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Assessing The Cost Of Coastal Land Creation Using Dredged Material

F. RYAN CLARK, HARRIS C. BIENN, AND CLINTON S. WILLSON

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Introduction

This report attempts to study the factors that influence the cost of building coastal land using dredged material, to aid the 2012 Master Plan for a Sustainable Coast Marsh Creation project implementation (Master Plan, CPRA, 2012). It builds on previous efforts, and provides recommendations for cost-saving strategies. It includes a discussion of the motivation for large-scale ecosystem restoration in coastal Louisiana, and how dredging plays a role in the implementation of that effort. It discusses the drivers of marsh creation cost, and how the implementation of the Master Plan can affect those costs. The report provides a brief overview of dredging technology, and a summary of the marsh creation process using dredged material. Targeted areas for improving efficiency and cost savings are discussed, and recommendations are offered for possible future work. The locations and project size in acres of the Marsh Creation projects included in the Master Plan are shown in Figure 1.

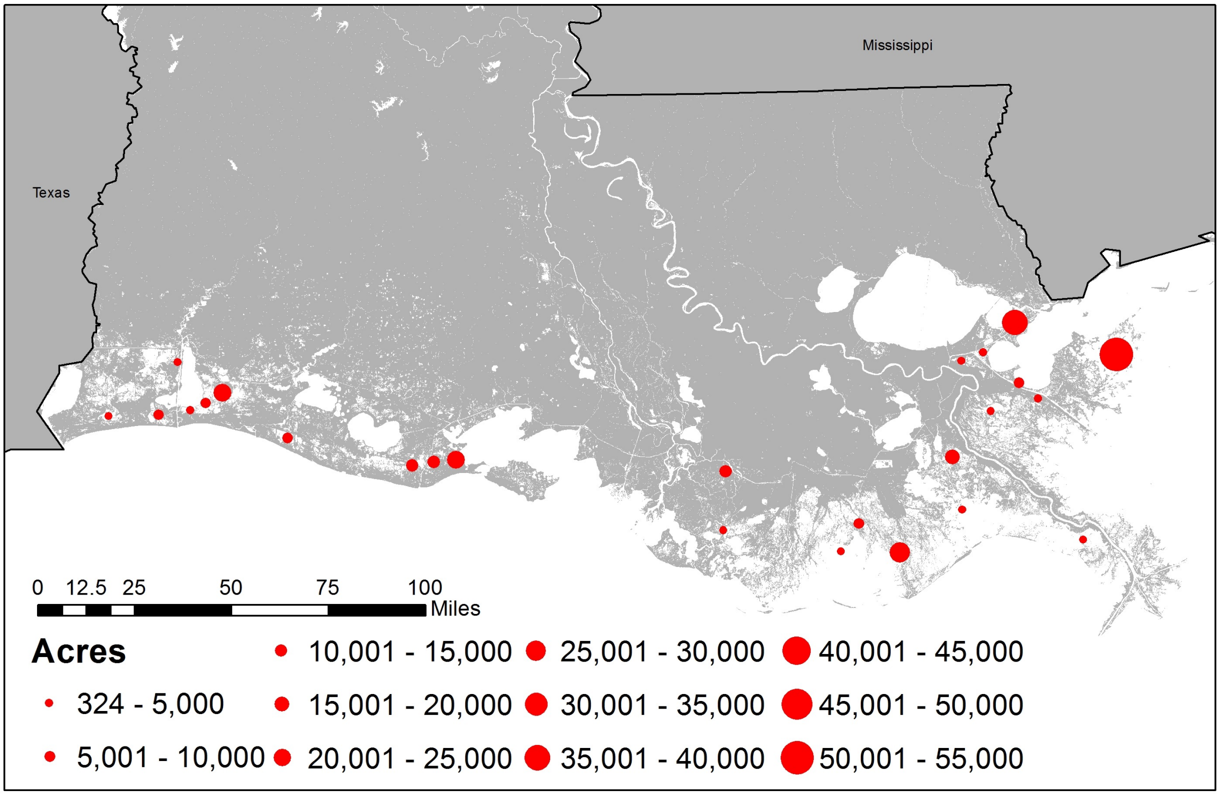

Figure 1. Marsh creation project size in acres. In the coming decades, the state of Louisiana is projected to spend approximately $22 billion dollars on the 28 Marsh Creation projects included in Louisiana's 2012 Master Plan. (Figure created from project data included in 2012 Master Plan, Appendix A)

MOTIVATION

Marsh creation constitutes the largest budget percentage of all Master Plan project types (Figure 2). This effort aims to evaluate the methodology used to determine these costs and/or identify ways to reduce expenditures in those areas, where warranted. With this in mind, The Water Institute of the Gulf (the Institute) has determined many of the factors that make marsh creation projects so expensive.

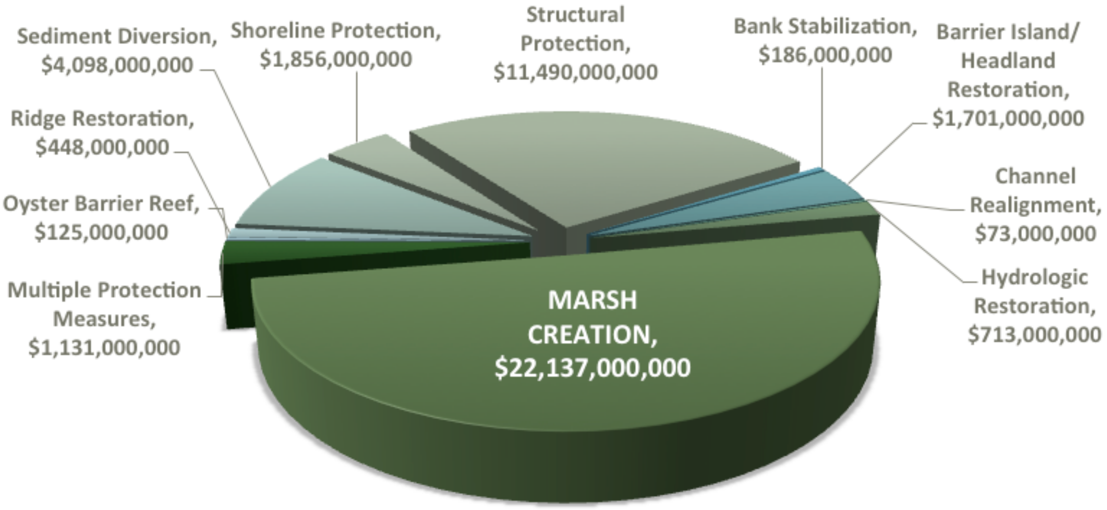

Figure 2. Estimated cost of Master Plan Project types.

The process followed for the development and construction of marsh creation projects generally includes the following five steps: (1) planning, (2) implementation, (3) performance assessment, (4) adaptive management, and (5) dissemination of results (Diefenderfer et. al., 2003). This study focuses on approaches contained within the planning and implementation steps. The planning step includes identification of goals, objectives, and performance criteria. The type of system to be restored is identified, and a potential site is selected. Geotechnical and biological site characterization investigations are performed during this stage. Planning activities also include determining the level of physical effort, producing engineering designs, cost, scheduling, and producing contingency plans. Project implementation includes bid/contracting for construction, mobilization of construction equipment, construction of containment features (if needed), dredging and conveyance of fill material, sculpting and ancillary construction activities, surveying, vegetative plantings, post-construction monitoring, and operation and maintenance.

According to the Marsh Creation Project Definitions in Master Plan Appendix A, construction costs contribute 85% of the total project cost, or $18.7 of the estimated $22 billion dollars. To be consistent with the Master Plan, all dollar amounts in this study are reported in 2012 dollars, and are not escalated into the future. Approximately 60% to 70% of the total construction cost is dictated by the unit cost of the marsh fill material. This marsh fill unit cost is influenced by the type of material to be dredged, the dredging distance, payment method, fuel costs, and dredging experience. Approximately 20% to 30% of the total construction cost is driven by the mobilization and demobilization of construction equipment. This cost is influenced by the project size, borrow source, dredging distance, pipeline corridor, dredging equipment, dredging volume, manpower, and contractor risk (CPRA, 2012).

The State of Louisiana could save $2.2 billion dollars for every 10% cost reduction on Marsh Creation projects.

Below is a summary of the projected cost of 2012 Master Plan Marsh Creation projects:

Master Plan Marsh Creation projects:	28
Master Plan total budget for Marsh Creation (in billions):	$22
Total project size, acres:	166,350
Average Cost per project (in millions):	$786 (min $32; max $3,102)
Median Cost per project (in millions):	$495
Average Size of project, acres:	6,161 (9.6 sq. mi.) (min 260 acres; max 33,280 acres)
Average fill volume, cubic yards (in millions):	38 (min 1.5; max 310.4)

The summary statistics above were calculated to present the scale, in terms of project cost and size, and to relate that to completed and ongoing marsh creation efforts in Louisiana and elsewhere. The number of Master Plan Marsh Creation projects, total budget, total land area created, and total fill volume were compiled from project data in Master Plan Appendix A. The average cost per project, median cost per project, average size of projects, and average fill volume per project statistics were calculated using these listed values. Locations of the 28 Master Plan Marsh Creation projects are provided in Figures 3-7.

Between 1997 and 2009, the Coastal Protection and Restoration Authority (CPRA) implemented 28 dredging projects valued at over $300 million, for an average cost of about $29.0 million per year (Escude et al., 2011). Over the aforementioned period, CPRA dredging projects created over 5,000 acres of wetlands (Escude et al., 2011). This total land created is less than the average size of one Master Plan Marsh Creation project (i.e., 6,161 acres). When it is completed, the total land area to be created by all Master Plan Marsh Creation projects, at 166,350 acres, is approximately 11 times the size of the South Bay Salt Pond Restoration Project, the largest tidal wetland project on the West Coast of the United States (Trulio, et al., 2007). The largest Master Plan Marsh Creation project (001.MC.09 Biloxi Marsh Creation), is planned to be 33,280 acres. This is 220% larger than the South Bay Salt Pond Restoration Project. These examples are included in order to provide a sense of scale to the Master Plan Marsh Creation projects, and their potential importance to the state-of-practice of marsh creation techniques, as well as the need to optimize the cost-effectiveness of their implementation. Based on the above statistics, the 28 Master Plan Marsh Creation projects are significantly larger, in terms of budget and average size in acres, than most or all past projects of this type undertaken in Louisiana and throughout the United States.

Implementation of the Master Plan Marsh Creation projects will result in the creation of 166,350 acres (260 sq. mi.) of land. This will take place over two implementation periods during the course of the 50-year schedule. Table 1 below indicates the acres created, volumes of sediment required, and average costs over those implementation periods, as well as the number of standard 30-inch cutter suction dredges (CSDs) necessary to implement the work. The 30-inch CSD is a common piece of dredging equipment often used for marsh creation projects in the Louisiana coastal zone.

Table 1. Summary of Master Plan dredging requirements.

	Acres Created	Fill Vol (yd^3)	Cut Vol (yd^3)	Avg Cost/Fill (yd^3)	Avg Cost/Acre
1st Implementation Period	84,110	460,8756,000	599,138,000	$20.21	$126,336
2nd Implementation Period	82,240	567,351,000	737,557,000	$30.63	$163,367
Total	166,350	1,028,227,000	**1,336,695,000**	$23.30	$137,308
Each Year in 1st Implementation Period	4,206	23,044,000	**29,957,000**		
Each Year in 2nd Implementation Period	2,741	18,912,000	**24,585,000**		

Two dredging scenarios were compared, one using the dredging assumptions used to develop the Master Plan project definitions in Master Plan Appendix A (called “30-inch Master Plan CSDs” in the Table below), and the other using the average of actual daily dredging production values from five randomly selected 30-inch CSDs used on recent (i.e., 2012 to present) United States Army Corps of Engineers – New Orleans District (USACE-MVN) dredging projects in Louisiana (Corbino, pers. comm). More detail on the USACE dredging projects is provided later in this report. The Master Plan scenario assumes a dredge cutting 6,400,000 yd^3 per year as per the 2012 Master Plan project definitions. The USACE averaged scenario assumes a dredge cutting 40,700,000 yd^3 per year. Both scenarios assume that dredging work is distributed evenly across the full implementation period, with effective project sequencing and little to no mobilization time between projects. As shown in Table 2 below, the number of dredges required annually to implement the Master Plan Marsh Creation project varies from one to five, depending on the assumptions used in project planning.

Table 2. Number of standard dredges required for Master Plan Marsh Creation implementation.

	30-inch Master Plan CSDs Needed	30-inch USACE Averaged CSDs Needed
Each Year in 1st Implementation Period	5	1
Each Year in 2nd Implementation Period	4	1

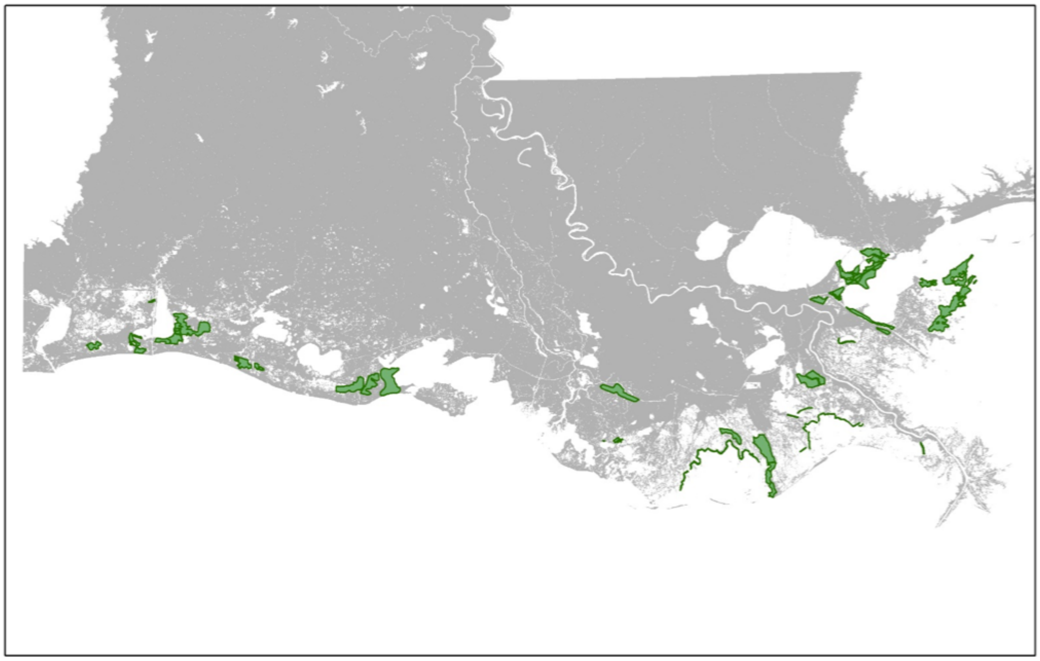

Figure 3. Master Plan Marsh Creation Projects.

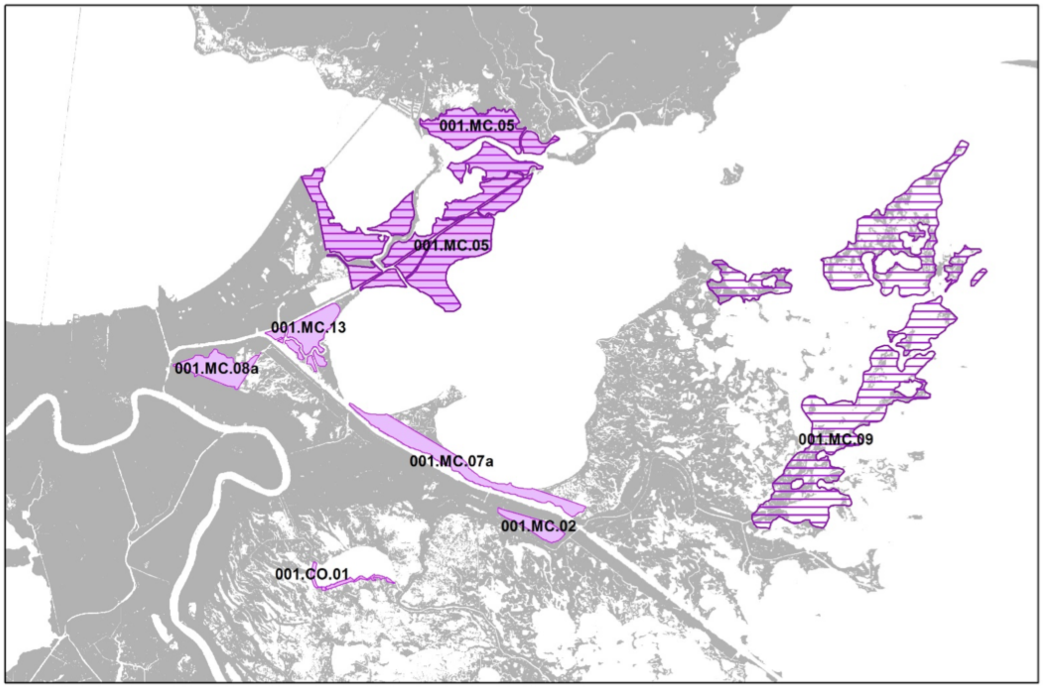

Figure 4. Master Plan Marsh Creation Projects, southeast coast. Solid fill indicates first Master Plan implementation period, and cross-hatched fill indicates second Master Plan implementation period.

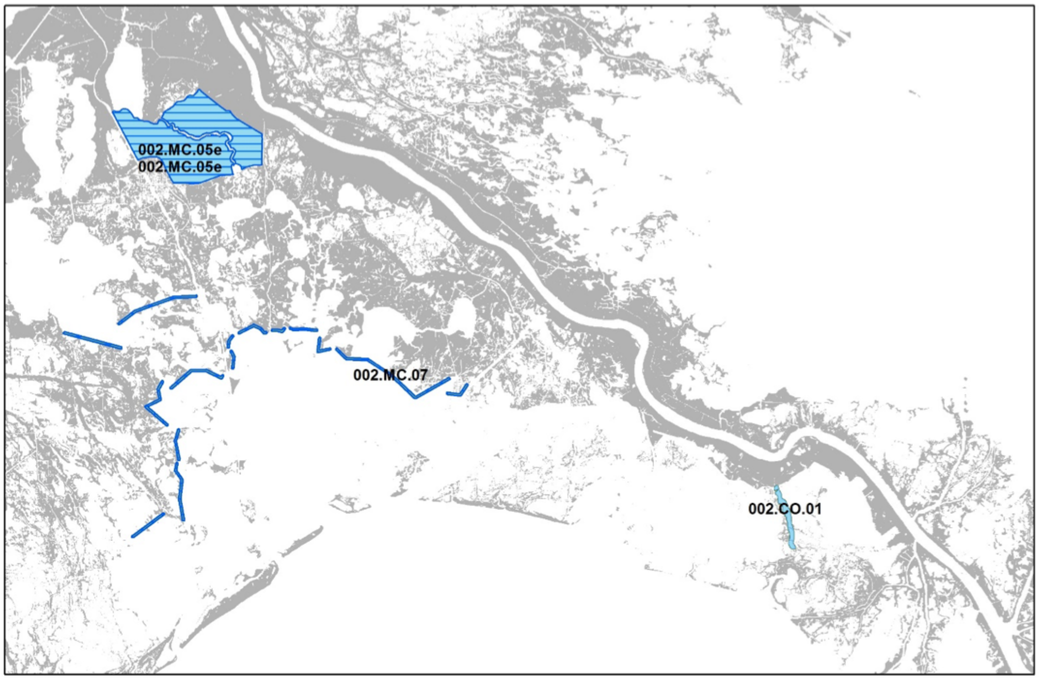

Figure 5. Master Plan Marsh Creation Projects, Barataria area. Solid fill indicates first Master Plan implementation period, and cross-hatched fill indicates second Master Plan implementation period.

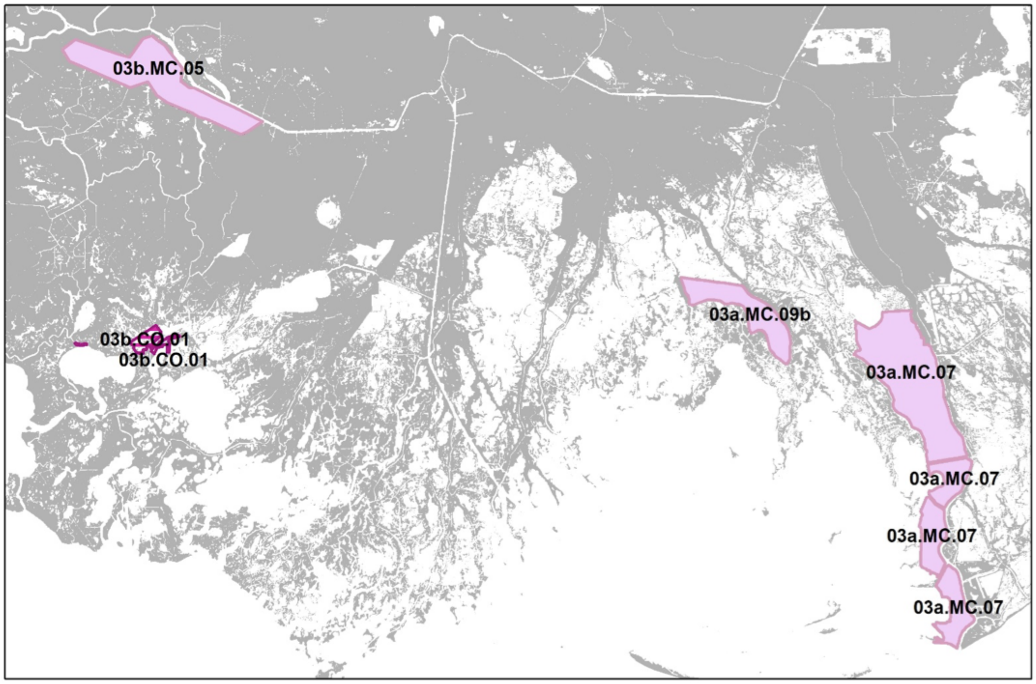

Figure 6. Master Plan Marsh Creation Projects, west central coast. Solid fill indicates first Master Plan implementation period, and cross-hatched fill indicates second Master Plan implementation period.

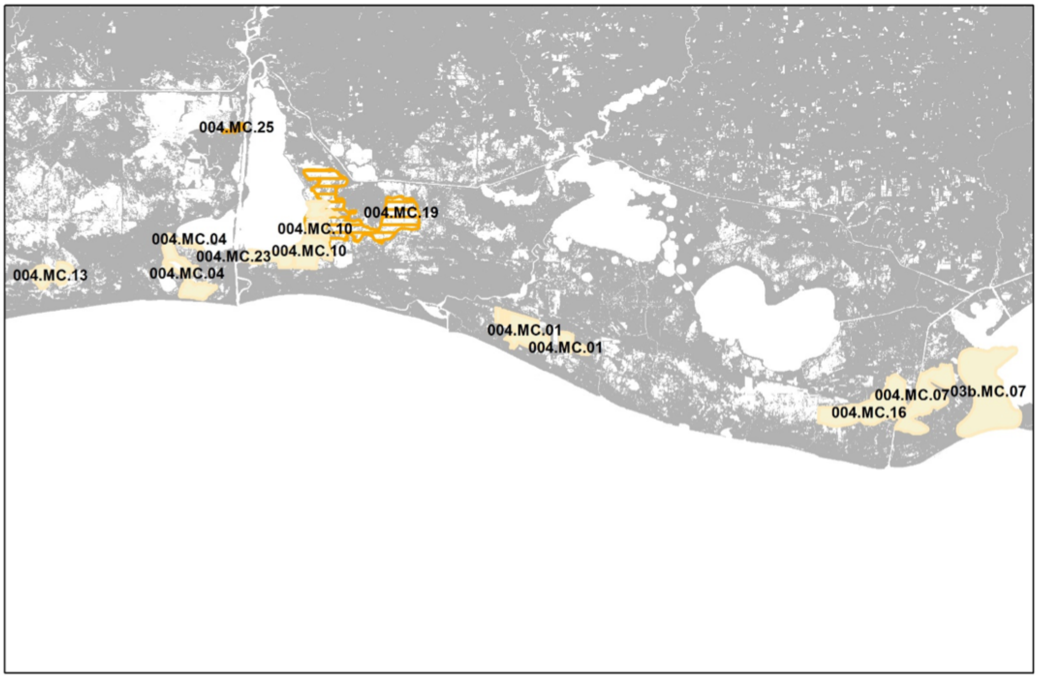

Figure 7. Master Plan Marsh Creation Projects, southwest coast. Solid fill indicates first Master Plan implementation period, and cross-hatched fill indicates second Master Plan implementation period.

When taking elevation into account, volumetric expression in cubic yards (yd^3) is an important project attribute, along with the area created, expressed in terms of acres. According to the 2012 Master Plan Project Attributes, Marsh Creation projects will use 1,336,694,000 yd^3 of fill material over the course of both implementation periods (CPRA, 2012). A unit that is often employed to describe large volumes is the acre-foot. An acre-foot is the volume of one acre of surface area to a depth of one foot, and is equal to 1613.3 yd^3.

The Marsh Creation projects identified in the Master Plan will require 828,531 acre-feet of dredged fill material to construct. That is more than the volume of water in Lake Tahoe (USDA, n.d.). Over the 50-year duration of the Master Plan, that equates to an average of 16,571 acre-feet of dredged fill material per year.

The Master Plan Marsh Creation projects will create 166,350 acres (260 sq mi) of marsh. This area is also 53% larger than Orleans Parish, Louisiana (US Census Bureau, 2010). Since the 1930s, Louisiana has lost approximately 1,880 sq mi of coastal land (CPRA, 2012). The amount of land creation proposed by Master Plan Marsh Restoration Projects aims to restore 14% of that original amount of coastal marsh.

DREDGING FUEL COSTS

Dredging is energy intensive work. Using the two dredging scenarios developed above (30-inch Master Plan CSDs and 30-inch USACE Averaged CSDs, with and without four booster pumps), a fuel consumption projection was estimated. The projected amount of fuel required to complete Master Plan Marsh Creation projects ranges between 186 million gallons and 1.4 billion gallons, depending on the number of dredges in use and the ancillary equipment (e.g., booster pumps) needed to move sediment. The fuel required annually ranges between 4 million and 33 million gallons, costing between $15 million and $115 million each year over the 50-year implementation. In 2012 dollars, this much fuel would cost the state between $652 million and $5.1 billion for the dredging component of Master Plan Marsh Creation project implementation. Both scenarios used the 320-operating day assumption in Master Plan Appendix A (CPRA, 2012). Much of the difference between the two fuel consumption estimates is due to two factors: (1) the disparity between the daily output of the two dredge scenarios, and (2) the effects of adding booster pumps for longer distance conveyance of dredged material. To determine the effect of adding booster pumps for long distance conveyance on fuel costs, standard specifications for four 4,500 hp Caterpillar 3612 engines were used to determine annual fuel consumption operating under the same assumptions as the dredges, and added to both dredging scenarios for an upper bound of fuel consumption (Caterpillar, 2002).

The low estimate of fuel consumption, 186 million gallons, is based on the standard Master Plan dredge with no booster pumps. The highest fuel consumption estimate is based on an averaged dredge from scenario two above, operating with four booster pumps. The range of values indicates the importance of the effects of project planning decisions, especially distance of conveyance and its effects on the number of booster pumps required. If a 10% savings can be realized on marsh creation energy costs, fuel consumption can be reduced by between 18.6 million and 140 million gallons, or roughly $65.2 million to $510 million dollars. Finding more efficient ways to use fuel is advantageous in light of rising energy costs. The cost of diesel fuel used in the Master Plan was assumed to be $3.50 per gallon and the Energy Information Agency (EIA) projects diesel costs to rise to $4.32 per gallon in 2030 and $6.34 per gallon in 2040 (EIA, 2014).

COST SAVING METHODS FOR IMPLEMENTATION

Louisiana can continue to develop a sustained dredging program focused on Master Plan Marsh Creation. A sustained state marsh creation/dredging program in close collaboration with the dredging industry could have some impact on lowering dredging costs. Methods that could be employed to provide cost savings on Marsh Creation project implementation include:

1. Alternative Dredging Contracting and Payment Methods;
2. Equipment Optimization;
3. Borrow-Transport-Placement Optimization (Project Geography);
4. Management of Energy Costs (Fuel); and
5. Fill Material Placement Methods.

The first two methods, Alternative Dredging Contracting and Payment Methods and Equipment Optimization, were examined in detail in previous work (Escude et al., 2011), and were briefly re-examined for this report using data from the USACE Beneficial Use Program in subsequent sections of this report.

Implementation of the Master Plan will require a significant, sustained dredging program. This dredging program will be able to sustain a group of dredges continuously over decades. With this type of continuous work stream, CPRA may have the opportunity to influence the process under which it currently uses dredging services. Although CPRA has constructed approximately 10 Marsh Creation projects (CPRA, 2015) using dredging, most of these projects have been implemented on a standalone basis, and not part of a continuous stream of work. This shift from ad hoc, on-off projects using available equipment, to the sustained utilization of equipment, may have several market-driven advantages.

There may be opportunities for CPRA to save through fuel cost management, including the use of owner (i.e., CPRA) supplied fuel. CPRA could identify additional cost savings that could further reduce the unit cost of sediment for restoration projects. CPRA could implement an advanced, large-scale fuel management program, as utilized in other sectors that consume large amounts of fuel. These sectors include airlines, railroads, and maritime transportation industries (Salverson, 2010). Fuel management companies serve large industries and optimize the processes of fuel purchasing and transportation to the site. CPRA could expand the economy of scale to purchase fuel for multiple projects and across multiple dredging contractors, as opposed to the individual dredgers purchasing fuel on a job-to-job basis, as well as avoiding any markups on fuel purchased by the dredgers themselves. This fuel management practice could also reduce the unit cost of dredged fill material by alleviating the risk of fuel cost fluctuations from the dredging contractors.

Contracting agreements can be modified by using multiyear contracts and project sequencing to possibly reduce: (1) mobilization and de-mobilization costs (mob/de-mob), and (2) contractor risk, by ensuring a longer-term workflow, with defined geographic and temporal information about future projects. Multiyear contracts and other strategies can be used to provide stability and continuity for dredgers, potentially reducing costs further by reducing competitive forces from competing customers, and reducing the need for mobilization to and from other jobs. Reducing contractor risk, or accepting more calculated risk as a contracting agency, could further drive costs down. Strategies to do this could include the collection of detailed geotechnical information on the borrow and fill sites, reducing uncertainty in the quantity and quality of borrow material, and the response of the placement site foundation to the load of the constructed project (USACE, pers. comm.). The pay approach for each project or sequence of projects can be optimized by target elevation, cut volume, or fill volume. Schedules can be optimized so contractors can work individual projects into their schedule for other projects and clients, which drives down uncertainty, downtime, and cost. Linking and sequencing projects will also serve to reduce or eliminate these scheduling issues and further drive down costs.

OVERVIEW OF DREDGING TECHNOLOGY

Cutter Suction Dredge (CSD)

CSDs are the most common dredge types used for restoration projects in coastal Louisiana (Escude et al., 2011). A CSD consists of a hydraulic cutting head paired with an electric or diesel-driven motor, affixed to a floating hull via a ladder structure. The basic components of a CSD are illustrated in Figure 8. Sediment is loosened by the cutter head prior to pumping into the dredge, and effluent is pumped through a pipeline to the disposal location or to a barge located nearby. Affixed to the stern is a spud structure consisting of a main working spud, and a secondary walking spud. When in operation, the main spud is driven into the river or seabed and the dredge pivots laterally about the spud that provides incremental forward movement. Domestic CSDs have discharge diameters ranging from 6-40 inches with output power in excess of 15,000 kW (20,000 hp) depending on the design application (Sargent, 1989). Most CSDs in operation in the United States require a tender boat to move any significant distance. Self-propulsion can be found on modern sea-going CSDs, but these vessels do not typically have the draft less than 10 feet necessary to access shallow coastal waters. Dredging companies in the Netherlands have pushed the envelope in terms of designing large capacity CSDs. These Jumbo class CSDs have a total installed power in excess of 25,000 kW (33,500 hp) and are capable of self-propulsion. When considering the world’s dredging fleet, only 25% of large CSDs are self-propelled (Overhagen et al., 2005). CSDs are capable of dredging all types of material and are inherently more accurate than other dredge types due to the control of movement around the spud pole. Dredge depths are limited to 120 feet even on the largest CSDs. With increasing dredging depth, the need for a wider, stronger pontoon construction arises as well as a more stable ladder system. Suction depth determines whether an underwater, ladder-mounted pump is necessary in order to obtain the required production capacity. Without an underwater pump, the diameter and head of the suction pipe must be increased and the density (i.e., concentration) of the sediment-water mixture must be reduced. This subsequently increases the effluent concentration of water and reduces the economic viability of the dredge. Often the need for a greater dredging depth leads to a pontoon with deeper draft and thus to a reduction in the minimum dredging depth. Thus the usability of the dredger increases with increasing dredging depth, yet it decreases as a result of the related smaller minimum dredging depth. CSDs are stationary dredges and require at least two anchor points to the port and starboard, subsequently obstructing shipping channels and limiting applicability. Offshore conditions such as swell and wave activity will negatively affect an unpowered pontoon-based CSD, thus limiting its effectiveness in periods of inclement weather and high swell (Vlasblom, 2005). An issue affecting cost and applicability is the limited distance possible between the borrow site and subsequent fill location due to pumping power and discharge pipe length. Booster pumps paired with the dredge mounted pump can increase pumping distances but will affect costs (Escude et al., 2011).

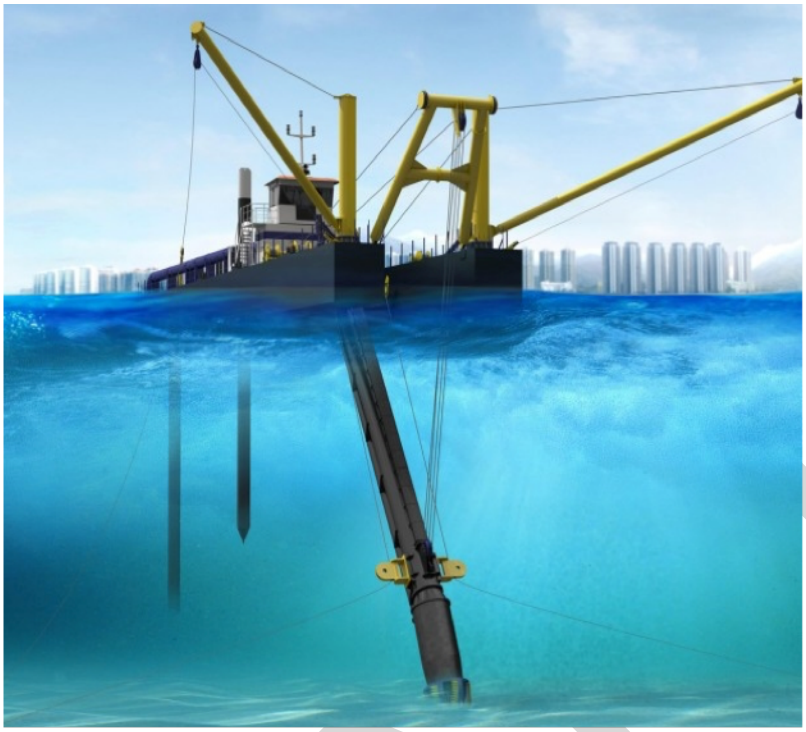

Figure 8. Cutter suction dredge. A Damen Standard CSD (CSD650). All major elements of an unpowered CSD are visible in this rendering. The ladder is submerged, suspended from the deck via a wench system and tower. The cutter head seen dredging the seabed is guided by a wench system attached to two anchor points. The spud system is located at the stern of the vessel (Retrieved from: http://www.seaplant.com/latest-updates/latest-news/new-larger-cutter-suction-dredger-joins-the-damen-standard-series/).

Trailing Suction Hopper Dredge (TSHD)

TSHDs are designed as self-contained vessels that can mobilize under their own power, as opposed to CSDs, which are stationary while actively dredging. TSHDs require forward movement in order to maintain operation. Dredged material is excavated by a trailing suction head, shown in Figure 9 as the two extensions to port and starboard, and pumped into an onboard hopper. After loading, the dredger will either relocate to an offshore disposal site (in the case of most navigable dredging) or move to a pump-out location (in the case of land reclamation projects). In the case of land reclamation projects, a TSHD may deploy to a staging location after loading and deposit the material via bottom doors onto the seabed for double handling by a CSD and transfer to a pipeline. TSHDs operate in a manner similar to all other ocean going vessels and do not require the use of a spud or anchorage system. This maneuverability is limited by the deeper draft necessary for a self-propelled ocean-going vessel as well as the width of the channel in which it is operating. A growing number of TSHDs have pump-ashore capabilities in response to the economic need for such a feature. These designs incorporate the addition of a discharge outlet located in the hopper as well as a set of upper doors. These vessels can attach directly to a shore discharge line or power a booster pump through the propulsion engines. TSHDs have a high rate of production in soft or loose sediments, but due to the nature of the trailing suction head, are limited in scenarios that require the dredge to excavate hard clays and cemented sediments. Due to the nature of the hull design, TSHDs can tolerate greater swell and wave climates than pontoon-based dredges. Mediumsized TSHDs have hopper sizes extending to 3,500 yd^3 and can dredge to depths of 115 feet (Sargent, 1989). According to the international market analysis conducted as a component of the Innovative Dredging Initiative report (Escude et al., 2011), the average size of TSHDs that operate in Europe has quadrupled in the last two decades. There are currently plans for TSHDs with an approximate volume of 65,000 yd^3. In comparison, the maximum capacity of TSHDs in the U.S. domestic dredging fleet is 16,000 yd^3 (TAMU, 2008). The main issue associated with the increasing size of TSHDs is that the draft of the vessel increases as well, and as the draft increases, the vessel's ability to access shallower coastal waters decreases (Escude et al., 2011).

Figure 9. Trailing suction hopper dredge. A 7,000 yd3 self-propelled TSHD. The trailing suction arms can be seen to the port and starboard sides of the vessel attached to boom cranes on the deck (Retrieved from: http://www.theartofdredging.com/stpmfordummies.htm).

Clamshell/Grab Dredge

This type of dredge is most analogous to modern land-based excavation equipment. It consists of a prime mover affixed to a floating hull. It ranges in design from small hydraulic cranes mounted to narrow barges (for use in canal dredging scenarios) to large backhoes mounted on spudded pontoons capable of excavating 40 yd^3 in a single stroke (Sargent, 1989). The largest drawback with grab-type dredges is the resuspension of sediment during operation (Escude et al., 2011).

Toyo Pump

A Toyo Pump is a relatively small (compared to onboard pumps on CSDs and TSHDs), submersible lower velocity hydraulic suction pump, which is often portable and can be lowered with a winch or crane from a working barge.

The Terrebonne Levee and Conservation District (TLCD) performed a 90-day demonstration to test the feasibility of using a 12-inch Toyo pump to create marsh in a 360-acre project constructed with hydraulically dredged sediment from an inland sediment source. The project was originally designed to utilize a 24-inch or 30-inch CSD with pipelines and booster pumps to place the dredged material and included construction of several thousand linear feet of containment dike. Upon further analysis the TLCD decided to use a 12-inch submersible hydraulic suction pump. The motivation of the project was to significantly reduce the cost of construction by utilizing a smaller, lower velocity pump as a suction dredge, thus reducing the need to build costly containment structures (Escude et al., 2011).

Booster Pumps

Booster pumps provide an extended pipeline (generally greater than five miles) with enough displacement head to overcome the resistance associated with increased pumping distance. Generally speaking, for every five miles of pipeline, one booster pump is required to keep the head at a velocity conducive to continuous flow (Escude et al., 2011). The density of the material being pumped has direct implications on the head required to pump that material. More viscous slurry will require more energy input than less dense slurry. A fine line is drawn between pumping efficiency and sediment density efficiency (Anderson et al., 2008). The skill associated with controlling sediment effluent density falls mainly on the dredge operator. It is their responsibility to maintain the appropriate dredging depth and pumping speed to ensure that the sediment density remains within acceptable levels.

POWER SOURCES FOR DREDGING EQUIPMENT

Diesel

Diesel engines provide a self-reliant energy source that is available in sizes from a few horsepower to over 10,000 hp (Acberli, 2007). Relatively speaking, diesel engines are small, inexpensive, powerful, fuel efficient, and extremely reliable if properly maintained (Overhagen et al., 2005).

Diesel – Electric

Diesel-electric powertrains combine a diesel engine with an electric motor to provide constant output power for extended operations. The electric motor is driven by a diesel engine and constant power is achieved within a specific revolutions per minute range.

Electric

Electric powertrains can be paired with different mechanisms to generate power. An all-electric dredge can be paired with a diesel-powered generator barge or can be attached directly to the power grid through a bankside substation. Infrastructure becomes one of the most important aspects, as all electric powertrains are limited by the availability of medium voltage power lines or the availability of fuel for the generator barge (DSC, 2012).

Liquefied Natural Gas (LNG)

LNG vessels are starting to become a reality as domestic natural gas production increases. LNG is now the most cost effective method for power generation when considering other fossil fuels such as diesel and coal (Lopez, 2008). Several shipbuilders have begun production on LNG vessels and LNG-powered dredges are already in planning (Hamworthy, 2014). LNG can be paired to an electric powertrain in a similar way as a diesel-electric.

FLEET AVAILABILITY

Profile of the International Dredging Industry

The global dredging market has primarily evolved around one major market (Escude et al., 2011). High volume ports in East Asia require almost continuous navigational dredging to provide passage for deep draft vessels. However, since the end of the 1990s, the international market has seen a shift to land reclamation projects in the Persian Gulf, and as of 2011, more than one third of the world's dredging activity occurs in this region. The global dredging industry has seen its dredged volumes more than double since 2000. The United States and China are the only two countries that have dredging markets limited to domestic companies and when compared, China is the only closed market that has seen an increase in domestic dredging volumes. In general, the United States domestic dredging industry has seen little net growth in the past 15 years (Escude et al., 2011).

Profile of U.S. National Dredging Industry

USACE is the largest customer of dredging contracts within the domestic industry, and many domestic dredging companies tailor their equipment needs to contracts provided by USACE. Private industry carried out 85% of the 216 million yd^3 of sediment dredging by USACE in 2008. Over the span of a decade, the volume of dredged material has remained roughly the same, yet the average unit cost has nearly doubled, from \$2.86 per yd^3 in 1999, to \$5.10 per yd^3 in 2009 (Escude et al., 2011).

Marsh Creation Overview

OVERVIEW OF MARSH CREATION PROJECT PLANNING, DESIGN, AND CONSTRUCTION

Marsh creation in Louisiana has three main sediment sources: (1) inland, (2) offshore, and (3) riverine. These sediment sources can have different characteristics, including grain size, that lend their use to different types of restoration projects. Inland sediment sources are characterized by being located in non-riverine navigable waters. Some examples of inland, non-riverine navigable waters include the Gulf Intracoastal Waterway (GIWW) and the Calcasieu Shipping Channel in southwest Louisiana. Offshore sediment sources are often offshore sand shoals. Offshore sediment sources, i.e., those that are not in rivers or other inland protected waterbodies, are of particular importance if the project calls for a greater proportion of sand for land building. Riverine borrow sites in Louisiana are primarily located within the boundaries of the Mississippi and Atchafalaya Rivers. Navigational dredging is the primary consideration for riverine dredge sites, and many navigational projects also use the dredged riverine material for coastal restoration. Some riverine dredging projects have been carried out for the purpose of land creation in coastal Louisiana, including the Lake Hermitage Marsh Creation project.

Inland Borrow Source

The use of inland, in-system borrow sources is restricted in the Master Plan (CPRA, 2012). Marsh creation sites in the past have been constructed using sediment from nearby inland borrow sources, if project planners and designers could not feasibly retrieve sediment from an offshore or riverine borrow site due to excessive conveyance distance or other project restraints. Ecological concerns need to be accounted for in these situations, as inland waterbodies are extremely susceptible to small variations in turbidity, dissolved oxygen, and temperature change (Allen & Hardy, 1980). When considering an inland borrow source, an important factor is the depth of the water body being used as the borrow source. This in turn will limit the size and type of equipment to be used.

Inland Borrow Source Example: Barataria Bay Waterway Wetland Restoration (Coastal Wetlands Planning, Protection, and Restoration Act [CWPPRA] Project BA-19)

The Barataria Bay Waterway Wetland Restoration (BA-19) project is a beneficial use of dredged material project located on Queen Bess Island. Queen Bess Island is located within the southwestern portion of Barataria Bay, east of the Barataria Bay Waterway (BBW) and north of Grand Isle and Grand Terre Islands in Jefferson Parish, Louisiana. In 1989, the island was one of three remaining nesting habitats for Louisiana's state bird, the endangered brown pelican (*Pelicanus occidentalis*). Due to significant erosion over the last several decades, the island was reduced in size from 45 acres (1956) to 17 acres (1989). Its elevation had been so reduced that the island was frequently overwashed by small storms further degrading its role as a crucial nesting habitat for the brown pelican (CPRA, 2002). A summary of restoration dredged volumes, areas created, costs, approximate conveyance distances, and sediment type used is presented in Table 3.

Table 3. Summary of restoration cost and key parameters for the inland borrow source example project.

Project	Year	Cost	Dredged Volume (yd^3)	Area Created (acres)	Cost per yd^3	Cost per acre	Approximate Conveyance Distance (miles)	Sediment Type/ Source
BA-05b	1990	$561,250	82,000	8	$6.84	$70,156	1.4	Fine-grained/ interior waterway
BA-19	1996	$945,678	51,950	9.6	$18.20	$98,508	1.0	

(USACE, n.d.), and (OCPR, 1997)

The initial project design aimed to use maintenance-dredged sediments to create marsh in shallow water areas adjacent to the BBW. However, oyster leases in or adjacent to the proposed marsh creation sites precluded this. As an alternative, dredged material from the BBW was used to enlarge Queen Bess Island. The size of Queen Bess Island increased from 17 acres in 1989 to 34.6 acres in 1996 as a result of the combined efforts of this project and the BA-05b project (Smith, 2003). An aerial view of Queen Bess Island is depicted in Figure 10.

Figure 10. Barataria Bay Waterway Queen Bess Island wetland restoration. (Source: CPRA, 2002)

Offshore Borrow Source

A project in close proximity to the coast may be able to use sediment from an offshore borrow source. Sand shoals are often used as borrow sites because they provide high quality sand. Due to the usually sufficient depth at the sand shoals, larger draft vessels such as TSHDs can be utilized. Conversely, the distance of a sand shoal from a restoration site can increase costs due to longer conveyance distances.

Offshore Borrow Source Example: East Grande Terre (CWPPRA Project BA-30)

East Grande Terre Island is located in the Barataria Basin on the southeastern coast of Louisiana. The overall goals behind the East Grande Terre project were to: (1) restore 2.8 miles of barrier shoreline through construction sand dune system, (2) construct 450 acres of marsh platform north of, and parallel to, the beach and dune fill to provide a barrier against continuing shoreline retreat, and (3) create and restore 620 acres of Barrier Island immediately post-construction. A summary of restoration dredged volumes, areas created, costs, approximate conveyance distances, and sediment type used is presented in Table 4.

Table 4. Summary of restoration cost and key parameters for the offshore borrow source example project.

Project	Year	Cost	Dredged Volume (cu yd^3)	Area Created (acres)	Cost per yd^3	Cost per acre	Approximate Conveyance Distance (miles)	Sediment Type/ Source
BA-30	2010	$29,801,701	3,962,558	621	$7.52	$47,990	1.7	Offshore sand and fine-grained overburden

* Total project cost included project elements in addition to marsh creation (beach/dune, etc.). No detailed cost breakdown was available for marsh creation or beach/dune construction (including mobilization, containment dikes, post-construction surveys, etc.) Therefore, the information represents the project costs as a whole, with no specific cost information about the individual marsh creation or beach/dune components of the project. (CPE, 2011).

The contractor was paid for the placement of 2,179,039 yd^3 of beach fill and 965,211 yd^3 of marsh fill. Marsh fill material was placed after completion of the beach so the beach fill could act as the southern containment dike. Due to the existing terrain, a secondary containment dike was constructed offset to the north of the existing dune, spanning the length of the island. The secondary containment dike was to enclose dredged material placed during marsh construction (CP&E, 2011). Figure 11 depicts satellite imagery of East Grande Terre Island before and after construction.

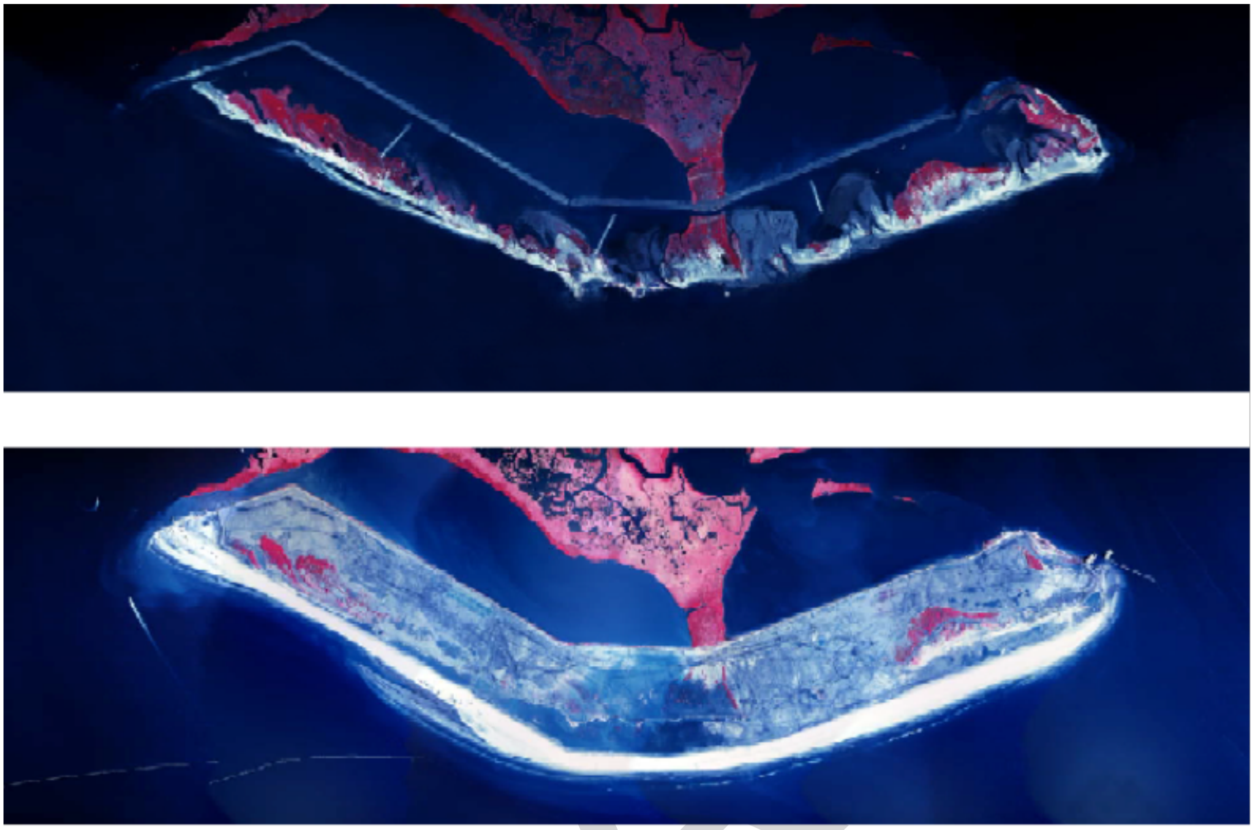

Figure 11. East Grande Terre Restoration during construction (top) and after (bottom). (Source: CP&E, 2011).

Riverine Borrow Source

In some river reaches, navigational dredging must be completed on a routine basis. Some riverine borrow sources are naturally recharged over a specific time period. When staged properly, they can provide marsh restoration projects with a continuous source of available sediment.

Riverine Borrow Source Example: Bayou Dupont (CWPPRA Project BA-39)

The Bayou Dupont Marsh Creation Project (BA-39) is located adjacent to Bayou Dupont, southeast of Cheniere Traverse Bayou and northwest of Myrtle Grove, Louisiana. The borrow site was located in the Mississippi River between river miles 63 and 65. A summary of restoration dredged volumes, areas created, costs, approximate conveyance distances, and sediment type used is presented in Table 5.

Table 5. Summary of restoration cost and key parameters for the riverine borrow source example project.

Project	Year	Cost	Dredged Volume (yd^3)	Area Created (acres)	Cost per yd^3	Cost per acre	Approximate Conveyance Distance (miles)	Sediment Type/ Source
BA-39	2011	$24,708,935	2,578,240	568	$11.04	$43,502	6.0	Mississippi River sand

(ABMB, 2011)

The Bayou Dupont project represented an example of pipeline transport of sediment from the Mississippi River to build marsh as a CWPPRA project. Over six miles of pipeline conveyed borrow material from the river to the project area. A booster pump was used to convey the dredged slurry. The pipeline discharged into an area of open water and broken marsh in the rapidly eroding and subsiding section of the Barataria land bridge. The dredged material was contained primarily by existing land features (Thomas, 2007). An aerial view of the project is shown in Figure 12 with the borrow area (red), sediment pipeline (yellow), and marsh creation area (green).

Figure 12. Bayou Dupont Restoration Area. Elements of project BA-39 illustrated above: borrow area (red), sediment pipeline (yellow), and marsh creation area (green). (Source: Thomas, 2007)

Long Distance Sediment Pipeline

A significant factor in the selection of marsh creation projects is the availability of usable sediment. Consequently, a problem inherent to marsh restoration is the geographic proximity of a restoration site to its associated borrow site. The Mississippi River carries millions of cubic yards of sediment per day and is a constantly recharging source of land-building material. In order to harness this potential and apply it to distant coastal restoration sites, pipelines can be used to move sediment for land building. A dredge located on the borrow site can pump, with the assistance of boosters, the sediment slurry through a pipeline. The outflow pipe can be maneuvered periodically and the effluent is shaped with heavy equipment. The Bayou Dupont and BA-40 Scofield Island projects are examples of long distance sediment pipelines. The defining factor for a long distance sediment pipeline is the conveyance distance between the borrow site and the restoration site. If this distance exceeds approximately five miles, then the pump located on the dredge will not create enough head to push the effluent through (CPRA, 2012). In cases such as these, booster pumps are implemented to maintain adequate head pressure. The use of booster pumps increases fuel expenditure and can have implications toward the cost of a project.

The Effects of Conveyance Distance and the Use of Booster Pumps on Project Cost

As seen in Figure 13, moving sediment 20 miles instead of five miles (using four booster pumps instead of the dredge alone) results in at least double the project fuel cost. This increase only accounts for fuel, and does not include increases in cost for mob/de-mob, pipeline right-of-way access and improvements, or the costs associated with the booster pumps themselves and associated labor.

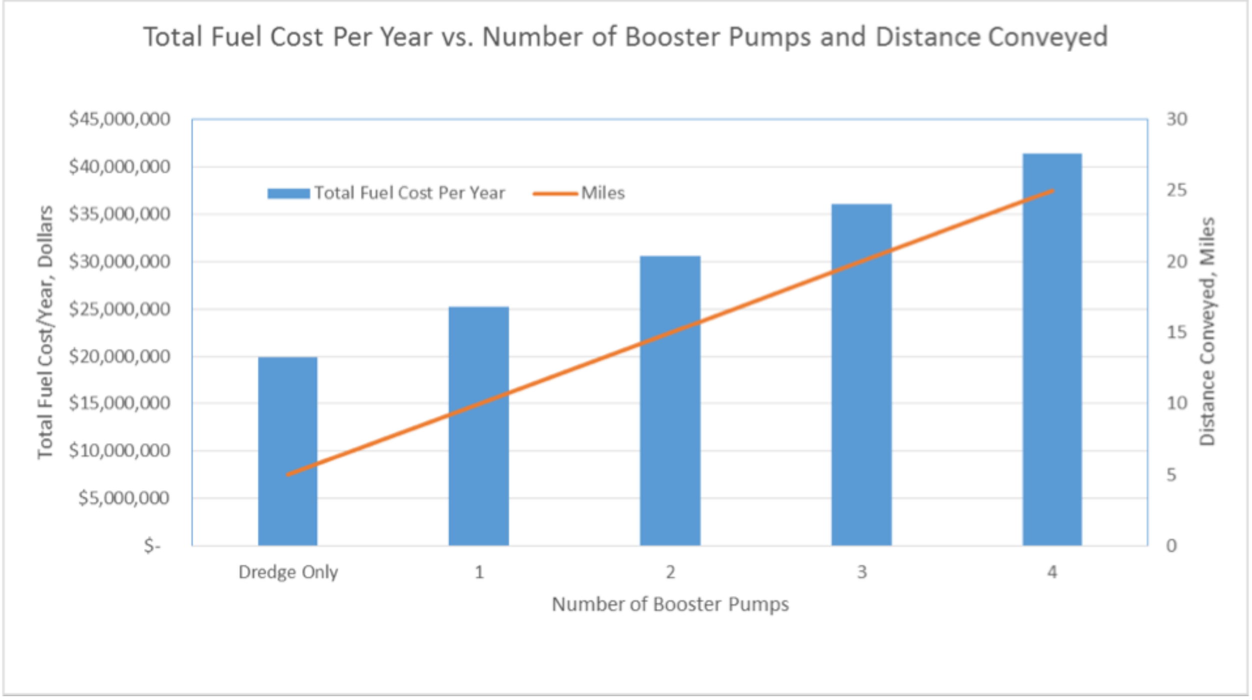

Figure 13. Total fuel cost per year for a single dredge versus the number of booster pumps.

The effects of conveyance distance on the cost of 2012 Master Plan Marsh Creation Projects were examined on a unit cost (per cubic yard) and on cost per land area created (in acres). The 2012 Master Plan project attributes of sixteen Marsh Creation projects planned for construction in the first implementation period were examined. As seen in Figure 14, conveyance distance has a linear relationship with cost per cubic yard for the projects analyzed, with a correlation coefficient of 0.8779. The linear trend predicts that for every mile of conveyance, the cost per cubic yard would increase by \$1.66. This results in a difference between \$10.06/cy^3 with 5 miles of conveyance, and \$35.05/cy^3 with 20 miles of conveyance. Conveyance distance also has a linear relationship with cost per acre for the projects analyzed, with a correlation coefficient of 0.8437 (Figure 15). The linear trend predicts that for every mile of conveyance, the cost per acre would increase by \$12,381. This results in a difference between \$54,200 per acre with 5 miles of conveyance, and \$239,900 per acre with 20 miles of conveyance. These results demonstrate the strong relationship between conveyance distance and project cost, on both a unit price (per cubic yard) and area created (per acre) basis.

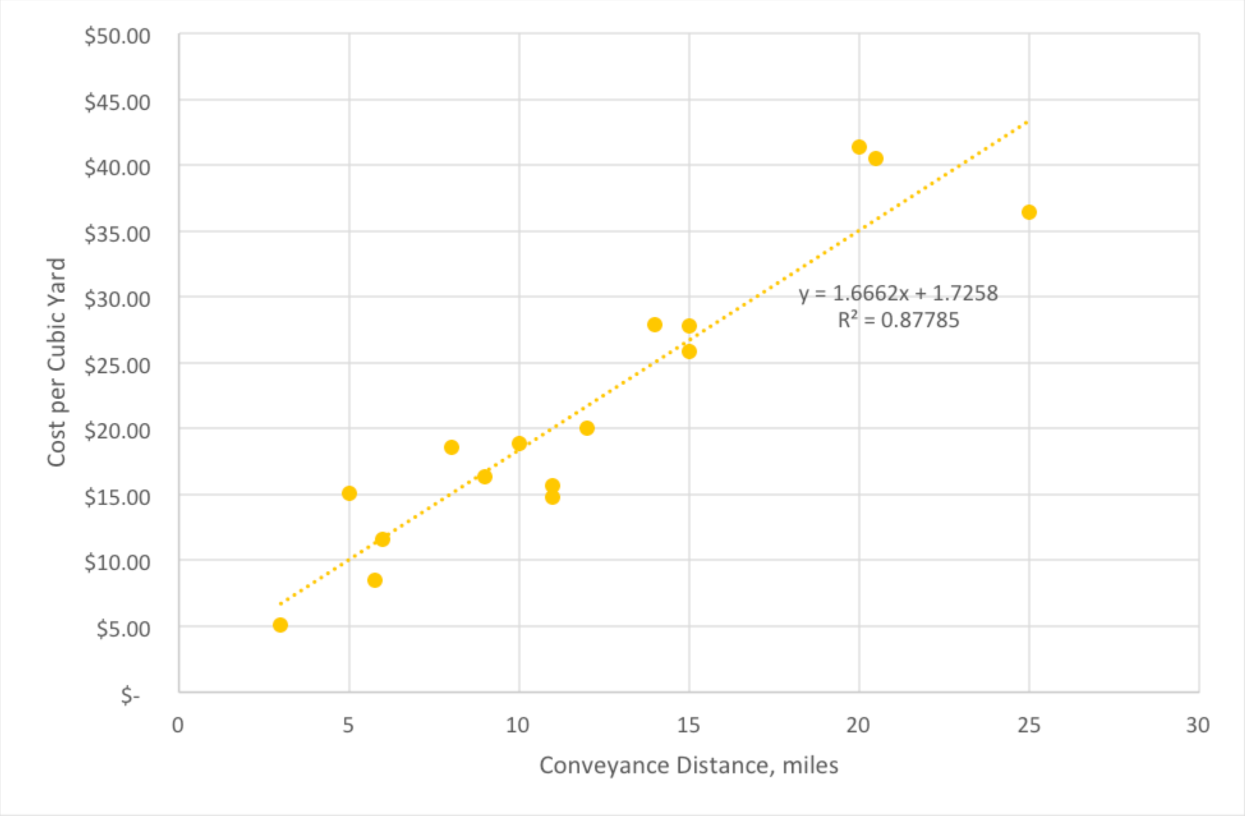

Figure 14. Conveyance Distance vs. Cost per Cubic Yard, 2012 Master Plan Marsh Creation Projects, 1st Implementation Period.

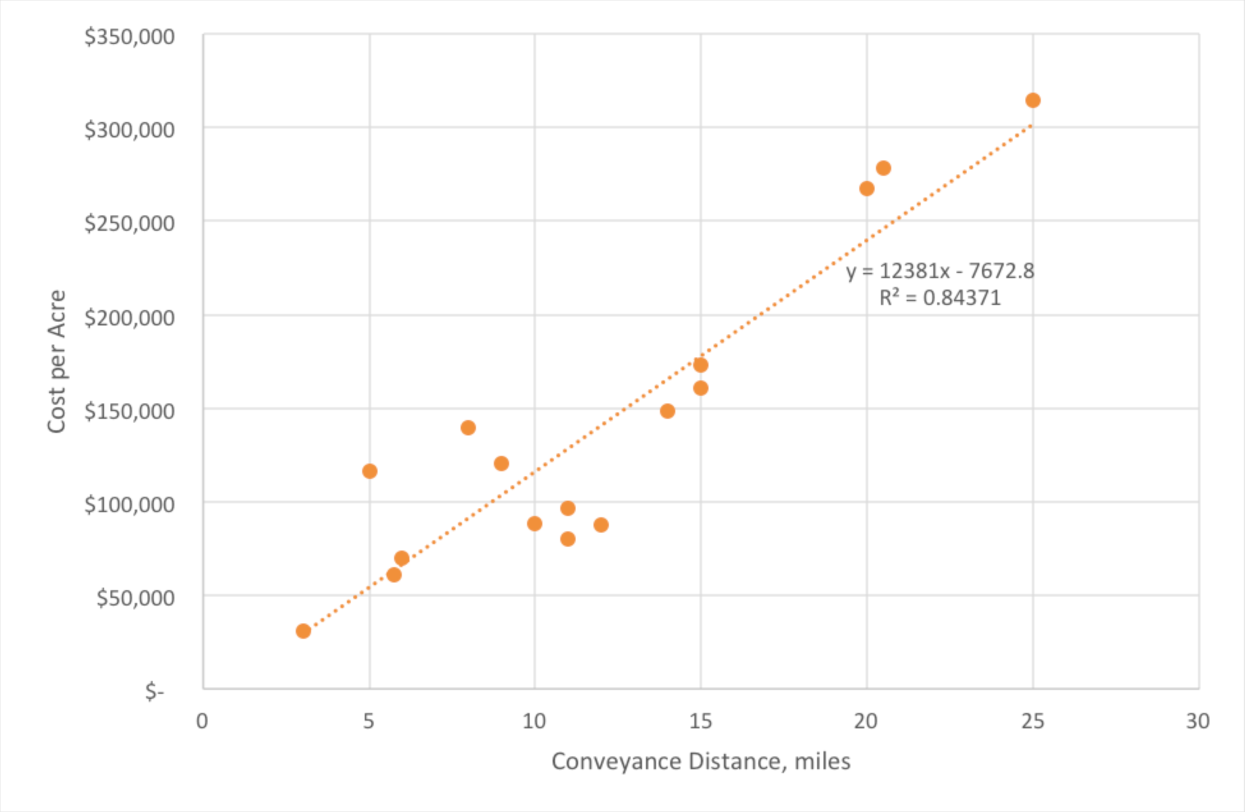

Figure 15. Conveyance Distance vs. Cost per Acre, 2012 Master Plan Marsh Creation Projects, 1st Implementation Period.

Long Distance Sediment Pipeline Example: Scofield Island (CWPPRA Project BA-40)

Project BA-40 utilized sand dredged from the Mississippi River to restore the environmental and ecological form and function of critical barrier island habitat (Figure 16). Construction of the Scofield Island Restoration Project required 22 miles of pipeline and four booster pumps. The pipeline crossed two hurricane protection levees, under two highways, and crossed a 10-mile navigable waterway to the Gulf of Mexico and then east to Scofield Island. The project features included the construction of approximately 100 acres of dune and 330 acres of supratidal berm, slopes, and marsh platform (CEC, 2010). A summary of restoration dredged volumes, areas created, costs, approximate conveyance distances, and sediment type used is presented in Table 6.

Table 6. Summary of restoration cost and key parameters for the long distance sediment pipeline example project.

Project	Year	Cost	Dredged Volume (yd^3) placed	Area Created (acres)	Cost per yd^3	Cost per acre	Approximate Conveyance Distance (miles)	Sediment Type/ Source
BA-40	2014	$53,138,010	3,372,456	510	$15.76	$104,192	22 Mississippi River/ 3 offshore	Mississippi River sand/ offshore mixed

* Total project cost included project elements in addition to marsh creation (beach/dune, etc.). No detailed cost breakdown was available for marsh creation or beach/dune construction (including mobilization, containment dikes, post-construction surveys, etc.) Therefore, the information represents the project costs as a whole, with no specific cost information about the individual marsh creation or beach/dune components of the project. (CEC, 2014)

Figure 16. Scofield Island Restoration Project before (left) and post construction (right; Source: CEC, 2010).

Double Handling

In situations where a borrow site is located a significant distance away from the restoration site, two options become feasible: (1) the use of a long distance sediment pipeline, or (2) the use of double handling. In scenarios where a long distance pipeline is not feasible (e.g., offshore borrow sites) the movement of sediment is facilitated by multiple vessels. Generally, a TSHD or a CSD fills a hopper with sediment. This hopper is subsequently moved from the borrow site to a location near the restoration site. A second dredging vessel pumps sediment out of the hopper and into the nourishment area. The use of double handling significantly affects the cost of restoration activities by involving multiple dredging vessels.

Double Handling Example: Caminada Headlands Restoration (CWPPRA Project BA-45)

The Caminada Headland Beach and Dune Restoration Project resides within the Bayou Lafourche barrier island complex, approximately 47 miles west of head of passes and about 50 miles south of New Orleans. The Caminada Headland spans the shoreline between Belle Pass and Caminada Pass located adjacent to Port Fourchon, Louisiana (Figure 17). A summary of restoration dredged volumes, areas created, costs, approximate conveyance distances, and sediment type used is presented in Table 7.

Table 7. Summary of restoration cost and key parameters for the double handling example project.

Project	Year	Cost	Dredged Volume (yd^3)	Area Created (acres)	Cost per yd^3	Cost per acre	Approximate Conveyance (barged) Distance (miles)	Sediment Type/ Source
BA-45	2014	$70,000,000	3,300,000	303	$21.21	$231,023	27	Ship Shoal offshore fine sand

* Figures for cost and volumes are estimates, taken from published project planning and design reports. (CEC, 2012), and (http://coastal.la.gov/project/caminada-headland-beach-and-dune-restoration/). Final construction documents were not available at the time of this report.

Figure 17. Caminada headlands restoration (Source: CEC, 2012).

The goal of the project was to safeguard and preserve the structural integrity of the headland shoreline, in turn reducing wave energy and saltwater intrusion from the Gulf of Mexico into back-barrier environments. The double handling method was utilized in this project and is illustrated in Figure 18. The left picture illustrates a secondary dredge, in this case a CSD, pumping out of a barge filled with offshore material dredge by a primary vessel. The right picture shows the terminal section of the pump-to-shore pipeline and ancillary sculpting equipment actively moving dredged sediment (CEC, 2012).

Figure 18. An example of double handling utilized for the Caminada Headlands Restoration project. The left picture illustrates a secondary dredge, in this case a CSD, pumping out of a barge filled with offshore material dredge by a primary vessel. The right picture shows a terminal section of the pump to shore pipeline and ancillary sculpting equipment actively moving dredged sediment (Source: CEC, 2012).

THE USACE BENEFICIAL USE PROGRAM: AN ANALOG TO THE MASTER PLAN MARSH CREATION PROGRAM

The sediment used to create land in beneficial use projects is a by-product of the USACE mission to maintain navigation. Because the cost of disposal of this material cannot exceed the Federal Standard, or the cost of normal best practice disposal, the practices used to create land using this material have led to low costs for land-building projects. These projects are characterized by close proximity to the borrow source such as a navigable waterway, minimal placement site preparation (or minimal containment), and minimal post-placement rehandling or shaping (USEPA & USACE, 2007). Projects constructed using these approaches were analyzed for this study in an effort to identify practices that could be applied to land-building efforts in the future.

Analysis of Beneficial Use Projects

Fifty-five Beneficial Use projects, created between 2007 and 2013, were analyzed for this study (Figure 19). Of these projects, 39 USACE classified as Wetland Development, while the other 16 were Bird Island projects. Of the total number of projects, 35 were determined to be 100% beneficial use (i.e., no sediments were disposed of by conventional means according to the Federal Standard). These 35 projects (seven Bird Island and 28 Wetland Development) are analyzed in more detail below.

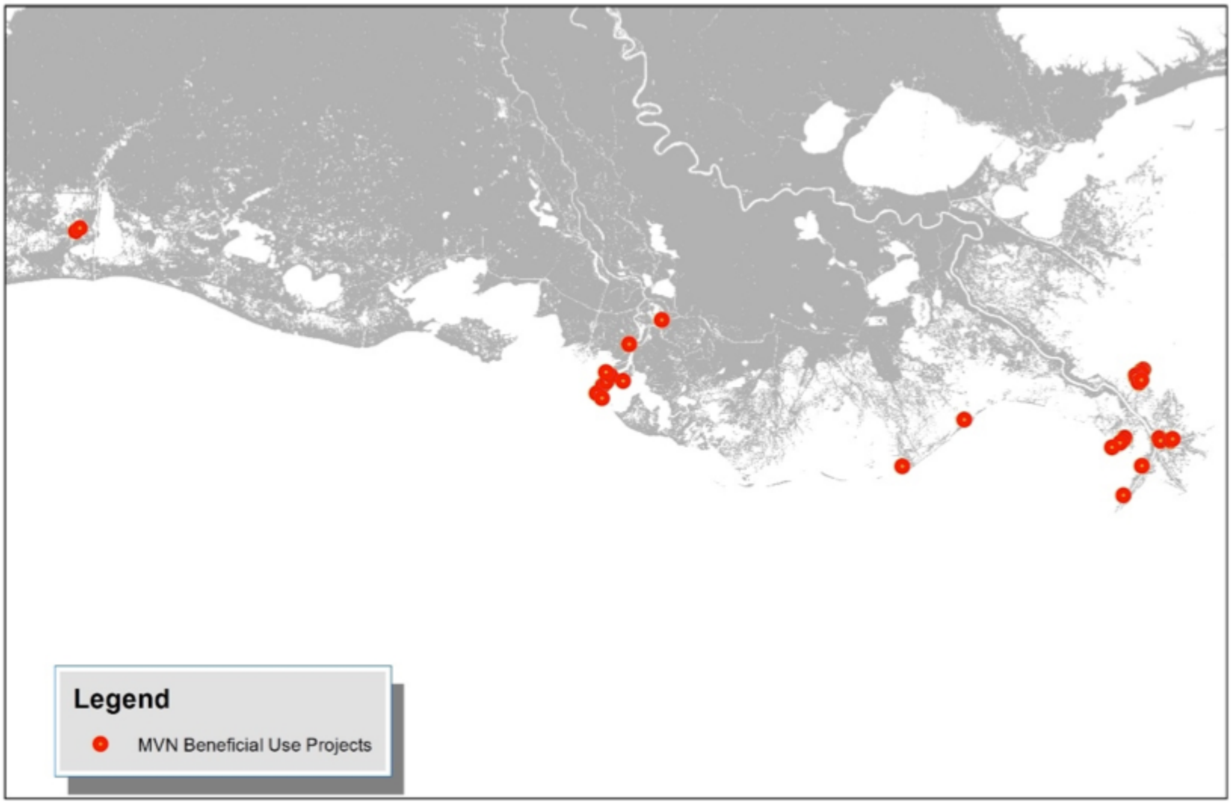

Figure 19. USACE New Orleans district statewide beneficial use projects from 2007-2013.

Bird Islands are constructed in slightly deeper water (2 m average water depth), with minimal to no containment, typically using a single-point discharge. They are created as specialty habitat for shorebirds. Most Bird Islands are small (i.e., less than 20 acres), and are often relatively expensive on a cost-per-acre basis, when compared to wetland development projects. This method is capable of producing high-value niche habitat, and can prove to be similar in cost to wetland development projects, especially in projects over 100 acres in size and/or over 2,000,000 yd^3 of cut volume. Bird Island projects create niche habitat for shorebirds, and have different success criteria than wetland development projects, so direct cost comparisons between the two project types is of limited effectiveness for determining value and ecosystem services.

The 28 Wetland Development projects that were considered 100% beneficial use were also analyzed for this study. A summary of project attributes is provided in Table 8. They show similar trends of land-building efficiency, in which projects less than 100 acres in size, and/or less than 2,000,000 yd^3, have a very high variability in cost per acre (from less than $20,000 to over $400,000), and in cost per cubic yard of dredged material (from less than $2 to over $18). Projects over 100 acres in size exhibit a significant reduction and stabilization of cost, to an average of $35,685 per acre. This average cost per acre is approximately 79% less than the cost of the average planned Master Plan Marsh Creation project, with a cost of $132,311. Cost information for the USACE Beneficial Use projects, in terms of cost per acre and cost per cubic yard, are presented in Figures 20 and 21, respectively.

Table 8. USACE Beneficial Use Project Summary.

Ref. Num.	Fiscal Year	Contract Number	Contract Type	Dredge	Project Name (Borrow Site)	Borrow Site Sub-Reach	BU Placement Site	BU Volume (CY)	BU Area (Acres)	Cost per Placed CY	Cost per Acre
1	FY09	09C0028	Cubic Yard	Pontchartrain / Alaska	Tiger Pass	Mile 7.3 to 14	WD Sites 1-5	2,148,270	24	$ 4.12	$ 283,365
2	FY09	09C0025	Leased	EW Ellefsen	Mississippi River	Southwest Pass	West of Channel	2,896,991	46	$ 4.77	$ 231,064
3	FY10	10C0028	Leased	RS Weeks	Mississippi River	Southwest Pass		3,192,431	50	$ 4.17	$ 204,566
4	FY08	08C0085	Leased	Tom James	Atchafalaya River	Horseshoe	Site I	1,024,290	25	$ 6.07	$ 191,168
5	FY08	08C0040	Cubic Yard	Dredge 32	Baptiste Collette	Jetties	Sites C & E	350,973	23	$ 14.78	$ 173,446
6	FY10	09C0124	Cubic Yard	Venture	Tiger Pass	Mile 7.3 to 14		1,779,723	50	$ 4.79	$ 131,201
7	FY08	08C0075	Leased	G.D Williams	Atchafalaya River	Bay Channel	Mathies Island	277,512	42	$ 17.97	$ 91,336
8	FY11	09C0071	Cubic Yard	Florida / California	Mississippi River	HDDA	DNWR Peninsula E	1,805,022	70	$ 4.51	$ 89,553
9	FY12	12C0034	Cubic Yard	McCaskill	Mississippi River	HDDA	DNWR	787,274	70	$ 9.53	$ 82,448
10	FY12	12C0024	Cubic Yard	Missouri H	Tiger Pass	Miles 7.3 TO 14	WDA-4	650,427	20	$ 3.03	$ 75,694
11	FY13	12C0042	Cubic Yard	EW Ellefsen	Atchafalaya River	Bay Channel	Bennett Island	1,153,627	65	$ 5.09	$ 69,479

Ref. Num.	Fiscal Year	Contract Number	Contract Type	Dredge	Project Name (Borrow Site)	Borrow Site Sub-Reach	BU Placement Site	BU Volume (CY)	BU Area (Acres)	Cost per Placed CY	Cost per Acre
12	FY10	09C0090	Cubic Yard	California	Baptiste Collette	Jetties	Site E	224,338	13	$ 4.88	$ 64,743
13	FY10	09C0086	Leased	Venture	Atchafalaya River	Bay Channel	Mistrot Island	754,604	74	$ 6.63	$ 51,973
14	FY13	13C0021	Leased	Captain Frank	Mississippi River	Southwest Pass		5,430,960	228	$ 2.67	$ 48,992
15	FY10	09C0071	Cubic Yard	Florida / California	Mississippi River	HDDA	DNWR	6,527,685	466	$ 4.48	$ 48,317
16	FY11	11C0015	Cubic Yard	John Laquay / JN Fisher	Baptiste Collette	Jetty Channel	Site G	512,964	40	$ 4.86	$ 47,910
17	FY12	11C0063	Cubic Yard	Missouri H	Baptiste Collette	Bar Channel	Site E	310,069	26	$ 4.58	$ 42,034
18	FY13	12C0041	Cubic Yard	E Stroud	Baptiste Collette	Bar Channel	Peninsula E South	234,773	26	$ 4.78	$ 33,235
19	FY08	08C0039	Cubic Yard	Tom James	Mississippi River	HDDA	DNWR	4,013,912	340	$ 2.93	$ 26,588
20	FY12	12C0024	Cubic Yard	Missouri H	Tiger Pass	Miles 7.3 TO 14	WDA-2	227,482	20	$ 3.03	$ 26,473
21	FY12	12C0024	Cubic Yard	Missouri H	Tiger Pass	Miles 7.3 TO 14	WDA-3	492,212	44	$ 3.03	$ 26,037
22	FY12	12C0021	Leased	California	Mississippi River	Southwest Pass		5,066,405	530	$ 3.51	$ 25,804
23	FY13	12C0034	Cubic Yard	McCaskill	Mississippi River	HDDA	DNWR	7,480,477	795	$ 3.36	$ 24,304

Ref. Num.	Fiscal Year	Contract Number	Contract Type	Dredge	Project Name (Borrow Site)	Borrow Site Sub-Reach	BU Placement Site	BU Volume (CY)	BU Area (Acres)	Cost per Placed CY	Cost per Acre
24	FY07	07C0022	Cubic Yard	Meridian	Mississippi River	HDDA	DNWR	4,266,078	388	$ 2.70	$ 22,809
25	FY11	10C0119	Cubic Yard	Kelly L	Barataria Bay Waterway	Bayou Rigaud	Fifi Island	342,602	130	$ 10.05	$ 20,366
26	FY10	09C0090	Cubic Yard	California	Baptiste Collette	Jetties	Site B	744,527	149	$ 4.88	$ 18,747
27	FY12	12C0024	Cubic Yard	Missouri H	Tiger Pass	Miles 7.3 TO 14	WDA-1	183,624	33	$ 3.03	$ 12,951
28	FY12	12C0041	Cubic Yard	E Stroud	Baptiste Collette	Jetty Channel	Sites E&F	229,119	100	$ 5.71	$ 10,070

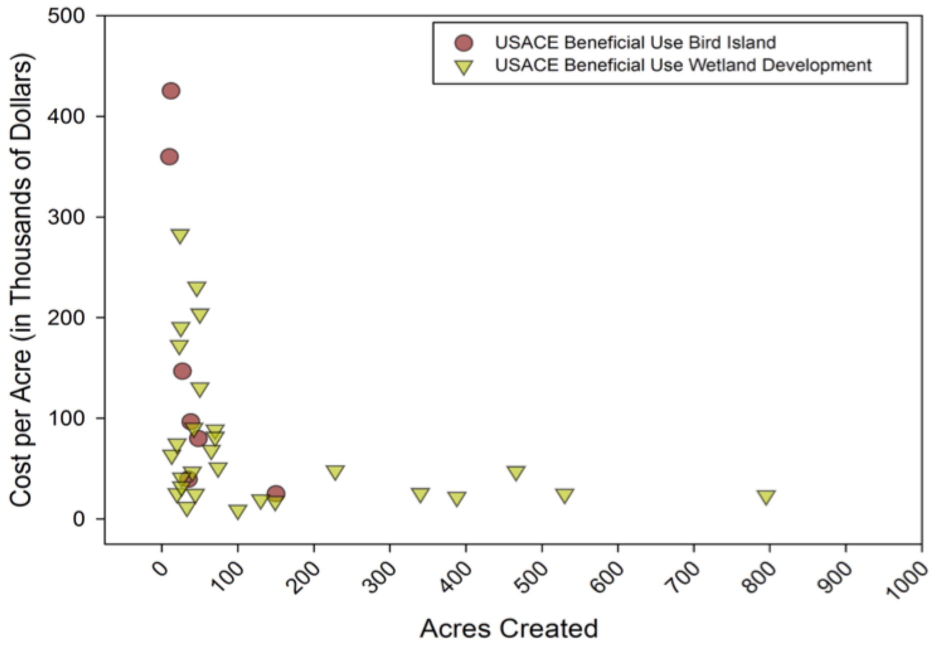

Figure 20. USACE beneficial use acres created versus cost per acre.

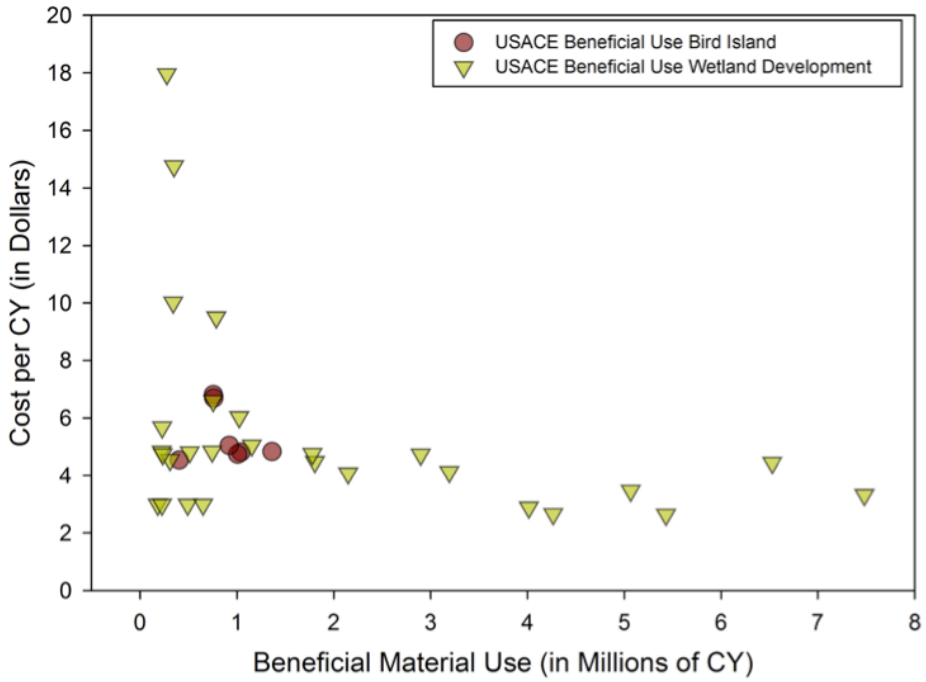

Figure 21. USACE beneficial use material versus cost per cubic yard.

Figure 24 depicts the USACE Beneficial Use Wetland Development projects in terms of cost per acre (red line), cost per cubic yard (blue bars), and acres created (numbers in boxes) In general, both cost per acre and cost per cubic yard decrease as project size increases. The numbers on the x-axis correspond to the project reference numbers in Table 8.

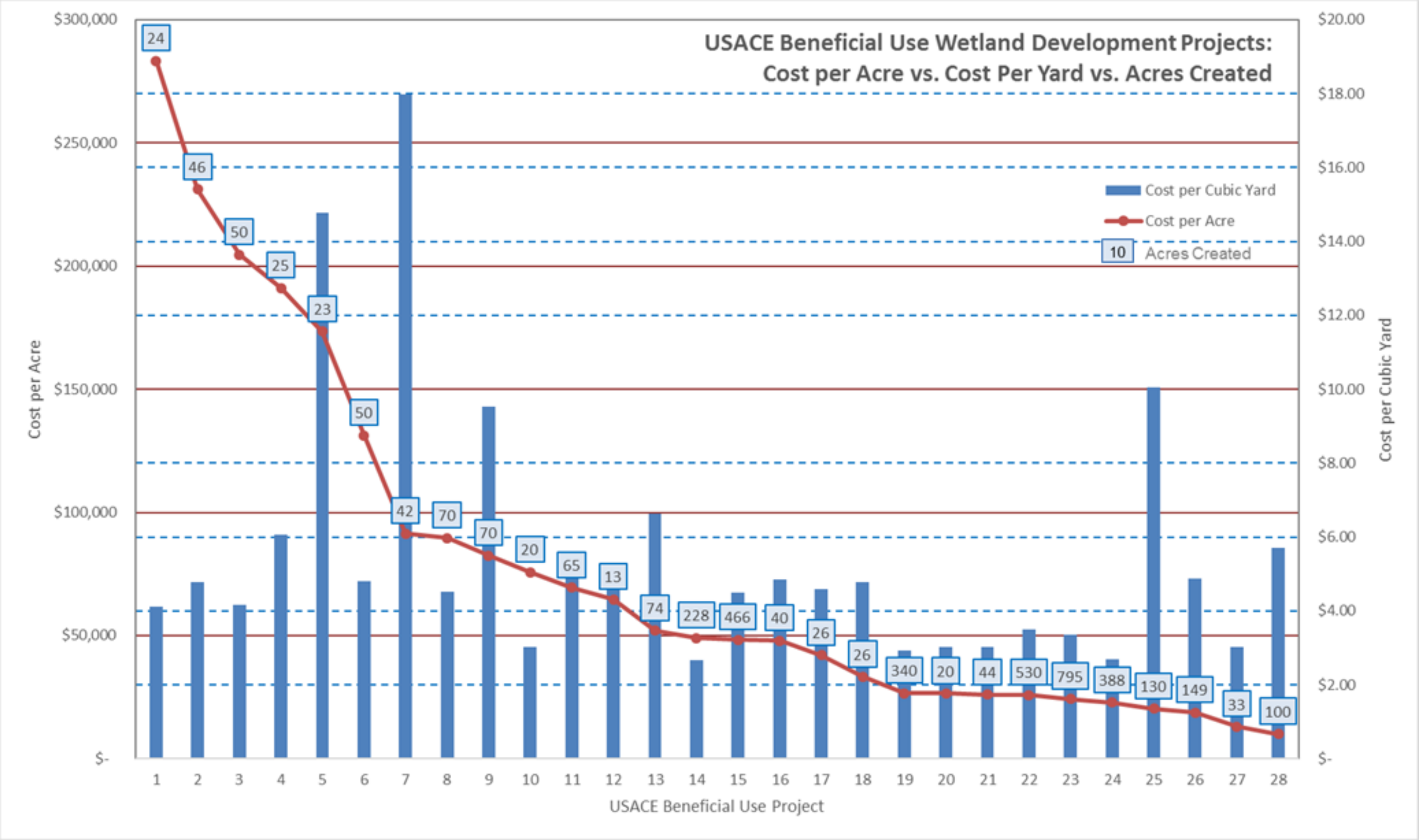

Figure 22. Cost and area created for USACE Beneficial Use Wetland Development Projects.

Comparison of Completed USACE Beneficial Use Wetland Development Projects to Proposed Master Plan Marsh Creation, Completed CPRA, and In-Progress CPRA Projects

Twenty-eight Beneficial Use Wetland Development projects were compared, with respect to cost per acre and cost per yard, to the proposed Master Plan Marsh Creation projects, as well as a selection of completed and in-progress CPRA Marsh Creation projects. This comparison is not intended to be an apples-to-apples comparison, as there are inconsistencies between the different project types. While the Beneficial Use projects are complete, some of the CPRA projects are in-progress, and the Master Plan projects have very basic conceptual designs and budgets which will be significantly refined in the future as projects develop through the engineering and design process. A cursory review of a limited selection of CPRA completed and in-progress projects was performed, using readily available project documents such as design and project completion reports. A list of references for these projects is included in Appendix II. A summary of the CPRA projects (or the marsh creation components of multiple-type projects) included in this study is provided in Table 9. Comparisons of the USACE Beneficial Use Wetland Development projects to completed CPRA, in-progress CPRA, and proposed Master Plan Marsh Creation projects, in terms of cost per area is presented in Figure 23. USACE Beneficial Use Wetland Development projects and proposed Master Plan Marsh Creation projects, in terms of cost per cubic yard, are compared in Figure 24.

Table 9. CPRA completed and in-progress example projects.

CPRA (Completed)	Acres Created	Cost per Acre	Total Cost
(BA-30) East Grand Terre Island Restoration	456	$68,677	$31,289,395
(BA-36) Dedicated Dredging on the Barataria Basin Landbridge	504	$72,024	$36,300,000
(BA-39) Bayou Dupont Sediment Delivery	568	$42,276	$24,012,739
(BA-42) Lake Hermitage Marsh Creation	593	$64,588	$38,300,898
(CS-28-1) Sabine Refuge Marsh Creation, Cycle 1	214	$36,047	$7,714,071
(CS-28-3) Sabine Refuge Marsh Creation, Cycle 3	232	$65,276	$15,143,935
(PO-33) Goose Point/Point Platte Marsh Creation	566	$26,475	$14,984,787
(TV-21) East Marsh Island Marsh Creation	165	$139,548	$23,025,451
	Average Acres Created	**Average Cost per Acre**	**Average Total Cost**
	412	**$64,364**	**$23,846,410**

CPRA (In Progress)	Acres Created	Cost per Acre	Total Cost
(BA-171) Caminada Headlands Back Barrier Marsh Creation	300	$103,447	$31,034,094
(BA-173) Bayou Grande Chenier Marsh & Ridge Restoration	342	$85,102	$29,104,945
(BA-68) Grand Liard Marsh and Ridge Restoration	328	$129,816	$42,579,616
(ME-32) South Grand Chenier Marsh Creation – Baker Tract	400	$63,605	$25,441,833
	Average Acres Created	**Average Cost per Acre**	**Average Total Cost**
	343	**$95,492**	**$32,040,122**

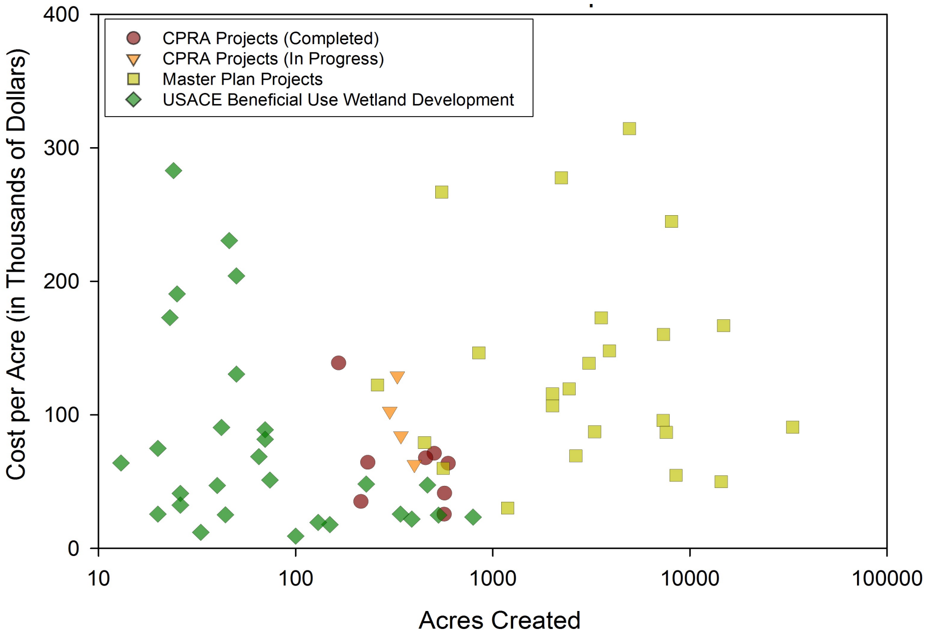

Figure 23. USACE Beneficial Use and Master Plan projects, acres created versus cost per acre.

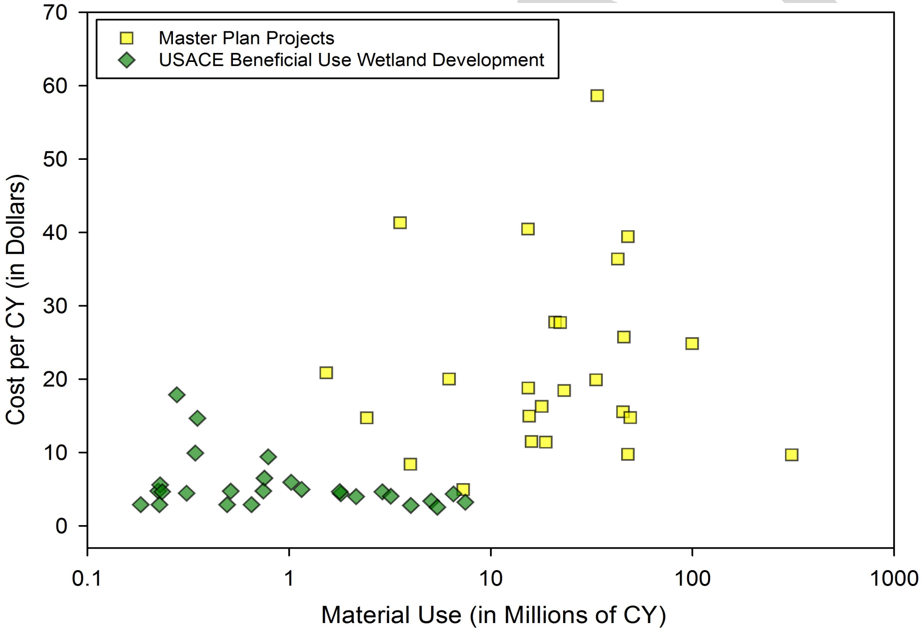

Figure 24. USACE Beneficial Use and Master Plan projects, fill volume versus cost per cubic yard.

The objectives and goals of the Master Plan Marsh Creation projects are different than the goals and objectives of the USACE Beneficial Use projects. The Master Plan seeks to create marsh in order to restore coastal habits and their associated benefits. The primary goal of the USACE Beneficial Use Program is to dispose of sediment in a cost-effective manner to aid navigation, and the creation of habitat is an added benefit of that process. Because the differences in goals including the need to create marsh in areas that would maximize benefits, sediment will likely have to be conveyed farther than the minimal distances of the USACE Beneficial Use projects. Two types of innovations could lead to cost reduction in Marsh Creation projects that involve conveying sediments over several miles from borrow to placement sites. First, any planning efforts that could be made to limit conveyance distance of sediment, while not negatively affecting the benefits and desired outcomes of projects, could serve to reduce the cost of delivering sediment to the site. These could include slight adjustments/optimization of borrow and placement site locations and their geometry, as well as optimization of the conveyance corridor itself. Second, innovations that make the process of conveying sediment more efficient could provide cost reduction. These could include optimizations of pump power systems, pipelines, sediment slurry mixtures, or other parts of the process.

USACE Rental versus Traditionally Bid Contract Analysis

An analysis was conducted to compare the cost-effectiveness of traditionally-bid unit price (cubic yard) USACE Beneficial Use projects to those that were constructed using rental, that is, leased contracts. Although rental contracts were thought to offer potential cost savings to the contracting agency, the data in this study show no significant difference, either in terms of cost per acre or cost per cubic yard, as seen in Figures 25 and 26, respectively.

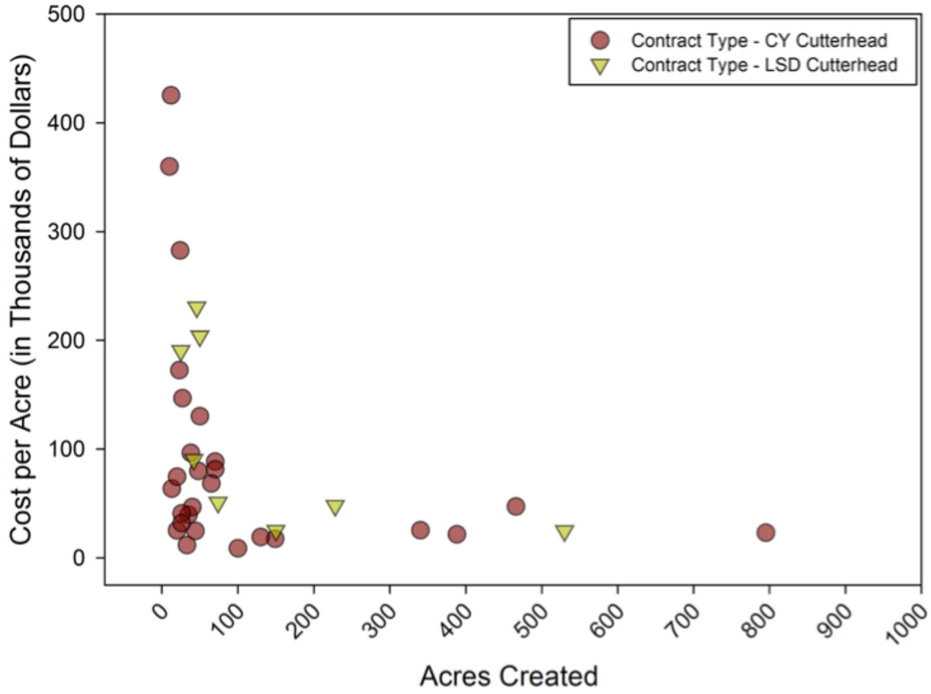

Figure 25. Leased versus cubic yard contracted dredge cost comparison, cost per acre.

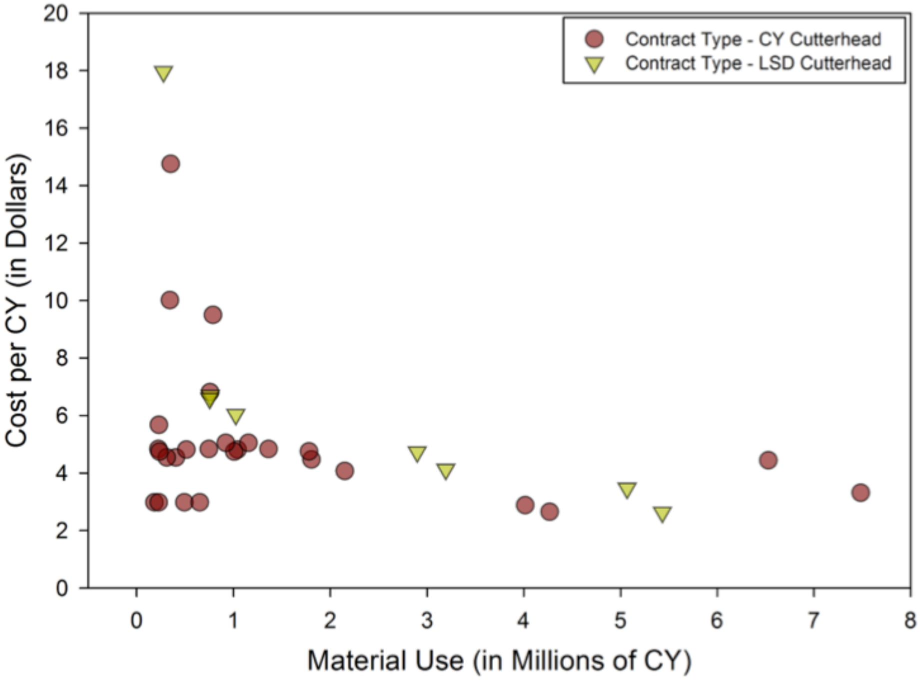

Figure 26. Leased versus cubic yard contracted dredge cost comparison, cost per cubic yard.

Effect of Dredging Technology on Land Building Cost

To study the effects of dredging technology on project cost, the USACE Beneficial Use projects were analyzed with respect to the dredging equipment used. Plots of the Beneficial Use project dredge equipment versus cost per acre and cost per cubic yard are presented in Figures 27 and 28, respectively. Two examples illustrate some key issues, and are discussed in more detail here.

First, the electric dredge *California* was used for three projects on the same contract in fiscal year 2010. All three of the projects were dredged from Baptiste Collette Bayou, a distributary channel of the Mississippi River. It is on the east side (east descending bank) of the river, 11.5 miles above Head of Passes. These projects ranged in size from 12 - 149 acres, and from 224,338 - 1,361,526 yd^3, all used entirely beneficially. One project, Willet Island, was a Bird Island. Its completed size was 12 acres, utilized 1,361,526 yd^3 of material, and was the least cost effective project, at $425, 678 per acre. Willet Island is the least cost-effective project analyzed in this study. Another project, Baptiste Collette Wetland Development "Site B," created 149 acres, at a cost of $18,747. This was one of the most cost-effective projects studied. This example shows that expected project outcomes (Bird Island vs. Wetland Development) and project planning and design can have an impact on project cost that is independent of the equipment used, when almost all other variables are held constant (e.g., contract type, equipment used, borrow source, etc.), and this effect can be significant (in this case, a factor of 22 difference in project cost). Factors that influence this include the water depth of the placement site, placement site selection with respect to using semi-enclosed embayments as natural confinement as opposed to an open water site, and the geotechnical character of the placement site. In this instance, sediment that escaped from previous unconfined or semi-confined wetland development projects adjacent to Site B led to improved load bearing of its substrate, thus enabling the creation of more land using less dredged material (USACE, pers. comm.).

Second, the diesel dredge *McCaskill*, built in 2012, was used for two projects: one in fiscal year 2012, and one in 2013, while being under the same contract. In both cases, it was used to dredge the Hopper Dredge Disposal Area (HDDA) at the Mississippi River Head of Passes, to create Wetland Development projects in the Delta National Wildlife Refuge (DNWR). One project created 70 acres at a cost of $82,448 per acre, using 787,274 yd^3 of cut material. The other project created 795 acres at a cost of $24,304 per acre, using 7,480,477 yd^3. This example shows that project size, both in terms of acres created and cubic yards utilized, can have an impact on project cost independent of the equipment utilized, and this effect can be significant (in this case, a factor of 3-4 difference in project cost.) This effect on cost is especially apparent when project size is higher than the 100-acre and 2,000,000 yd^3 thresholds. It also shows that modern, efficient equipment, when used on large projects, can deliver highly cost effective results. But the resulting cost savings can be small in magnitude, compared to the effects of choices made in project planning and design, such as determining the size of the project in the planning phase.

Expected project outcomes, project planning, and design can have an impact on project cost that is independent of the equipment used, when almost all other variables are held constant.

Project size, both in terms of acres created and cubic yards utilized, can have an impact on project cost, independent of the equipment utilized, and this effect can be significant (in this case, a factor of 3-4 difference in project cost.) This effect on cost is especially apparent when project size is greater than the 100 acres or uses more than 2,000,000 yd^3 of fill material.

Modern, efficient equipment, when used on large projects, can deliver highly cost effective results, but do not affect cost as much as project planning and design considerations (distance from borrow to placement sites, water depth at the placement site, geotechnical character of the borrow and placement sites, expected project outcomes, and project size in acres and cubic yards.

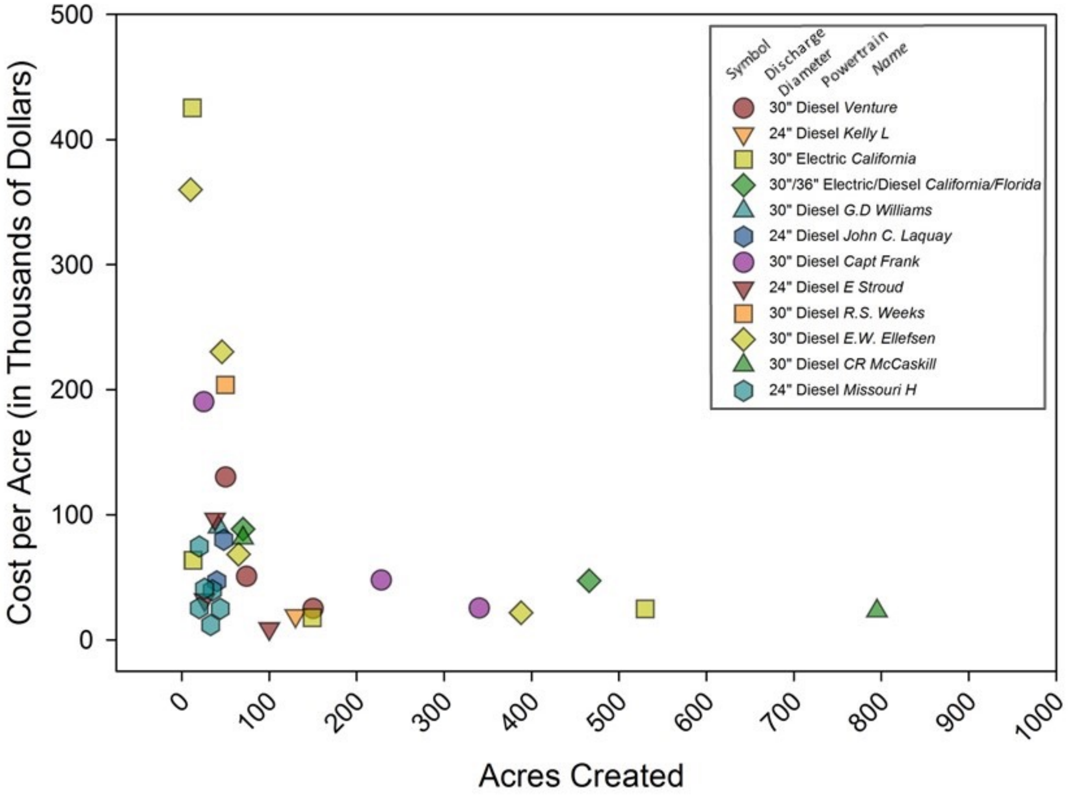

Figure 27. USACE Beneficial Use cost per acre by dredging equipment.

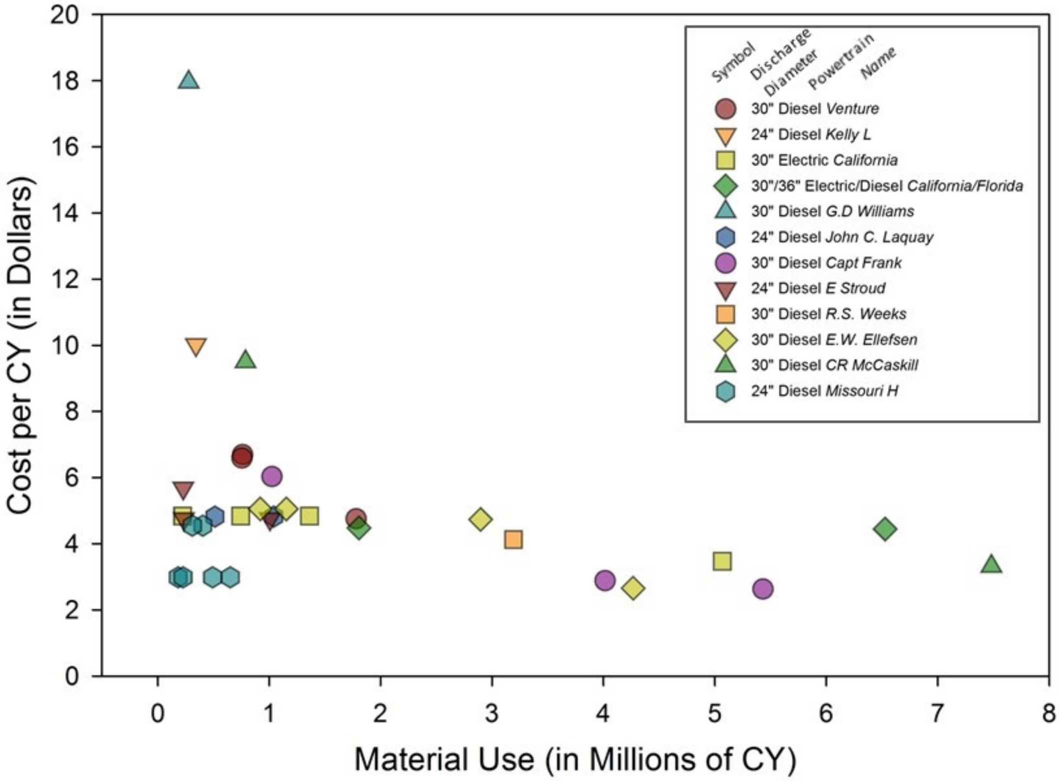

Figure 28. USACE Beneficial Use cost per cubic yard by dredging equipment.

Targeted Areas for Improved Efficiency and Cost Savings

OWNER-SUPPLIED FUEL

The Marsh Creation component of the Master Plan could potentially turn Louisiana into a major customer for the purchase of fuel.

Dredging is a highly specialized, equipment intensive, and fuel consuming process. Fuel expense is a volatile aspect of the cost of the dredging process. Fuel can represent 30% of dredging costs (Murphy, 2012). The dredging community has no control over fuel costs. Any method that can either reduce fuel costs or fuel cost risk or take fuel cost fluctuations into account can have a significant return on a dredging project. Possible methods for addressing these issues include:

- Include fuel cost escalation in contract preparation to reduce contractor risk inherent on a large percentage of the project cost estimate;
- Utilize multi- year and/or multi-event (project or project component) contracts; and
- Use owner-provided fuel.

Owner-provided fuel can reduce project costs directly by bulk purchases. Dredging companies often purchase marine fuel at a discount by purchasing in bulk, and not paying highway fuel taxes (Murphy, 2012). The owner may be able to purchase fuel more economically than the dredgers themselves, by doing the following:

- Purchasing fuel in bulk for more than one project at a time, and for more than one dredging contractor at a time (being a larger bulk customer than the dredgers themselves);
- Taking advantage of sales tax and other potential savings that are afforded to government agencies;
- Eliminating any markups that may be applied and passed on to the owner by the contractor for fuel purchases;
- Employ state-of-the art fuel management practices from other sectors (e.g., railroad, airline, and large fleet operators), including the hiring of specialized fuel management consulting companies that service these industries; and
- Owner-supplied fuel can further drive down costs by also eliminating or greatly reducing uncertainty to the contractor with respect to the cost of fuel, thereby potentially reducing the unit cost of dredging and bottom-line bid prices.

EQUIPMENT OPTIMIZATION FOR THE MASTER PLAN

The restoration of Louisiana inland marshes has specific requirements and constraints that limit the dredging technologies applicable for use. Inland marshes generally have a water depth less than four feet and nearby open waterways and channels are approximately 4-8 feet in depth. These factors limit the direct ability for certain larger dredges to access sites and employ short conveyance distances, and may require longer conveyances and the use of booster pumps to move sediments from more distal borrow sources to the shallower, less accessible areas.

The most significant improvements to dredging technologies in recent years have been to the capacity of TSHDs. The highest-capacity TSHDs are available in the European market where, due to the increase in vessel size, the TSHD production rate has increased by 400% and cost per cubic yard has decreased by 50% in the last three decades (Hollinberger, 2010). However, high capacity trailing dredges often require drafts that substantially exceed the depth limitations associated with a typical Louisiana marsh. Due to the unique environmental restrictions associated with marsh creation projects, a pontoon-based, unpowered dredge will be more likely be successful. Recent improvements in CSD design have increased cutting power, resulting in higher production rates and increased torque for dredging cemented sediments. While the current international trend is in the development of jumbo dredges, these capacity improvements could be applied domestically to CSDs and economies of scale could be realized. According to industry interviews, of the current national fleet of CSDs, the dredge which optimizes size, accessibility, and site requirements for marsh creation projects is the 20-inch CSD (Escude et al., 2011). A few technological innovations are available in this size of hydraulic dredging, including low-draft dredges, dustpan dredges, and Toyo pumps.

It is common practice for dredging equipment manufacturers to customize the design and construction of dredge equipment. In cooperation with these companies, CPRA can design dredging equipment specific to restoration needs. This can be accomplished by complementing a standard product with modifications that meet specific project conditions. Tailored equipment can provide optimum project performance. In addition, most dredge equipment companies provide technical assistance, including computerized dredge production reports, pipeline analyses, and cutter calculations to help assist with project tracking and recording.

RISK MITIGATION AND ASSIGNMENT METHODS

Dredging Contracting and Payment Methods

Traditional Bidding

The bidding method is a way to advertise for the services of a dredging contractor to construct a designed project in an open and public manner. The bidding process also notifies interested contractors of relevant project details and requirements so that they may submit a responsive bid or proposal. The standard bidding method often pays the contractor by volume of dredged material, either by the cut volume or in-place volume, in cubic yards.

Design-Build Procurement

The design-build method is the process by which a single entity provides both the design and construction of a project through one contract. Contractors are typically selected through a two-phase prequalification process.

Rental (Time and Materials)

A rental, or time and materials contract, provides for acquiring services on the basis of specified hourly rates for activities and expenses. For dredging, these contracts often specify the general type of dredging equipment necessary, a number of hours for the equipment to operate, the duration of the contract, the general geographic vicinity (e.g., body of water), and possibly the number and possible locations for work within that area. This type of contract differs from traditional bid contracts, in that it shifts some of the risk to the contracting agency by not specifying specific volumetric goals for payment. It also may limit mobilization costs between job locations, as well provide flexibility to the contracting agency to adaptively manage projects or shift resources from project to project.

Multi-Year Contract

A multiyear contract allows for the purchase of supplies or services for more than one, but typically not more than five years. This can be applied to traditional bid as well as rental contract types, and may provide cost benefits for both types.

ALTERNATIVE FILL MATERIAL PLACEMENT METHODS

Restoration using dredged materials may have benefits when combined with other restoration strategies. Creation of land terraces near inputs of water and sediment, either natural or at diversions, could increase the flowpath length, enhance the settlement of sediments in the vicinity, and create more land.

The Fort St. Phillip project area is located on the east side of the Mississippi River near Boothville in Plaquemines Parish, Louisiana. It is located at the site of the old Fort St. Phillip, across the river from Fort Jackson, approximately at mile 19 above Head of Passes. This project was intended to enhance marsh growth by diverting fresh water and sediment through six newly constructed crevasses into shallow, open-water receiving areas.

The project consisted of work in two areas. Area 1 contained 174 acres of emergent marsh and 678 acres of open water. Area 2 consisted of three triangular-shaped regions containing 126 acres of emergent marsh and 327 acres of open water. Three crevasses were constructed in each of the two areas. Earthen terraces were constructed in Area 1 to further aid in trapping sediment and promote marsh-building processes, as well as to immediately offset land loss. The project was completed in 2006 and has subsequently been monitored (ABMB, 2011).

Figure 29. An aerial view of the terracing at the Fort St. Philip restoration project (Source: Google Earth, 2012).

VERTICAL TOLERANCES IN PLACEMENT METHODS, ANCILLARY SCULPTING ACTIVITIES, AND THEIR EFFECT ON COST

A review of two recent CWPPRA project design reports were reviewed: CS-54 Cameron-Creole Watershed Grand Bayou Marsh Creation, and BA-39 Mississippi River Sediment Delivery System− Bayou Dupont. The purpose of this review was to determine the effects of vertical tolerances in placement methods and ancillary sculpting activities on project cost. The methodology for determining the appropriate design height for created marsh, and the vertical tolerances associated with the design height, were examined in the two example projects. The general design process for determining marsh elevation, based on these two reports, was to survey existing marshes in the project area, determine which one/s of those are healthy, and apply that healthy marsh elevation as the design elevation for the creation project at the end of its 20-year design life. Employing this technique yielded a design height for the CS-54 project of +1.08 feet NAVD88.

Using this elevation for the design for the marsh creation area site, settlement curves were constructed to result in an elevation as close to this value as possible at the end of the 20-year design life of the project. Next, a vertical tolerance was chosen for each project. For CS-54, the tolerance of the marsh elevation was decided to be 0.5 feet, according to the design report. For BA-39, a final, post-settlement constructed marsh fill elevation of +2.0 feet NAVD88 with a vertical construction tolerance of ±0.3 feet was chosen for the project.

After construction, the project is surveyed, and accepted, based upon the criteria below.
In the BA-39 example, the marsh must be constructed to an initial vertical elevation of 2 feet, 9 inches +/- 3 inches. Eighty-percent of the points surveyed must fall within this tolerance, or the contractor may be required to either place more fill or cut excess fill prior to final payment.

This statement was listed in the "lessons learned" section of the BA-39 Project Completion Report: "The effort required to uniformly meet the target elevation with a tight tolerance should be explored for cost reduction. Consider alternatives to rigid target elevation over the entire area that would allow flexibility to deal with placement capabilities and existing terrain." A re-examination of the survey and tolerance determination methods may be a way to drive down the cost of marsh creation projects in the future, by decreasing contractor risk. This could reflect in lower unit costs of fill material placement and bottom line bid prices.

Conclusions and Recommendations

Planning and design decisions, especially concerning the distance of conveyance from borrow site to placement site, can have very large impacts on the cost of project implementation. This is mainly due to the increased energy required to pump dredged material over increased distances. Modern, efficient equipment, when used on large projects, can deliver highly cost effective results. But the resulting cost savings can be small in magnitude when compared to the effects of conveyance distance on the overall cost of the project. The objectives and goals of the Master Plan Marsh Creation projects are different than the goals and objectives of the USACE Beneficial Use projects. The Master Plan seeks to create marsh in order to restore coastal habits and their associated benefits. The primary goal of the USACE Beneficial Use Program is to dispose of sediment in a cost-effective manner to aid navigation, and the creation of habitat is an added benefit of that process. Because the differences in goals including the need to create marsh in areas that would maximize benefits, sediment will likely have to be conveyed farther than the minimal distances of the USACE Beneficial Use projects. Two types of innovations could lead to cost reduction in Marsh Creation projects that involve conveying sediments over several miles from borrow to placement sites. First, any planning efforts that could be made to limit conveyance distance of sediment, while not negatively affecting the benefits and desired outcomes of projects, could serve to reduce the cost of delivering sediment to the site. These could include slight adjustments/optimization of borrow and placement site locations and their geometry, as well as optimization of the conveyance corridor itself. Second, innovations that make the process of conveying sediment more efficient could provide cost reduction. These could include optimizations of pump power systems, pipelines, sediment slurry mixtures, or other parts of the process.

Project size, both in terms of acres created and cubic yards utilized, can have an impact on project cost, independent of the equipment utilized, and this effect can be significant (in the case of the USACE Beneficial Use projects studied, a factor of 3-4 difference in project cost.) This effect on cost is especially apparent when project size was greater than 100 acres or used more than 2,000,000 yd3 of fill material.

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Appendices

APPENDIX I: SUMMARY TABLE OF MASTER PLAN MARSH CREATION PROJECTS

Project Number	Project Name	Implementation Period	Acres Created	Square Miles Created	Fill Volume (yd^3)	Cost per yd^3	Cost Per Acre	Cost Estimate
001.CO.01	South Lake Lery Marsh Creation	1 (2012-2031)	450	0.7	2,426,644	$14.84	$80,000	**$36,000,000**
001.MC.02	Hopedale Marsh Creation	1 (2012-2031)	550	0.9	3,551,851	$41.39	$267,273	**$147,000,000**
001.MC.05	New Orleans East Landbridge Restoration (1st Period Increment)	1 (2012-2031)	8,510	13.3	47,846,879	$9.89	$55,582	**$473,000,000**
001.MC.07a	Lake Borgne Marsh Creation-Component A	1 (2012-2031)	2,230	3.5	15,291,649	$40.55	$278,027	**$620,000,000**
001.MC.08a	Central Wetlands Marsh Creation-Component A	1 (2012-2031)	2,010	3.1	15,511,285	$15.09	$116,418	**$234,000,000**
001.MC.13	Golden Triangle Marsh Creation	1 (2012-2031)	2,440	3.8	17,873,885	$16.39	$120,082	**$293,000,000**
002.CO.01	Grand Liard Marsh/Ridge Restoration	1 (2012-2031)	560	0.9	3,986,966	$8.53	$60,714	**$34,000,000**
002.MC.05e	Large-Scale Barataria Marsh Creation-Component E (1st Period Increment)	1 (2012-2031)	8,070	12.6	33,739,636	$14.67	$61,338	**$495,000,000**

Project Number	Project Name	Implementation Period	Acres Created	Square Miles Created	Fill Volume (yd^3)	Cost per yd^3	Cost Per Acre	Cost Estimate
004.MC.01	South Grand Chenier Marsh Creation	1 (2012-2032)	7,330	11.5	45,227,932	$15.65	$96,589	**$708,000,000**
004.MC.04	Mud Lake Marsh Creation	1 (2012-2032)	3,910	6.1	20,842,745	$27.88	$148,593	**$581,000,000**
004.MC.07	West Rainey Marsh Creation	1 (2012-2032)	3,550	5.5	22,109,689	$27.82	$173,239	**$615,000,000**
004.MC.10	Southeast Calcasieu Lake Marsh Creation	1 (2012-2032)	7,600	11.9	33,267,816	$20.02	$87,632	**$666,000,000**
004.MC.13	Cameron Meadows Marsh Creation	1 (2012-2032)	3,290	5.1	15,337,513	$18.91	$88,146	**$290,000,000**
004.MC.16	East Pecan Island Marsh Creation	1 (2012-2032)	7,340	11.5	45,683,759	$25.83	$160,763	**$1,180,000,000**
004.MC.23	Calcasieu Ship Channel Marsh Creation	1 (2012-2032)	2,640	4.1	15,925,031	$11.62	$70,076	**$185,000,000**
03a.MC.03p	Terrebonne Bay Rim Marsh Creation Study PLANNING AND DESIGN ONLY.	1 (2012-2032)		0.0				
03a.MC.07	Belle Pass-Golden Meadow Marsh Creation (1st Period Increment)	1 (2012-2032)	14,420	22.5	49,213,925	$14.87	$50,763	**$732,000,000**

Project Number	Project Name	Implementation Period	Acres Created	Square Miles Created	Fill Volume (yd^3)	Cost per yd^3	Cost Per Acre	Cost Estimate
03a.MC.09b	North Terrebonne Bay Marsh Creation-Component B	1 (2012-2032)	4,940	7.7	42,635,044	$36.47	$314,777	**$1,555,000,000**
03b.MC.05	Terrebonne GIWW Marsh Creation	1 (2012-2032)	1,190	1.9	7,295,398	$5.07	$31,092	**$37,000,000**
03b.MC.07	East Rainey Marsh Creation	1 (2012-2032)	3,080	4.8	23,107,681	$18.57	$139,286	**$429,000,000**
001.MC.05	New Orleans East Landbridge Restoration (2nd Period Increment)	2 (2032-2061)	8,510	13.3	47,846,879	$39.50	$222,092	**$1,890,000,000**
001.MC.09	Biloxi Marsh Creation	2 (2032-2061)	33,280	52.0	310,441,079	$9.81	$91,526	**$3,046,000,000**
002.MC.05e	Large-Scale Barataria Marsh Creation-Component E (2nd Period Increment)	2 (2032-2061)	8,070	12.6	33,739,636	$58.68	$245,353	**$1,980,000,000**
002.MC.07	Barataria Bay Rim Marsh Creation	2 (2032-2061)	2,010	3.1	18,729,545	$11.53	$107,463	**$216,000,000**
004.MC.19	East Calcasieu Lake Marsh Creation	2 (2032-2061)	14,840	23.2	99,644,923	$24.93	$167,385	**$2,484,000,000**
004.MC.25	Kelso Bayou Marsh Creation	2 (2032-2061)	260	0.4	1,526,764	$20.96	$123,077	**$32,000,000**

Project Number	Project Name	Implementation Period	Acres Created	Square Miles Created	Fill Volume (yd^3)	Cost per yd^3	Cost Per Acre	Cost Estimate
03a.MC.07	Belle Pass-Golden Meadow Marsh Creation (2nd Period Increment	2 (2032-2061)	14,420	22.5	49,213,925	$59.48	$202,982	**$2,927,000,000**
03b.CO.01	North Lost Lake Marsh Creation	2 (2032-2061)	850	1.3	6,208,660	$20.13	$147,059	**$125,000,000**

APPENDIX II: SELECTED REFERENCES FOR CPRA PROJECTS (COMPLETE AND IN-PROGRESS)

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