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National Regional Sediment Management Program

Building Elevation in Mangrove Communities

Use of Regional Sediment Management to Increase Coastal Wetland Resilience to Sea-Level Rise

Gina Paduano Ralph, Fred Sklar, Carlos Coronado, Matthew Schrader, Stephanie Verhulst, William Reilly, and Robert Kirby

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Final report

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Abstract

This Regional Sediment Management technical report outlines initial steps to implement a proof-of-concept physical model to develop demonstration-scale evidence that supports managed wetland transgression through sediment augmentation via a thin-layer placement strategy. The proof-of-concept physical model will evaluate the ability of thin-layer placement to increase elevation and enhance recruitment within coastal scrub mangrove wetlands most vulnerable to sea-level rise. The investigation sought to identify feasible project locations, sediment sources that included beneficial use of dredged material opportunities, and environmentally acceptable construction techniques. Results of this initial step will be used to secure funding to permit, construct, implement, and monitor the proof-of-concept physical model. The results of this initiative will inform and direct management measure development for the ongoing Biscayne Bay Southeastern Everglades Restoration Project, the only coastal component of the Comprehensive Everglades Restoration Plan and the only component with an obligation to increase habitat resilience. Results are applicable to areas throughout the Gulf, Atlantic, and Pacific Coasts of the United States where direct preservation, enhancement, and restoration of mangrove and other coastal wetland communities will build coastal resiliency, reduce storm hazards damage, and create habitat for a variety of fish and wildlife species, particularly as sea levels rise.

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Preface

This study was conducted for the National Regional Sediment Management Program under Funding Account Code 6751JC; AMSCO Code 008303. The technical monitor was Dr. David W. Perkey.

The work was performed by the Planning Division, Jacksonville District, US Army Engineer Corps of Engineers (CESAJ-PD). At the time of publication of this report, Ms. Angela Dunn was chief of the Planning and Policy Division. The deputy director of the US Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), was Mr. Keith W. Flowers, and the director was Dr. Ty V. Wamsley.

The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

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1 Introduction

1.1 Background

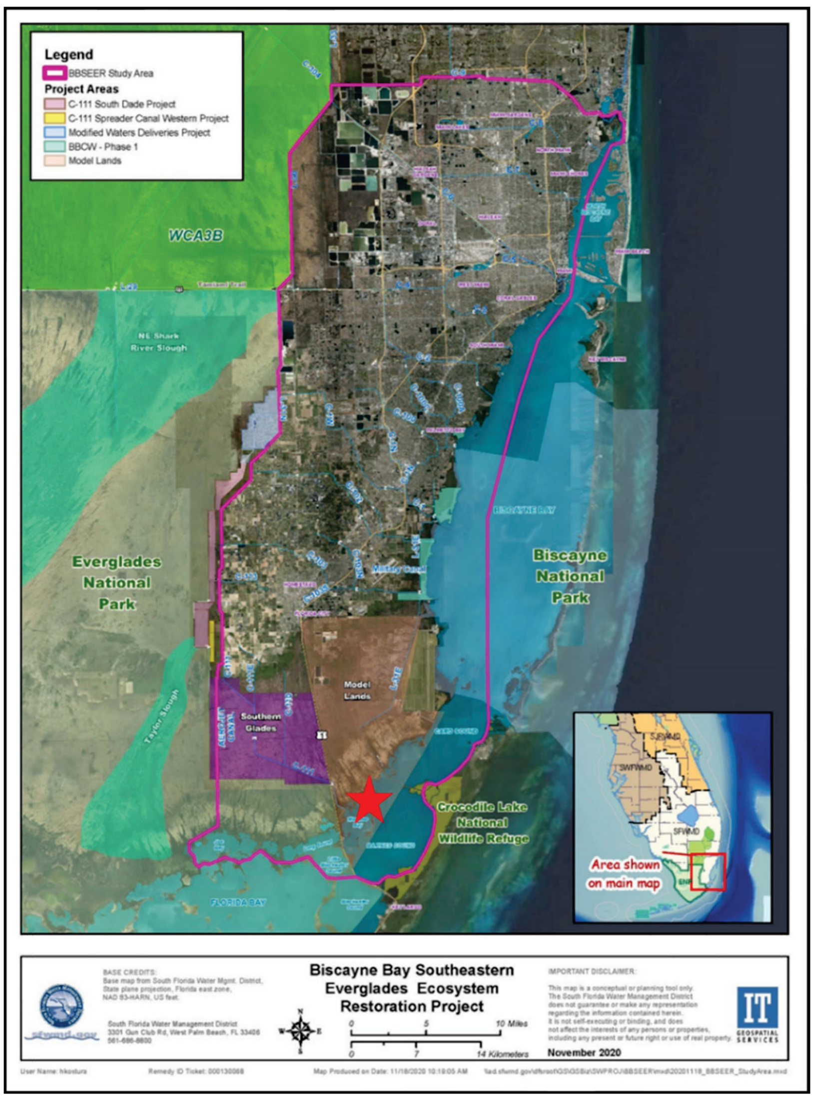
Sea-level rise (SLR) is expected to affect natural and urban areas by shifting habitats and inundating coastal developments in South Florida. Given this challenge of SLR, building resiliency within South Florida's natural communities is imperative, not only to protect an abundance of fish and wildlife species, including important recreational and commercial fisheries, but also as a means of reducing risk to the built environment from coastal storm hazards and saltwater intrusion. For coastal wetlands to exist into the future, soil accretion must match or outpace SLR. Beneficial uses of dredged material such as thin-layer placement (TLP) can build landscape resilience by increasing soil elevation, improving soil fertility, and enhancing vegetation density (DeLaune et al. 1990; Croft et al. 2006; La Peyre et al. 2009; VanZomeren and Piercy 2020).

In 2000, the US Congress authorized the federal government, in partnership with the State of Florida (South Florida Water Management District [SFWMD]) to embark upon a multidecade, multibillion dollar, Comprehensive Everglades Restoration Plan (CERP) to protect and restore the remaining Everglades ecosystem while providing for other water-related needs of the region. The purpose of CERP is to modify structural and operational components of the Central and South Florida project to achieve restoration of the Everglades and the South Florida ecosystem. Over the next 2 yr* (2023–2024), the Biscayne Bay Southeastern Everglades Ecosystem Restoration project (BBSEER), the only coastal component of CERP (Figure 1), will evaluate opportunities to incorporate water storage, active and passive water management features, water quality features, and alterations to regional water control structures (i.e., canals and levees), in its planning process. The goals of BBSEER are to (1) improve quantity, timing, and distribution of freshwater to estuarine and nearshore subtidal areas, including mangrove forests and seagrass beds; (2) improve downstream salinity regimes and reduce damaging pulse releases; (3) improve freshwater wetland water depth, ponding duration, and flow timing within the Model Lands, Southern Glades, and eastern

* For a full list of the spelled-out forms of the units of measure and unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248–52 and 345–7, respectively. https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

panhandle of Everglades National Park to maintain and improve habitat value; (4) improve ecological and hydrological connectivity between Biscayne Bay coastal wetlands, the Model Lands, and Southern Glades; and (5) increase resiliency of coastal habitats in southeastern Miami-Dade County to SLR (USACE 2021). This initiative focuses primarily on BBSEER Objective 5: increasing resiliency of coastal habitats. Demonstration-scale evidence provided through this proof-of-concept physical model will support inclusion of managed wetland transgression through sediment augmentation via a TLP strategy as a BBSEER management measure.

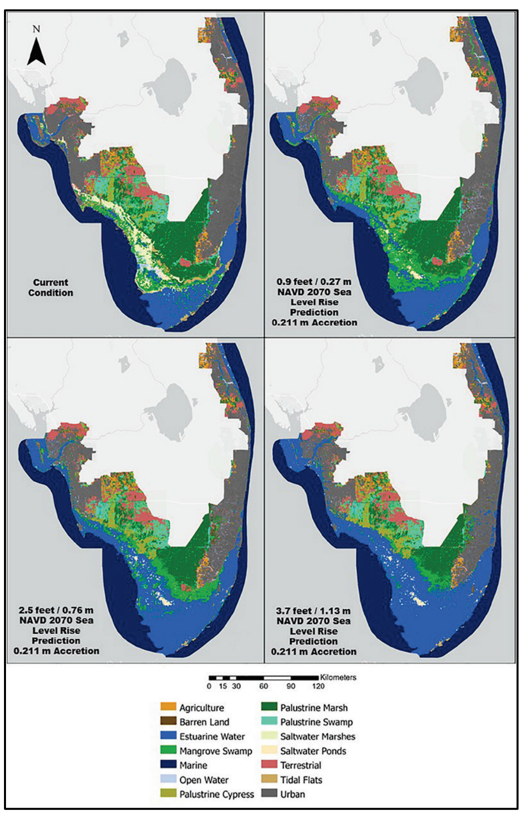
Figure 1. Location of Biscayne Bay Southeastern Everglades Ecosystem Restoration Project (BBSEER), Miami-Dade County, Florida, USA. The *red star* depicts the approximate location of the proposed thin-layer placement sites (TLP).



The coastal wetlands distributed between the freshwater Everglades, Florida Bay, and southern Biscayne Bay support a mosaic of mangrove forests, tidal creeks, salt marshes, coastal lakes, tropical hardwood hammocks, and coastal basins (Egler 1952; Ross et al. 2000). Reduction in freshwater heads and flows from the Everglades, in concert with SLR, have caused coastal wetlands to subside (Ross et al. 2000), tidal creeks to fill in (Meeder and Parkinson 2018), peat to collapse (Wilson et al. 2019), and plant communities to degrade into open water habitats (Meeder and Parkinson 2018). Mangrove forests and coastal marshes within the Everglades ecosystem rely on external inorganic sediment input (including flows from the Everglades) and autochthonous organic matter generated to maintain a vertical soil elevation that have allowed them to keep pace with SLR (McKee et al. 2007; Parkinson et al. 1994). The resilience of the coastal mangrove ecosystems to continue to keep pace with SLR and migrate upstream into brackish and freshwater habitats will depend upon the ability of the BBSEER project to provide the hydrodynamics (i.e., increased flow and hydroperiods and lower porewater salinities) and the ecological connectivity (i.e., canal and levee removal) to foster mangrove transgression and marsh transformation. Without actively reducing overdrainage, the current trajectory of SLR will continue to reduce ecosystem health, biodiversity, and resiliency. Intervention that promotes increasing soil elevation to maintain or outpace SLR in key coastal communities (e.g., those adjacent to historic tidal creeks) will result in a myriad of ecosystem benefits, including mangrove growth, habitat expansion for wildlife, and storm-damage reduction. To plan for a sustainable South Florida ecosystem, it is important to identify ecological vulnerabilities to SLR and ask how one might direct Everglades restoration and water management to minimize saltwater intrusion, peat collapse (Sklar et al. 2019; Sklar et al. 2021) and land loss. Based upon projections over the next 50 yr, SLR will threaten the structure and function of coastal wetlands in South Florida (COMPACT 2019); rising at rates that will inundate most lowlands distributed along the coasts (Ross et al. 2000; Sweet et al. 2017; Sklar et al. 2019).

Wetlands with relatively high freshwater inputs and clear hydraulic connectivity to coastal bays and marshes, such as Taylor Slough, can keep up with modest rates of SLR (Sklar et al. 2021). However, in the southeast areas of the Model Lands, Southern Glades, and Eastern Panhandle of Everglades National Park, recent projections of accelerated rate of sea-level change means that soil accretion may need to be 5 to 10 times higher than the observed rates in previous years. Without intervention, the BBSEER coastal wetlands will probably accrete less than 2 mm/yr. (Sklar et al. 2021) and will not be able to overcome even a low SLR scenario (Figure 2). In a future with TLP and improved hydrology, accretion could reach 4–6 mm/yr, which means that BBSEER coastal wetlands would be able to overcome low or intermediate rates of SLR, with only a fraction of the study area transitioning from wetland cover to open water in the next 50 yr (Sklar et al. 2021). Local experts suggest that, in a future with continued freshwater starvation, the transitional marshes and the scrub mangroves could move 6 to 10 mi farther inland over the next 30 to 50 yr (Ross et al. 2000; Meeder and Parkinson 2018). Without some intervention, such as TLP, this expansion could increase soil subsidence, ponding, and exacerbation of the effects of coastal storm hazards.

Figure 2. Habitat transition model results using a wetland accretion rate of 4.2 mm yr^{-1}. (*A*) Current habitat distribution; (*B*) projected habitat distribution by 2070 with a sea-level rise (SLR) of 0.27 m (0.9 ft); (*C*) projected habitat distribution by 2070 with a sea-level rise (SLR) of 0.76 m (2.5 ft); (*D*) projected habitat distribution by 2070 with an SLR of 1.1 m (3.7 ft). (Image reproduced with permission from Sklar et al. 2021.)



Several previous demonstration projects have highlighted the success of TLP in restoration of coastal communities, primarily within salt marshes along the Atlantic coast and Louisiana (DeLaune et al. 1990; Croft et al. 2006; La Peyre et al. 2009; VanZomeren et al. 2018; VanZomeren and Piercy 2020). However, there is little information pertaining to the application of TLP within mangrove communities. Sedimentation thresholds are not fully understood for mangrove survival, yet reduced growth and mangrove death can occur when aerial roots are buried by sedimentation, with the severity of the impact depending on amount and type of sediment and mangrove species (Ellison 1998).

Mangrove forests are found in areas where sedimentation is possible from both terrestrial sources and marine movement of material. Within the study area, sediment and nutrient limitations do not allow for adequate accretion to keep pace with SLR. Mangrove species have varying tolerances for water depth and thus elevation is a determinant of species diversity and spatial distribution along the coast. A change in sea level can therefore translate to changes throughout the mangrove ecosystem.

Mangrove communities experience daily tidal cycles and extreme weather events. Castaneda-Moya et al. (2020) underscore the ability of hurricanes and large storm events to create beneficial nutrient-rich sediment deposits in mangrove forests that increase productivity and resilience through internal feedback mechanisms. These deposits release trees from nutrient limitations and stimulated productivity (Castaneda-Moya et al. 2020). In addition, Liu et al. (2021) findings reveal that mangroves that are higher within the tidal frame are better able to retain sediment primarily due to a correlation between rates of accretion and elevation change with total suspended matter within the water. Accretion for elevation gain is related to sediment inputs and resuspension. The information gained from these studies, along with the success of TLP in salt marshes, suggests that actions such as TLP, combined with plantings, can enhance wetlands by trapping additional material for accretion, reduce water velocity, and stabilize sediments creating positive feedback loops (Liu et al. 2021).

To determine whether TLP is a viable management measure to build elevation in mangrove communities by jumpstarting internal mechanisms of peat accretion, SFWMD (CERP's nonfederal sponsor) will implement the Everglades Mangrove Migration Assessment (EMMA) plan. EMMA is a large-scale field manipulation of sediment designed to enhance the resilience of coastal mangroves. EMMA represents a nature-based solution that will increase mangrove soil elevation, promote vegetative growth, and provide coastal storm hazard protection. SFWMD is seeking funding from the Florida Department of Environmental Protection to design, permit, construct, and monitor EMMA. The US Army Corps of Engineers (USACE), Jacksonville District (SAJ), Regional Sediment Management (RSM), effort will inform aspects of EMMA and is considered the initial step in the implementation process.

1.2 Objective

The primary objective of this initial step is to identify feasible project locations, sediment sources, and environmentally acceptable construction techniques to support permit application to implement the proof-of-concept physical model (i.e., EMMA). Results of this initial step will be used to secure funding sources for final design, permitting, construction, and monitoring the proof-of-concept physical model. Leveraging this initial coordination with multiple stakeholders and work by others, the project is intended to advance understanding of the following issues and challenges:

- viability of TLP as a method to maintain ecosystem function of mangrove wetlands
- improved understanding of TLP applications in mangrove wetlands
- methods, logistics, and costs involved with TLP in mangrove wetlands
- options to beneficially use dredged material as well as other sediment sources
- understanding of mangrove wetland benefits to coastal storm risk management. While this is not an explicit goal of the effort, collaboration with USACE and potentially additional stakeholders will be included to inform ongoing and future efforts related to natural and nature-based features functions of mangrove wetlands

Sediment will be placed at target elevations within selected sites to identify (1) whether TLP is a viable option to build elevation and increase the adaptive capacity of coastal wetlands to SLR and (2) whether TLP can also promote biological processes of peat accretion (i.e., root growth, organic matter, and carbon sequestration) within coastal wetlands, including mangrove communities. The results of this project will also inform and direct management measure development for the ongoing BBSEER project. If shown to be successful, TLP can potentially be applied at a larger scale to select locations within BBSEER as a management measure to increase spatial extent of wetlands, promote habitat for fish and wildlife species, improve resiliency to SLR, reduce effects of coastal storm hazards, and manage risk to the human environment from related damages.

1.3 Approach

The approach taken for this initial step was designed to identify information needed to support permit application to construct and implement the proof-of-concept physical model. The approach consisted of four main tasks. A brief description of each task, along with the benefits and products of each task, are outlined in the following:

1. Task 1: Partner and Stakeholder Coordination Workshops
    a. Description: Six Partner and Stakeholder Coordination Workshops were held to develop and finalize the conceptual design, select potential plots, define quantity and quality of sediment necessary to achieve desired results, and identify environmentally acceptable construction techniques.
    b. Benefits: Coordination and input from partners and stakeholders were essential for the success of this proof-of-concept physical model. These coordination workshops allowed the SAJ-RSM team to obtain valuable information from local agencies, academia, RSM practitioners, and the public to ensure the effort supports local, state, and USACE RSM strategies.
    c. Products: Workshop presentations and summaries.
2. Task 2: Literature Search and Coordination
    a. Description: Conduct a literature search on TLP within estuarine communities to define sediment characteristics and application depths necessary for estuarine restoration. This task also included coordination with permitting agencies to gather information on permitting requirements.
    b. Benefits: This information was used to finalize the proof-of-concept physical model conceptual design and support permit application for construction and implementation of the proof-of-concept physical model.
    c. Products: Annotated bibliography.

3. Task 3: Identification of TLP Sediment Sources
    a. Description: This task included coordination with RSM practitioners to identify appropriate sediment sources for TLP application within the proof-of-concept physical model. This task also defined the cost and methodology for transport of the selected source to the proof-of-concept physical model site.
    b. Benefits: This information was used to finalize the proof-of-concept physical model conceptual design and support permit application for construction and implementation of the proof-of-concept physical model.
    c. Products: Sediment Matrix, Initial Cost Estimate.

4. Task 4: Technical Transfer and Presentation of Findings
    a. Description: This task included documentation and presentation of the conceptual design within a technical report. In addition, the SAJ-RSM team developed a funding proposal for the final design, permitting, construction, and monitoring of the proof-of-concept physical model (i.e., EMMA). The SAJ-RSM team will present the results of this initiative at the RSM National In-Progress Review in November 2022. Technical transfer opportunities also include an SFWMD newsletter article, poster submission for the Restore America's Estuaries Conference (December 2022), and presentation at the 2023 Greater Everglades Ecosystem Restoration Conference (https://conference.ifas.ufl.edu/geer/, April 2023).
    b. Benefits: Dissemination of information to professional peers; opportunity to build on this initiative with future funding.
    c. Products: The products of Task 4 included a technical report, an associated presentation to the RSM Team, permit application requirements, and a proposal for funding of future design, construction, and monitoring of the proposed proof-of-concept physical model. Potential funding sources include Florida Department of Environmental Protection and the US Environmental Protection Agency.

2 Planning Framework

2.1 Stakeholder Education—Setting the Stage for Success

The majority of project stakeholders are deeply invested and involved in CERP, participating regularly in multiagency project delivery teams for CERP planning and implementation. However, the majority of these key CERP stakeholders are unaware or only vaguely aware of the other USACE mission areas, including navigation and coastal storm risk management. Thus, the first order of business was to educate stakeholders concerning beneficial use and RSM practices. To accomplish this objective, the first workshop was intended to provide an overview of RSM, introduce the proof-of-concept physical model purposes, introduce SAJ-RSM Team members, and obtain valuable information from local agencies, academia, and RSM practitioners to ensure the effort supports USACE RSM strategies and aligns with local and state resiliency initiatives. In addition, the first workshop also provided a forum for interaction with the US Army Engineer Research and Development Center (ERDC) scientists to convey the state of the science as related to use of TLP in mangrove environments. In fact, little information is available from previous efforts in mangrove communities, and this is an area of study ripe with opportunities to understand how TLP might affect mangrove communities and whether it is a viable tool to build resiliency. Additional workshops focused on design elements such as selection of sediment source and identification of environmentally acceptable construction techniques.

Another goal of the stakeholder engagements was to ensure that regulatory agencies were involved at project initiation and throughout the conceptual design process. In previous RSM efforts, the regulatory permitting process has been challenging; therefore, regulatory partners were included in all workshops to ensure that all required regulatory permits could be obtained to implement the proof-of-concept physical model. This ongoing, open, and transparent coordination with stakeholders and regulatory personnel was key to informing the conceptual design. Permitting requirements became a fundamental factor that guided most aspects of the project, from site identification to experimental design to sediment source identification. Another regulatory challenge was reframing the regulatory discourse that in all circumstances, adding sediment to wetlands is ecologically detrimental. In some circumstances, as is the case with this proof-of-concept physical model, this established notion needs to be challenged, especially in areas most vulnerable to SLR. In the case of this proof-of-concept physical model, if no intervention is implemented, the sites will transgress to an open-water community where the structure and function of the existing community is lost forever. The fact that the sites will be irrevocably altered in the future assisted to reframe the existing mindset and allow regulatory personnel to view the project in a more favorable light, congruent with ecosystem restoration.

2.2 Site Identification

Reconnaissance surveys were performed using aerial imagery to identify an initial suite of potential project locations for further field investigation. Criteria used to select the initial suite of sites included location within the BBSEER Project footprint, proximity to Biscayne Bay (Biscayne Bay Aquatic Preserve and Biscayne Bay National Park), proximity to potential sediment sources, density of existing mangroves, access, containment, ownership, and local knowledge. Field investigations were then conducted to obtain additional information in order to determine the final project locations.

The SAJ-RSM Team hosted a field visit with members of SFWMD, regulatory agencies (Florida Department of Environmental Protection and Miami-Dade County), academia (Florida International University), and Florida Power and Light. The field visit included an aerial overflight via helicopter (services provided by SFWMD), identification and sampling of potential sediment sources, identification of potential staging areas and construction routes, and discussions with key regulatory personnel. A video of the area was captured during the aerial overflight (SFWMD, n.d.) The field visit commenced with the helicopter overflight to provide an unobscured aerial overview of potential project sites and allow for ground-truthing of aerial imagery used for initial site selection. The team then traveled via vehicle and foot to explore sites along Canal 111 (C-111) and Levee 31 East (L-31E) to further evaluate potential sites based upon the established site-selection criteria. As part of the field visit, members of the SAJ-RSM Team also collected sediment samples from locations within the C-111, Intracoastal Waterway (IWW), and Biscayne Bay for subsequent laboratory testing and analysis.

Following aerial and land-based ground-truthing efforts, final project locations were determined by three key factors: real estate and land ownership, density of existing mangroves, and access. Two sites were selected: the Charley Site and the S-197 Pocket (Figure 3). The Charley Site is located on the east side of the C-111 levee, is in the process of being acquired by Miami-Dade County, and is directly adjacent to the proposed sediment source. The S-197 Pocket is located on the west of the C-111 between the levee and US Highway 1. The S-197 Pocket is owned by SFWMD and is upstream of the proposed sediment source. Additionally, both sites feature topography and constructed features (e.g., spoil piles and dirt maintenance road adjacent to C-111) that can serve to contain the placed sediment, potentially reducing the need for added containment during construction to attain target elevations and manage turbidity impacts in adjacent waters.

Figure 3. Location of the Jacksonville District (SAJ), Regional Sediment Management (RSM), project sites in Miami-Dade County, Florida. The *red star* depicts the approximate location of the two placement sites. Site 1: Charley Site is outlined in *yellow* in the *bottom-right figure*, and Site 2: S-197 Pocket is the *green square* in the *top-left panel*.

2.3 Sediment Source

To identify a sediment source for the proof-of-concept physical model, the SAJ-RSM Team compiled a matrix of federally authorized navigation projects in southeast and east-central Florida with the potential to supply sediment. Figure 4 displays a draft version of the sediment source list and locations conveying the broad nature of the sediment search. Navigation sources included channels as well as upland dredged-material management areas. Upland quarries and additional sediment sources were added to the matrix in coordination with stakeholders through the workshop process. The sediment sources were placed within a sediment matrix, evaluated, and ranked based upon selected criteria including distance (in miles) from the project location, transportation method, sediment quality, sediment quantity, and renewability of the sediment source (Table 1). Sediment-source evaluation was approached from two perspectives of scale: the proof-of-concept physical model scale and the larger scale of BBSEER (potential management measure). The key differences between the two scales were being a much smaller volume of sediment needed and less significance placed on transportation costs for the proof-of-concept physical model scale. Sediment quantity and renewability of the sediment source were important considerations in the evaluation at the BBSEER scale. In addition, at the BBSEER scale, distance of the sediment source from the placement site was also an important criterion, both for cost considerations and ease of use for the larger-scale application.

The sediment source matrix was shared with stakeholders at a workshop and based upon feedback received, two additional categories were added: (1) constructability and (2) environmental considerations. Constructability was added to address the concern of sediment transport, how easy it would be to acquire (e.g., through dredging) and transport (e.g., truck haul, hydraulic transport via pipeline) the sediment to the placement location. Environmental considerations were added to denote the concern that the presence of environmental resources may impact the ability to either access sediment at a source or obstruct transport from the sediment source to the placement sites. For example, areas within the IWW in the vicinity of the project have not been dredged for some time, and thus, seagrasses have established within the channel, increasing regulatory hurdles that would have to be overcome. Additionally, seagrasses are located between the IWW and the placement sites limiting transport options of sediment via submerged pipeline from the IWW. Although there are other methods to transport the sediment (e.g., scow barge), at the proof-of-concept physical model scale, this additional factor reduced the IWW's ranking; however, at the larger BBSEER scale, as a renewable sediment resource, the IWW would still be considered.

Figure 4. Draft potential sediment source list and locations for use in the SAJ-RSM proof-of-concept physical model (DMMA = Dredged Material Management Area; IWW = Intracoastal Waterway).

	Sediment Source
1	Miami Harbor (inside)
2	Ocean Reef Club (Marina and Waterways
3	IWW (Key Lago)
4	Barnes and Card Sound
5	Port Everglades
6	Canaveral Harbor
7	Tributaries/tidal creeks near placement sites
8	IWW Miami to Crossbank
9	Miami River
10	Canaveral Barge Canal
11	EAA (Belle Glade) upland
12	Relic Borrow Areas off-shore Miami Dade
13	Weston Reservoir
14	DMMA-M-8
15	Palm Beach Harbor (Turning Basin)
16	Bluewater Quarry, Florida City (upland)
17	Virginia Key DMMA
18	DMMA O-7
19	IWW Jupiter (Pam Beach County)
20	IWW (St Lucie County)
21	DMMA-MSA M-5
22	DMMA-PB-PI
23	DMMA- 641 A
24	Florida Power & Light (FPL) drainage canal
25	C-111 canal
26	Hole in the Donut Mitigation Site, Everglades National Park
27	Hypothetical Source 1: Sediment quality mix (combination of sources for desired sediment quality).
28	Hypothetical Source 2: Sediment volume mix (combination of small volume sources to achieve desired volume.)
29	Hypothetical Source 3: Miami Dade DERM source for Wetland Restoration (mentioned by DERM at Workshop #1)

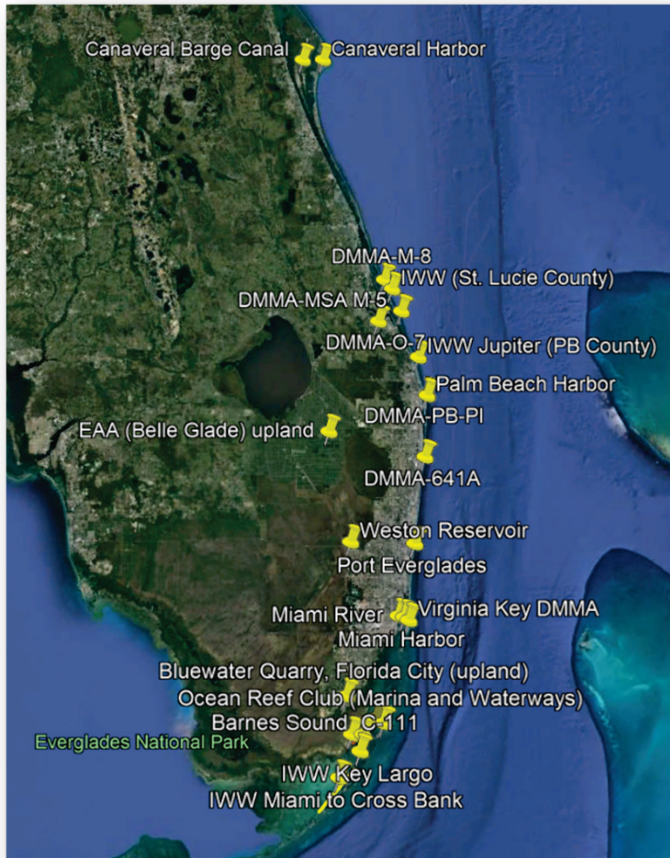


Table 1. Final sediment source matrix rankings of potential sources of sediment for the proof-of-concept physical model and scale-up Biscayne Bay Everglades Ecosystem Restoration (BBSEER) scale.

Sediment Source	Sediment Quality						Environmental Considerations		Quantity Estimate		Proof-of-Concept totals	
	Silt		Clay Content		Organic Matter		Comment	Rank	Cu Yd	Rank	Total Pilot Rank	Total Pilot Rank Adjusted per Significance
	%	Rank	%	Rank	%	Rank						
Port Everglades	30%–50%	1	<10%	1	0%–10%	4	–	1	100,000	1	8	12
Miami Harbor (inside)	30%–70%	1	<10%	1	unknown	4	–	1	100,000	1	8	12
Canaveral Barge Canal	30%–90%	1	<10%	1	unknown	4	–	1	100,000	1	8	12
Palm Beach Harbor (Turning Basin)	20%	2	0%	1	unknown	4	–	1	100,000	1	9	14
C-111 spoil mounds (80% crushed limestone and 20% silt)	20%–30%	2	<10%	1	0%–5%	4	–	1	3,000	1	9	14
DMMA-M-8	30%–70%	1	<10%	1	unknown	4	–	2	80,000	1	9	15
Bluewater Quarry, Florida City (upland)	10%	3	0%	1	unknown	4	–	1	>500,000	1	10	16
IWW Jupiter (Pam Beach County)	10%	3	0%	1	unknown	4	–	1	100,000	1	10	16
IWW (St Lucie County)	10%	3	0%	1	unknown	4	–	1	100,000	1	10	16
Unusable Borrow Areas off-shore Miami Dade	20%–30%	2	0%	1	unknown	4	–	2	>400,000	1	10	17
Canaveral Harbor	30%–90%	1	<10%–60%	4	unknown	4	–	1	200,000	1	11	18
DMMA O-7	0%–10%	3	0%	1	unknown	4	–	2	560,000	1	11	19
DMMA- Material Storage Area (MSA) M-5	0%–10%	3	0%	1	unknown	4	–	2	260,000	1	11	19
DMMA-Palm Beach (PB)-PI	10%–20%	3	0%	1	unknown	4	–	2	200,000	1	11	19
DMMA- 641 A	10%–20%	3	0%	1	unknown	4	–	2	60,000	1	11	19
EAA (Belle Glade) upland	30%–70%	1	0-50%	4	10%–20%	4	–	2	500,000	1	12	21
Barnes and Card Sound	40%	1	<10%	1	10%–20%	4	seagrass	4	100,000	1	11	21
IWW (Key Lago)	80%–90%	3	<10%	1	10%–20%	4	seagrass	4	100,000	1	13	25
C-111 canal	80%–90%	3	<10%	1	10%–20%	4	–	2	unknown	–	–	–
Weston Reservoir	50%	1	unknown	–	unknown	4	–	2	400,000	1	–	–
Virginia Key DMMA	sand, rock, silt	–	0%	1	unknown	4	–	2	150,000	1	–	–
Florida Power and Light (FPL) drainage canal	unknown	–	unknown	–	unknown	4	–	2	unknown	–	–	–
L-31	80%–90%	3	40%–60%	4	10%–20%	4	–	2	unknown	–	–	–
IWW Miami to Crossbank	50%–90%	1	unknown	–	unknown	4	seagrass	4	100,000	1	–	–
Miami River	20%–50%	2	unknown	–	unknown	4	–	2	100,000 (?)	1	–	–
Ocean Reef Club (Marina and Waterways	60%–90%	1	unknown	–	unknown	4	–	2	10,000	1	–	–
Tributaries/tidal creeks near placement sites	unknown	–	unknown	–	unknown	4	seagrass	4	unknown	–	–	–
Hole in the Donut Mitigation Site, Everglades National Park	unknown	–	unknown	–	unknown	4	–	–	2,200,000	1	–	–
Hypothetical Source 1: Sediment quality mix (combination of sources for desired sediment quality).	unknown	–	unknown	–	unknown	4	–	–	–	–	–	–
Hypothetical Source 2: Sediment volume mix (combination of small volume sources to achieve desired volume.)	unknown	–	unknown	–	unknown	4	–	–	–	–	–	–

Table 1 (cont.). Final sediment source matrix rankings of potential sources of sediment for the proof-of-concept physical model and scale-up BBSEER scale.

Sediment Source	Quantity Estimate		Distance		Transportation		Renewable		BBSEER TOTALS	
									Total Scale-Up Rank	Total Scale-Up Rank Adjusted per Significance
–	Cu Yd	RANK	Miles	Rank	Type	Rank	Years	Rank		
Port Everglades	100,000	3	70	3	barge	2	5	2	18	25
Miami Harbor (inside)	100,000	3	35	2	barge	2	7	2	17	23
Canaveral Barge Canal	100,000	3	280	4	barge	2	10	2	19	27
Palm Beach Harbor (Turning Basin)	100,000	4	135	4	barge	2	5	2	21	30
C-111 spoil mounds (80% crushed limestone and 20% silt)	3,000	4	1	1	Conveyor or pump	1	no	4	19	25
DMMA-M-8	80,000	4	200	4	Truck or barge	2	>10	3	22	32
Bluewater Quarry, Florida City (upland)	>500,000	1	10	2	truck	1	no	4	18	26
IWW Jupiter (Pam Beach County)	100,000	3	130	4	barge	2	7	2	21	31
IWW (St Lucie County)	100,000	3	200	4	barge	2	7	2	21	31
Unusable Borrow Areas off-shore Miami Dade	>400,000	1	40-50	3	barge	2	no	4	20	30
Canaveral Harbor	200,000	2	280	4	barge	2	4	1	20	31
DMMA O-7	560,000	1	150	4	Truck or barge	2	>10	3	21	33
DMMA-MSA M-5	260,000	2	150	4	Truck or barge	2	>10	3	22	34
DMMA-PB-PI	200,000	2	135	4	Truck or barge	2	>10	3	22	34
DMMA- 641 A	60,000	4	80	3	Truck or barge	2	no	4	24	35
Everglades Agricultural Area (Belle Glade) upland	500,000	1	125	4	truck	3	no	4	24	37
Barnes and Card Sound	100,000	3	1	1	pump	1	15	3	19	30
IWW (Key Lago)	100,000	3	1	1	pump	1	15	3	21	34
C-111 canal	unknown	–	1	1	–	–	–	–	–	–
Weston Reservoir	400,000	1	100	4	truck	3	no	4	–	–
Virginia Key DMMA	150,000	3	35	2	barge	2	no	4	–	–
FPL drainage canal	unknown	–	1	1	–	–	–	–	–	–
L-31	unknown	–	1	1	–	–	–	–	–	–
IWW Miami to Crossbank	100,000	3	20-30	2	barge	2	15	3	–	–
Miami River	100,000 (?)	3	35	2	barge	2	20	3	–	–
Ocean Reef Club (Marina and Waterways	10,000	4	1	1	pump	1	5	2	–	–
Tributaries and tidal creeks near placement sites	30,000	4	1	1	pump	1	15	3	–	–
Hole in the Donut Mitigation Site, Everglades National Park	2,200,000	1	30	2	truck	3	no	–	–	–
Hypothetical Source 1: Sediment quality mix (combination of sources for desired sediment quality).	–	–	–	–	–	–	–	–	–	–
Hypothetical Source 2: Sediment volume mix (combination of small volume sources to achieve desired volume.)	–	–	–	–	–	–	–	–	–	–

Table 1 (cont.). Final sediment source matrix rankings of potential sources of sediment for the proof-of-concept physical model and scale-up BBSEER scale.

Reasoning for Ranking	Desired sediment quality is sand with 50% silt. Organic and phosphorus content is desirable.	Less than 10% ideal	Higher organic content is desirable.	Qualitative measure of how the presence of environmental resources (e.g., seagrass, reef) may impact the ability to use a source or transport sediment to placement sites.	The volume for the Pilot Project is approximately 8,200–12,500 cu yd (all four sites). All sources have more than 8,000 cu yd, so all are rank = 1.	Sources with a greater available quantity are ranked higher.	Currently considered to be the most important cost criterion and given 2× weight. Proximity to the placement area is desirable. Costs increase with distance.	Pumping is the most effective method, followed by barging. Truck hauling is costly and requires double handling of the material.	Renewable sediment sources are important to potential future scaling up of the pilot and periodic placements. Sources with short renewability cycles are desired for continuing sediment availability.
Criteria Significance	2×	2×	1×	3×	1×	1× (Scale up only)	2× (Scale up only)	1× (Scale up only)	1× (Scale up only)
Ranks	Silt (%)	Clay (%)	–	Scale of impact (based on source)	Volume cu yd	Volume cu yd	Distance miles	Means of transportation	Renewable years
1	40%–79%	<10%	<60%–80%	1 (potential impacts unlikely)	>8,000	>400,000	0–5	pump	<5
2	20%–39%	NA	<40%–60%	2 (unknown but unlikely potential impacts)	6,000–8,000	200,000–400,000	5–35	barge	5–10
3	80%–100%, 0%–19%	NA	<20%–40%	na	2,400–6,000	100,000–200,000	35–100	truck	>10
4	na	>10%	<0%–20%	4 (potential impacts or presence of environmental resources)	<2,400	<100,000	>100	–	Not Renewable

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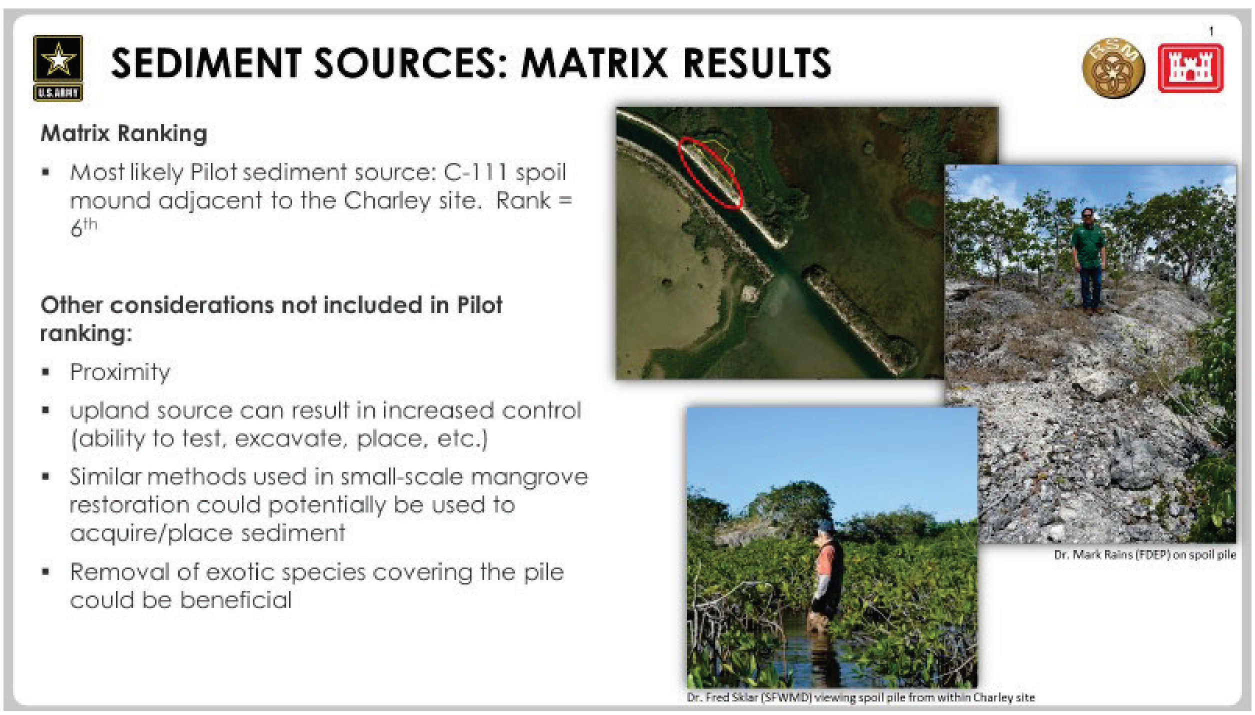
Another criterion of significant discussion among stakeholders was the nutrient content of the sediment source. Mangrove communities within the BBSEER project area are nutrient limited, suffering from lack of freshwater flow due to the extensive compartmentalization and structurization of water flow within the area (Ross et al. 2000). In the 1970s, canal construction and associated water-management operations conducted south of the Tamiami Trail, as part of the South Dade Conveyance System, greatly impacted freshwater flow to freshwater and coastal wetlands in the southeastern part of the peninsula (Sklar et al. 2019). The resulting manipulation of canal water levels and flows have had direct effects on the depth of water and duration of inundation within the freshwater and coastal wetlands. This manipulation, along with encroachment of a rising sea, has reduced the areal extent of freshwater vegetation communities within these wetlands leading to a decline in the quality of habitat that they provide. Most noticeable of the phenomena of altered sheet flow is the expansion of a White Zone (Ross et al. 2000; Meeder and Parkinson 2018). Coastal White Zone occurs in lowland areas inland from normal tide influence where limited freshwater flow is present. The zone’s name comes from its light color as seen from the air or in aerial photographs. Productivity in White Zones is notably low compared to other coastal communities and especially compared to fringe and riverine mangrove communities (Sklar et al. 2021). Adding sediment with high nutrient concentrations (primarily nitrogen and phosphorus) could further promote internal mechanisms of peat accretion within the mangrove communities (Wilson et al. 2022).

From the regulatory perspective, nutrient content was a cause for concern based upon potential containment issues and the proximity of the project sites to Biscayne Bay National Park, Biscayne Bay Natural Aquatica Preserve and the Florida Keys National Marine Sanctuary. Nutrient enrichment in these areas results in increased potential for algal blooms leading to reduction in seagrass communities and impacts to wildlife resources. Concern with nutrient enrichment of the coastal waters was counterbalanced by the knowledge that mangroves within the BBSEER restoration footprint are nutrient limited and that an increase in elevation alone may not allow these areas to accrete at a rate necessary to offset SLR. In the end, the SAJ-RSM team determined that the initial focus for the proof-of-concept physical model would be limited to elevation (i.e., reduce covariables) and that in a future project phase, varying doses of nutrient enrichment could be assessed.

Miami-Dade County provided the SAJ-RSM Team an overview of a 2012 mangrove mitigation enhancement project that employed TLP. The purposes of the Miami-Dade County project were to address erosion and enhance a failing mitigation project. The project utilized sediment from an adjacent spoil mound which consisted of dredged material from canal construction. The material was processed and screened on-site, then placed using a high-speed conveyor sand shooter depositing a thin layer of dry (i.e., not hydrated) material throughout the placement site to a defined elevation. The fact that Miami-Dade County had previously permitted this type of sediment for wetland fill, along with the expressed request from Miami-Dade County to use canal spoil material, led the SAJ-RSM Team to consider spoil mounds adjacent to the proposed project sites as sediment sources. Canal spoil material is ranked fifth in the sediment matrix (Table 1) and its proximity to the placement site and added benefit of exotic removal resulting from its use ultimately contributed to its selection as the preferred source for the proof-of-concept physical model. Figure 5 displays the spoil pile sediment source adjacent to the Charley placement site. A similar spoil pile exists adjacent to the S-197 Pocket.

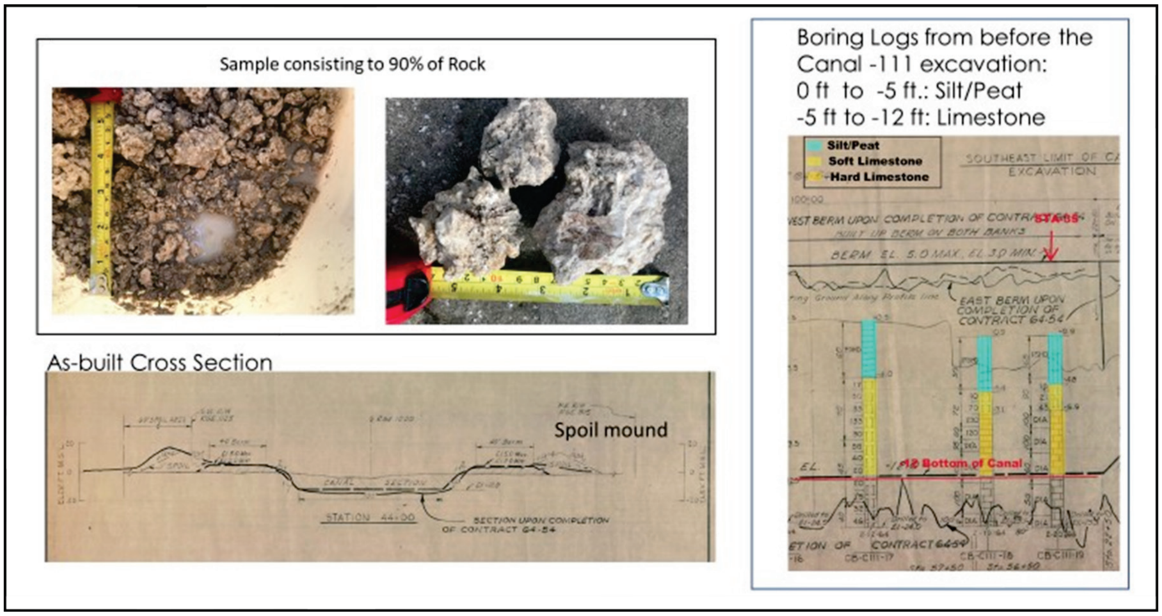
Figure 5. Stakeholder workshop slide depicting information and images of the C-111 spoil pile sediment source adjacent to the Charley placement site.



The spoil pile is a result of the construction of the C-111. Sediment samples from this site were collected in May 2022 and assessed by the SAJ-RSM team geologist. As-built cross sections from the C-111 were also reviewed to identify the type of material excavated. The original sediment cores from the bottom of the C-111 show that the top 4–5 ft were peat underlain by limestone (Figure 6); the composition was described as 30% sand and silt and 70% rock. Grab samples taken in May 2022 contained 90% rock presumably as a result of the excavated material being placed in the spoil mound in reverse of how it would be found in situ (i.e., limestone originally excavated at the canal's bottom is now at the top of the spoil mound). The usable portion of the spoil bank is approximately 10 ft in height above the adjacent road elevation, with the top approximately 2 ft likely unsuitable for the project due to growth of exotic and native nuisance vegetation species and the presence of large limestone rocky material. An ancillary benefit of use of this spoil mound is the removal of exotic and native nuisance vegetation that has populated the area.

This sediment source was chosen based upon input from Miami-Dade County stakeholders, regulatory ease, sediment availability, and proximity to the project sites. The SAJ-RSM Team acknowledges that for the BBSEER scale, there is insufficient sediment and that another sediment source would need to be identified. The sediment matrix (Table 1) indicates that federal navigation projects in southeast Florida (e.g., Miami Harbor, Port Everglades) may be more suitable sources for the BBSEER scale due to volumes of sediment available and sediment compatibility within the ranges of criteria evaluated for this assessment.

Figure 6. Sediment samples and as-built drawings from the C-111 levee spoil mound that will be used for the SAJ-RSM proof-of-concept physical model. (Images reproduced from USACE 1968. Public domain.)



2.4 Conceptual Design and Construction Methodology

The SAJ-RSM team collaborated with key stakeholders and regulatory agency staff on all conceptual design and construction considerations. Considerations can be divided into three major categories: placement area considerations, sediment source considerations, and other considerations. Table 2 summarizes information for each of these categories for placement in both the Charley Site and S-197 Pocket as well as use of the C-111 spoil piles as a sediment source. Development of design and construction considerations displayed in Table 2 was aided by use of draft TLP guidelines developed by ERDC (Mohan et al. 2021). Coordination with ERDC TLP subject matter experts aided in development of specific design and construction components such as how, or if, containment would be needed.

2.4.1 Design Considerations

Design considerations included collaboration between the SAJ-RSM team, key stakeholders, and ERDC. The need to establish constructable target elevations to meet goals of the proof-of-concept physical model design while minimizing potential damage to existing mangroves was a design topic that required considerable coordination. To minimize potential impacts to mangroves, a limitation on the thickness of placed sediment over areas of existing mangroves of no more than 1.5 ft was established.

Using 2018 lidar data available from the National Oceanic and Atmospheric Administration, this constraint resulted in a target elevation of 1 ft North American Vertical Datum of 1988 (NAVD 88) being established for the Charley Site and 0 ft NAVD 88 for the S-197 Pocket. Particularly for the Charley Site, future TLP may be needed to achieve an elevation conducive to the goals of EMMA since it appeared that +1 ft NAVD 88 was the minimum elevation at which mangroves in the region appeared healthy (qualitative analysis of lidar and aerial photography). However, mangrove health also depends on nutrient availability, tidal flow, and other factors. An additional topographic survey with increased accuracy will be required and may determine that an alternate target elevation is necessary for final design. Based on the conceptual design target elevations and 2018 lidar, sediment volume needs for each placement site were calculated. Similarly, potential sediment availability from the spoil piles was calculated and determined to be adequate to meet needs of the placement sites. Summary details of these volumes can be seen in Table 2.

Containment concerns centered around water quality, turbidity, regulatory requirements, and blockage of tidal flow. Both placement sites feature topography and constructed features (e.g., spoil piles and dirt maintenance road adjacent to C-111) that can serve to contain the placed sediment, potentially reducing the need for added containment during construction to attain target elevations and manage turbidity impacts in adjacent waters. Although some containment will likely be needed at both sites, particularly at tidal inlets to the Charley site, current lessons learned from similar efforts suggest that too much containment can cause unintended impacts such as impeding tidal flow, increased sediment thickness at the containment barrier, or negative impacts to the project area from placing and removing containment post project. Additional design considerations are summarized in Table 2.

Table 2. Conceptual design considerations checklist for thin-layer placement in the Charley Site and S-197 Pocket (following checklist suggested by Mohan et al. 2021).

		Checklist:	Charley Thin-Layer Placement Site	The Pocket Thin-Layer Placement Site	Notes
Placement Area Considerations	1	Placement area layout	See Workshop #4: conceptual design presentation.	—	—
	2	Placement area topography or bathymetry	National Oceanic and Atmospheric Administration (NOAA) 2018	NOAA (2018)	—
	3	Buffer zones—around placement site to manage potential impact to environmental resources	None	None	—
	4	Project area (limits of work)	See Workshop #4: conceptual design presentation. Generally assume 100 linear feet beyond placement area.	See Workshop #4: conceptual design presentation. Generally assume 100 linear feet beyond placement area. Control area must be located directly west of placement or treatment site.	—
	5	Placement target elevation	Fill to 0 ft NAVD88 This is the threshold elevation that minimizes impact to existing mangroves by minimizing fill thicknesses greater than 1.5 ft. Note: This may be lower than the ideal elevation for mangroves to thrive and additional future placements may be needed.	1.0 ft NAVD88	—
	6	Placement area volume needed	2,000 cu yd (fill to 0 ft NAVD88)	800–1,600 cu yd (fill to 1 ft NAVD88)	Miami-Dade County has used 1 ft (NAVD88) as target elevations for mangrove restoration.
	7	Elevation tolerance	±3 in.	±3 in.	Miami-Dade County used a percentage (dry material). Dry placement may allow greater control, but too much control may be cost prohibitive.
	8	Material elevation (consolidation, settling, etc.)	Minimal consolidation expected due to water present on site. Consolidation could potentially occur over time, but to account for that would need a higher construction threshold which could end up being too thick and adverse impacts could occur if consolidation is not realized.	Minimal consolidation expected due to water present on site. Consolidation could potentially occur over time, but to account for that would need a higher construction threshold which could end up being too thick and adverse impacts could occur if consolidation is not realized.	SFWMD expects consolidation.

Table 2 (cont.). Conceptual design considerations checklist for thin-layer placement in the Charley Site and S-197 Pocket (following checklist suggested by Mohan et al. 2021).

		Checklist:	Charley Thin-Layer Placement Site	The Pocket Thin-Layer Placement Site	Notes
Placement Area Considerations	9	Containment (if any)	Containment needed at tidal inlets (approximately two on north side). Coconut coir logs were discussed. Hay bales, pine needle bales, etc., potential options but not discussed. - 200 linear feet of containment (two locations) Lessons learned from Jeykll Creek: - Don't remove coconut coir logs, biodegrade in 6–12 months, - Use stakes that will degrade (not oak), - Logs can clog with sediment and impede water flow. Note that Jeykll was a slurry and not dry placement. Lessons learned from New Jersey USACE (Monica Chasten): - The less containment, the better	- If placement area has standing water, will need containment on sides not controlled by topography. -Any reason why the polygon can't be turned sideways and tie into the road ROW? Doing so would reduce the linear feet of containment. Pocket is approximately 500 linear feet across. Therefore 1,000 linear feet of containment may be needed. - Is it possible to not use containment? Lessons learned from New Jersey are that the less containment used, the better. From an engineering standpoint, containment would only be needed if it's necessary to reach an elevation. - Additionally, containment would need to be weaved between existing mangroves: very difficult, potentially costly, and impacts to mangroves.	- Will likely be needed at all sites to achieve target elevations, reduce material loss and impacts to surrounding area -Dry material introduces only the soil volume and is easier to control. - Slurry (wet placement) introduces more volume with water and needs more containment. -Containment needs and strategies are likely site specific. -Need to consider vehicle access to place containment (airboat, marsh buggy, etc.).
	10	Site drainage and turbidity control	Needed at tidal inlets: - Permitting will require turbidity monitoring plan - Turbidity curtains. Assume redundancy and multiple curtains. Assume 200 linear feet of curtain needed. - Permit required—performance based <29 Nephelometric Turbidity Unit (NTU) above background OFW <0 NTU above background	- Likely needed at work boundary - Assume equal to or more curtain needed than containment. - Curtain would need to weave through mangroves (see note on "#9).	—
	11	Construction access and staging areas	SFWMD claims vehicles cannot access site. Access and staging - Access along main road - Allow for turning area - Provide enough room for contractor to have multiple pieces of equipment Assume no tracked or wheeled vehicles Performance based limitations (e.g., do not break mangroves) Would need specification to limit damage to existing mangroves	Access appears better than Charley site. Elevations should be higher. However, may assume same means and methods as Charley for conceptual design. Overall, there seems to be low stakeholder tolerance for construction impacts to sites.	—
	12	Erosion and sediment control	Covered under Containment for conceptual design	Covered under Containment for conceptual design	—
	13	Flood and scour protection	na	na	—

Table 2 (cont.). Conceptual design considerations checklist for thin-layer placement in the Charley Site and S-197 Pocket (following checklist suggested by Mohan et al. 2021).

		Checklist:	Charley Thin-Layer Placement Site	The Pocket Thin-Layer Placement Site	Notes
Sediment Source Considerations	14	Source(s)	Spoil pile adjacent to Charley	Spoil piles adjacent to the Pocket	
	15	Source volume (including losses, etc.)	2,000+ cu yd	4,840 cu yd in example area adjacent to placement site based on same assumptions used for Charley (3 vertical feet of suitable material gained from piles). Spoil piles north/south of TLP site contain additional material.	Dry material, once excavated, is assumed to be same volume as needed placement since it will not be compacted.
	16	Volume relationship (in situ versus placement bulking)	- Assumed 1:1 for 15% design. However, placed material will be higher volume than excavated.	- Assumed 1:1 for 15% design. However, placed material will be higher volume than excavated.	Upland sources will have volume loss if fluffed compared to in situ—potential loss of 15% if compacted
	17	Desired grain size	Desired sediment quality is sand with 50% silt. Material processing may include screening or pulverizing.	Desired sediment quality is sand with 50% silt. Material processing may include screening or pulverizing.	—
	18	Buffer zones around sediment source	Needed during excavation or processing? Excavating to road grade elevation may lead to runoff into mangrove area during and after construction. Area may need to be stabilized, sloped, geotextile used, etc. Could specify general grading plan (e.g. shaped back to preconstruction grade.)	Needed during excavation/processing? Excavating to road grade elevation may lead to runoff into mangrove area during/after construction. Area may need to be stabilized, sloped, geotextile used, etc. Could specify general grading plan (e.g. shaped back to preconstruction grade.)	—
	19	Disposal of cleared vegetation and screened material	Disposal needed: vegetation, screened material (rock, etc.). Department of Environmental Resource Management (DERM) noted that screened rock may be of use in nearby plugs. Or can rock be spread on roadway or used to stabilize excavation?	Disposal needed: vegetation, screened material (rock, etc.). DERM noted that screened rock may be of use in nearby plugs. Or can rock be spread on roadway or used to stabilize excavation?	—
	20	Environmental impacts	Covered in sediment source matrix	Covered in sediment source matrix	—
	21	Sediment biogeochemistry	Local material. na	Local material. na	—
Additional Considerations	22	Sediment transport (during and after TLP)	Covered under Containment for conceptual design	Covered under Containment for conceptual design	—
	23	Environmental impacts	Impact to Cost. Environmental survey likely needed. Would need specification to limit damage to existing mangroves. Turbidity control measures (see above).	Impact to Cost. Environmental survey likely needed. Would need specification to limit damage to existing mangroves. Turbidity control measures (see above).	—
	24	Optimal placement method (spray, shooter, pipe, etc.)	- Sand shooter from C-111 access road: would need extension, equipment w/I placement area to get dry material throughout site (100 ft max range) - Slurry material and use small 4 in. pipe, moved by hand, to spread material throughout area - Do not restrict contractor unless there is a permit reason to limit. Cost Engineer to price out all feasible methods and determine what a well-equipped competent contractor would do.	- Sand shooter from C-111 access road: would need extension, equipment w/I placement area to get dry material throughout site (100 ft max range) - Slurry material and use small 4 in. pipe, moved by hand, to spread material throughout area - Do not restrict contractor unless there is a permit reason to limit. Cost Engineer to price out all feasible methods and determine what a well-equipped competent contractor would do.	—

Table 2 (cont.). Conceptual design considerations checklist for thin-layer placement in the Charley Site and S-197 Pocket (following checklist suggested by Mohan et al. 2021).

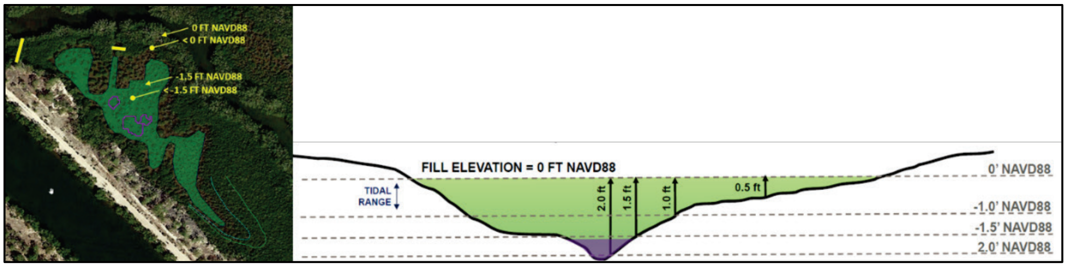
		Checklist:	Charley Thin-Layer Placement Site	The Pocket Thin-Layer Placement Site	Notes
Additional Considerations	25	Equipment type	Sediment transport: C-111 spoil piles—excavator, dump trucks, screening equipment, barge (if additional material is needed from spoil pile beyond the end of C-111 road) Sediment placement: All material will get wet when placed (even if it's placed dry) Dry—conveyors, sand shooter Hydraulic—pipeline/hoses, high pressure spray	Sediment transport: C-111 spoil piles—excavator, dump trucks, screening equipment, barge (if additional material is needed from spoil pile beyond the end of C-111 road) Sediment placement: sand shooter OR 4" pipe OR other manual method	—
	26	Real estate considerations	SFWMD or DERM are planning to purchase placement site. Who owns spoil piles and roadway?	Who owns spoil piles and roadway? Who owns placement site?	—
	27	Access corridors for pipelines/vehicles	See Construction access/staging areas.	See Construction access/staging areas	—
	28	Sequence of work	To be determined (TBD). Environmental survey (#23) may be a first step. Attempt to not limit contractor to the maximum extent practicable.	TBD. Environmental survey (#23) may be a first step. Attempt to not limit contractor to the maximum extent practicable.	—
	29	Measurement and payment methods	Either require third-party surveyor or higher surveyor under a different contract.	Either require third-party surveyor or higher surveyor under a different contract.	—
	30	Permit conditions	—	—	—
	31	Planting and restoration	Not included in conceptual design.	Not included in conceptual design.	—
	32	Environmental monitoring during construction	Monitoring likely needed for endangered species during construction	Monitoring likely needed for endangered species during construction	—
	33	Long-term monitoring	Not included in conceptual design.	Not included in conceptual design.	—

2.4.2 Construction Considerations

Existing vegetation on the C-111 spoil mound would be cleared, grubbed, and hauled to an offsite disposal area. Due to the prevalence of poisonwood (*Metopium toxiferum*) on the spoil mound, on-site burning was not a viable option. Poisonwood trees contains urushiol, which can cause rashes and mucous membrane irritation in humans, including from smoke inhalation from burning parts of the tree. The spoil pile would be excavated to road elevation, and it is assumed that the top few feet will likely not be usable and thus transported offsite for disposal. The remainder of the material will be processed (i.e., screening, crushing, etc.) and stockpiled onsite. Based upon lidar, it is estimated that approximately 2000+ yd^3 of usable material will be available for placement (NOAA, n.d.).

One recurring question was the quantity of sediment that would be needed, acknowledging that the quantity necessary was dependent upon the thickness of placement (i.e., the depth of material to be placed). There was much discussion among key stakeholders regarding the tolerance of mangroves to sedimentation and how much sediment could be placed prior to resulting in adverse effects on existing mangroves. After considerable discussion, the SAJ-RSM Team focused on a maximum thickness of 1.5 ft as a threshold for mangrove tolerance to sedimentation. In consideration of this threshold, along with lidar estimates of site elevation, the SAJ-RSM team decided that TLP would consist of deposition of sediment at the Charley Site and S-197 Pocket to an elevation of +1 ft and 0 ft NAVD 88, with an allowable tolerance of ±0.25 ft (±3 in.). Prior to placement, the site would be surveyed, and the threshold elevations would be staked and marked. Since both project sites contain areas of open water with sparse mangroves and TLP will be confined to those areas (Figure 7), there is minimal risk to existing mangroves due to sedimentation. The SAJ-RSM team acknowledges that the application elevation may be lower than the ideal elevation for mangroves to thrive. It is an initial first step in understanding the acceptable placement tolerances and will build resiliency by increasing opportunities for plants to colonize the area.

Figure 7. Conceptual design for the Charley Site. The fill template shows the approximate depth of the fill based upon lidar imagery.



2.4.3 Proposed Construction Methodologies

In general, the SAJ-RSM Team recommends minimizing the amount of prescribing construction means and methods to potential contractors to allow for innovation. In lieu of prescribing means and methods, the preference is to include language in the construction specifications regarding performance expectations (e.g., threshold elevations, turbidity limits, effects on existing mangroves). The proof-of-concept physical model has been specifically designed to be small scale, using small volumes of material, with close proximity of source and placement to minimize potential impacts to environmental resources within the project vicinity.

Existing vegetation on the C-111 spoil mound would be cleared, grubbed, and hauled to an offsite disposal area, with the remainder of material processed (i.e., screening, crushing, etc.) to a desired sediment size range and then stockpiled on-site. Transporting the sediment from the stockpile to the placement area will be accomplished by one of two options: dry (mechanically) or wet (hydraulically). Due to the low existing and target elevations of this project, the material will get wet when placed whether it is transported mechanically or hydraulically. Mechanical placement may include methodologies such as a long-arm excavator dropping the sediment (but may not be able to reach the farthest placement areas), a series of conveyor belts carrying the sediment, or a single high-speed conveyor belt (i.e., sand shooter) launching the sediment (Figure 8). Hydraulic placement would entail fluidizing the sediment by mixing it with water from C-111 and then pumping the slurry to the placement areas. A flexible hose could be used with someone tending the discharge in the water or in a Jon boat. Alternatively, a manifold system of rigid pipelines (e.g., PVC) could be used with valves utilized to dictate where the slurry discharges. Last, a high-pressure hydraulic discharge could be used to spray the material into the placement areas. The specifications would state that any placement operation cannot damage existing mangroves, allowing for the contractor to determine how to best construct the project without impacting existing mangroves. However, it is recommended to explicitly not allow any tracked or wheeled equipment in the placement area due to the high likelihood of impacting existing mangroves.

Figure 8. Sand transfer system (sand shooter) used to place sediment in a 2012 mangrove mitigation enhancement project in Miami-Dade County (photos credit: Miami-Dade County, Florida).

Other construction considerations include access, containment, turbidity, and stabilization of the spoil pile area following excavation. Access to the Charley Site would be along the C-111 levee road. There is sufficient space along the access site for large vehicles to turn as well as for several pieces of construction equipment. Containment will be needed at tidal inlets at the Charley Site. Types of containment may include coconut coir logs or hay bales. Other means of containment that still allow water flow, but blockage of sediments, may also be considered. Performance-based turbidity limits at the inlets will be required by the permit. The contractor will likely need to install turbidity curtains within the tidal creek adjacent to the Charley Site. Following excavation of the spoil mound, the area may need to be graded and stabilized to avoid excessive runoff into the existing mangrove area.

2.5 Projected Cost

An initial rough order of magnitude (ROM) cost estimate was prepared in accordance with Cost Engineering Regulations and utilized Micro-Computer Aided Cost Engineering System (Table 3). Current cost libraries that support this software were used along with current fuel prices and economic indices to reflect labor, equipment, and material costs at Fiscal Year 2022 price levels. This ROM represents the estimated construction cost only, including prime contractor markups including job office, home office, profit, and bond. A contingency of 40% has been applied to this ROM estimate. This would be considered a Class 5 cost estimate because it is based upon preliminary technical information with less than 5% design. Additionally, the scope and estimate have considerable risk and uncertainty (USACE 2016) (reference ER 1110-2-1302 [USACE 2016] for additional information). The ROM estimate does not include final design and permitting costs, real estate, costs for easements, supervision, and administration of the construction contract or postconstruction monitoring. These items would need to be budgeted for separately. The estimate has been structured to follow the Civil Works Work Breakdown Structure, which helps to organize and outline the costs in a logical manner. Additional information regarding costs, how they were estimated, and potential cost savings is included below.

Table 3. Rough order of magnitude (ROM) cost for the SAJ-RSM proof-of-concept physical model for both the Charley Site and S-197 Pocket.

Charley Placement Site	ROM Costs
Environmental Species Monitoring	$7,000
Site Preparation	$41,000
Turbidity Monitoring	$67,000
Erosion and Turbidity Control	$19,000
Coir Log Containment	$9,000
Debris Removal	$15,000
Construct TLP System	$200,000
Excavation of Spoil Pile, Material Processing, Stockpile for TLP	$95,000
Thin Layer Placement	$94,000
Surveys (Pre-Construction, Prefinal, Final)	$10,000
Site Clean-Up	$38,000
—	
Subtotal	$595,000
Mobilization and Demobilization (20%)	$119,000
Contingency (40%)	$286,000
Total for Charley Placement Site	**$1,000,000**

Table 3 (cont.). Rough order of magnitude (ROM) cost for the SAJ-RSM proof-of-concept physical model for both the Charley Site and S-197 Pocket.

S-197 Pocket Placement Site	—
Environmental Species Monitoring	$10,000
Site Preparation	$41,000
Turbidity Monitoring	$46,000
Erosion and Turbidity Control	$19,000
Coir Log Containment	$38,000
Debris Removal	$15,000
Construct TLP System	$150,000
Excavation of Spoil Pile, Material Processing, Stockpile for TLP	$76,000
Thin Layer Placement	$75,000
Surveys (Pre-Construction, Pre-Final, Final)	$39,000
Site Clean-Up	$38,000
—	
Subtotal	$547,000
Mobilization and Demobilization (20%)	$110,000
Contingency (40%)	$263,000
Total for Pocket Placement Site	**$920,000**
Total for Both Sites	**$1,920,000**

Note: All costs are rounded for presentation purposes.

2.5.1 Explanation of Construction Costs

- Estimated construction costs identified in Table 3 are further explained below.
- Environmental Species Monitoring: The estimated cost for this work item accounts for a qualified biologist on-site during construction activities to observe and monitor for species of concern such as smalltooth sawfish and American crocodile.
- Site Preparation: The estimated cost for this work item accounts for the setup of initial project requirements such as staging areas, temporary security fencing, and safety fencing. Other necessary site preparation costs are accounted for in the job office overhead markup, which is evenly distributed across the work items.
- Turbidity Monitoring: The estimated cost for this work item accounts for a taking turbidity readings during construction adjacent to the work

and at the prescribed background distance to ensure that the construction operations do not exceed permitted levels.

- Erosion and Turbidity Control: The estimated cost for this work item accounts for placing and removing both silt fencing and floating turbidity curtains adjacent to construction operations and in locations where run-off water may mix with tidal inlets connected to the bay system.
- Coir Log Containment: The estimated cost for this work item accounts for placing coconut coir log containment. The containment at the Charley Site would be perpendicular to and before the tidal inlets. The containment at the S-197 Pocket would be a perimeter that would encompass the placement area.
- Debris Removal: The estimated cost for this work item accounts for clearing and grubbing of the spoil area and transportation of that material to the nearest environmentally acceptable land fill where it would be disposed of at the required fee.
- Construct TLP System: The estimated cost for this work item accounts for purchasing necessary materials (pipe, valves, couplings, etc.) and then fabricating a system of either HDPE pipe or PVC pipe that would, through a system of valves, be able to distribute the material hydraulically as TLP. The pipe used may be HDPE or PVC depending on the size of the pump used, pumping distance, material type, etc. No impacts to mangroves are allowed, so the placement sites will need to be set up by laborers in waders and possibly small boats. This work item accounts for all necessary materials, labor, and equipment needed to assemble the system. This cost is also thought to be conservative enough to account for other possible means and methods of completing the work such as conveyors or sand shooters. Hydraulically placing the material was chosen as the assumed method for estimating purposes for several reasons. It seems to provide good control of the placement; it offers a high likelihood of success because of its self-leveling properties; and it requires less of a footprint within the mangroves thereby reducing the risk of impacts to the existing trees. The other methods seem to bring with them limitations or additional risks or both in related to the reasons mentioned.
- Excavation of Spoil Pile, Material Processing, Stockpile for TLP: The estimated cost for this work item accounts for all labor, equipment, and materials necessary to excavate the material from the stockpile, process the material, and then stockpile it until it is placed in the project sites. The material is assumed to be excavated with a hydraulic excavator and

then transferred into a crushing and screening plant by a front-end loader. The material would leave the screening and crushing plant on a conveyor to be stockpiled until loaded for placement.

- TLP: The estimated cost for this work item accounts for all labor, equipment, and materials necessary for placing the material beneficially into the TLP site. The estimate currently assumes that the material will be pumped with a small dredge pump attachment on a hydraulic excavator. The material will be pumped from a holding container such as a type of bin or possibly even construction dumpsters. To be pumped, the material will need to be turned into a slurry by adding water from the C-111. Once pumping begins, the material would discharge through the TLP system of pipes into the placement site. This operation may be an iterative process, and the contractor may need to adjust on-site until the operation runs smoothly. The cost estimate takes this into consideration based upon the durations assumed for the task and in the contingency assumed.
- Surveys (preconstruction, prefinal, final): The estimated cost for this work item accounts for up to three surveys. These surveys may be required for payment purposes, but they could also be required for scientific purposes to establish a baseline and final condition needed to help monitor success of the TLP.
- Site Cleanup: The estimated cost for this work item accounts for the cleanup of the project requirements such grading of staging areas, removal of temporary security fencing, and removal of safety fencing. It also accounts for seeding of the areas where spoil material was excavated. Other necessary site clean-up costs are accounted for in the job office overhead markup, which is evenly distributed across the work items.

2.5.2 Construction Duration

Both sites contain a relatively small but similar quantity of material to be placed. Therefore, they are thought to have approximately the same construction duration. They both have several tasks that would need to be completed before TLP could begin. No less than 30 calendar days is probably reasonable for a commencement time frame after the contractor receives a Notice to Proceed (NTP). This would be the time from award of a contract until the contractor is on-site. After that, approximately 15 days is assumed to get all tasks complete leading up to excavation of the spoil material. Excavation, processing, and TLP is estimated to be completed in 30 calendar days. This would be followed by 15 calendar days of site cleanup. That would be a total duration from NTP to completion of work of 90 calendar days or 3 months for each placement site. If projects were consolidated into one contract, that duration could possibly be reduced to approximately 150 calendar days or 5 months. Keep in mind that contract requirements and thereby construction duration may be impacted by which agency may contract this work. Typically, in SAJ contracts, the construction duration or Period of Performance assumes no less than 60 calendar days for commencement to allow for necessary submittals to be submitted and approved. This would push the durations out an additional month to 4 months instead of 3 months.

2.5.3 Potential Cost Savings

- Single contract versus Separate: There is no specific order of work currently specified or required. The estimate currently assumes that each site may be constructed as its own contract action. Ideally, each site would be completed in one contract action and in series so that the lessons learned, materials, and equipment could be taken from one site to the other site, which would possibly result in some cost savings, especially if materials could be reused and if equipment is already on-site.
- Contract Design: Keeping the requirements for this type of project as simple as possible is probably best to receive the lowest price possible. Limiting design efforts as much as possible (leaning towards a work statement) and allowing for flexibility is helpful because it allows interested contractors to come up with innovative means and methods for performing this work. Applying restrictions or prescribing too tight of tolerances or both for placement or payment or both can increase the level of difficulty and risk to the contractor which will increase the prices received.
- Acquisition Strategy and Contract Mechanism: A small business would be ideal for this work, but going with a sole source to a small business is likely to result in higher costs compared to a competitive invitation-for-bid (IFB). If possible, IFB would allow for competition and likely result in the best price. Partnering with other agencies may allow opportunities for labor or other resources or both to be volunteered or donated since these are pilot type efforts.
- Alternate Borrow Sources for Beneficial Use: The cost for acquiring the material for this TLP process is very expensive in this scenario because the material must be cleared and grubbed and then processed before it can be used. During the brainstorming and design of this

project, alternate sites for borrow material should be explored that may result in a lower cost if it is already clean material that may only need to be hauled.
- Turbidity Monitoring: The S-197 Pocket is far north of Biscayne Bay and bounded by US Highway 1 to the west and the C-111 levee and road to the east. Based upon discussions with regulatory agencies, if turbidity monitoring was not required at the S-197 Pocket, that would result in some potential cost savings.
- Containment: Containment is primarily considered to help contain material as it is placed in each site. Some secondary benefits may be reduction in turbidity. If containment is not necessary given the nature of each site, there may be the possibility of removing this as a requirement, which would result in some potential cost savings.

2.5.4 Permitting Requirements

Based upon discussions with the regulatory agencies, local, state, and federal permits would be required for implementation of the SAJ-RSM proof-of-concept physical model. Input obtained through coordination workshops with regulatory stakeholders was instrumental in shaping the conceptual design to ensure that it is permittable.

Miami-Dade County Code requires that a Miami-Dade County Class I Permit be obtained prior to performing any work in, on, over or upon tidal waters or coastal wetlands of Miami-Dade County or of any of the municipalities located within Miami-Dade County. A Class I Permit is also required for most mangrove trimming, alteration, or removal. A Class I permit is utilized to manage impacts from construction on coastal wetlands and tidal waters. Through the Class I Permit application process, proposed projects are reviewed to identify potential environmental and other impacts. Before the permit is issued, Miami-Dade County may require modification of the project to eliminate avoidable impacts and to minimize other impacts. Compensation (mitigation) is required for unavoidable impacts as part of the permit (Miami-Dade County 2022). The primary concerns voiced by Miami-Dade County regulatory staff were containment, thickness of fill, and impacts to existing mangroves within the project footprint.

A State of Florida Environmental Resource Permit is also required for the project. The Environmental Resource Permit program regulates activities involving the alteration of surface water flows. This includes new activities in uplands that generate stormwater runoff from upland construction, as well as dredging and filling in wetlands and other surface waters (Florida Administrative Code 2023) . Primary concerns voiced by the Florida Department of Environmental Protection, the State agency that will permit the project were turbidity, containment, and stabilization.

Although the State of Florida assumed Clean Water Act Section 404 responsibilities from USACE, the Charley Site and the majority of the S-97 Pocket are contained within conserved waters; thus, a federal permit is also required. The project qualifies under a Nationwide 27 Permit (NWP 27 Aquatic Habitat Restoration, Enhancement, and Establishment Activities), which allows ". . . activities in waters of the United States associated with the restoration, enhancement, and establishment of tidal and non-tidal wetlands and riparian areas, the restoration and enhancement of non-tidal streams and other non-tidal open waters, and the rehabilitation or enhancement of tidal streams, tidal wetlands, and tidal open waters, provided those activities result in net increases in aquatic resource functions and services." For a project to qualify under NWP 27, the ". . . aquatic habitat restoration, enhancement, or establishment activity must be planned, designed, and implemented so that it results in aquatic habitat that resembles an ecological reference." An ecological reference may be based on the characteristics of an intact aquatic habitat or riparian area of the same type that exists in the region. (USACE 2017). The ecological reference used for this proof-of-concept physical model is the mangrove communities adjacent to the Charley Site that exist at approximately 0.0 ft NAVD 88. Primary concerns voiced by USACE regulatory staff were containment and water quality within Biscayne Bay.

Based upon coordination with key regulatory stakeholders during the workshops, the Florida Department of Environmental Protection informed the group that a uniform mitigation assessment method (UMAM) would need to be conducted to determine whether any mitigation would be required as part of this project. The SAJ-RSM Team conducted a UMAM based upon the field visit, aerial overflight, and subsequent visits to the project sites and shared the results with all regulatory stakeholders. The results of the UMAM revealed that at the Charley Site and the S-197 Pocket, no mitigation would need to be performed to offset potential adverse effects on existing mangroves within the project footprint. The

SAJ-RSM team also acknowledged that each regulatory agency would need to conduct a site visit to verify the initial UMAM calculations.

3 Next Steps

The following steps were identified for implementing the proof-of-concept physical model.

- Final Design Surveys: A topographic and bathymetric survey will need to be performed of the spoil pile and fill template to verify volumes and have necessary information for a set of construction plans. Geotechnical surveys of the spoil pile and sediment within the placement areas will also need to be collected and undergo laboratory testing and analysis.
- Permitting: In addition to preliminary and final construction design and specifications, a preconstruction wildlife survey will need to be performed to understand the presence of wildlife resources, including those listed under the Endangered Species Act. A field inspection will be needed to confirm the SAJ-RSM UMAM. The EMMA experimental designs and monitoring plan will also need to be finalized and submitted in conjunction with the permit applications. Last, permit-level drawings of the project need to be included in the permit application. Drawings from this report or from the workshops could be submitted, but agencies may require more detailed drawings closer to final design level.
- Plans and Specifications: Development of the construction plans and specifications to provide the necessary details to the contractor to construct the project, establish payment criteria, and adhere to the permit conditions.
- Contracting: The project will need to undergo the SFWMD contracting process for solicitation and award.

4 Conclusions

Coordination with stakeholders was key to informing the project design and understanding from a regulatory perspective what may be permittable. The notion that fill in wetlands is detrimental was a refrain from some of the members of the stakeholder team not familiar with situations when the opposite may be true (Croft et al. 2006; DeLaune et al. 1990). However, this preexisting notion needs to be challenged, especially in areas most vulnerable to SLR. Without intervention, the environment under consideration for the pilot project will transgress to an open-water community where the structure and function of the existing community are lost forever.

Information gained from this proof-of-concept physical model will not only inform management measures, adaptive management, and monitoring options for inclusion within the BBSEER Project but will also address uncertainties associated with construction of natural and nature-based features to promote ecosystem restoration and resiliency in the face of changes in sea level within the South Florida ecosystem. There are multiple long-term opportunities associated with this effort for the entire State of Florida. Benefits include cost savings associated with use of dredged material from navigation improvement projects; reduction in damages associated with coastal storm hazards; and numerous benefits to fish and wildlife, including important recreational and commercial fisheries species.

Implementation of beneficial-use actions resulting from the information is on the order of tens of millions of dollars in environmental benefits and economic sustainability for Florida and for the entire nation. Recreation, tourism, agriculture, and commercial fishing industries are key components of the Florida economy. Restoration of the south Florida ecosystem will help make these industries stronger and more sustainable. These industries also make a significant contribution to the national economy. Visitors from around the country, and the world, travel to the Everglades, Florida Bay, and the many other natural areas of south Florida. Fish and seafood harvested from Florida’s coastal waters are shipped to markets across the country and the world. CERP’s greatest strength is that it integrates both natural and human system objectives into a single design, which is supported by a wide array of stakeholders. Coastal projects, like the one presented here, will help guide and lead toward national-scale solutions for climate change and sea-level rise.

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Abbreviations

BBSEER	Biscayne Bay Southeastern Everglades Ecosystem Restoration
CERP	Comprehensive Everglades Restoration Plan
COMPACT	Southeast Florida Regional Climate Change Compact Sea-level Rise Work Group
DERM	Department of Environmental Resource Management.
DMMA	Dredged Material Management Area
EMMA	Everglades Mangrove Migration Assessment
ERDC	US Army Engineer Research and Development Center
FPL	Florida Power and Light
HDPE	High-density polyethylene
IFB	Invitation-for-bid
IWW	Intracoastal Waterway
MSA	Material storage area
NAVD 88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NTP	Notice to Proceed
NTU	Nephelometric Turbidity Unit
PB	Palm Beach
ROM	Rough order of magnitude
RSM	Regional Sediment Management
SAJ	Jacksonville District

SFWMD	South Florida Water Management District
SLR	Sea-level rise
TBD	To be determined
TLP	Thin-layer placement
UMAM	Uniform mitigation assessment method
USACE	US Army Corps of Engineers

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14. ABSTRACT

This Regional Sediment Management technical report outlines initial steps to implement a proof-of-concept physical model to develop demonstration scale evidence that supports managed wetland transgression through sediment augmentation via a thin-layer placement strategy. The proof-of-concept physical model will evaluate the ability of thin-layer placement to increase elevation and enhance recruitment within coastal scrub mangrove wetlands most vulnerable to sea-level rise. The investigation sought to identify feasible project locations, sediment sources that included beneficial use of dredged material opportunities, and environmentally acceptable construction techniques. Results of this initial step will be used to secure funding to permit, construct, implement, and monitor the proof-of-concept physical model. The results of this initiative will inform and direct management measure development for the ongoing Biscayne Bay Southeastern Everglades Restoration Project, the only coastal component of the Comprehensive Everglades Restoration Plan and the only component with an obligation to increase habitat resilience. Results are applicable to areas throughout the Gulf, Atlantic, and Pacific Coasts of the United States where direct preservation, enhancement, and restoration of mangrove and other coastal wetland communities will build coastal resiliency, reduce storm hazards damage, and create habitat for a variety of fish and wildlife species, particularly as sea-levels rise.

15. SUBJECT TERMS

Coasts--Wetlands; Dredging spoil--Reuse; Mangrove forests; Mangrove restoration; Sea level

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