603	55,547,603
2054	0	56,103,079	56,103,079
2055	0	56,664,110	56,664,110
2056	0	57,230,751	57,230,751
2057	0	57,803,059	57,803,059
2058	0	58,381,089	58,381,089
2059	0	58,964,900	58,964,900
2060	10,000,000	59,554,549	69,554,549
2061	0	60,150,095	60,150,095
2062	0	60,751,596	60,751,596
2063	0	61,359,112	61,359,112
2064	0	61,972,703	61,972,703
2065	0	62,592,430	62,592,430

2066	0	63,218,354	63,218,354
2067	0	63,850,538	63,850,538
2068	0	64,489,043	64,489,043
2069	0	65,133,934	65,133,934
2070	0	65,785,273	65,785,273
		LCC -->	$970,276,242