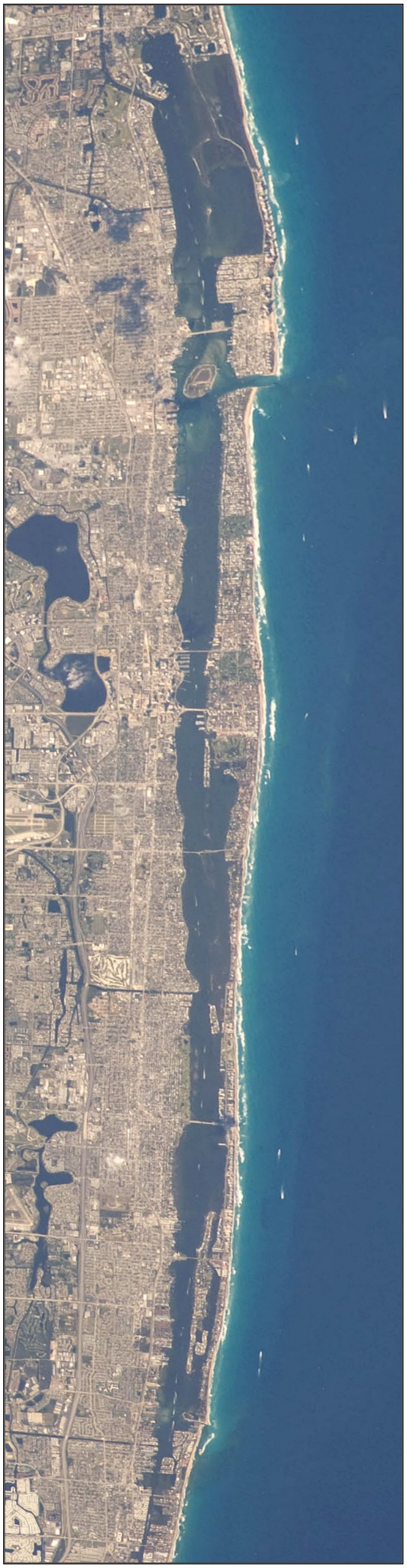
Continuing Authorities Program
Section 1135 Project



Engineering Appendix

For

Lake Worth Lagoon
Ecosystem Restoration Project

West Palm Beach, Florida

November 2016

US Army Corps
of Engineers
Jacksonville District

PALM BEACH COUNTY
FLORIDA

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Table of Contents

List of Tables

List of Figures

List of Attachments

Attachment A – References

Attachment B – Lake Worth Lagoon Watershed

Attachment C – Lake Worth Lagoon Past Projects

Attachment D – Peanut Island Phase I ESA

Attachment E – Geotechnical Data

Attachment F – Past Permits

List of Acronyms

ACES	Automated Coastal Engineering System
ac-ft	Acre-feet
ADCP	Acoustic Doppler current profiler
ASTM	American Society of Testing and Materials
C&SF	Central and South Florida
CAP	Continuing Authorities Program
Corps	United States Army Corps of Engineers
cfs	Cubic feet per second
cy/s	Cubic Yard(s)
DBHYDRO	SFWMD hydrologic database
DERM	Department of Environmental Resources Management
D&I	Design and Implementation
DMMA	Dredged Material Management Area
ER	Engineering Regulation
ETL	Engineering Technical Letter
FDEP	Florida Department of Environmental Protection
FEMA	Federal Emergency Management Agency
FIND	Florida Inland Navigation District
GHCN	Global Historical Climatology Network
IWW	Intracoastal Waterway
LS	Lump Sum
LWL	Lake Worth Lagoon
MHHW	Mean Higher-High Water
MHW	Mean High Water
MLLW	Mean Lower-Low Water
MLW	Mean Low Water
mph	miles per hour

MSC	Major Subordinate Command
MSL	Mean Sea Level
MTL	Mean Tide Level
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum 1928
NOAA	National Oceanic and Atmospheric Administration
PBC	Palm Beach County
PBHNP	Palm Beach Harbor Navigation Project
PDT	Project Delivery Team
POR	Period of Record
psu	Practical salinity unit
ROM	Rough Order of Magnitude
RSL	Relative Sea Level
SFWMD	South Florida Water Management District
SLC	Sea Level Change
SPF	Standard Project Flood
USACE	US Army Corps of Engineers
WRDA	Water Resources Development Act

1.0 PROJECT INFORMATION

1.1 Project Title

Lake Worth Lagoon Continuing Authorities Program, Section 1135, Ecosystem Restoration Project

1.2 Project Identification Number

The P2 number for the Lake Worth Lagoon project is 447752.

1.3 Project Authorization

Lake Worth Lagoon Project is authorized under Section 1135, Project Modification for Improvement of the Environment of the Water Resources Development Act (WRDA) of 1986, 33 USC 2309a; funding and cost-sharing guidance is covered under Public Law 99-662. Section 1135 provides the authority to review the operation of water resources projects constructed and determine the need for improving the quality of the environment degraded by existing Corps projects. Section 1135 purpose is to restore the degraded ecosystem structure, function, and dynamic processes to a less degraded, more natural condition considering the ecosystem's natural integrity, productivity, stability and biological diversity. This authority is primarily used for altering the hydrology in and along bodies of water, including wetlands and riparian areas. Section 1135 falls under the Continuing Authorities Program (CAP), which focuses on water resource related projects of relatively smaller scope, cost and complexity than typical USACE efforts. CAP is a delegated authority to plan, design, and construct certain types of water resource and environmental restoration projects without specific Congressional authorization. Additional Information on this program can be found in Engineering Regulation 1105-2-100, Planning Guidance Notebook, Appendix F.

1.4 Project Non-Federal Sponsor

Project Sponsor is Palm Beach County Board of Commissioners; however, the project is managed by the Palm Beach County (PBC) Department of Environmental Resources Management (DERM).

1.5 Project Setting

Lake Worth Lagoon (LWL) is on the Atlantic Coast of Florida approximately 53 miles south of Ft. Pierce Harbor, 40 miles north of Port Everglades, and 65 miles north of Miami Harbor. LWL is approximately 21 miles long, and up to a mile wide. The lagoon provides an important habitat for native plants, fish, and wildlife, and various recreational activities. LWL is separated from the Atlantic Ocean by two barrier islands, Singer Island and Palm Beach Island; the lagoon depths are generally eight feet deep. Ocean access is provided by two inlets: Lake Worth Inlet and South Lake Worth Inlet (locally known as Boynton Inlet). Lake Worth Inlet is a Federally maintained deep draft inlet and serves as an entrance to the Palm Beach Harbor. South Lake Worth Inlet is approximately 18.5 miles south of Lake Worth Inlet and was constructed in 1927 to improve circulation of the southern end of LWL. The Intracoastal Waterway (IWW) runs the entire length of the lagoon (**Figure 1-1**).

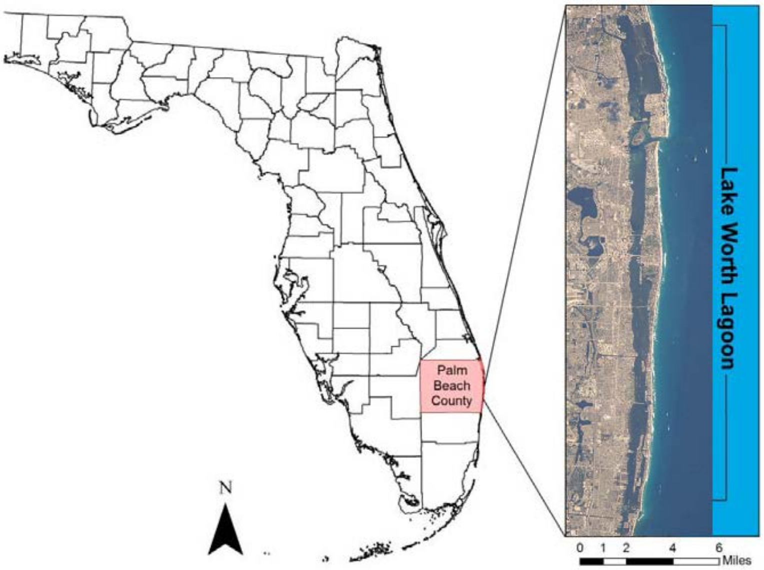

Figure 1-1 – Project Location

1.6 Project Description

Florida’s coastal lagoons and estuaries are extremely important ecosystems, as they support unique and important fish and wildlife populations, and LWL is no exception. LWL provides an inland to coastal marine-connected system where juvenile marine animals hatch before venturing into the open ocean. Coastal lagoons are typically long narrow, shallow water bodies separated from the ocean by one or more barrier islands. Coastal lagoons are connected to the ocean by one or more inlets, and can vary in salinity between a freshwater to hypersaline. The geological, hydrological, and climatological factors which influence the conditions within LWL are numerous, complex, and interrelated. Therefore, the engineering analysis of this project is presented in this appendix in order of problem evolution: Understanding the Project Area (Chapter 2); Understanding the Problem – synthesizing the data (Chapter 3); and Fixing the Problem – determining the main source of the problem and the best way to fix it (Chapter 4). Lastly, Chapter 5 discusses the outstanding needs of the project that will be addressed by Design and Implementation (D&I) phase.

1.7 Acknowledgement

This report and its findings would not be possible without the assistance of Palm Beach County's Department of Environmental Resource Management (DERM). Their tireless efforts and commitment to the well-being of this viable resource have made this report possible.

2.0 UNDERSTANDING THE PROJECT AREA

Coastal lagoons are impacted by natural forces and anthropogenic adaptations, and LWL is no exception. To gain a better understanding of the project area, this chapter will explore on the geology of LWL, its anthropogenic changes over time, and natural forces which have influenced LWL. The features that will be discussed, namely canals (C-51, C-16, and C-17), associated flood control structures (S-155A, S-155, S-41, and S-44), LWL, Lake Worth Inlet, and Boynton Inlet are shown on **Figure 2-1**.

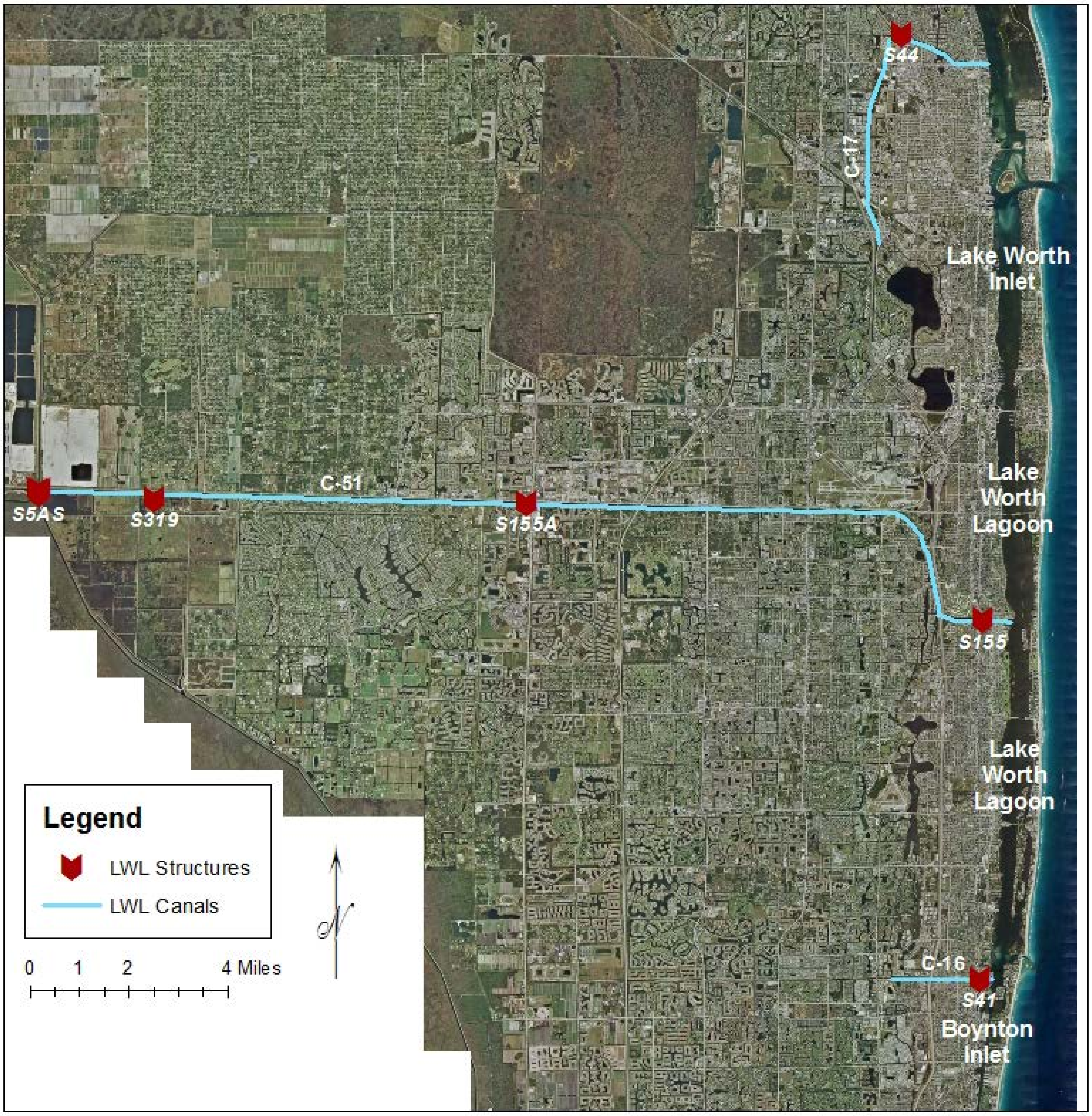

Figure 2-1 – Project Area Features

2.1 Geological

The geological history of the project area and the sequence of changes in levels of land and sea, which have resulted formation of the coastal lagoon are discussed below.

2.1.1 Regional Geology

The Florida Peninsula occupies a portion of the much larger geologic unit called the Florida Plateau. Deep water in the Gulf of Mexico is separated from deep water of the Atlantic Ocean by this partially submerged platform nearly 500 miles long and 450 miles wide. Since the Mesozoic Era, approximately 200 million years BP (before present), the plateau has been alternately dry land or covered by shallow seas. During that time up to 20,000 feet of carbonate and marine sediments were deposited in central and southern Florida. Either following or concurrent with one of the later periods of emergence, there appears to have been a tilting of the Florida Plateau about its longitudinal axis. The west coast was partially submerged, as indicated by the wide estuaries and offshore channels, while the east coast was correspondingly elevated, showing the characteristics of an emergent coastline (Randazzo and Jones, 1997).

During the last million years, a series of four glacial periods, or ice ages, brought about significant changes in sea level. As a result of these sea level fluctuations, the Florida peninsula was again covered and uncovered by shallow seas. Following the first glacial period, sea level rose 270 ft. above its present level. Dry land on the Florida peninsula was then restricted to a few small islands along the central Florida ridge and in northeast Florida. **Figure 2-2** shows the present Florida coastline with previous sea level stands, and the extent of the carbonate platform.

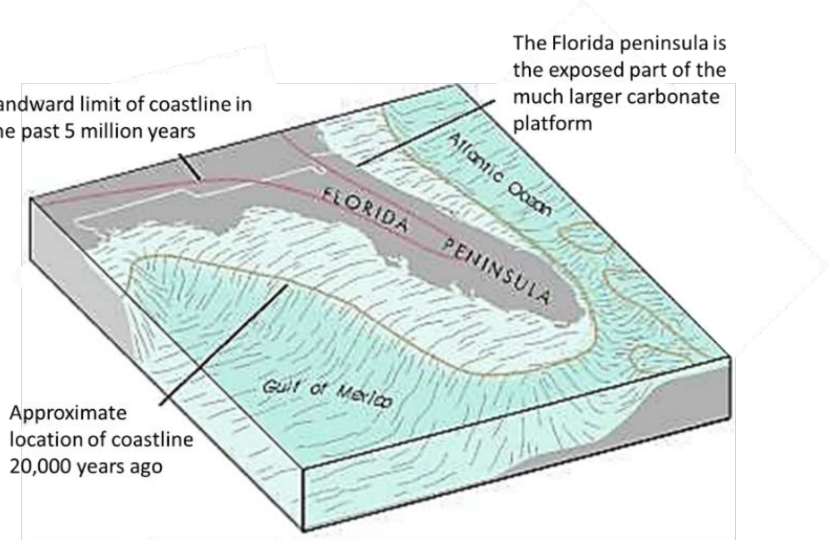

Figure 2-2 The Florida Peninsula.

About 100,000 years ago, the last glacial period began. Sea level fell to 300 feet below its present level and the Florida Plateau emerged as dry land. Approximately 15,000 years ago, sea level began its most recent rise towards present sea level (Shinn, 1988). Sea level rose at an average rate of 30 feet per 1,000 years. About 7,000 years ago, the rate of sea level rise slowed when the sea level was about 30 feet below its present level. It was at this most recent slowing of sea level rise that the modern barrier islands of southeast peninsular Florida formed.

2.1.2 Local Geology

Palm Beach County is made up of three physiographic areas: The Atlantic Coastal Ridge, the Sandy Flatlands, and the Everglades. The formations exposed at the surface include sand, coquina, and limestone deposited during the glacial epochs starting 1 to 2 million years ago.

With the exception of the Everglades and the Loxahatchee Marsh area, where organic soils cover the surface, a layer of surface sand (Pamlico sand) overlies all of Palm Beach County. On the sandy flatlands between the Everglades and the coastal ridge, this sand is one to two feet thick, increasing to 10 feet along the ridge and adjacent barrier islands.

The Anastasia Formation immediately underlies the surficial sands. This formation is composed of sand, coquina, sandstone, limestone and shell beds. The Anastasia underlies all of eastern Palm Beach County from the beaches, where it ranges from 40 to 50 feet thick, to the edge of the Everglades, where it can be up to 200 feet thick. The Everglades is underlain by the Fort Thompson Formation, which consists of marine sands, shell beds, sandstone, limestone and freshwater marl. This formation is of the same age as the Anastasia formation and ranges from 20 to 50 feet thick.

The Caloosahatchee marl underlies the Fort Thompson and Anastasia Formations, and is composed of sandy shell marl, and shelly sand with only minor amounts of sandstone and limestone. This formation can range from 30 to 110 feet in the Everglades and 230 to 330 feet in the coastal areas. Subsequent formations include the Tamiami, Hawthorne, Tampa, Suwannee limestone, Ocala Group and the Avon Park limestone.

Most of the barrier islands in Palm Beach County are founded on the Anastasia Formation. This rock formation appears at several places in the county as a submerged reef that generally parallels the shoreline. The exposed formation appears at various locations from the high water line to approximately 1,000 feet (ft) offshore. Nearshore rock outcroppings exist in the project area. The most prominent outcropping occurs near Florida Department of Environmental Protection (FDEP) coastal monitoring range monument R-18 (Jupiter, FL). A portion of this outcropping extends above mean high water, and the remainder extends into the nearshore area.

The project area is located within LWL, a part of the Atlantic coastal ridge region. The drainage basin of LWL is also of interest to the study, and this area, covering Canals C-16, C-17, and C-51, extends into the sandy flatlands. Typical substrates found within LWL range from muck/mud (nearly all silt/clay with some organics) to sand and shell.

2.2 Hydrology

The hydrology of LWL is complex, as it involves inland processes from the canals and flood control structures, and coastal processes from waves, tides, and currents. The unique hydrologic factors of LWL are discussed in the sections below.

2.2.1 <u>Inlets</u>

LWL was originally a 20-mile landlocked freshwater lake (Lake Worth) fed by a wetland area along its western edge, and bordered by a barrier island to the east, which separated Lake Worth from the Atlantic Ocean (**Figure 2-3**). During Lake Worth's freshwater history, temporary connections to the Atlantic Ocean through the barrier island (inlets) occasionally formed at the north end of the lake due to extreme high tides, waves, and high lake water levels (Linehan 1980). Eventually ephemeral ocean linkages were made permanent with dredging and channel protection structures (jetties, seawalls, etc.).

Figure 2-3 Lake Worth in the 1870s-1880s when it was primarily a freshwater lake

2.2.1.1 *<u>Lake Worth Inlet</u>*

Lake Worth Inlet (also known as Palm Beach Inlet) was originally dredged to provide access to the ocean from Lake Worth. Immediately, the lake began to change from a freshwater lake to a saltwater esturine system. **Table 2-1** provides a historical account of the construction of Lake Worth Inlet.

Table 2.1 - Lake Worth Inlet Construction Sequence

Year	**Event**
1860’s	August O. Lang dug a narrow trench from Lake Worth to the ocean, lowering lake levels. Had to be re-dug many times due to instabilities (Pierce 1970)
1877	Relocated trench in a rocky area 1 mile north of Lang’s Inlet, called “Black Rocks” so excavated rocks could form natural jetties, hoping to create a more stable inlet (Pierce 1970, SFWMD 1977). Was still unstable, and also had to be re-dug many times.
1893, 1905	Henry Flagler financed inlet enlargement (Historical Society of Palm Beach County)
1915	Florida State Legislature chartered the Lake Worth Inlet District (later called the Port of Palm Beach District)
1917	After a public vote and a detailed survey by Isham Randolph, the inlet was re-excavated with two short jetties, in the original Lang Inlet location (Knott 1980).
1919	Channel was widened to 100 feet and dredged to 10 feet deep at low tide by local interests
1920	More robust jetties were constructed, and the channel was deepened to 12 feet by local interests (Knott 1980).
1923	Jetties were extended, and local interests further deepened the channel to 16 feet (Knott 1980).
1925-1926	All jetty construction was completed by local interests (USACE 1988). Channel was ultimately deepened to a depth of 18 feet, and 60,000 cy of rock was removed from the mouth. Dredge spoils were used to create Peanut Island.
1935-1941	Federal Government took over, adding rocks and concrete caps to the jetties, and deepening the channel to 20 feet (USACE 1988).
1948-1967	Re-dredged several times to an ultimate depth of 35 feet.
1946	USACE studies indicated erosion along 8.5 miles of shorefront south of the south jetty due to interruption of natural littoral drift.
1957-1958	A sand transfer plant was installed on the north side of the north jetty to pump sand south across the inlet for deposition on the eroded beach.
1985	USACE chinking stone to the jetties and filled with grout to prevent transport of sand through the jetty and into the inlet.
1990-1996	Sand transfer plant shut down due to transfer pipe failure.

Year	Event
1996	Sand transfer plant resumed operation after plant upgrades and pipeline replacement.

2.2.1.2 *South Lake Worth Inlet*

South Lake Worth Inlet (also known as Boynton Inlet or Ocean Ridge Inlet), also a man-made inlet, is located in the southern portion of LWL. The Palm Beach County Board of Commissioners manages the inlet channel and associated structures. Local residents and visitors use South Lake Worth Inlet for recreational boat access to the Atlantic Ocean. Excavation of the channel occurred in 1925 and jetties were constructed in 1927 to keep sand from entering the inlet. **Table 2-2** provides a historical construction sequence.

Table 2.2 – South Lake Worth Inlet Construction Sequence

Year	Event
1915	State of Florida approved an act to create a Special Taxing District in Palm Beach County, the South Lake Worth Inlet District
1924	USACE issued a permit to construct an inlet at South Lake Worth
1925-1927	Construction of jetties and inlet.
1932-1934	Homeowner south of inlet constructed a 2,000-ft seawall (the “McCormick Wall”) and seven support groins in an effort to reduce erosion of sand along his property. These proved to be ineffective (Caldwell 1950).
1936	Sand was being transported around north jetty and shoaling inside south LWL (Strock 1983).
1937	Sand transfer plant was constructed on the north jetty.
1942-1945	Sand transfer plant shut down due to fuel shortage during World War II.
1948	Improvements made to sand transfer plant (Strock 1983)
1953	Training wall constructed along north side of inlet in an effort to channelize sand accumulation (Strock 1983).
1948-1952	Interior dredging of shoals likely occurred during this period, according to inlet budget records (Strock 1983).
1961-1969	Dredging of interior shoals with disposal of dredge spoil on the eroded beach south of the inlet (Strock 1983).
1964	University of Florida completed a study recommending inlet improvements to decrease shoaling in LWL (University of Florida 1964).

Year	Event
1971	A spur was constructed on the north jetty (Marino and Mehta 1986).
1996	Governor Lawton Chiles abolished the taxing district, and Palm Beach County (PBC) took over operation of the sand transfer plant.
Mid- 1990's	Beer Can Island became Bird Island with an enhancement project that included exotics removal, native vegetation recruitment, and a rookery creation.
1997-1998	Groin field constructed and beach nourishment completed to address erosion due to inlet, and sand transfer plant capacity was upgraded.
2001	PBC removed a rock ledge from the inlet and created a sand trap behind the training wall.
2001, 2008	PBC performed maintenance dredging of the sand trap and parts of the IWW Dredge sediments were deposited south of the inlet.
2009	PBC approved a contract to replace the sand transfer plan with a new one, rehab both jetties, and construct a new seawall at Bird Island.

2.2.2 Intracoastal Waterway (IWW)

During the Civil War Reconstruction Period, canal companies were given land to develop water transportation facilities; because of this, the East Coast Canal was developed. By the late 1890s, a canal began to cut across the sawgrass marshes and various ridges to connect Lake Worth to Jupiter Inlet to the north. The channel was cut 5 ft deep and made 50 ft wide and extended from Jacksonville to Miami (Vines 1970). The canal was completed in 1898, making Lake Worth part of a larger the larger Intracoastal Waterway system. Excavated materials from the construction were placed upon existing low-lying upland areas or created scattered spoil islands. In 1929, the state of Florida purchased the East Coast Canal, deeded it to the U.S. Government, and renamed to the Intracoastal Waterway (IWW).

2.2.3 Flood Control Features

Multiple local drainage districts, municipalities, and the South Florida Water Management District (SFWMD) manage the LWL watershed and stormwater drainage system. Other than the rainfall that falls directly on the LWL basin, stormwater is routed through either C-17, C-51, or C-16 canals. The construction and operations of these three canals have created unnatural point sources of freshwater into the lagoon as compared to a more evenly distributed overland flow through natural historical streams or adjoining upland areas.

The history of the major flood conveyance canals and drainage features that discharge east into LWL watershed date back to the year 1919. **Figure 2-4** depicts the LWL watershed. All the water in the watershed drains into LWL (Refer to EN Attachment B for further characterization of the LWL watershed and Land Use statistics). The State of Florida Everglades Drainage District originally started construction of the West Palm Beach Canal (C-51) beginning in 1919 and completed construction in 1929. However, as part of the Central & South Florida (C&SF) Project (1948), multiple features, structures, and improvements to the LWL watershed and the original West Palm Beach Canal were designed and constructed over the course of 60 years by the USACE and subsequently transferred to the sponsor, the SFWMD.

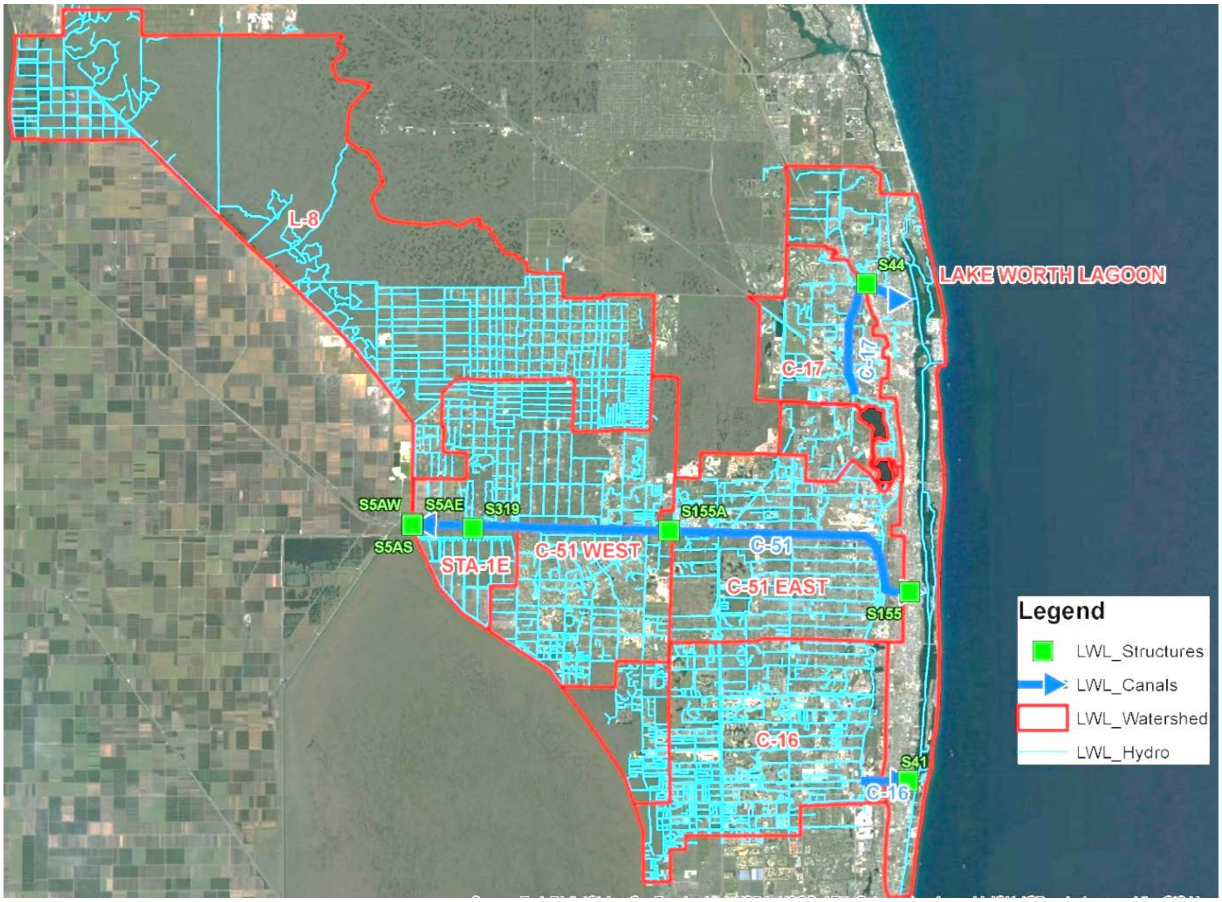

Figure 2-4 Lake Worth Lagoon Watershed.

2.2.3.1 *Central & South Florida Project*

The history of the major Federal features affecting freshwater discharges into the LWL are described in the following sections. The authorization of the "Central and South Florida Project for Flood Control and Other Purposes" originates from the *Flood Control Act of 1948, Section*

203 of Public Law 858, 80th Congress, 2nd Session. However, subsequent congressional authorizations following the original 1948 legislation specify individual C&SF project features for the LWL watershed (**Table 2-3**). The construction completion dates of the major features affecting the LWL are listed in **Table 2-3**. **Table 2-4** provides logistics for each of the canals that lead into LWL and includes the respective structures within Canal.

Table 2.3 - Lake Worth Lagoon Watershed Features

Feature	**Authorization**	**Construction Completion***
C-51	Flood Control Act of 1962	NA
S-44	Flood Control Act of 1948	Feb 1957
C-17	Flood Control Act of 1948	Jan 1958
S-5AE	Flood Control Act of 1948	Apr 1955
C-16	Flood Control Act of 1954	Aug 1965
S-41	Flood Control Act of 1954	Aug 1965
S-155	Flood Control Act of 1962	Jun 1987
S-155A	Flood Control Act of 1968	Dec 2002
S-319	Flood Control Act of 1968	Mar 2004

***"C&SF Project for Flood Control and Other Purposes, Master Water Control Manual, East Coast Canals, Vol. 5, March 1995"*

Table 2.4 - Canal and Control Structures within each Canal

Canal	**C-17**	**C-51**				**C-16**
Length (mi.)	6.3	21.0				2.2
Level of Protection	60% SPF	30% SPF for Agricultural Areas and 60% for Urban and Citrus Areas				60% SPF
Design Water Surface (ft -NAVD88)	-0.05 to 10.5	7.0 to 11.5				0.1 to 7.5
Structure Name	**S-44**	**S-319**	**S-5AE**	**S-155A**	**S-155**	**S-41**

Canal	C-17	C-51				C-16
Structure Type	Spillway	Pump Station	Spillway	Spillway	Spillway	Spillway
Design Discharge (cfs)	2,070	3,980	700	1,460	4,800	4,500
Level of Protection	60% SPF	NA	NA	30% SPF for Agricultural Areas and 60% for Urban and Citrus Areas		60% SPF
Headwater (ft NAVD88)	7.5	9.5 to 11.0	10.0	10.0	7.0	6.6
Tailwater (ft NAVD88)	-4.6 to +2.4	NA	8.5	9.1	-2.5 to 0.5	0.3

C-17 Canal and S-44

The S-44 structure construction was completed in February 1957 (**Table 2-3**). The purpose of the C-17 canal is to drain flood waters from the low area west of the coastal ridge between Lake Mangonia and the Earman River. The C-17 canal will remove 60 percent of the standard project flood (SPF) from the drainage area. The outlet of C-17 is the S-44 spillway structure, which is designed to pass 2,070 cfs and release flood runoff from C-17 into LWL.

C-51 Canal, S-5AE, S-155, and S-155A

The C-51 canal (West Palm Beach Canal) is approximately 21 miles long with S-5AE at the headwaters of the canal in the west and by the S-155 spillway structure at the east end of the canal. Along the C-51 canal, approximately 11.2 miles upstream of S-155, is S-155A spillway structure, which separates the C-51 West basin from the C-51 East basin. Construction completion for S-5AE, S-155, and S-155A was in April 1955, June 1987, and December 2002, respectively (**Table 2-3**). The C-51 canal intercepts flows from the west, and was designed to remove 30 percent of the SPF from agricultural lands and 60 percent of the SPF from citrus and urban areas. C-51 discharges through the S-155 spillway structure into LWL to the east. The S-155A structure provides additional control of water in the C-51 canal from the C-51 West subbasin. The S-155 and S-155A spillway structures maintain optimum water levels in the C-51 canal by preventing over-drainage while simultaneously discharging flood and regulatory flows from the canal.

C-16 canal and S-41

Construction for S-41 was completed in August 1965 (**Table 2-3**). The C-16 canal (Boynton Canal) will remove 60 percent of the SPF from the drainage area. The purpose of the C-16 canal is to provide an outlet to Lake Worth through the coastal ridge at Boynton Beach. The outlet of C-16 is the S-41 spillway structure is designed to pass 4,600 cfs (60 percent of the 5,300 SPF), to maintain desirable water stages in C-16 upstream during low-flow periods, discharge up to design capacity without exceeding desirable stages, restrict discharge during floods that will not cause damaging velocities, and prevent salt water intrusion into the canal.

2.2.4 Dredge/ Muck Holes

Common practice in the early 20th century was to dredge out portions of the lagoon and fill in low-lying areas along the LWL shoreline. These dredge holes are numerous and scattered throughout LWL, and is visible in the bathymetry data shown in **Figure 4-4**. In addition to dredging, the existing vegetative shorelines, which once inhabited the lagoon and trapped "muck" sediments, were replaced with vertical shoreline stabilization structures (i.e., bulkheads, seawalls, revetments, etc.) rather than natural wetlands or mangroves.

2.3 Climate

LWL is influenced by rainfall, local and regional winds, periodic storms, ocean tides, and water levels.

2.3.1 Rainfall

The LWL is subject to a cyclic dual season of meteorology; a wet and dry season. These seasons are defined as May to October for the wet season and November to April for the dry season. During the wet season, the LWL typically experiences frequent (often daily) brief and sometimes intense rainfall events. Additionally, the watershed is prone to Atlantic tropical cyclonic events which produce large amounts of rain over a significant area. Several of the major flooding events into the LWL were caused by these tropical events (

Table 2-5) and observed through a nearby flood structure, S-155.

Table 2.5 Maximum Flow Events through S-155 and Named Storms

Date	S-155 Flow (cfs)	Named Storm
16 Jan 1991	4,605.30	N/A
18 Oct. 1995	5,364.87	N/A
16 Oct. 1999	7,141.80	Hurricane Irene

Date	S-155 Flow (cfs)	Named Storm
26 Sep 2004	4,896.06	Hurricane Jeanne
27 Aug. 2012	5,057.81	Hurricane Isaac

According to the West Palm Beach International Airport (NOAA gage ID: USW00012844) from the Global Historical Climatology Network Database (GHCN), the average, maximum, and minimum annual water-year (May to April) rainfalls are 61.12, 102.90, and 32.85 inches, respectively, for the period of record 1938-2016. The wet season (May to Oct.) contains the majority of the rainfall averaging 41.97 inches and the dry season averages 19.15 inches (**Table 2-6**).

Table 2.6 Rainfall Statistics and Seasonal Allocation at

NOAA Gage USW00012844, West Palm Beach International Airport

Statistic	Dry Season (Nov to April)	Wet Season (May to Oct)	Water Year (May to April)
Percent	31%	69%	100%
Average (in.)	19.15	41.97	61.12
Minimum (in.)	4.06	21.33	32.85
Maximum (in.)	42.56	75.61	102.90

2.3.2 Wind Climate

Winds influence water levels, currents, and waves in LWL. The representative station used to describe the wind climatology in the lagoon is the West Palm Beach Airport, Station PBI, which has a period of record from 1970 to the present. **Figure 2-5** shows a wind rose plot of percent occurrence of wind speed and direction for all records at station PBI. The majority of the winds are from the northeast, east, and southeast directions, and to a lesser extent from the northwest. During the months of October and November the predominate wind direction is from the northeast to east with an average wind speed of about 10 mph (8.7 knots), with more frequent occurrences of wind speeds of 15 mph (13 knots) to 20 mph (17 knots) and greater. During the months of December through February the predominate wind directions are from the east to southeast and from northwest with an average wind speed of about 10 mph (8.7 knots), with more frequent occurrences of wind speeds of 15 mph (13 knots) to 20 mph (17 knots) and greater. During the months of March through May the predominate wind directions are from the east to southeast with an average wind speed of about 11 mph (9.6 knots), with more frequent occurrences of wind speeds of 15 mph (13 knots) to 20 mph (17 knots) and greater. During the months of June through September the predominate wind directions are from the east to southeast with an average wind speed of about 8 mph (7 knots), with more frequent occurrences of wind speeds of 10 mph (8.7 knots) to 15 mph (13 knots).

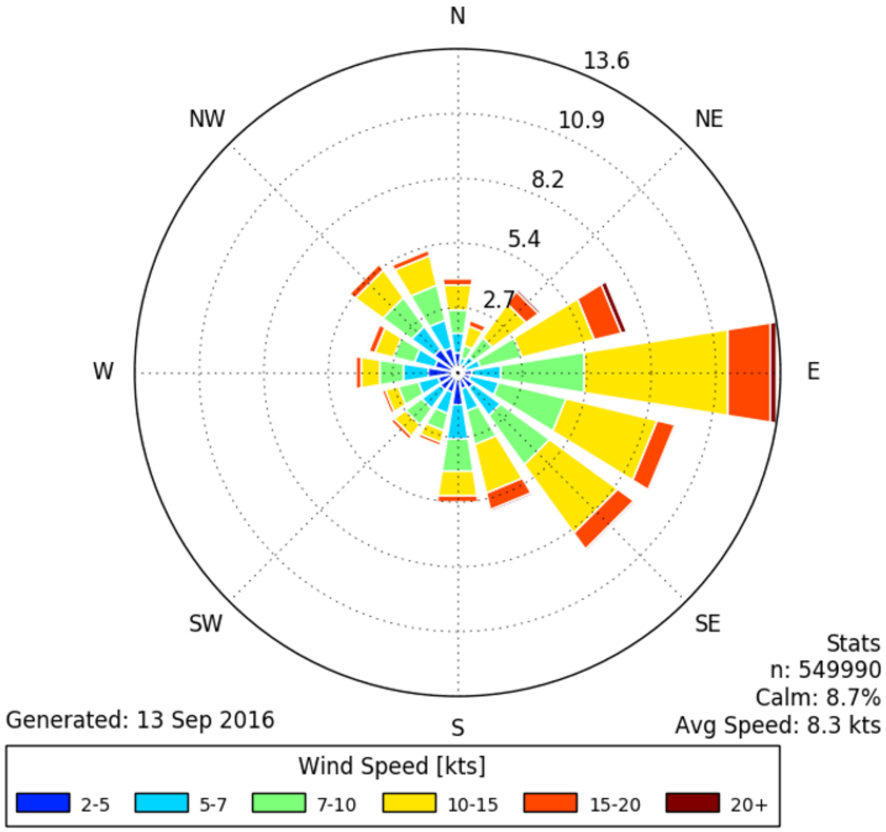

Figure 2-5 Wind Rose for Lake Worth Lagoon

2.3.3 Wave Climate

LWL experiences wind generated waves from north and south directions where fetches are 1 to 3 miles, and east and west directions where fetches are a few tenths of a mile to 0.5 miles for the width of the lagoon. Wind waves generated within the lagoon demonstrate typical conditions and design conditions based on an extreme tropical event condition with a return period of 50 years, or a 2 percent chance of occurring in any year, which corresponds to a Category 2 hurricane with wind speed of 96 knots. Typical conditions within LWL show wave heights ranging from 0.3 ft to 1.1 ft, having wave periods ranging from 0.9 seconds to 2.1 seconds, as shown in **Table 4-4**.

The Automated Coastal Engineering System (ACES) was used to estimate wave heights and periods for typical (20 knots) and design (96 knots) conditions for LWL exposure directions and fetches. The program was run in shallow water mode with average water depths based on the 2002-2003 bathymetric survey by Morgan & Eklund, Inc. and the Federal Emergency Management Agency (FEMA) 50 year surge height for the design condition.

2.3.4 Water Levels

The astronomical tide dominates the water level fluctuations throughout the lagoon while canal discharge has a minor effect primarily in the central portion of the lagoon near the C-51 canal. Tides in LWL are semi-diurnal with two high tides and two low tides each day. At the Port of West Palm Beach near the Lake Worth Inlet, NOAA station 8722588, the mean tide range is 2.72 ft. Near the South Lake Worth (Boynton) Inlet at Ocean Ridge, NOAA station 8722718, the mean tide range is 2.47 ft. In the central portion of the lagoon, at the mouth of C-51, NOAA station 8722654, the mean tide range is 2.46 ft (**Figure** 2-6). Canal discharge from C-51, during high flow conditions, usually associated with releases due to high rainfall periods, typically increases water level in the central portion of the lagoon near C-51 by a few tenths of a foot.

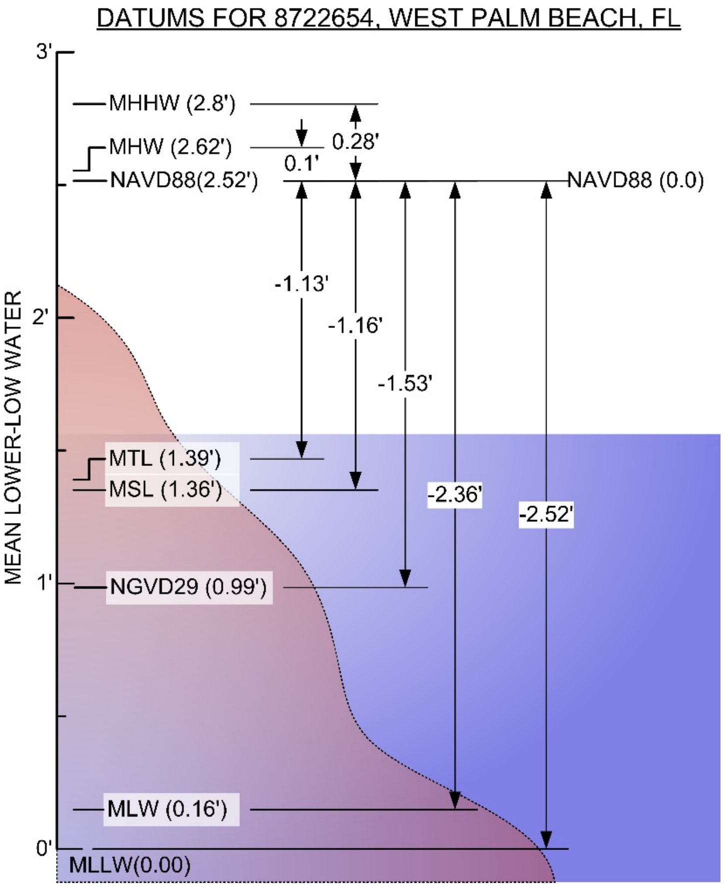

Figure 2-6 – Tidal Datums

2.3.4.1 *Storm Surge*

Storm surge is defined as the rise of the ocean surface above its astronomical tide level due to physical forces. Surges occur primarily as a result of atmospheric pressure gradients and surface stresses created by wind blowing over a water surface. Strong onshore winds pile up water near the shoreline, resulting in elevated water levels along the coastal region and inland waterways. In addition, the lower atmospheric pressure, which accompanies storms, also contributes to a rise in water surface elevation. Extremely high wind velocities coupled with low barometric pressures (such as those experienced in tropical storms, hurricanes, and very strong northeasters) can produce very high, damaging water levels. In addition to wind speed, direction and duration, storm surge is also influenced by water depth, length of fetch (distance the wind blows over water), and frictional characteristics of the nearshore sea bottom.

The storm surge events can provide insight into the vulnerabilities of a given location through comparison with the existing topography. Water level (with storm surge) time series are critical for input into shoreline response and coastal storm risk modeling applications. A history of storms impacting LWL is displayed in **Figure 2-7**, showing the storm paths of 48 tropical storms and hurricanes which have passed within 50 km of the project area since 1851. The return period of hurricanes for this region is 3.4 years per storm event, as calculated by dividing the POR by the number of storms. **Table 2-7** provides peak storm surge heights by return period for Lake Worth Inlet, Florida. Storm surge levels versus frequency of occurrence presented in **Table 2-7** were obtained from data compiled by the University of Florida for the Florida Department of Transportation (Sheppard and Miller, 2003).

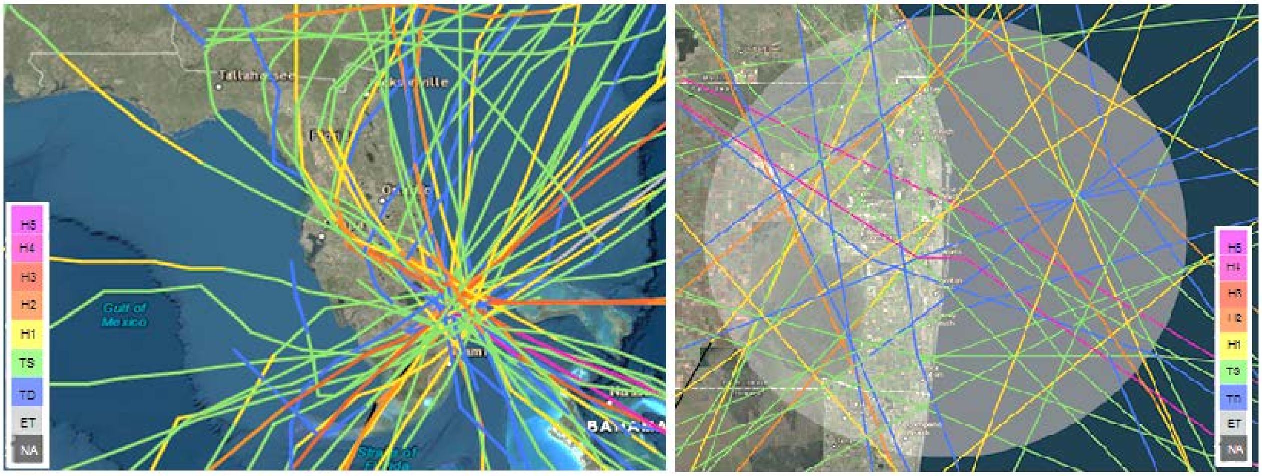

Figure 2-7 – LWL Storm History

Table 2.7 - Peak Storm Tide Elevations

Storm Return Period (Years)	Peak Storm Surge Height		
	ft-NGVD29	ft-NAVD88	ft-MSL
10	5.7	7.3	8.5
20	7.6	9.2	10.4
50	9.7	11.3	12.5
100	11.1	12.7	13.9
200	12.5	14.1	15.3
500	15.0	16.6	17.8

2.3.4.2 Sea Level Change

Relative sea level (RSL) refers to local elevation of the sea with respect to land, including the effects of lowering or rising land through geologic processes such as subsidence and glacial rebound. It is anticipated that the global mean sea level (MSL) will rise within the next 100 years. To incorporate the direct and indirect physical effects of projected future sea level change (SLC) on design, construction, operation, and maintenance of coastal projects, the USACE has provided guidance in the form of Engineering Regulation, ER 1100-2-8162 (USACE, 2013) and Engineering Technical Letter, ETL 1100-2-1 (USACE, 2014).

ER 1100-2-8162 provides both a methodology and a procedure for determining a range of SLC estimates based on global SLC rates, the local historic SLC rate, the construction (base) year of the project, and the period of Federal participation for the project. Three estimates are required by the guidance, a baseline (or “low” estimate, which is based on historic SLC and represents the minimum expected SLC, an intermediate estimate, and a high estimate representing the maximum expected SLC. More details are provided in the referenced ER and ETL.

The LWL project area is located approximately 60 miles from NOAA tide gauge #8723170 at Miami Beach, Florida. The historical local sea level rise rate taken from this gauge was determined to be 2.39 mm/year, with a 95% confidence interval of +/- 0.43 mm/yr based on monthly mean sea level data from 1931 to 1981, which is equivalent to a change of 0.78 feet in 100 years (USACE, 2015; NOAA, 2016). Given the project’s base year of 2019, a table of SLC rates is included for each of the three required scenarios through 100 years from the project base year (**Table 2-8**). **Figure 2-8** provides a graphic representation of the three levels of projected future SLC for the 50-year planning horizon of the project (2019 to 2069) as well as an additional 50 years (to 2119). By 2069 RSL rise predictions equal 0.39 ft, 0.85 ft, and 2.32 ft for the baseline, intermediate, and high SLC curves, respectively.

The local rate of vertical land movement is found by subtracting the regional MSL trend from local MSL trend. The regional MSL trend is assumed equal to the eustatic MSL trend of 1.7 mm/year (USACE, 2015). Therefore, at the LWL project, there is 0.69 mm/year of local vertical land movement.

Table 2.8 - Relative sea level rise for Lake Worth Lagoon

Year		**Baseline (Historic)**		**Intermediate (NRC Curve I)**		**High (NRC Curve III)**	
		m	**ft**	**m**	**ft**	**m**	**ft**
Base Year	2019	0.0000	0	0.0000	0	0.0000	0
	2020	0.0030	0.01	0.0030	0.01	0.0091	0.03
	2025	0.0152	0.05	0.0244	0.08	0.0549	0.18
	2030	0.0274	0.09	0.0457	0.15	0.1067	0.35
	2035	0.0396	0.13	0.0671	0.22	0.1646	0.54
25 Year	2040	0.0518	0.17	0.0915	0.3	0.2287	0.75
	2045	0.0640	0.21	0.1189	0.39	0.2988	0.98
	2050	0.0762	0.25	0.1433	0.47	0.3720	1.22
	2055	0.0854	0.28	0.1738	0.57	0.4543	1.49
	2060	0.0976	0.32	0.2012	0.66	0.5396	1.77
	2065	0.1098	0.36	0.2348	0.77	0.6311	2.07
50 Year	2069	0.1098	0.39	0.2348	0.85	0.6311	2.32
	2070	0.1220	0.4	0.2652	0.87	0.7287	2.39
	2075	0.1341	0.44	0.2988	0.98	0.8323	2.73
	2080	0.1463	0.48	0.3354	1.1	0.9390	3.08
	2085	0.1585	0.52	0.3720	1.22	1.0549	3.46
75 Year	2090	0.1707	0.56	0.4085	1.34	1.1738	3.85

Year		**Baseline (Historic)**		**Intermediate (NRC Curve I)**		**High (NRC Curve III)**	
		m	**ft**	**m**	**ft**	**m**	**ft**
	2095	0.1829	0.6	0.4482	1.47	1.2988	4.26
	2100	0.1951	0.64	0.4878	1.6	1.4299	4.69
	2105	0.2073	0.68	0.5305	1.74	1.5671	5.14
	2110	0.2195	0.72	0.5732	1.88	1.7104	5.61
	2115	0.2287	0.75	0.6189	2.03	1.8567	6.09
100 Year	2119	0.2409	0.79	0.6555	2.15	1.9817	6.5

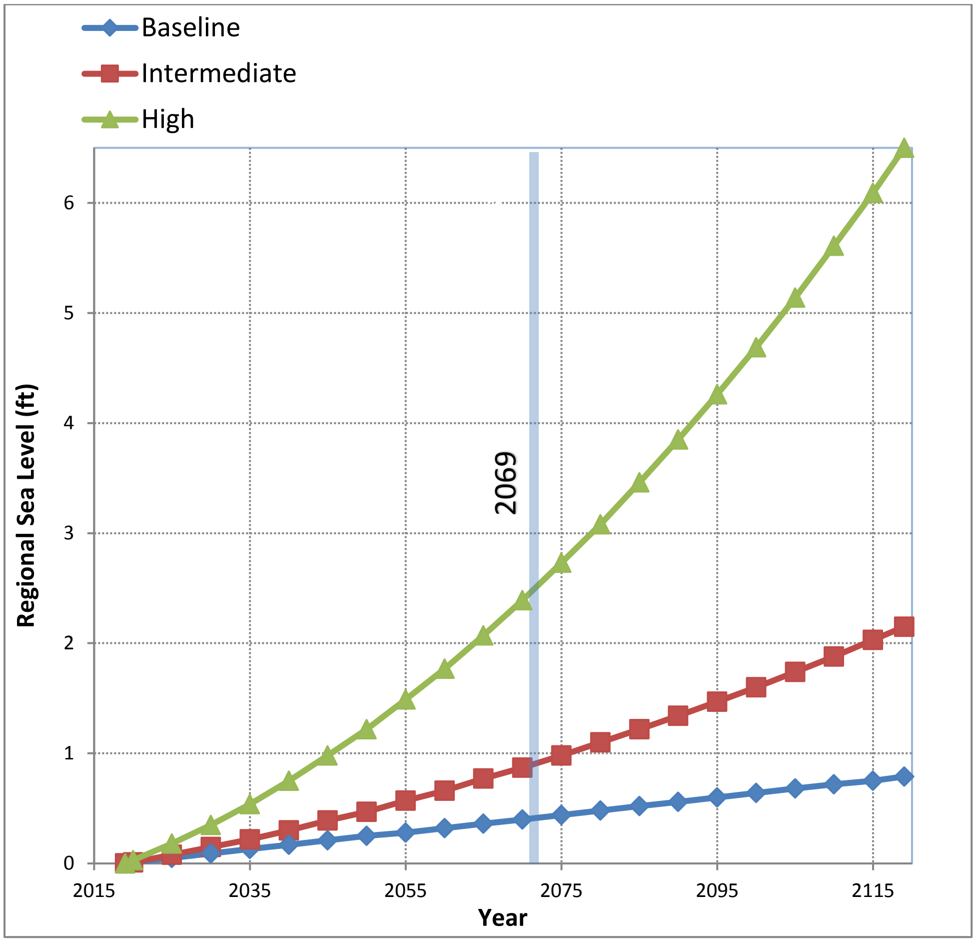

Figure 2-8 – Relative sea level change

3.0 UNDERSTANDING THE PROBLEM: SYNTHESIZING THE DATA

The sponsor, PBC DERM, provided the Corps with a plethora of data collected within and outside LWL. Many components are interdependent and inseparable. Therefore, the sources of the problem must be understood and then analyzed before a solution can be determined. In essence, the Corps was presented with one problem with two potential sources: a degraded environment within LWL, which was caused by muck (sediment) accumulation and salinity changes brought about by Corps projects.

3.1 Salinity

The salinity regime in LWL is strongly influenced by episodic freshwater flows from the C-17, C-51, and C-16 canals, and ranges from freshwater to hypersaline. Other controlling factors and processes include saltwater inflows from the ocean through the Lake Worth and South Lake Worth tidal inlets. Freshwater inflows combined with marine processes operating at tidal, meteorological, and seasonal time scales determine the overall salinity regime within LWL. All of these variables were analyzed to show salinity regime within the lagoon.

3.1.1 Tidal Prism

The salinity regime in LWL is strongly influenced by episodic freshwater flows from the C-17, C-51, and C-16 canals through their respective control structures. Other controlling factors and processes include saltwater intrusion from the Lake Worth tidal inlets, precipitation, and evaporation. Freshwater inflows combined with marine processes operating at tidal, meteorological, and seasonal time scales determine the salinity regime of the LWL.

Determining the tidal prism is a simple way to approximate the flushing of a lagoon or estuary. This estimates the overturning or flushing rate as the estuary volume divided by the freshwater volume plus estuary tidal prism (**Eq.** 1).

$$\tau = \frac{LagoonVolume(ft^3)}{Q_{FW} + Q_{SW}\left(\frac{ft^3}{TideCycle}\right)} \qquad \textbf{Eq. 1}$$

As noted earlier, the Lagoon is connected to the Atlantic Ocean by two inlets, Lake Worth Inlet and South Lake Worth (Boynton) Inlet. The dimensions for each inlet are provided in **Table 3-1**.

Table 3.1 – Lake Worth Lagoon Inlet Dimensions

Inlet	**Width**	**Depth**
Lake Worth Inlet	800 feet	35 ft
South Lake Worth Inlet	130 feet	6-12 feet

Table 3-2 shows the tidal prism estimates for the Lake Worth Inlet and the South Lake Worth (Boynton) Inlet. The Lake Worth inlet tidal prism is based on an empirical relationship between tidal prism and cross sectional area of the inlet (Jarrett 1976). The South Lake Worth (Boynton) Inlet tidal prism is based on a 13 month average of flow calculations from an acoustic Doppler current profiler (ADCP) monitoring effort (Stamates 2013). The lagoon volume is based on the 2002- 2003 bathymetry survey conducted by Morgan and Eklund. The canal flow volume is typical of the total flow represented by measurements from June 6, 2007. The overturning rate given by this approximation is 2.3 tidal cycles. This is a rough approximation, which assumes LWL is fully mixed and there is a complete exchange of water during each tidal cycle. The actual overturning rate is likely higher, needing more tidal cycles for flushing, but this estimate gives some indication of the influence of the tidal flow within LWL.

Table 3.2 - Lake Worth Tidal Prism Flushing Rate

	Water Volume (ft^3)	**Incoming Volume Flow Rate (ft^3/tidal cycle)**	**Number of Tidal Cycles**
Lake Worth Inlet (1)	n/a	9.32E+08	n/a
South Lake Worth (Boynton) Inlet (2)	n/a	1.22E+08	n/a
Canal Flow Volume (June 6, 2007)	n/a	2.65E+07	n/a
Lagoon Volume (2002-2003 Bath Survey)	2.47E+09	n/a	n/a
Totals	**2.50E+09**	**1.08E+09**	**2.3**

3.1.2 Currents

Currents in the LWL are influenced primarily by tides moving through two inlets, Lake Worth Inlet and South Lake Worth (Boynton) Inlet which connect the lagoon to the Atlantic Ocean. During the flood tide at Station 4 the average current is about 0.3 knots. Observed current measurements are available from two current meters located near Currie Park (Station 4) and Bryant Park (Station 3), which collected velocity data between July and October 2001 as part of the salinity and flow management study preformed for the SFWMD (Zarillo 2002).

The flood tide produces an average current of about 0.75 knots at Station 4. During ebb tide at Station 4, the average current is about 0.5 knots. The flood tide produces a maximum current of about 1.25 knots at Station 4. During the flood tide at Station 3 the average current is about 0.25 knots. The flood tide produces a maximum current of about 0.7 knots at Station 3. During the ebb tide at Station 3 the average current is about 0.4 knots. The flood tide produces a maximum current of about 1.0 knot at Station 3.

3.1.3 Freshwater Flows

June 1987 – August 2016 was used as the period of record (POR) for this analysis as the most recent major update to the hydraulics of the LWL system was the construction completion of S-155 in 1987. The seasonality of the LWL watershed is defined by a wet season (May to October) and dry season (November to April) with the water year defined as May to April. Daily average flow was acquired through SFWMD's DBHYDRO online database for the entire POR. For the POR, the majority of the freshwater flows into LWL came from S-155, composing 65% of the total volume. The S-41 structure conveyed 25% of the total volume, and S-44 carried 10% of the total volume (**Figure 3-1**). The wet and dry season allocation differences were minimal as compared to the total allocation results showing that S-155 and the C-51 canal are providing the most freshwater inflows into LWL (**Figure 3-2** and **Figure 3-3**). Data used in the charts is provided in **Table 3-3**.

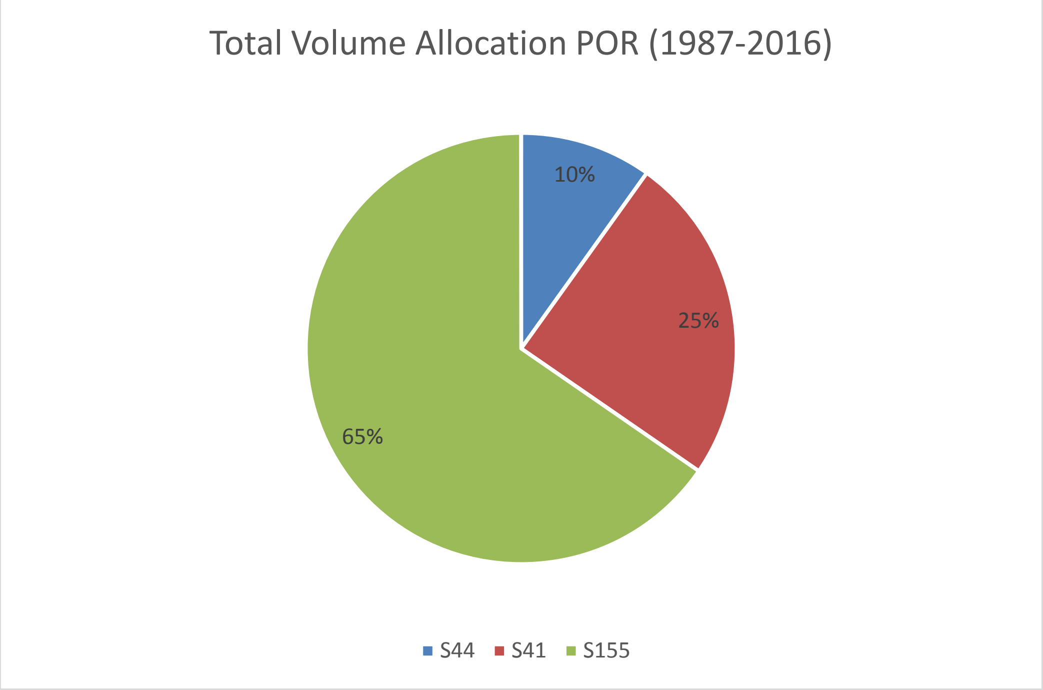

Figure 3-1 - LWL Total Fresh Water Inflow

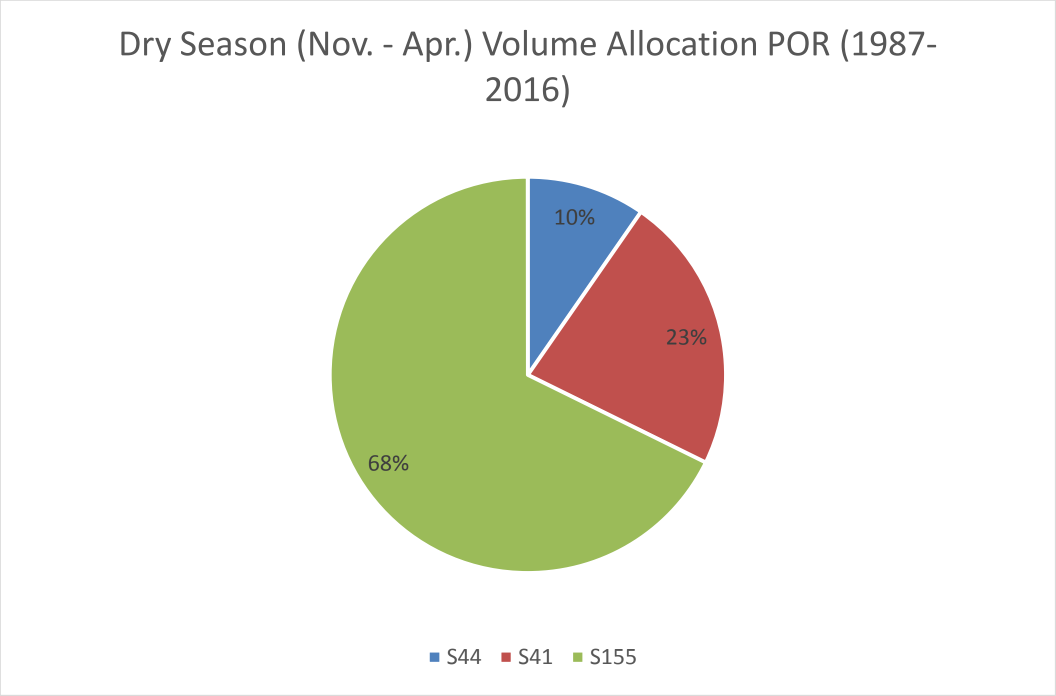

Figure 3-2 LWL Dry Season Fresh Water Inflow

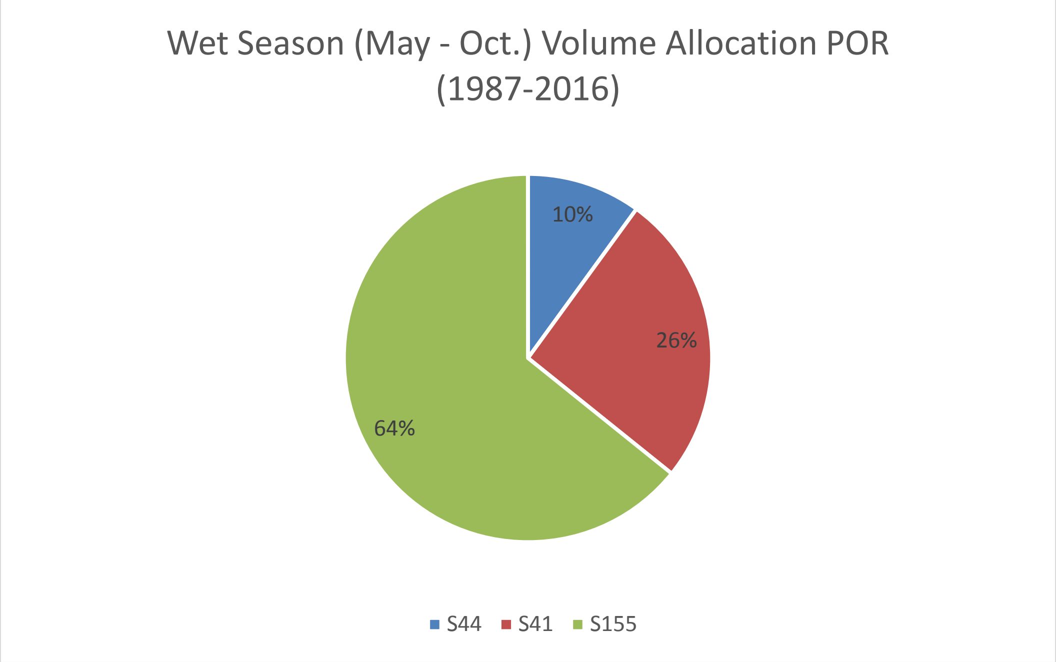

Figure 3-3 LWL Wet Season Fresh Water Inflow

Table 3.3 - Freshwater Flow Allocation from Structures S-44, S-41, and S-155 into LWL

	Total		Dry Season (Nov-Apr)		Wet Season (May-Oct)	
Structure	**Vol. (ac ft)**	**%**	**Vol. Dry (ac ft)**	**%**	**Vol. Wet (ac ft)**	**%**
S-44	1,334,114	10%	431,571	10%	902,543	10%
S-41	3,335,160	25%	1,009,983	23%	2,325,177	26%
S-155	8,820,452	65%	3,025,071	68%	5,795,380	64%
Total	13,489,725	100%	4,466,625	100%	9,023,100	100%

The annual flows from S-155, S-44, and S-41 were aggregated for each wet and dry season (**Figure 3-4**). The wettest years (water years) were 1995, 1996, and 1998 with volumes totaling 828,358 ac-ft, 814,227 ac-ft, and 805,168 ac-ft, respectively. By contrast the driest years were 1990, 2012, and 2007 with volumes totaling 75,912 ac-ft, 132,705 ac-ft, and 224,771 ac-ft, respectively.

The majority of the flows into LWL are from C-51 and released through the S-155 spillway structure. The average flows through S-155 for the POR are 431 cfs with a minimum of 0 and maximum of 7,142 cfs, which occurred on Oct. 16, 1999 due to Hurricane Irene.

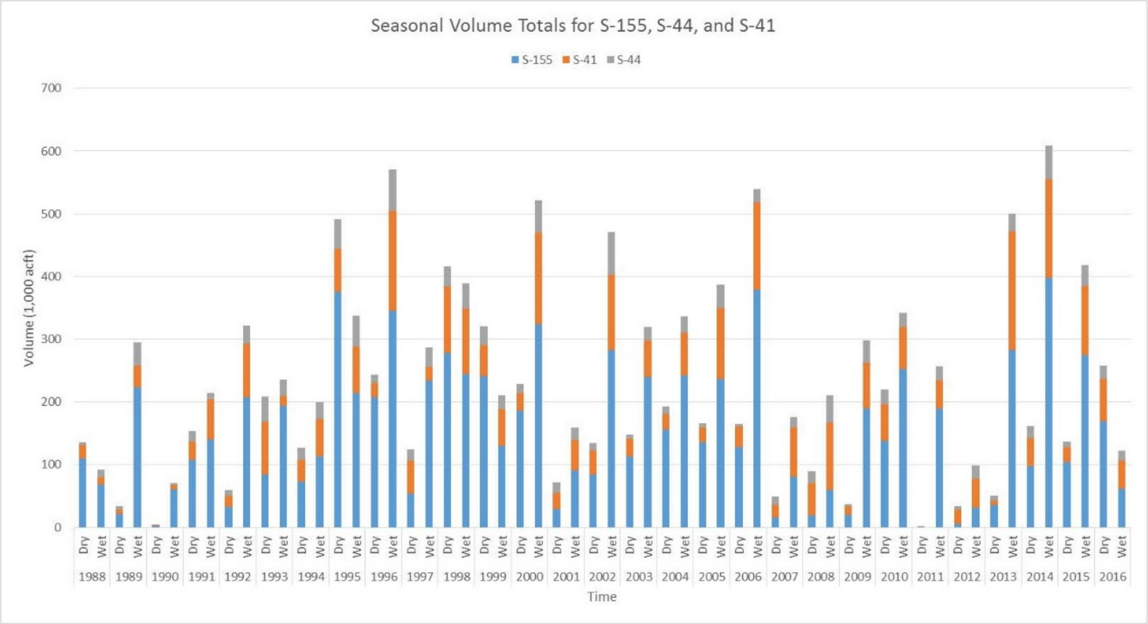

Figure 3-4 - Freshwater Flows by year

Based on the discharge data from the S-44, S-41, and S-155 spillway structures, it can be concluded that the C-51 canal and its associated basins are responsible for the majority of the freshwater flows into the LWL. The LWL will likely experience decreased salinity based on proximity and magnitude of freshwater discharges through S-155.

3.1.4 Freshwater Effects

An understanding of the tidal flow and freshwater flow effects on salinity in the lagoon are presented in the series of reports prepared for the SFWMD on hydrodynamic modeling for LWL (Zarillo 2002). The report indicates that LWL can be divided into three zones, characterized by different salinity regimes (North, Central, and South). The Northern zone (relatively high salinity in the LWL) is predicted to occur from the vicinity of Palm Beach Inlet and northward. Also within the northern zone, low salinity events occur with the same frequency as in the central zone, but salinity values are predicted to remain above 20 psu and generally occur in the range of 20 to 25 psu. A central zone between Palm Beach Inlet and South Lake Worth Inlet is characterized by frequent low salinity events occurring at the meteorological time scale of a few days to two weeks. Salinity levels during these events dropped to values of 5 to 15 psu and generally rebound to levels at or below 25 psu. A third southern zone of the Lagoon is predicted to be subject to low salinity levels similar to those of the central zone. However, salinity levels generally rebound to levels between 25 and 30 psu compared to levels in the central zone where rebound is between 15 and 25 psu. **Figure 3-5** shows the three zones represented by the model output station.

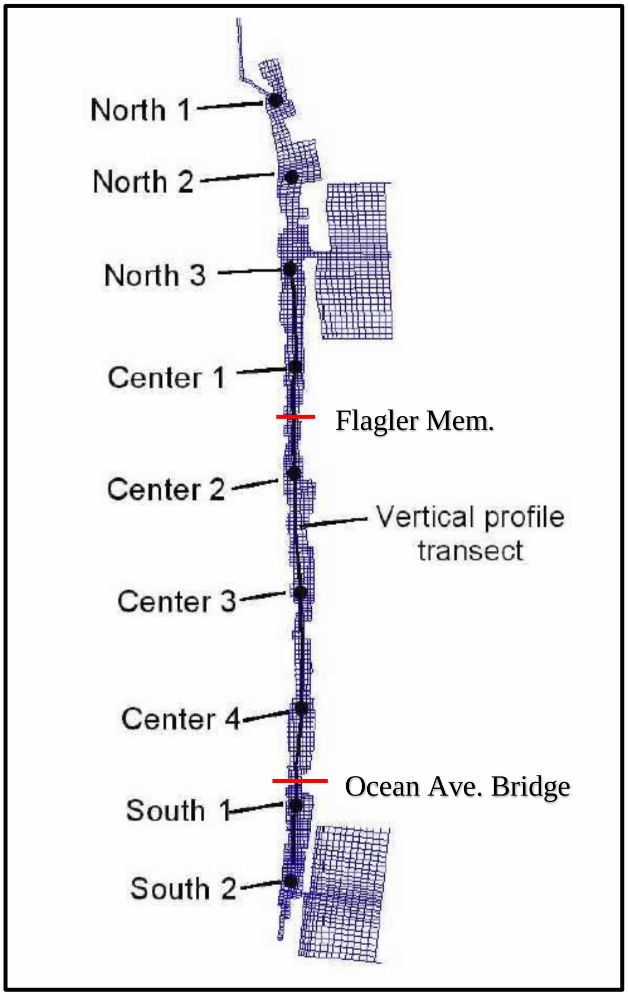

Figure 3-5 Numerical salinity recording stations used to analyze results of EFDC model test cases.

Tidal prism flushing and salinity in LWL canalso be modified by wind. **Figure 3-6** shows the effect of a wind from the north on the tidal prism at the South Lake Worth (Boynton) Inlet. The wind from the north pushes water in LWL to the south, which increases the ebb tide volume and suppresses the flood tide volume. Alternately, wind from the south pushes water to the north away from the Boynton Inlet, reducing the ebb tide volume and increasing the flood tide volume. The opposite is generally true for Lake Worth Inlet at the north end of the lagoon.

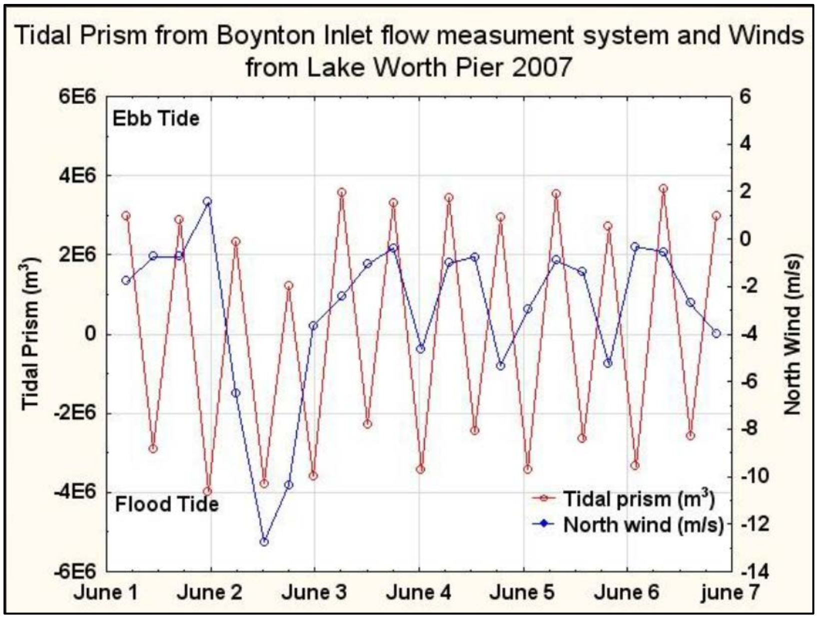

Figure 3-6 A time series of the tidal prism estimate and the average of the north component of the wind velocity for the period of those tides. (Stamates 2013)

3.1.5 Johns Island Salinity Study

Salinity was also monitored at John's Island by PBC DERM staff beginning in April 2010 to study salinity changes due to stormwater releases from C-51 in the central LWL. The primary monitoring site southeast of John's Island was selected due to its proximity to SFWMD's S-155 spillway and adjacent to PBC estuarine restoration projects (discussed in Chapter 4). PBC DERM staff deployed and maintained one multi-parameter in-situ sonde at this location continuously from April 2010 to present.

Overall there are several trends in the data that clearly show the close relationship between discharge events at the S-155 structure and salinity levels in the central LWL (**Figure 3-7**). As expected, the wet season typically brings increased rainfall totals and eventually leads to associated stormwater releases from the S-155. Immediately following each release a corresponding decrease in salinity has been observed and sustained until S-155 flow slows/stops. Local rainfall without associated S-155 discharge events appears to have little significant impact on salinity levels. This is apparent as during the 2011 dry season there were multiple rainfall events that occurred without associated S-155 discharge, while salinity remained high during the same period.

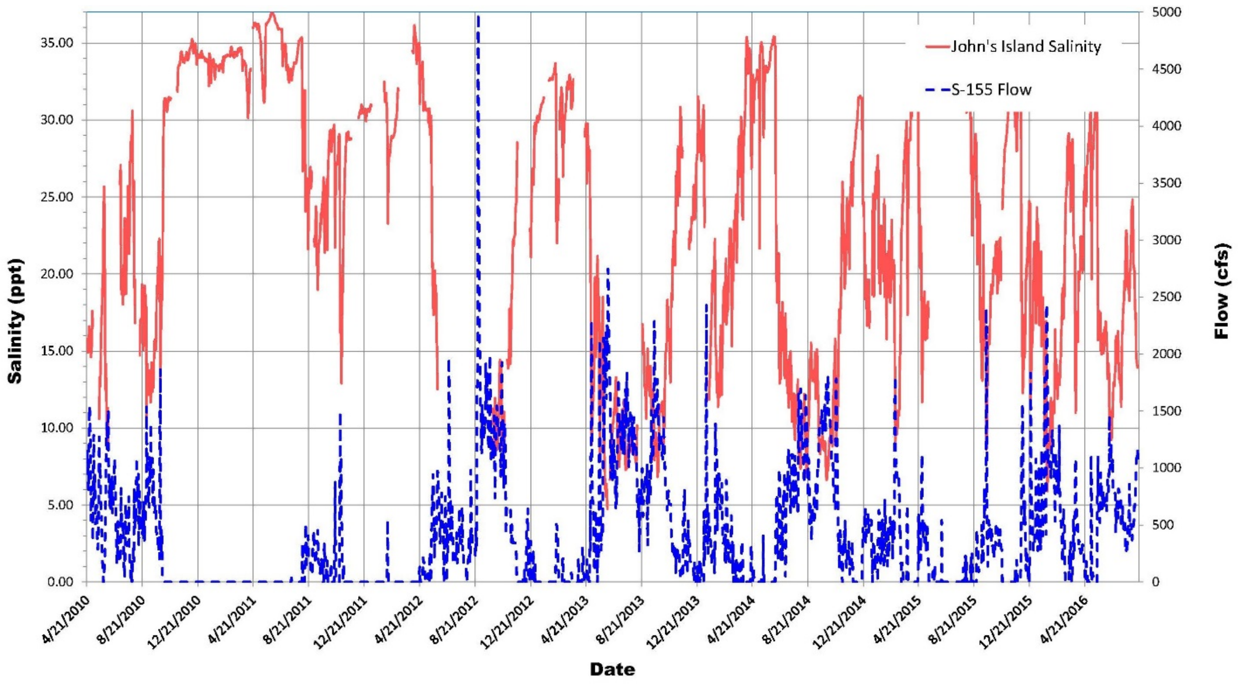

Figure 3-7 Johns Island Salinity Measurements

3.2 Overall Sediment Composition within Lake Worth Lagoon

Stormwater discharge is a major source of sediment input to the LWL that negatively impacts water quality and estuarine habitats (Refer to EN Attachment B for Land Use discussion). PBC conducted a study in 2008 to assess the sediments entering central LWL through the C-51 canal. C-51 contributes approximately half of the freshwater inflow to the LWL, and brings sediments from the agricultural areas of the sandy flatlands and Lake Okeechobee. Once various organic matter and fine sediment rests upon the lagoon bed, the material flocculates into a clayey/sticky foul smelling material aptly named “muck” (**Figure 3-8**). In shallow-water areas, portions of the muck is re-suspended during low-frequency wind/ wave events which then settles into other deeper areas within the lagoon (i.e., dredge holes). Once the muck settles within the dredge holes, the muck layer will continue to accumulate. DERM, in cooperation with SFWMD, conducted a study in 2011 which indicated that between 1.2 and 1.9 million cubic yards of muck deposits exist within 2.5 miles of the C-51 (PBC 2013).

Results from a 2008 sediment sourcing study showed that organic matter makes up 19% of the sediment composition in the LWL and 65% of this organic matter is derived from terrestrial (on land) sources. Sod probably contributes <10% of the inorganic fraction of the muck sediment but it likely contributes 30-50% of the sediment found in tributary canals in the C-51 east basin. Sediment inputs from the C-51 east basin and the M1 and Wellington Canals in the C-51 west basin collectively contribute <30% of the inorganic matter. A large fraction of the inorganic component (>70%) is likely to be derived from source areas west of Loxahatchee in the western reaches of the C-51 basin and farther west.

Figure 3-8 – LWL Muck grab sample

Organic matter made up an average of 19% of the dry sediment mass in LWL and gave the muck sediments their characteristic black color and high oxygen demand. Sources of this organic matter were determined using stable carbon isotopes. The results show that an average of 65% of the organic matter in LWL sediments was derived from terrestrial sources (i.e., land derived) and 35% was produced through primary production in LWL. Calculations using the various metal/metal ratios support the following statements:

(1) Sod probably contributes <10% of the inorganic fraction of the muck sediment in LWL;

(2) Sod probably contributes 30 to 50% of the sediment found in tributary canals in the C-51 east basin such as the E1 to E4 series of canals;

(3) Sediment inputs to LWL from the C-51 east basin (the E1 to E4 canals mentioned above) seem to account for <30% of the inorganic matter found in LWL sediments; and,

(4) A large fraction of the inorganic component of the sediment in LWL seems to be derived from areas west of Loxahatchee in the western reaches of the C-51 west basin and farther west.

The LWL sediment thickness study was performed in 2009 to investigate, map and quantify the horizontal and vertical extent of the reported sediment/muck deposits within areas centered about the C-51 discharge canal. The study area ranged from the northern most site at 12 Oaks to the southern extremity at Bryant Park, and included the dredge holes/ areas of Currie Park, South Cove, Palm Beach Atlantic University, Everglades, Ibis Isles, Snook Islands, and Blossom's Hole.

The results of the muck/sediment thickness study indicate much of the original bottom in the study area is overburden with a thick semi-fluid muck layer. Analysis of the data shows a strong correlation between the relative depths of water and the thickness of the muck layer, as well as the type of material present. In general, holes or deeper areas contained thicker layers of muck sediment.

Additionally, within each site the thicker layers of muck corresponded to a higher percentage of fines within the sediment analyzed. Overall, sites closest to the C-51 discharge had the highest percentage of fines and thickest muck. Average percentage of fines for Ibis Isle North, Ibis Isle South, and Snook Islands, and within those areas the highest percentage of fines, was generally found in the thickest muck.

3.2.1 C-51 Sediment Trap

To address the incoming sediment from C-51, in January of 2006, a collaboration between the SFWMD, PBC DERM, and the City of West Palm Beach, initiated construction and monitoring of a sediment trap upstream of the S-155 spillway in the C-51 canal, just west of I-95 highway. Construction was completed in July 2008 (**Figure 3-9**).

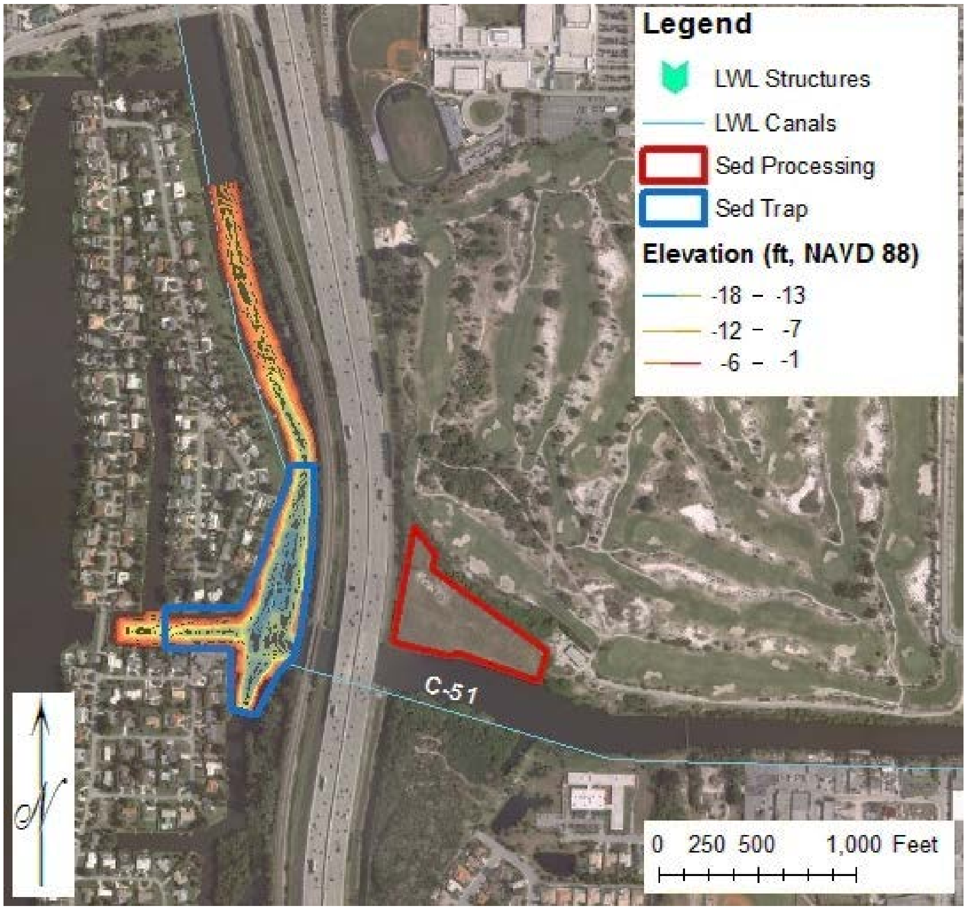

Figure 3-9 Sediment Trap Location

The sediment trap is approximately one mile in length of C-51 canal and was initially dredged in 2007. Over 100,000 cubic yards of muck were hydraulically dredged from the C-51 canal and transported through pipes to settling ponds. The muck was then dewatered, treated, and hauled away for beneficial uses. The sediment trap has not been dredged for muck since the initial construction and dredging. The SFWMD is responsible for operating and maintaining the sediment trap, which has been surveyed every year since construction completion (**Table 3-4**).

The sediment trap surveys and analysis shown in **Table 3-4** show the accumulation and scouring of the trap area. Early surveys show the accumulation of inbound sediment was trapped and reduce the amount of muck entering LWL. Due to expense of removing and treating of muck, the sediment trap has not been dredged since original construction. The sediment trap surveys also indicate that when the muck is allowed to attenuate through lack of maintenance, it can be re-suspended and pushed in the direction of flow once a cavity has been filled. Qualitatively, this muck dispersement could be theorically happening within the LWL with each incoming tide or low frequency event. PBC has commented on several occasions that muck waves move in and around the lagoon covering over existing dredge holes and eventually covering over existing habitat.

Table 3.4 - Sediment Trap Annual Volume Survey Results

Year	Accretion (Cu. Yds.)	Erosion (Cu. Yds.)	Net (Cu. Yds.)
Nov 2007 – Oct 2008	8,325.01	2,500.06	5,824.95
Oct 2008 – Aug 2009	8,403.27	195.21	8,208.06
Aug 2009 – Sept 2010	2,144.20	2,384.72	-240.52
Sept 2010 – June 2013	11,471.85	1,707.86	9,763.99
June 2013 – Jan 2014	2,573.22	3,247.06	-673.84
Jan 2014 – June 2014	789.16	9,734.09	-8,944.93
June 2014 – Jan 2015	3,083.79	2,048.87	1,034.92
Nov 2007 – Jan 2015	18,979.98	4,007.35	14,972.64

3.3 Final Problem Statement

LWL has encountered losses in seagrass, mangrove, and oyster habitat due to dredging and filling operations and large-scale freshwater discharges into LWL. The Corps' dredging and filling activities have been previously constructed a section 1135 project (i.e. Peanut Island). The flood water discharges occur from Canals 16, 17, and 51 (C-16, C-17, and C-51, respectively). Since C-16 and C-17 are both in close proximity to the inlets to the ocean, C-51 is the main contributor to reduced salinity and increased sediment load within the central portion of LWL. C-51 is a component of the Central and Southern Florida (C&SF) project and provides both flood risk management and water supply to the LWL watershed. Freshwater releases from C-51 are controlled by an automated gated spillway structure (S-155) into the LWL based on the stages in the canal. However, operational changes to freshwater pulses from C-51 to alleviate the salinity drop and sedimentation loads are not possible within the scope of CAP.

Due to tides and other climatic factors, low salinity values are short lived outside the influence of C-51 freshwater flows where salinity fluctuations are more prevalent. Farther away from C-51 lagoon areas have more tidal exchange and less fluctuations. Therefore, the suspended organic sediments for which freshwater pulses are laden with are impacting the lagoon's capability to sustain a viable benthic community. After each freshwater pulse, more sediment is accumulating and eventually trapped within the lagoon. Over time, the accumulated sediment within LWL covers existing benthic habitats and potentially threatens other habitable areas.

4.0 FIXING THE PROBLEM – DETERMINING THE SOLUTION

SAJ reviewed and analyzed all the information provided by the sponsor to understand the LWL system and narrow down the problem to a set of alternative solutions. CAP 1135 cannot solve the larger scale problems such as the salinity or sedimentation problems summarized in the preceding chapter. CAP is required to demonstrate that a project can provide environmental benefits within reasonable limitations of the project and project life cycle, as well as an agreed methodology and costs by sponsor and Federal government. This heading provides leading information to how the Project Delivery Team (PDT) determined a recommended solution by discussing the:

- Benefits of small ecosystem projects;
- Possible alternatives for CAP 1135 project;
- Ideal location for the habitat restoration;
- Sediment source for habitat creation; and
- Rough order of magnitude (ROM) for a selected set of alternatives.

4.1 Benefits of Ecosystem Creation

Florida's coastal lagoons and estuaries are extremely important ecosystems, as they support unique and important fish and wildlife populations. The following sections provide a summary of information acquired since 2008 on seagrass, mangroves, and oyster reefs within LWL. These components are critical elements in the alternative selection process for CAP 1135 and provide a window to current health of the system.

4.1.1 Seagrass Habitat

Seagrasses act as ecological engineers in coastal waters (Wright and Jones 2006), providing valuable ecological services to the marine environment (Orth et al. 2006, Costanza et al. 1997). These services include provision of physical habitat structure/shelter, alteration of water flow, nutrient cycling, organic carbon production and export, sediment stabilization, enhancement of biodiversity, trophic transfers to adjacent habitats, and food web structure (Hemming and Duarte 2000; Orth et al., 2006).

Halophila species, which are the dominant species in the Lagoon, are particularly sensitive to anthropogenic influences and experience rapid turnover from season to season, and rapidly recruit naturally. The earliest evaluation of seagrass in the LWL was compiled from a 1940 aerial survey and documented 4,271 acres of seagrass (PBCERM and FDEP 1998). In 1975, a resource inventory found that only 161 acres of seagrass remained in LWL. While there is uncertainty about the accuracy of methods used, the results indicate a substantial loss of seagrass. The loss was thought to be a result of extensive dredging and filling, sewage disposal outfalls that directly discharged to LWL, degraded water quality, and changes in salinity (PBCERM 1998). Historical change of the seagrass coverage within LWL is shown in **Table 4-1**.

Table 4.1 – Historic Extent of Seagrass in LWL

Year	Acres	Increase/ Decrease	Surveyor/ Source	Method	Percent of Lagoon
1940	4,271	n/a	PBC DERM 1990	aerial photography	55%
1975	161	Decrease	Braun 2006	resource inventory	2%
1990	2,110	Increase	Dames & Moore and PBC DERM	in-water surveys	27.2%
2001	1,646	Decrease	PBC DERM	aerial photography	21.2%
2007	1,688	Increase	PBC DERM	aerial photography	21.7%

In 2007, analysis of aerial photography showed that seagrass beds covered at least 1,688 acres, or 21.74%, of the Lagoon. Approximately 65%, or 1,090 acres, of seagrasses were identified in the northern segment (Little Lake Worth just north of PGA Blvd to Flagler Memorial Bridge); 12%, or 205 acres, were identified within the central segment (Flagler Memorial Bridge to Lake Ave. Bridge); 23%, or 393 acres, were mapped within the southern segment (Lake Ave Bridge to Ocean Ave Bridge in Boynton Beach). Since 2009, approximately 15 acres of additional seagrass habitat in the central LWL has been created as a result of PBC restoration projects.

4.1.2 Mangrove Habitat

Mangroves serve very important functions in the ecology of the LWL. They recycle nutrients and promote the nutrient mass balance of estuarine ecosystems. Mangrove leaves, wood, roots, and detrital material provide essential food chain resources, and provide habitat for many wildlife endangered and threatened species and species of special concern. They also serve as storm buffers, stabilizing shorelines and fine substrates with their roots, thereby reducing potential turbidity and enhancing water clarity.

The coverage of mangrove habitat in the Lagoon continues to increase as a result of restoration efforts. In 2007, aerial photography of the LWL was acquired to map the extent of essential fish habitats, including mangroves, and determine large-scale historical trends. After acquiring the aerial photographs, individual habitat boundaries were defined according to signatures apparent on the photography. Ground truthing methodologies were then applied to verify photographic signatures with actual field conditions. Including restoration projects completed since the 2007 survey, the Lagoon is estimated to contain approximately 295 acres of mangroves, which represents an 8% increase since 1985.

Between 1985 and 2007, increases in mangrove habitat were observed within the north (33.1 acres) and central (5.8 acres) portions of the lagoon, which can be partly attributed to PBC restoration projects, including Munyon Island, Peanut Island, John’s Island, and Snook Islands (EN Attachment C). The removal of exotics and the protection and natural recruitment of mangroves along the shoreline of John D. MacArthur Beach State Park are also believed to increase the mangrove habitat in the north segment of the LWL. A decrease of mangrove habitat was observed in the South LWL (-3.6 acres). Between 2008 and 2012, increases in mangrove habitat were observed primarily in the north (0.9 acre) and central (11.3 acres) Lagoon and are a direct result of restoration efforts.

4.1.3 Oyster Habitat

Oysters provide numerous ecological benefits including habitat diversity, erosion control and improvement of water quality. The LWL is a productive system with patches of healthy oyster beds that provide the recruitment necessary to seed large (e.g., Snook Islands) and small restoration projects (e.g., Peanut Island), as long as other environmental factors (salinity, hydrology, food availability) and substrate type (hard bottom, mud) are considered.

Based on a two year monitoring study by Scarpa et al., 2008 additional restoration projects should not only be successful, but would improve water quality, provide erosion control and increase habitat for associated species, such as other invertebrates, fish and birds. Since 2009, restoration projects sponsored by PBC have resulted in the addition of nearly 13 acres of oyster reefs in the south and central LWL. Additional details are in **Table 4-2** below.

Table 4.2 – Oyster reef creation projects within LWL

Project Name	**Location**	**Year Completed**	**Acres Created**
Boynton Beach/Ocean Ridge Mangrove Riprap Project	South LWL	2009	0.26
Lantana Preserve and Bicentennial Park Volunteer Oyster Projects	South LWL	2009	0.04
Ibis Isle Restoration	Central LWL	2010	0.80
South Cove Natural Area	Central LWL	2012	1.00
Johns Island	Central LWL	2012	10.00
Bryant Park Wetlands	Central LWL	2012	0.06
Snook Islands Natural Area	Central LWL	2013	0.45
Total			**12.61**

4.2 Alternatives

Even though the lagoon is impacted by salinity, muck, and nutrients, PBC DERM has built various ecosystem projects within LWL, which have improved the immediate areas to sustainable and viable benthic habitats. EN Attachment C lists all the ecosystem projects conducted within the lagoon by PBC DERM. Scarpa and Laramore (2010) measured and compared the growth, abundance, reproductive effort, and health of the Eastern Oyster (*Crassostrea virginica)* at three of DERM's projects: MacArthur, Ibis Isle, and Snook Island. Scarpa et al, quantatively concluded that LWL is a productive system with patches of healthy oyster populations that can be expanded by providing substrate and relying on natural recruitment. Island creation or sand capping projects raised the selected areas within the lagoon to inter-tidal elevations to avoid the reoccurring problem of the infilling of aquatic vegetation and established marine life due to submerged muck waves.

4.2.1 Island Creation

The Snook Islands restoration project was a 1.2-mile ecosystem restoration project completed by PBC DERM during the summer of 2005. The purpose of the project was to increase the acreage of the existing mangrove fringe by filling in a deep anoxic dredge hole (**Figure 4-1)** just offshore with coarser sediment and replacing the failing shoreline armoring with inter-tidal and submerged habitats. This dredge hole was created when the golf course to the west of the Snook Islands was created.

A total of 1.2 million cubic yards of fill was transported from Peanut Island, placed, and graded to create four distinctive inter-tidal habitats. To protect the newly created upland areas from incoming boat wakes and low-frequency wave events, approximately 28,000 tons of 1 to 3 feet diameter limestone riprap was used. This riprap enabled the successful incorporation of approximately 30,000 red mangroves (*Rhizophora mangle*) plants. These islands also prevented incoming waves from eroding the shoreline and provided habitat for oysters to attach and proliferate. Lastly, portions of the leeward side of the islands were left bare sandy areas; the upland area are preferred habitat for listed shorebirds, and the submerged areas can naturally recruit seagrass.

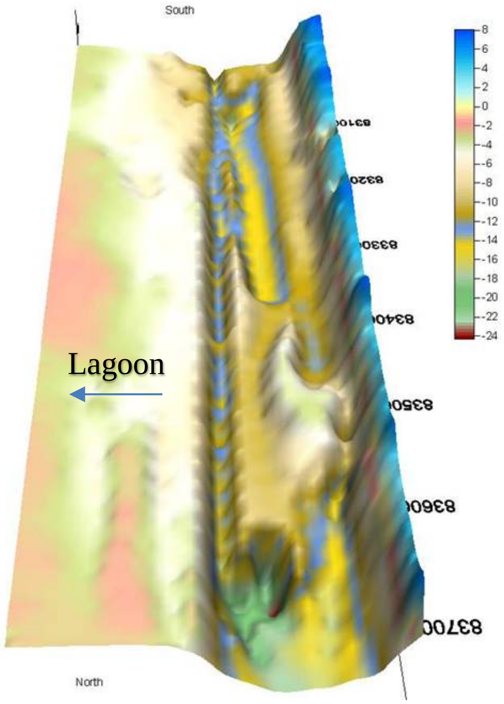

Figure 4-1 - Snook Island Pre project Bathymetry

4.2.2 Sand Capping

The Grassy Flats Project site, located in the Town of Palm Beach, was completed by PBC DERM in 2015. The project site was selected for restoration due to its close proximity to the C-51 Canal (approximately 1 mile south). The Grassy Flats area is on the eastern shoreline of LWL, east of the Snook Islands. The upland area to the east is a private golf course with an armored shoreline. The golf course was likely created using dredge sediment from the lagoon.

The Grassy Flats project created 13 acres of critical wetland habitat using 52,000 cy of sand to create two intertidal islands. A high-speed conveyor belt (“Sand Shooter”) was employed to evenly distribute sand across the large dredge hole so existing muck would not be displaced, creating a wave, during island creation. After the islands were established (**Figure 4-2**), a group of volunteers planted saltmarsh cordgrass and red mangroves leaving two open areas of high ground for nesting shorebirds.

Figure 4-2 – Grassy Flats Prior to Planting

4.3 Potential Project Sites

The sedimentation (muck) analysis showed a direct correlation between dredge hole depth, muck thickness, density of fines, and loss of habitat. This indicates that the presence of thick muck suggests significant habitat loss at, and around, these dredge holes (**Figure 4-3**). The Non-federal sponsor provided six existing dredge holes within the central portion of the lagoon: Currie Park, El Cid, Tarpon Flats, Snook East, Bryant Park South, and Bonefish Cove (**Figure 4-4** and **Figure 4-5**). Of these, Currie Park and El Cid are located north of C-51, and the other four sites (Tarpon Flats, Snook East, Bryant Park South, and Bonefish Cove) are located south of C-51. Each potential site has unique conditions, as outlined in **Table 4-3** and shown in their subheadings below.

The wave heights and peak wave periods for typical wind conditions discussed earlier for each of the six sites are shown in **Table 4-4**. Generally, wave heights for typical wind conditions range from 0.5 to 1.0 ft and peak periods range from 1 to 2 seconds.

Table 4.3 - Metadata of Potential Project Sites

Site Name	Dredge Hole Depth (ft)	Muck Depth (ft)	Distance from C-51 (N/S)	Site Acreage (ac)	Dredge Hole Acreage (ac)
Currie Park	-7.5 to -21.5	0 – 2.76	6.18 mi(N)	85.8	60.5
El Cid	-6.5 to -19.5	0 – 1.75	3.16 mi(N)	17.5	12.05
Tarpon Flats	-4.5 to -19.5	0 – 1.92	0.24 mi(S)	18.0	16.8
Snook East	-3.5 to -7.5	0 – >5.56	1.6 mi (S)	37.9	20.9
Bryant Park	-7.5 to -9.5	0 – 2.46	2.52 mi(S)	39.0	38.8
Bonefish Cove	-2.5 to -13.5	0 – 4	2.78 mi(S)	127.3	61.6

Figure 4-3 – LWL Habitat Loss

Figure 4-4 – 2002/ 2003 LWL Bathymetry Survey

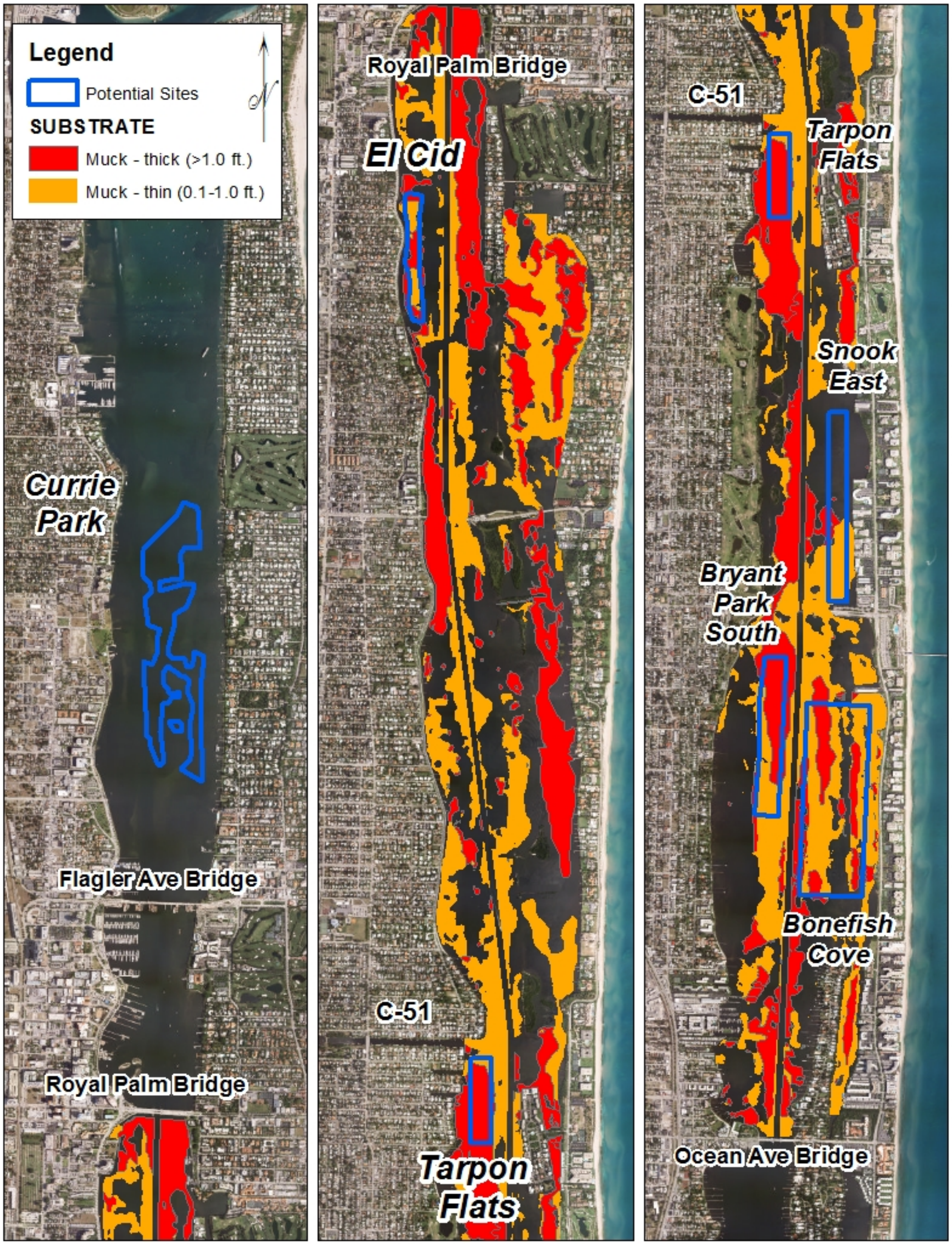

Figure 4-5 Six selected Ecosystem Sites within LWL with muck thickness (Cordy 2011)

Table 4.4 - Alternative Site Shallow Water Wave Growth- Typical Condition

Alternative Site	Fetch		Depth (ft)	Wave Height (ft)	Peak Wave Period (sec)
	Dir	Length (miles)			
Currie Park	North	2	10	0.9	1.9
	East/West	0.2	10	0.3	0.9
	E/W total	0.4	8.5	0.4	1.1
	South	3	7.7	1.1	2.0
El Cid	NE	3	9.5	1.1	2.1
	SE	0.75	7	0.6	1.4
	SSE	3	6	1.0	2.0
Tarpon Flats	NE	1	6	0.7	1.5
	SSE	1	8.5	0.7	1.5
Snook East	NNW	1.25	10.5	0.8	1.6
	NW	0.3	11	0.4	1.1
	SSW	2	8	0.9	1.8
Bryant Park	NNE	1	7.5	0.7	1.5
	NE	0.4	6.5	0.4	1.1
	SSE	1	7.0	0.7	1.5
	SE	0.4	8.5	0.4	1.1
Bonefish	NNW	2.5	10.5	1.0	2.0
	NW	0.45	6	0.5	1.2
	SSW	1.5	8.5	0.8	1.7
	SW	0.5	6	0.5	1.2

(Wind speed = 20 knots , Duration = 6 hours)

4.3.1 Currie Park

Currie Park dredge hole, the northernmost of the potential project sites, is the second largest dredge hole within LWL and is east of the IWW. The project site is approximately six miles north of C-51 canal. The seismic survey conducted by Dial Cordy (2011) did not extend north of Royal Palm Bridge, and thus overall sediment characterization is not available (**Figure 4-6**). In November 2014, USACE collected sediment probes within the Currie Park dredge hole to identify areas where muck is present. Sixteen (16) probes and four (4) grab samples were collected in this area; fourteen (14) probes encountered muck. Muck thickness varied from 0 to 3 feet thick, averaging 2.1 feet with a median of 0.3 feet. Other materials encountered in the site are silt (ML) and silty sand (SM).

East of the placement area, is a 2.2 mile armored residential coastline within the Town of Palm Beach which has various sheet pile walls and limited coastal vegetation. Residential docks exist which dock boats ranging from recreation boats to mega yachts. The Town of Palm Beach ranks among the most expensive real estate markets in the CONUS.

To the west of the project, is a 9.5-acre city Park within West Palm Beach Park, named Currie Park after the former mayor of West Palm Beach. The park offers walking paths along the lagoon, boat ramps, tennis courts, a playground for children, and a maritime museum. There are two (2) two-lane boat ramps and two (2) single-lane boat ramps. There is a fishing pier and an open grassy area for lounging or picnicking, and a Martin Luther King, Jr. memorial.

4.3.2 El Cid

The El Cid dredge hole (**Figure 4-7**) is west of the IWW and is located along the western shoreline of South Flagler Drive. South Flagler Drive is a 1.25 mile shoreline drive with an armored shoreline comprised of bulkhead - revetment. The El Cid dredge hole is located 3.7 miles north of C-51, and between crossing streets Barcelona Road to the north and Avla Road to the south (<0.5 miles). El Cid is a historic district within the City of West Palm Beach, located just south of the Downtown area.

USACE sediment probes collected in 2014 indicated that there are isolated areas where muck is present in the El Cid dredge hole. Six (6) probes and two (2) grab samples were collected in this area; four (4) probes encountered muck. Muck thickness varied from 0 to 3.8 feet thick, averaging 0.8 feet with a median of 0.5 feet. Material encountered in the site is silt (ML).

4.3.3 Tarpon Flats

The Tarpon Flats dredge hole (**Figure 4-8**) is located just south of the C-51 canal and west of the IWW. Adjacent upland areas to the west of Tarpon Flats are comprised of residential community within the Town of Lake Worth. The upland area was built using material from the Tarpon Flats dredge hole to construct two finger channels. Recently collected muck probes by Palm Beach County indicate that there is at least 2 feet of muck present at this location.

4.3.4 Snook East

Snook East (**Figure 4-9**) is not an easily defined dredge hole as compared to the previous mentioned areas. It is a lagoon parallel boundary area with a centrally identifiable dredge hole. Snook East is 1.6 miles south of C-51 and east of IWW. The Town of Palm Beach is east of the boundary area where upland areas is comprised of Condominiums at the southern boundary and pocket area to the north. The pocket area has a low manicured vegetative shoreline with a fronting beach where visitors and locals alike can enjoy this portion of the lagoon for its sunsets. Recently collected muck probes by Palm Beach County indicate that there is at least 5.5 feet of muck present at this location.

4.3.5 Bryant Park South

Bryant Park South, the southernmost potential project site, is a shallow but long narrow dredge hole that does not have easily definable boundaries. The project site provided is 2.5 miles south of C-51 (**Figure 4-10**). The dredge hole is longer than the area provided, and deeper muck areas exist generally within the area provided. The Bryant Park South site is located south of Lake Ave Bridge, east of IWW, and south of the recent living shoreline constructed in Bryant Park by the PBC. LWL begins to widen south of Lake Ave so the dredge hole extends further into the lagoon than previous areas. West of the area is a residential fronting property with various beach heads and vegetative residential shorelines. At the northwestern end, a public park exists, Bryant Park, which is a 3,000 foot armored lagoon shoreline park with two (2) two-lane boat ramps with docks and trailer parking. Recently collected muck probes by Palm Beach County indicate that there is at least 2.5 feet of muck present at this location.

4.3.6 Bonefish Cove

Bonefish Cove, the southernmost potential project site, is south of Lake Avenue Bridge, but east of the IWW and 2.7 miles south of C-51. Bonefish Cove is directly across the IWW from Bryant Park site and has a similar long narrow shallow dredge hole (**Figure 4-10**). East of Bonefish Cove is Ocean Boulevard, which is a lagoon fronting parallel roadway with pedestrian access to the lagoon and walking paths. Other than the park area, the shoreline to the east has a revetment with vegetation along the low areas of the lagoon. A finger island does exist to the north, which juts westward towards the lagoon, likely created by dredged lagoon material. Lastly, east of Ocean Boulevard, are very large condominium complexes. Recently collected muck probes by Palm Beach County indicate that there is 0 to 4 feet of muck present at this location.

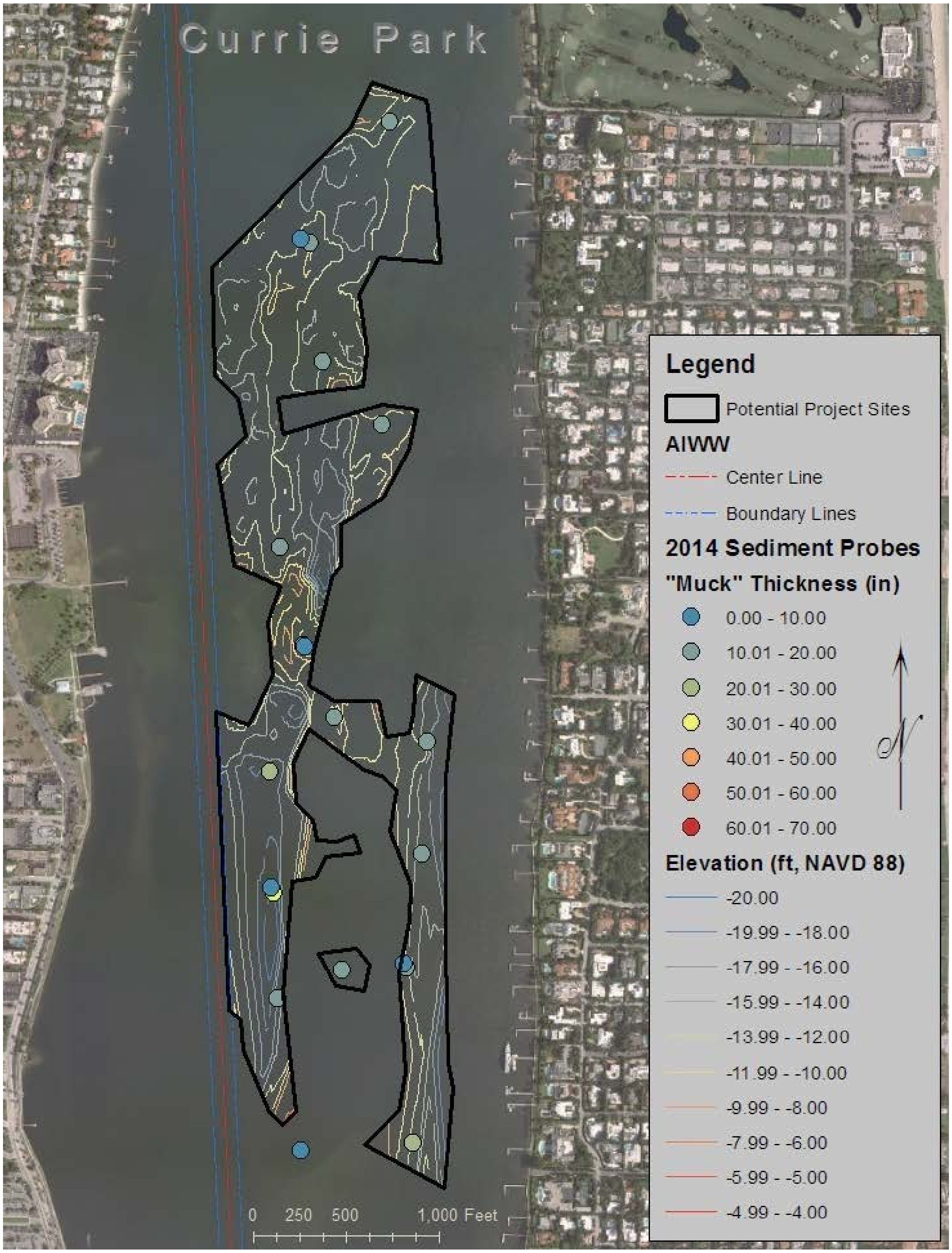

Figure 4-6 – Currie Park Site

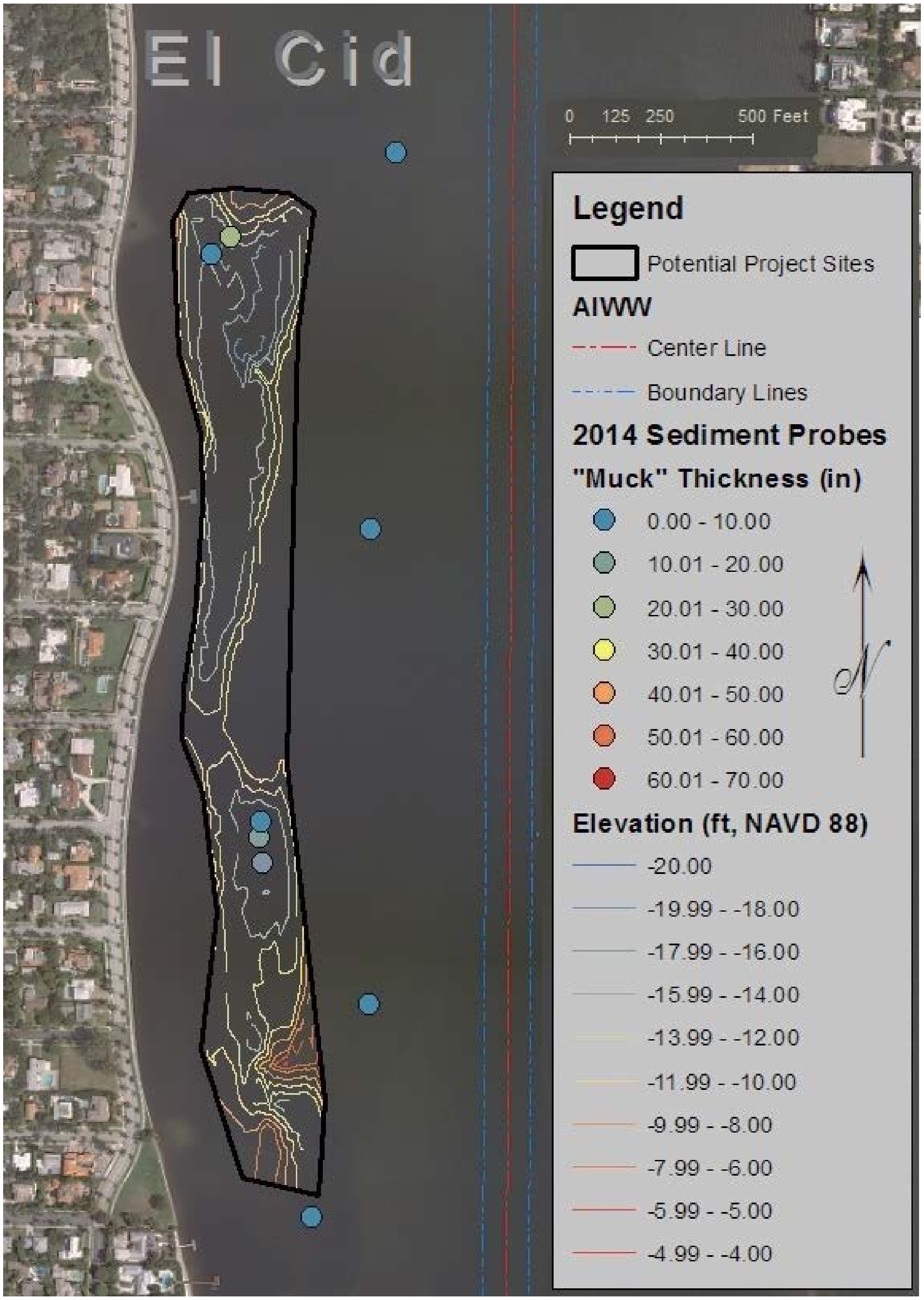

Figure 4-7 – El Cid Project Site

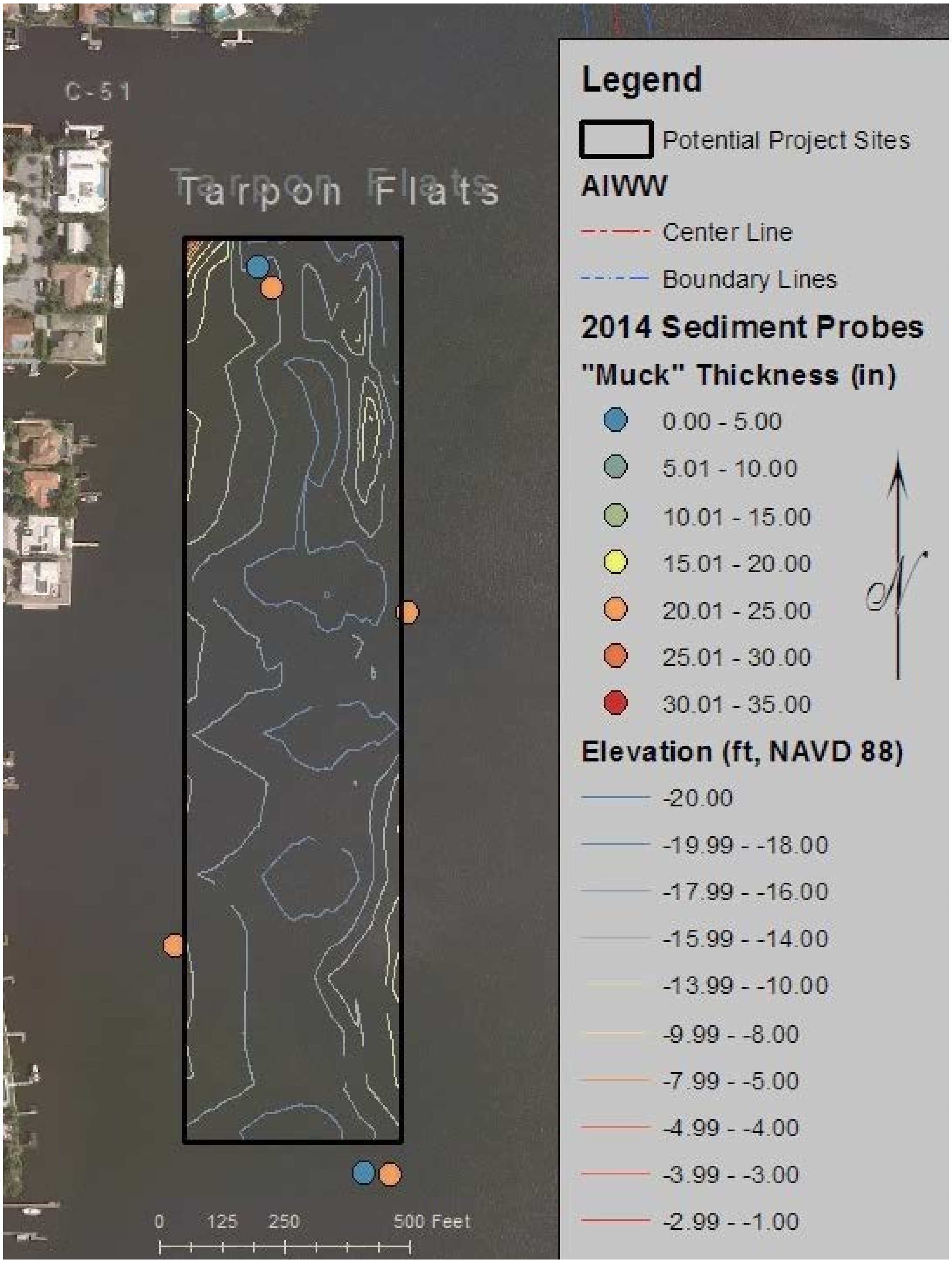

Figure 4-8 – Tarpon Flats Project Site

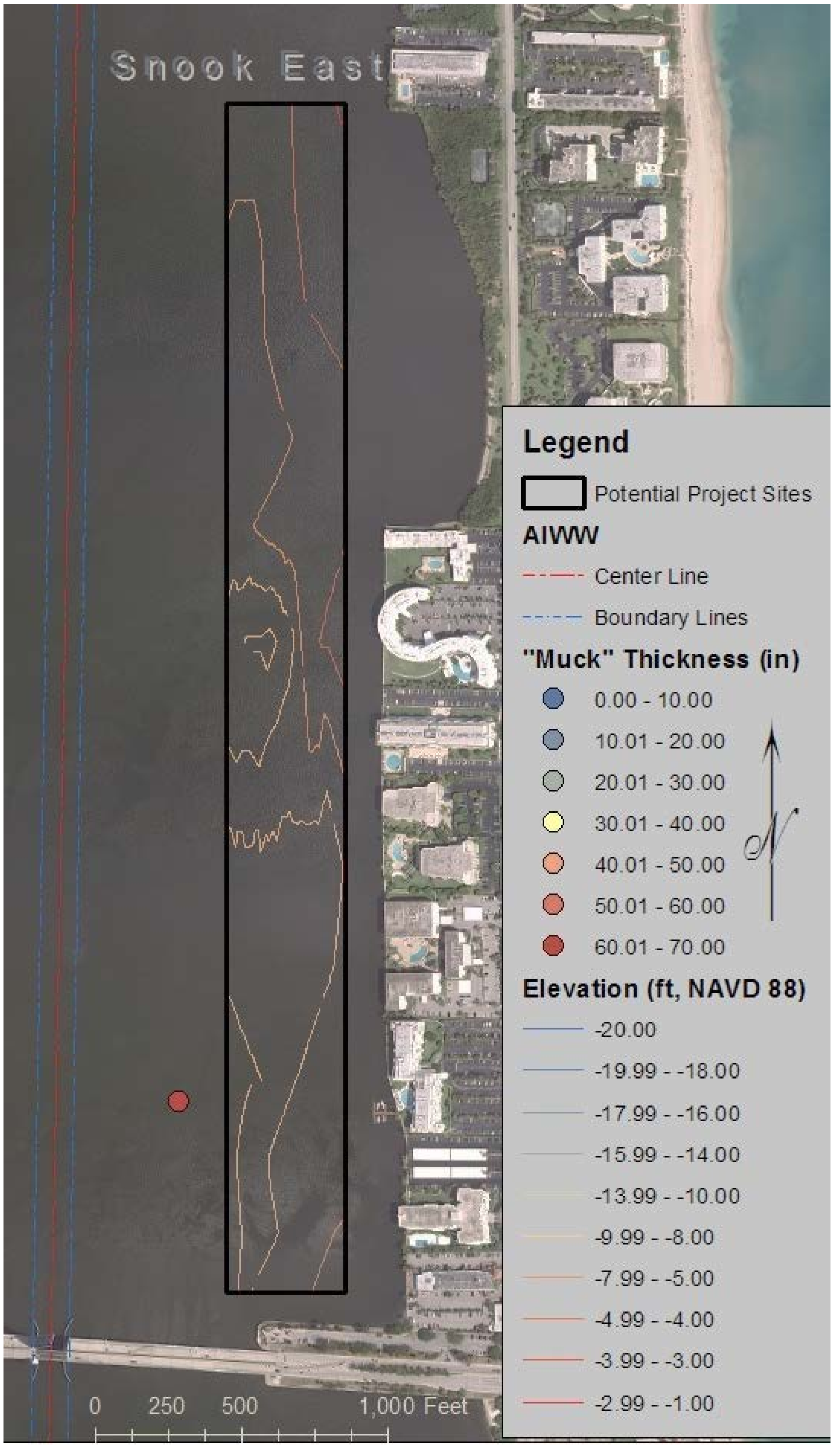

Figure 4-9 – Snook East Project Site

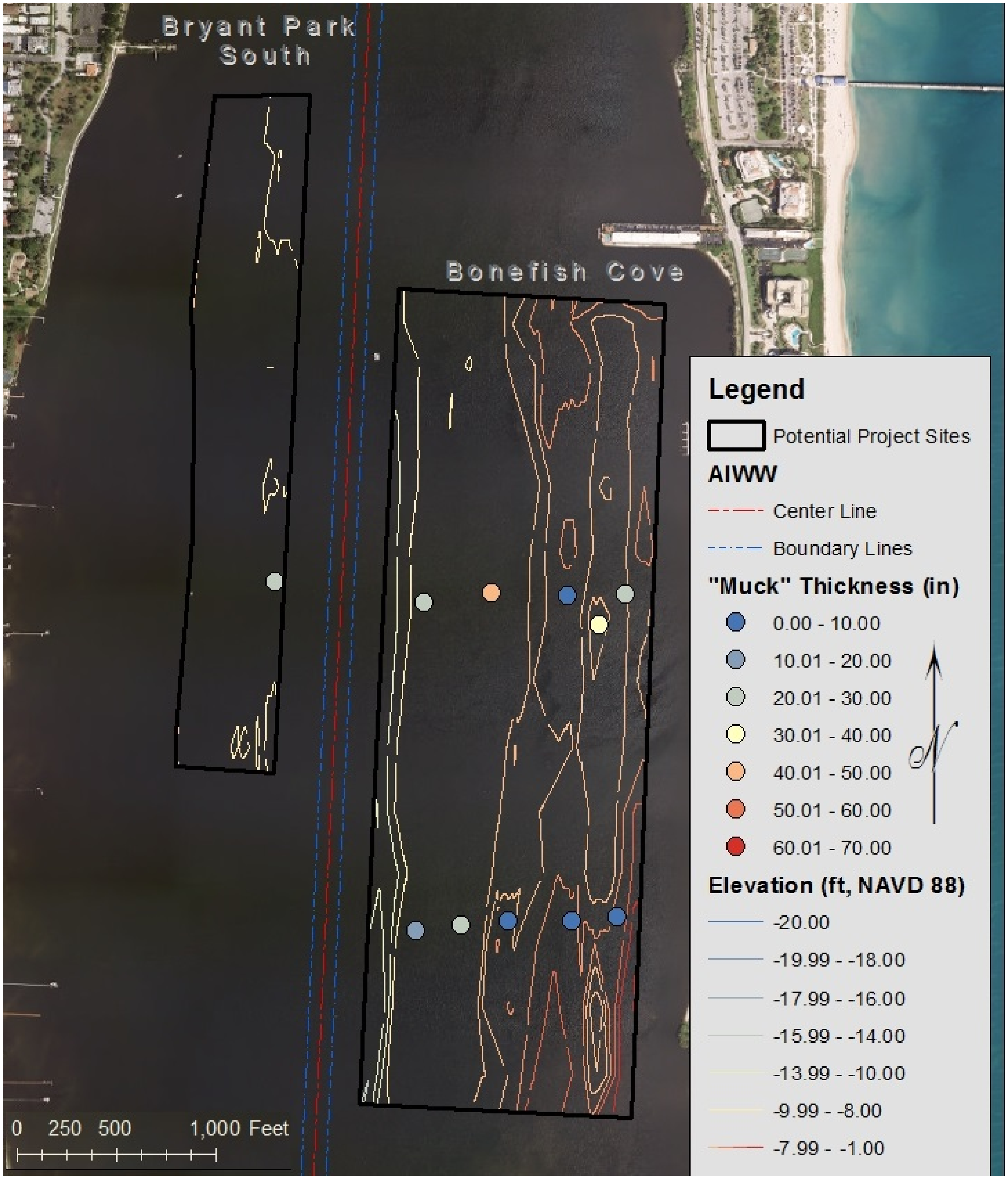

Figure 4-10 – Bryant Park and Bonefish Cove

4.3.7 Potential Sites Determination

Qualitatively, projects conducted at the Currie Park, Tarpon Flats, and Snook East areas could have negative results if an ecosystem restoration area would be placed in these areas, as large amounts of muck that have deposited in the dredge holes over time could be displaced, creating a wave. Currie Park is not a viable option for restoration because it is too far north of C-51 where most of the freshwater flow exists. Additionally, creating an intertidal restoration in the middle of the lagoon could be more hazardous to wildlife and people than areas closer to the shoreline. The Tarpon Flats area is subject to high fluctuations of salinity and flow because it is near the mouth of C-51 (**Figure 4-8**). Also, the lagoon is narrow in this location due to the presence of John’s Island to the north and Ibis Isle to the east. Tidal and wind driven currents, in addition to freshwater flow from C-51, are already high in this area would be exacerbated by putting another feature in this location. Lastly, the Snook East location is not viable because the pocket area previously mentioned could reduce the flushing of lagoon waters in this location, which would likely increase water impairment on the eastern shore. Flushing of water occurs with tides and wind generated waves within the lagoon. Winds, as previously noted, are typically from the east and will be diminished due to the high rise condominiums that are further to the east. Therefore currents in this location would likely decrease and not have enough energy to flush out water levels during normal tidal cycles.

The wind rose data provided in **Figure 2-5**, typical wave data shown in **Table 4-4**, and distance from C-51 were utilized to assess the remaining three areas: El Cid, Bryant Park, and Bonefish Cove. The western[1] dredge holes of the lagoon (e.g., El Cid and Bryant Park) would benefit from a Snook Island type of restoration project because of the wave shielding affect the island type creation would provide. El Cid has a higher wave climate than the other five potential project sites (**Table 5-1**). The shoreline west of El Cid is armored to protect the lagoon parallel access road. The creation of islands at El Cid and Bryant Park would protect the shoreline to the west, but the eastern area of the potential site would be subject to the swell/ storm waves in additions to wind driven waves and boat wakes, needing protection from riprap. Directly west of the Bryant Park area are residential beachheads, which face the lagoon. Flushing behind these proposed areas will likely be problematic due to decreased flow like at Snook East. Lastly, the Bonefish Cove area provides the least restrictive site because of the large area it occupies in the lagoon, as compared to El Cid and it is not directly near boat ramps like at Bryant Park. While

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[1] Western and Eastern refers to the location of the dredge hole in relation to the IWW.

all three potential sites experience boat wake, Bonefish Cove would have fewer fetch issues than El Cid and Bryant Park due to the presence of the high rise condos to the east of the project site.

Recruitment of seagrass should occur naturally at all three locations. El Cid is in close proximity to Lake Worth Inlet's influence, and may not have the high changes in salinity that Bryant Park and Bonefish Cove experiences. However, Bonefish Cove and Bryant Park are located in areas that are impacted by thicker muck deposits than El Cid; these sites would environmentally benefit by having a project within these locations due to the impacts of muck on lagoon habitat. Bryant Park has a boat ramp and the risks with creating an ecosystem project could impact the public boating in this area; Bonefish Cove is in the center of the lagoon and has no risk to boating. Lastly, established seagrasses exist to the southwest of Bryant Park, but the Bonefish Cove site is mostly devoid of seagrasses, based on a 2013 survey. Therefore, as far as alternative selection criteria, El Cid and Bonefish have the highest return with the least amount of impact.

4.4 Sediment Source: Peanut Island

Peanut Island was used as a sediment source for Snook Islands and Grassy Flat projects. Peanut Island was created in 1918 as a result of the creation of Lake Worth Inlet, and fill placement from numerous dredging projects occurring in LWL and Lake Worth Inlet. U.S. Army Corps of Engineers' records show that maintenance of the Lake Worth Inlet between 1929 and 1993 has resulted in the disposal of over 1.2 million cy of dredged material on Peanut Island, as the sand was mixed with rock and/or finer sediments and not suitable for beach disposal. Since 1934, the Corps has maintained the Palm Beach Harbor Navigation Project and has used Peanut Island as a disposal site for the maintenance of the IWW, turning basin, jetties, and inlet revetments.

4.4.1 Brief History of Peanut Island

In 1918, Peanut Island was called Inlet Island and was only 10 acres; Peanut Island, thus named for plans to use the island as a terminal for shipping peanut oil, is now 79 acres and contains a dredged material management area (DMMA), recreational facilities, historical interests, and military interests. The U.S. Coast Guard opened a lifesaving station and boathouse on Peanut Island on November 1, 1936 (placed in service in 1937), which remained active until it was moved in 1995; the station is now part of the Palm Beach Maritime Museum. Additionally, the Navy Seabees built a secure shelter and command post on Peanut Island for President John F. Kennedy in 1961, which was decommissioned in 1964; the bunker is also a part of the Palm Beach Maritime Museum (U.S. Coast Guard, 1997). In 1984, PBC and the Port of Palm Beach made an agreement to maintain the island; PBC, the Port of Palm Beach, and the Florida Inland

Navigation District (FIND) presently hold Peanut Island. The island's perimeter is for Palm Beach County public use; FIND, the Port of Palm Beach, and the Palm Beach Maritime Museum utilize the interior of the island (**Figure 4-11**).

Figure 4-11 – Oblique aerial of Peanut Island showing various uses.

4.4.2 Summary of Data from Peanut Island

Prior to recent construction activities involving ecorestoration of Peanut Island, or offloading material from the DMMA, a Phase 1 investigation was conducted by Palm Beach County in 1997. The conclusions of this investigation revealed no evidence of hazardous materials based on the American Society of Testing and Materials (ASTM) Standard 1527-94 based on a site inspection and review of all available information, and did not recommend additional investigations of the area for soil or groundwater contamination (EN Attachment D).

The sediments within the FIND DMMA were dredged from Lake Worth Inlet and the IWW within LWL. The in situ sediments (prior to dredging) consisted of gray to brown sands, fine sands with silt, and sands with gravel to sand sized shell and shell fragments. After dredging the sediments and placing them in the DMMA, the finer grained sediments were further washed out due to natural weathering processes, leaving a light gray fine grained sand with some shell and gravel. Detailed geotechnical data is provided in (EN Attachment E).

4.5 Rough Order of Magnitude (ROM) Estimate

PDT needed rough order of magnitude (ROM) estimates to rule out costly alternatives that are outside the financial capacity of CAP. All ROM estimates follow the ER 1110-2-1302 guidelines and are the least accurate estimate with an accuracy range between -25% to +25% based on the quality of input and historical provided to the Cost Engineer. For LWL, ROM estimates were conducted on three alternatives. Alternatives 1 & 2 focused on island creation and sand capping at the Bonefish Cove and El Cid potential project sites. Alternative 3 focused on dredging three (3) existing muck sites and capping those areas with sediment from peanut island.

Early in the planning process for LWL CAP, the PDT discussed the construction of a sediment trap within the vicinity of C-51. However, the likelihood of the sediment trap being maintained after construction is not likely due to cost of excavation and treatment of dredged sediments prior to acceptance at a disposal facility. This is the same reason the sediment trap constructed by PBC DERM and SFWMD upstream of the S-155 structure has not been maintained. Furthermore, the surveys of the sediment trap illustrate that once muck has accumulated within the sediment trap, muck can be displaced back into the water column. Lastly, the lagoon cross-sectional area near C-51 is narrow so velocities near or adjacent to C-51 are likely higher than other areas with wider portions of the lagoon. The increase velocity would continually re-suspend gathered muck in the sediment trap. Therefore, constructing a sediment trap would not benefit the LWL due to lack of maintenance of the trap, continued inflow of freshwater laden with sediment, and high current velocities re-suspending the muck in the lagoon.

4.5.1 Oyster Structures

For Oyster recruitment, the PDT used relief structures familiar to the team for oyster habitat (i.e., pre-fabricated artificial reef modules). Pre-fabricated artificial reef modules are self-sustaining units made of a neutral concrete mix for the successful recruitment of various marine organisms (i.e., oysters). These structures come in variety of sizes but the team chose the larger pre-fabricated artificial reef modules because they provide safe havens for smaller juvenile fish from predators.

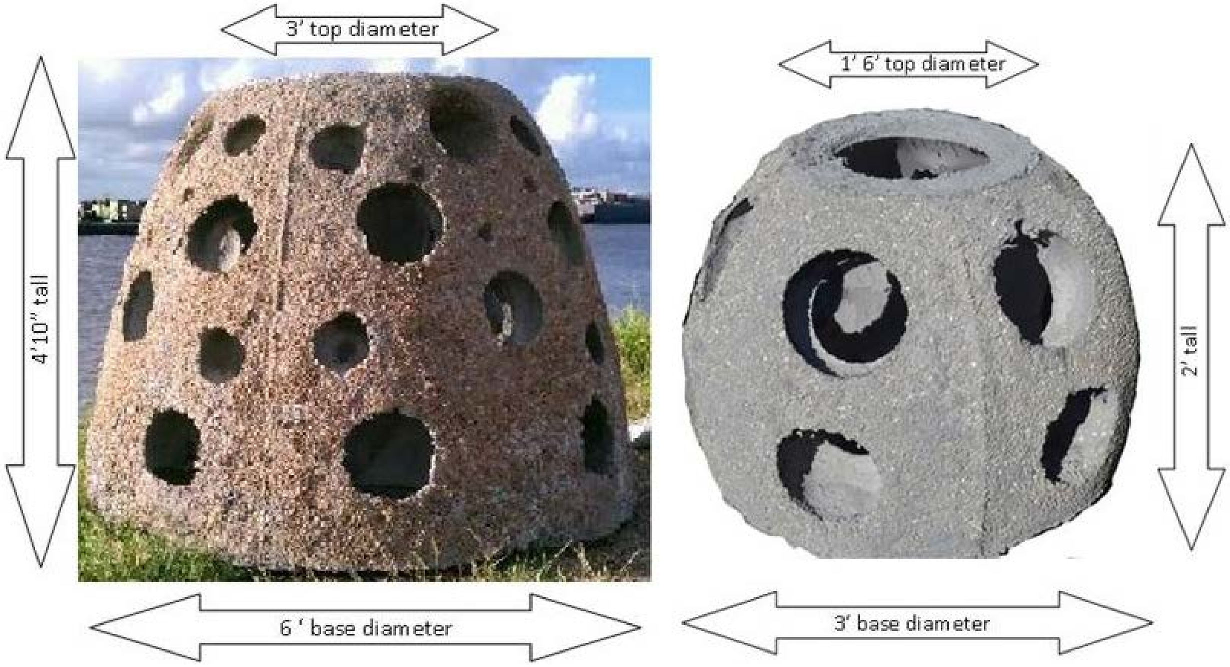

Figure 4-12 – Pre-fabricated artificial reef modules

4.5.2 Alternative 1 – Island Creation

The objective of this alternative is to raise the existing bathymetry to the intertidal range and cover the existing muck material with clean sand. Fill material to be used for the project will be excavated and transported from Peanut Island – the same sediment source used for creating the Snook Islands and Grassy Flats. Peanut Island is 6.0 miles and 11.8 miles away, respectively, from the El Cid and Bonefish Cove sites. The goal of this alternative is to create three upland islands for mangrove habitat that will be protected with riprap and internment oyster reefs in the form of Pre-fabricated artificial reef modules scattered around the islands. The construction effort will consist transporting the fill material from Peanut Island to the selected project site to create three different substrate levels. The base or bed of the island will be raised to - 5.5 feet NAVD88, which will be achieved on a 12.5 % slope (1 foot vertical to 8 feet horizontal) from existing bathymetry and offset from the IWW right-of-way. The interior base of the island which is where the pre-fabricated artificial reef modules will be placed will be elevated to - 3.5 feet NAVD88 on a 4% slope (1 foot vertical to 25 feet horizontal), approximately one foot below mean low water (MLW), or - 2.5 feet NAVD88. To complete the island creation project, three mangrove islands will be established to -0.5 feet NAVD88 on a 17% slope (1 foot vertical to 6 feet horizontal). In addition, the project would include the installation of riprap for shoreline protection and island stabilization. Riprap sizing is assumed to be similar to the type constructed at the Snook Islands and Grassy Flats projects (2’-3’ limestone boulders). The post-construction features will include the creation of red mangrove habitat and installation of Pre-fabricated artificial reef modules for oyster reefs. Seagrass will not be planted because it is anticipated the elevated substrates would provide enough benefit for natural seagrass recruitment. The prominent species of seagrass in LWL, *Halophila* species, recruits rapidly throughout the lagoon. **Table 4-5** provides the actual values used in the ROM for El Cid – Alternative 1A and Bonefish Cove – Alternative 1B. These values were attained using the Morgan and Ecklund bathymetry survey. **Figure 4-13** illustrates the plan layout for Alternative 1 for both locations, and **Figure 4-14** is typical cross-section for Bonefish Cove.

Table 4.5 – Alternative 1 Cost Line Items

Line	Line Item Description	Alt. 1A El Cid Qty.	Alt. 1B Bonefish Qty.	Unit
0001	Mobilization & Demob	1	1	LS
0002	Pre/Post- Construction Survey	1	1	LS
0003	Excavate & Transport Fill Material	191,033	374,306	CY
0003A	Spread Sand	191,033	374,306	CY
0004	Riprap (D50 Size 2-3 FT)	4,102	5,416	TON
0005	Geotextile	3,000	3,000	SY
0006	Oyster reef rock (Pre-fabricated artificial reef modules)	40	56	EA
0006A	Reef Rock Transportation/ Load/Installation/Crane/Diver	1	1	LS
0007	Mangrove Area	4.58	9.37	ACR
0008	Turbidity Curtains (Supply/Install/Maintain)	6,000	6,000	FT
0008A	Turbidity Monitoring/Reporting	1	1.00	LS
	Estimated ROM Costs	**$5,900,000**	**$10,500,000**	

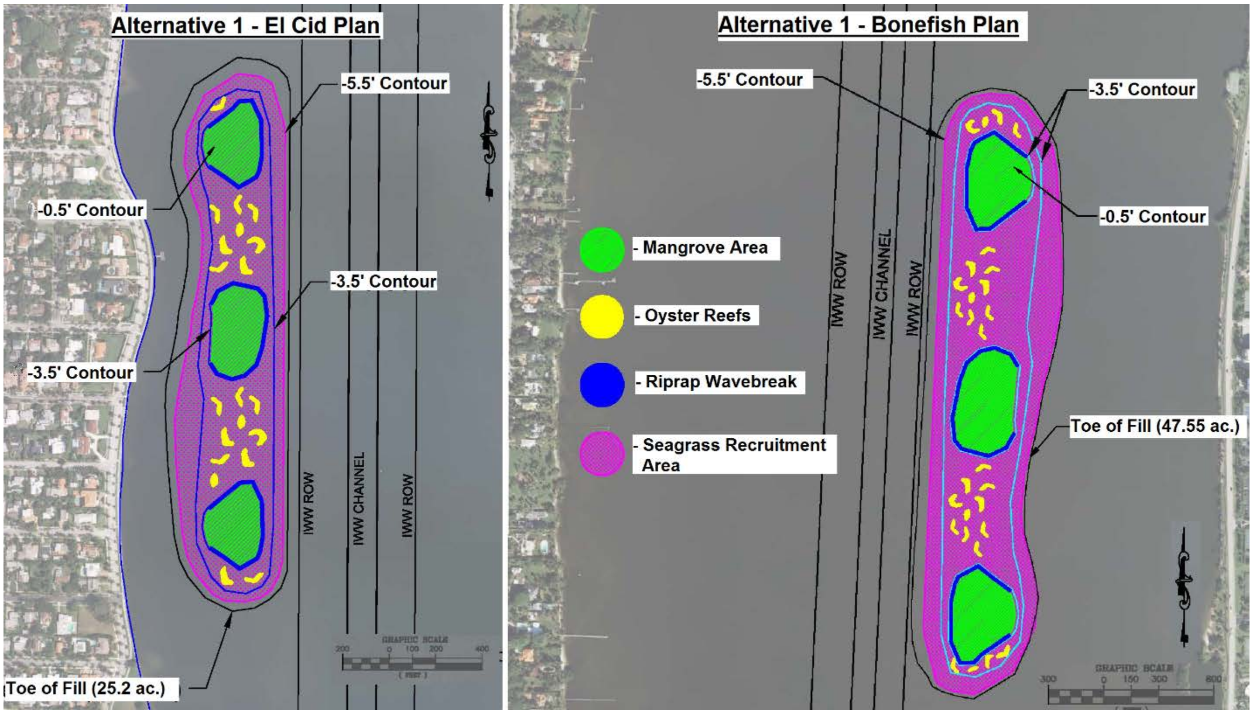

Figure 4-13 – Plan View of Alteranitve 1 (Island Creation)

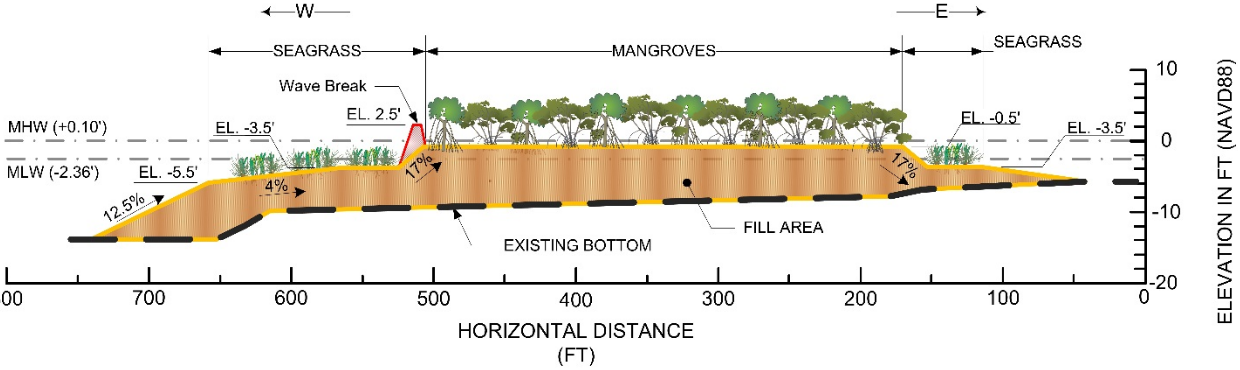

Figure 4-14 – Cross-section of Alternative 1 (Island Creation)

4.5.3 Alternative 2 – Sand Capping

Alternative 2 will have a similar habitat footprint as Alternative 1; sediment would also be excavated and transported exported from Peanut Island, but alternative 2 has a few differences. First, transported sediment would be remobilized into a mechanical shooter to thinly distribute the sediment over the project area to avoid muck displacement for the base substrate at – 5.5 ft NAVD 88. This technique was used for the creation of the Grassy Flats project with no muck displacement. Once the base substrate is created, then dump and fill technique will create the tier

2 substrate to - 2.5 feet NAVD88. The second difference between Alternative 2 and Alternative 1 is the absence of mangrove islands, which will be replaced with Pre-fabricated artificial reef modules, so the sand capping method would not require the third tier substrate at elevation - 0.5 feet NAVD88. The elevations for the base and second tier are exactly the same as island creation, thus the sediment quantity needed will be less than the island creation. The goal of this alternative is to cap the muck in place, create oyster reef habitat, and provide habitat for natural seagrass recruitment. **Table 4-6** provides the actual values used to determine the sand capping alternative ROM for the El Cid – Alternative 2A and Bonefish Cove – Alternative 2B. These values were attained using the Morgan and Ecklund bathymetry survey. **Figure 4-15** illustrates the plan layout for Alternative 2 for both locations, and **Figure 4-16** is typical cross-section for Bonefish Cove.

Table 4.6 – Alternative 2 Cost Line Items

Line	**Line Item Description**	**Alt. 2A El Cid Qty.**	**Alt. 2B Bonefish Qty.**	**Unit**
0001	Mobilization & Demob	1	1	LS
0002	Pre/Post- Construction Survey	1	1	LS
0003	Excavate & Transport Fill Material (6 Miles one way)	150,000	300,000	CY
004	Sand Broadcasting	150,000	300,000	CY
0006	Oyster reef rock (Pre-fabricated artificial reef modules)	40	56	EA
0006A	Reef Rock Transportation/ Load/Installation/Crane/Diver (Assuming 20 Miles)	1	1	LS
0007	Pre-fabricated Artificial Reef Modules	9	9	EA
0008	Turbidity Curtains (Supply/Install/Maintain)	6,000	6,000	FT
0009	Turbidity Monitoring/Reporting	1	1	LS
	Estimated ROM Costs	**$6,200,000**	**$11,200,000**	

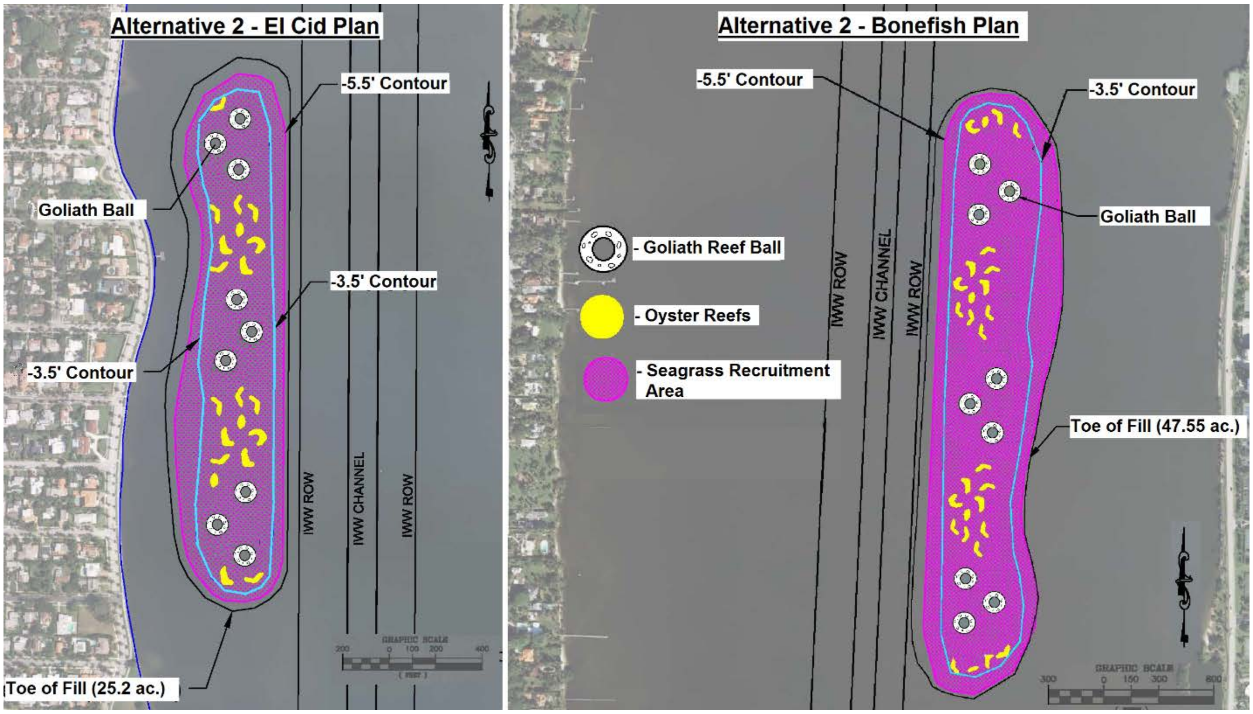

Figure 4-15 – Plan View of Alternative 2 (Sand Capping)

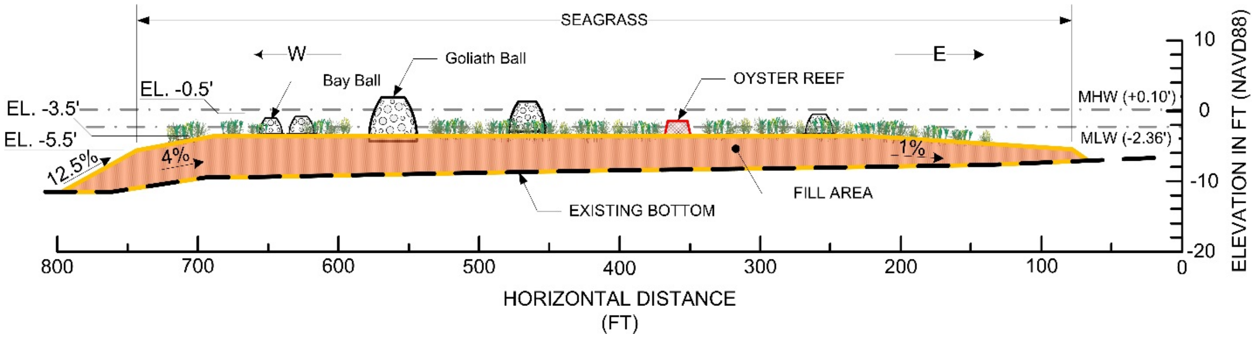

Figure 4-16 – Cross-Section of Alternative 2 (Sand Capping)

4.5.4 Alternative 3

During the alternative selection phase, additional sites were identified within the lagoon that would benefit from the removal of muck. Three (3) dredge sites were chosen using the Dial Cordy 2011 study and Morgan and Ecklund 2012 survey (**Figure 4-17**). Each location would be dredged to remove the existing muck; where the materials would to be transported to Peanut Island for dewatering, processing and disposal at a local facility. Once muck was removed, the area would be capped with coarser grain sands excavated from Peanut Island to elevation - 3.5

feet NAVD88. Pre-fabricated artificial reef modules would be placed intermittently within the elevated platform (**Figure 4-12**).

Table 4.7 – Alternative 3 Metadata and Cost Line Items

		Alt. 3A Muck_1512	**Alt. 3A Muck_1525 N**	**Alt. 3A Muck_1525S**	**Unit**
Metadata	Dredge Hole Depth (ft)	-15’	-5’ to -10’	-10’ to -15’	n/a
	Muck Depth (ft)	>5’	>5’	<5’	n/a
	Dist. from C-51 (N/S)	4 mi (N)	0.5 mi (S)	1.5 mi (S)	n/a
	Dist. from Peanut Is.	5 mi	9.6 mi	10.5 mi	n/a
	Site Acreage (ac)	22.1	42.5	22.5	n/a
Line	Line Item Description	n/a	n/a	n/a	n/a
0001	Mobilization & Demob	1	1	1	LS
0002	Pre/Post- Construction Survey	1	1	1	LS
0003	Dredge & Transport Muck (Dist. from Peanut)	120,000	200,000	100,000	CY
0004	Disposal Muck Material (Transportation)	120,000	200,000	100,000	CY
0004A	Material Filtration (Dewatering)	120,000	200,000	100,000	CY
0004B	MOD - Tank & Filtration System	1	1	1	LS
0005	Excavate & Transport Fill Material (5 Miles one way)	145,200	261,360	319,440	CY
0005A	Spread Sand	145,200	261,360	319,440	CY
0006	Turbidity Curtains (Supply/Install/Maintain)	4,600	6,000	6,000	FT
0006A	Turbidity Monitoring/Reporting	1	1	1	LS
0007	Oyster reef rock (Pre-fabricated artificial reef modules)	10	10	10	EA
0007A	Reef Rock Transportation/ Load/Installation/Crane/Diver (Assuming 20 Miles)	1	1	1	LS
	Estimated ROM Costs	**$7,500,000**	**$12,500,000**	**$11,500,000**	

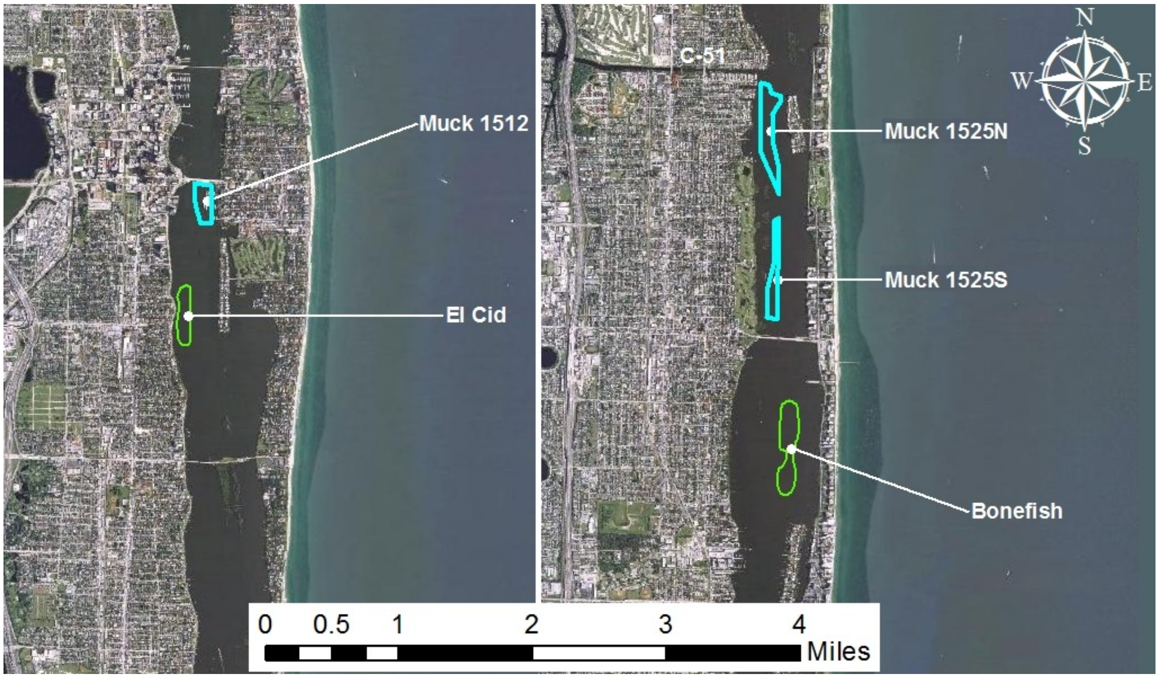

Figure 4-17 – Alternative 3 Project Locations

4.6 Alternative Selection: Summary

Changing or addressing the freshwater flows from C-51 entering LWL is not within the scope of CAP. These freshwater flows cause salinity fluctuations within the vicinity of C-51 canal, but also are the source of continued sedimentation within the central portion of the lagoon. Continued muck accumulation is the root cause of benthic habitat sustainability issues rather than salinity fluctuations. While the muck thickness in the lagoon will continue to increase, constructing a sediment trap will not provide as much ecosystem benefit as would raising the existing elevations of the lagoon to the intertidal range. Countless studies within the lagoon have shown fine sediments do not have a tendency to accumulate in intertidal areas, thus eliminating the construction a sediment trap as a viable option. Alternative 3 focused on dredging and removal of muck and then raising that area above the existing substrate. However, ROM costs show this alternative is too costly compared to Alternatives 1 and 2. The costs are very reflective of the construction of a sediment trap without sand placement. One critical component is that the muck being removed from LWL contains salt, and additional treatment is necessary prior to upland disposal, so this is why items 0004A and 0004B are added to the cost estimate for Alternative 3.

Table 4-8 compares the costs between Alternative 1 and 2, where costs for Alternative 2 (sand capping) are 4 to 6% greater than Alternative 1 (island creation). Therefore Alternate 2 is not as cost effective, nor does it provide as a diverse habitat as the island creation alternative, as this alternative does not include mangrove habitat. Mangroves provide an ecological benefit by consolidating fine sediments and facilitating nutrient uptake within the lagoon. Alternative 1 for El Cid is 44% less than alternative 1 for Bonefish Cove, but by dividing the cost by habitat area to be created at each location, the Bonefish Cove site provides the more ecological benefit than the El Cid site. Therefore, island creation at Bonefish Cove is the preferred alternative for LWL CAP 1135.

Table 4.8 – Side by Side Comparison of Alternatives 1 & 2

Placement Area	El Cid	Bonefish
Habitat Area (acres)	25.2	47.5
Alt 1 Costs ($)	$5,900,000	$10,500,000
Alt 2 Costs ($)	$6,200,000	$11,200,000
Alt 1 Costs per Habitat Area ($/Acres)	234,126.98	**221,052.63**
Alt 2 Costs per Habitat Area ($/Acres)	246,031.75	235,789.47

4.7 Detailed Cost Estimate

Once the preferred alternative was selected, a detailed cost estimate was prepared for Alternate 1B. The construction sequence and methods for island creation at Bonefish Cove is provided in the Cost Engineering Appendix. The Bonefish conceptual design needed changes to the footprint of the project area to be in compliance with National Environmental Protection Act (NEPA). First, the county hired a firm to review the bonefish placement location for historical resources. The survey indicated there were two targets with a high likelihood of significance. Second, a 2013 seagrass survey showed an area of potential seagrass habitat inside the placement area. Planners indicated that even though the survey was old, seagrasses could be within the project’s foot print. **Figure 4-18** is the current design of the Bonefish placement site where quantities of fill needed drop by 7%. The cost appendix also provides a specific breakdown of project costs for the selected alternative based on the preliminary design provided to the Cost Engineer.

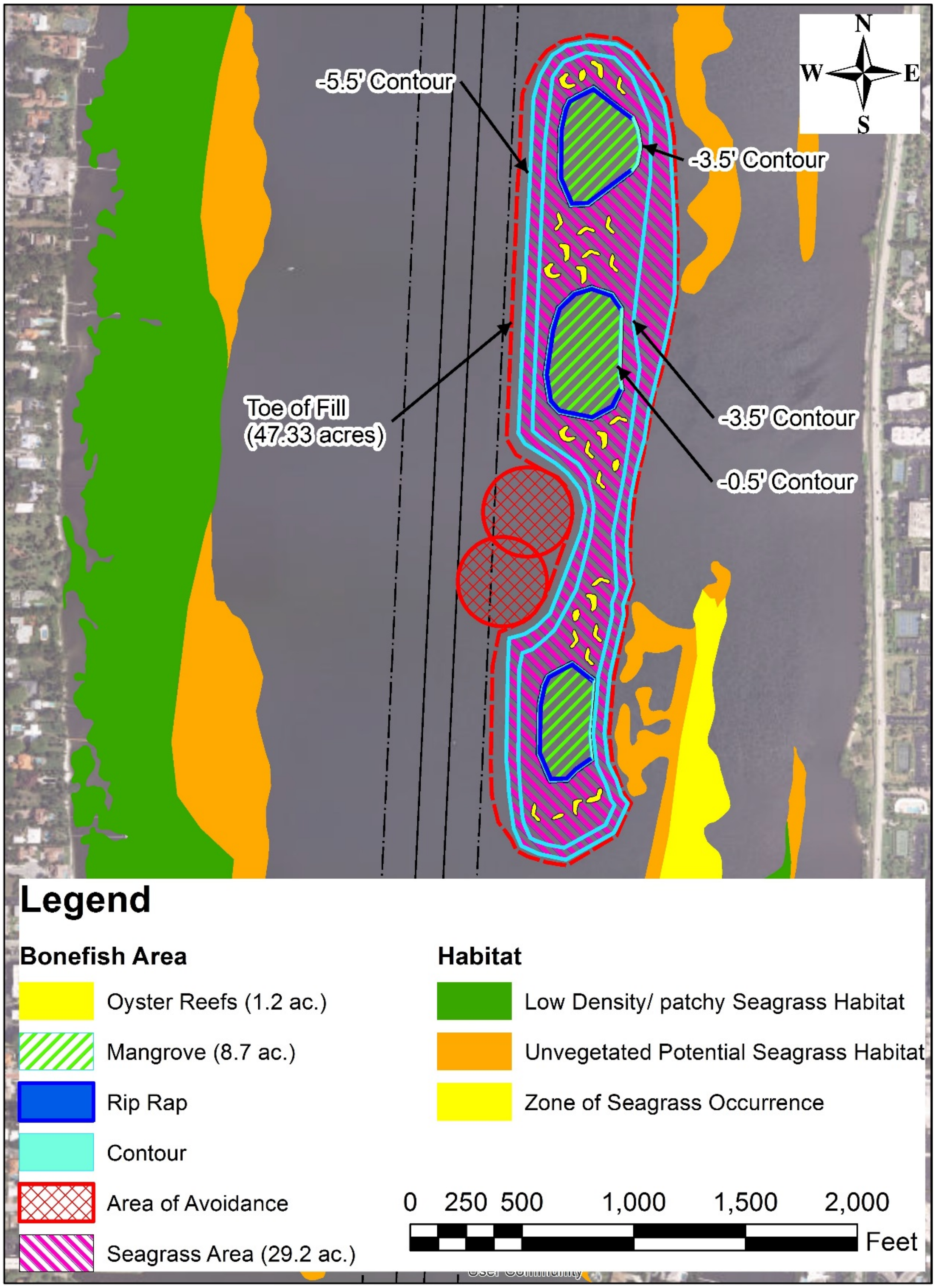

Figure 4-18 – Proposed Bonefish Project Design with Resources

5.0 DESIGN AND IMPLEMENTATION (D&I)

The Design and Implementation needs for the project are outlined in the following subheadings. This heading will provide the Major Subordinate Commander (MSC) an overview of what assumptions were used in the final design shown in **Figure 4-18**.

5.1 Bathymetry

For D&I, Jacksonville District's Operations Division (SAJ-OD) will collect multi-beam surveys at the project site to better estimate the bathymetry of the placement area. Engineer's used bathymetry data collected in 2002/2003 to develop the conceptual design used in the ROM and the final layout shown in **Figure 4-18**. Jacksonville District's Operations Division (SAJ-OD) did a bathymetric study of the lagoon in December 2015 where the 2015 survey was collected in current horizontal (North American Datum of 1983/1990 (HARN)) and vertical datums (North American Vertical Datum of 1988 (NAVD88)). The 2002/2003 survey was collected in HARN, but vertical control was based on the outdated National Geodetic Vertical Data of 1929 (NGVD29). Geomatics staff reviewed the survey and converted the 2002/2003 data to vertically reference NAVD88 using the data relationships provided in Chapter 2.

The problem with the 2015 data is not the data itself, but the survey limits did not extend beyond the southern footprint of Bonefish Cove and barely even captured the El Cid area. The 2015 survey did collected single beam data in high and low frequencies within the lagoon. High frequency pulses have narrow bandwidths and tend to reflect back bathymetric signals of unconsolidated material. Low frequency has a signal bandwidth which typically penetrates the loosely unconsolidated material and returns signals of consolidated sediment bathymetry. This method provides insight to the presence of muck holes.

Engineer conducted volume comparison between the 2002/2003 and 2015 surveys and determined the volume difference within the placement area was 1,000 cubic yards. Engineer also looked into the differences between the low and high frequency data which was about 400 cubic yards. This 12 year span between surveys and low volume difference clearly indicates the area within the placement area has a fairly stable bathymetry. **Figure 5-1** shows the cross-section of the two surveys in relationship to the IWW and the Bonefish placement area. At the IWW, there is little survey difference and 200 feet east of IWW centerline and generally is the current muck hole where 90% of the 2015 to 2002 volume difference mentioned earlier was captured.

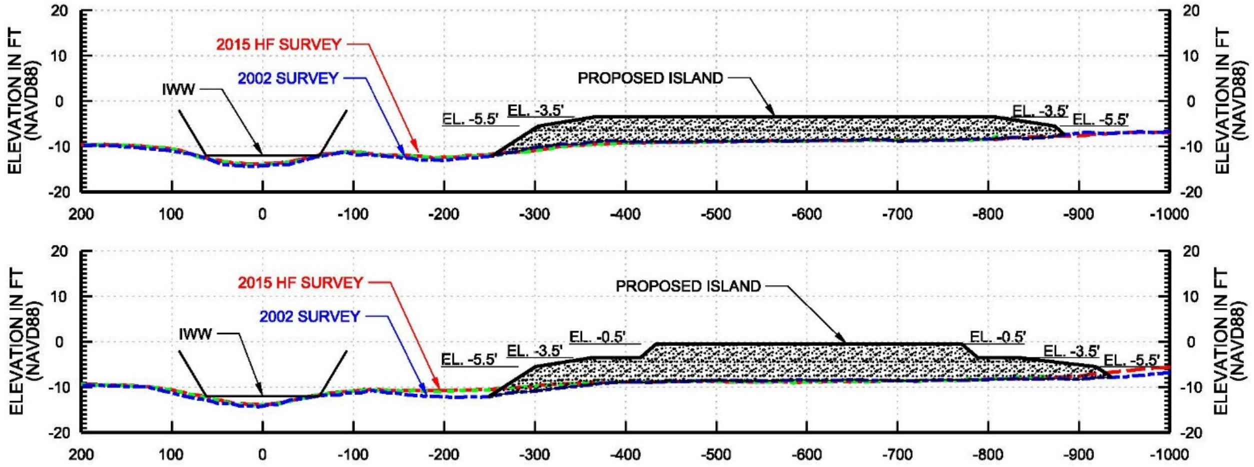

Figure 5-1 – 2002/2003 to 2015 survey comparison at Bonefish placement area

5.2 Turbidity/ Displacement of Muck

A muck wave was observed during construction of the Snook Islands project due to the extreme depth of the hole (**Figure 4-1**), the amount of sediment that came out of the C-51, and the amount of material that deposited in the dredge hole (i.e., the muck). After construction, the contractor had to knock down the muck wave along most of the project; however, no measures were taken in areas of the project where the muck wave was small, as features of the wave still exists to the present.

Covering muck, and not displacing muck in the form of a wave, will be a priority during the D&I phase and will depend upon the bathymetric data and additional sediment data collected to find out where the thickest layers of muck currently reside. Preliminary data show approximately two (2) to four (4) feet of muck exist within the Bonefish Cove project site, which is significantly less than the excess of ten (10) feet of muck at the Snook Islands project site. The contractor will use turbidity control measures to comply with State and Federal permits.

5.2.1 Sediment Probes

USACE (2014) and PBC (2016) collected sediment probe data within the preliminary projects sites to a reconnaissance level design. Contractors used a telescoping fiberglass leveling rod to push into the bottom until refusal. The difference between the Echo sounders depth and the depth of penetration of the rod resulted in the muck thickness values.

In order to better characterize the material within the selected project site, and determine the variation in the thickness of muck sediments, additional data will need to be collected during the D&I phase. A better understanding of the subaqueous sediments (i.e., muck thickness) will allow for better site management and prevention of a muck wave and turbidity issues during construction. More than likely, the sediment probes will be collected in tandem with a multibeam survey.

5.2.2 Construction Techniques

During D&I, engineers will review the various sand capping techniques to reduce the likelihood of muck displacement. After review, an industry day will be held with potential bidders and consultants to better determine which performance measures should be specified to measure successful completion of entrapment of muck.

5.3 Materials

Materials needed for island creation are sediment to cap and raise the area to be constructed, riprap to shield the living shorelines from incipient wind and waves and stabilize the islands, and lastly, elevated structures (riprap or reef balls), which are used for organism recruitment.

5.3.1 Available Sediment

Sediment to be utilized for the project will be excavated from the Peanut Island DMMA where PBC DERM estimated the quantity available is near 400 kcy. Peanut Island was the sand source used for the creation of the Snook Islands and Grassy Flats, and successfully received state and federal permits for use in both 2005 and 2015. **Figure 5-2** shows the primary source and secondary source of material within Peanut Island.

During D&I, topographic surveys of Peanut Island will be collected at the primary source as well as the secondary source of material. Engineers, biologists, and geologists will conduct a site visit of the DMMA site to assess the condition as well as the appropriate quality and quantity of sediment within this facility to ensure compliance with state water quality standards.

Figure 5-2 – Excavation Areas and Transporation Routes within Peanut Island.

5.3.2 Protective Riprap

Riprap sizing will be determined by geotechnical and coastal engineers during D&I. For the estimate, it was assumed that 2-3’ boulders mined from a local quarry would be used since it was the same material for the creation of the Snook Island and Grassy Flats projects. The current plan only has riprap on the western shoreline to protect the mangrove from constant boat wakes. Engineers will look into the sizing and area needed for rip-rap protection and will base their work on the following subheadings below.

5.3.2.1 Wind Analysis

The design life of the alternative considered is 50 years, which corresponds to a chance of occurrence of storm waves in any year of 2 percent. For the LWL area, this corresponds to a design wind speed similar to a Category 2 Hurricane with wind speeds of 96 to 110 mph (83 to 96 knots) (NIST 2012).

5.3.2.2 Waves Analysis

LWL is effected by extreme events such as tropical storms and hurricanes between June and November. The design life of the alternative considered is 50 years which corresponds to chance of occurrence of storm waves in any year of 2 percent. A water level elevation of 4.8 ft for hurricane surge with 2 percent annual chance frequency was determined for LWL (FEMA). The wave heights and peak wave periods for design wind conditions are shown in **Table 5-1**. Generally, wave heights for design wind conditions range from 2 to 6 ft, and peak periods range from 2 to 4 seconds.

Table 5.1 - Alternative Site Shallow Water Wave Growth- Design Condition

Alternative Site	Fetch		Depth + Surge (ft)	Wave Height (ft)	Peak Wave Period (sec)
	Dir	Length (miles)			
Bonefish Cove	NNW	2.5	15.5	5.8	3.8
	NW	0.45	11	2.9	2.2
	SSW	1.5	13.5	4.8	3.2
	SW	0.5	11	3.1	2.3

(Wind speed = 96 knots , Duration = 12 hours)

5.3.3 Oyster Structures

Initially the ROM was calculated for the inclusion of Pre-fabricated artificial reef modules as oyster reef creation areas. After extensive conversation with the Non-Federal sponsor, it was determined that limestone riprap has far more complexity and interstitial spaces which will support more and complex fish communities than the artificial reef modules. A study was completed in Palm Beach that compared hollow reef modules and reef modules filled with broken concrete (like a rock pile). The filled modules proved to be better habitat. Cost analysis shared by the county to the PDT show limestone rubble as a cheaper alternative than fabricated units due to hauling distance. Therefore, the PDT will use rock piles for oyster recruitment.

5.4 Construction Constraints

At the cost risk register meeting, the sponsor highlighted some construction constraints that the awarded contractor is likely to encounter while performing work on this project. The specifications will highlight these assumed project constraints for the Contractor. It is the responsibility of the Contractor to manage these constraints during the course of the contract; it is the responsibility of the Government to inform the Contractor of these risks early in the bidding process. There are exceptions to this and they are noted in each of the construction constraints discussed below.

5.4.1 Peanut Island Access

For the Snook Islands and Grassy Flats projects, barge access to the offloading area needed to be dredged prior to work. These were small quantities and placement occurred on the Port's DMMA. Bathymetric surveys of the DMMA will be attained during D&I to assess actual quantity to be removed. Please note Government specifications are performance based; since the Government does not know what kind of barges or the draft of those barges which will be brought. This additional line item could be paid as Lump Sum as a part of the DMMA preparation effort or as a contract line item as a unit price.

5.4.2 Bridge Restrictions

There are three (3) height restricted bridges within the 11.2 mile transport distance from Peanut Island to the placement site: Flagler Memorial Bridge, Royal Park Bridge, and Southern Boulevard Bridge. The bridge opening schedules are at set times within an hour to help facilitate marine traffic. The Flagler Memorial bridge opens once an hour at 15 minutes past the hour. Royal Park Bridge opens twice per hour at the on the hour and half past the hour. Lastly, the Southern Boulevard Bridge also opens twice per hour at 15 minutes and 45 minutes past the hour.

5.4.3 Operational Hours and Lighting Restrictions

The Town of Palm Beach will likely impose operational hours and lighting restrictions to the awarded Contractor. This has occurred on two recent USACE Corps projects: 2014 FCCE Palm Beach Erosion Control Project and 2014 and 2015 Jupiter Carlin Shore Protection Project. The Port of Palm Beach and the PBC have also experienced these operational hour restrictions when working adjacent to the Town's riparian rights. The operational hour restrictions are dependent on how close the project work is to Town residents. For the USACE contracts, contract language was inserted into the specifications that listed the Town of Palm Beach as the contact for operational hours and lighting restrictions within the Town limits. This worked flawlessly for both contracts where the Contractor was able to work 24 hours but with limited lighting. However, most of that work was just south of the port of Palm Beach and not work within the lagoon where many of the Town's residents reside. Likely restrictions could be between 7am to 10 pm with limited lighting at the placement site.

5.4.4 Shallow Water Areas

Within the project area, the contractor may have to light load their scows to the project site to avoid shallow water. Surveys of the IWW occur annually and will be provided to the Contractor during bidding.

5.5 Post Construction

After construction, there will environmental and physical monitoring to measure the success or failure of the project and physical monitoring to monitor for settlement and effects of SLR.

5.5.1 Sea Level Rise Scenarios

As presented in Section 2.3.4.2, the high USACE sea level trend curve projects a sea level increase of 2.32 ft. The mean tide range in the Lake Worth Lagoon varies between 2.5 ft and 2.7 ft. Since the purpose of the project is to create habitat to increase ecosystem function in the Lake Worth Lagoon by creating additional inter-tidal and submerged habitats, the effects of rising sea level due to SLC are to potentially reduce the submerged habitat area caused by deeper depths than required by seagrasses for example or reduce inter-tidal area as the aerial extent of the island is reduced due to rising sea level.

While sea level rise can reduce the acreage of habitat created by this project, the uncertainty in sea level rise rates will only impact the relatively small habitat acreage of the project. There are no risks to life safety, property, or critical infrastructure due to the project in the event of higher than expected sea level rise rates.

The primary strategy for project adaptation to maintain some level of functioning habitat is to add fill to the island's submerged and inter-tidal areas at a rate similar to the rate of sea level rise.

5.5.1.1 Qualitative Analysis of impacted Resources

A qualitative inventory of the density of impacted resources and receptors was conducted for the study area described in the feasibility study report. This study area is located within the horizontal and vertical extents bounded by the 100-yr high rate curve of SLC impacts. The 100-yr high rate curve SLC of 6.5 ft, impacts about 8,000 acres adjacent to the Lake Worth Lagoon, based on 2006 and 2009 Florida Department of Emergency Management coastal LiDAR data. The qualitative inventory is presented in Table 5.2.

Table 5.2: Qualitative inventory of critical resources in the Lake Worth Lagoon study area.

Critical Resources in Study Area	Density of Resource	Relevant Notes	Risk from Sea Level Rise*
Residential structures	3	Several medium to high density areas throughout the lagoon and some portions of evacuation routes	3
Commercial structures	3	Numerous commercial facilities affected (marinas, businesses).	2
Environment and habitat	2	Saltwater marshes, mangrove and sea grass beds are located throughout the lagoon within the project area. Potential habitat areas for several endangered or protected species are within the project area.	3
Ports and navigation structures	2	Ports with cargo shipments that vary from commercial commodities to industrial goods and wastes are within the project area. The majority are located on the east shore of Lake Worth Lagoon adjacent to the inlet. USACE jetty structures are located at the channel mouth of Lake Worth Inlet.	1
Infrastructure (roads, water/sewer lines, boardwalks, railroads, airports)	3	Storm water control structures associated with canals (C-17, C-16 & C-51) face potential risk. Several roadways, including county roads and State Highways 703, 704, and A1A, are located within the project area. Majority of boardwalks and/or piers found in the bay area are at risk of inundation.	3
Critical facilities (police, fire, schools, hospitals, nursing homes)	1	At least six school parcels, several fire and police facilities and two health facilities located in a potential (low-lying) area.	3
Evacuation routes	1	Inundation occurs along a 3.5 miles section of Sate Highway A1A, 703 on Singer Island and portions of A1A, South Ocean Blvd in Palm Beach Island. Local roadways located in low-lying residential areas.	2
Recreation	3	Large areas of beach recreation. Three golf courses. Fishing piers, both private and commercial.	3

***3=high, 2=medium, 1=low**

Sea level rise estimates provided earlier are added to the MHW line and graphically depicted onto the Alternative 1B cross-section (**Figure 5-3**). The baseline and up to the Intermediate SLR scenario will likely not impact the conceptual plan or inhibit future recruitment of seagrass or oysters. The mangrove islands will be fully established and be able to sustain wave overtopping. However, the High SLR case will overtop the proposed rip-rap and likely would have seagrass die-off due to lack of sunlight. In all likelihood, the locals will need additional material to be placed on top of the existing substrate to sustain the established benthic habitat.

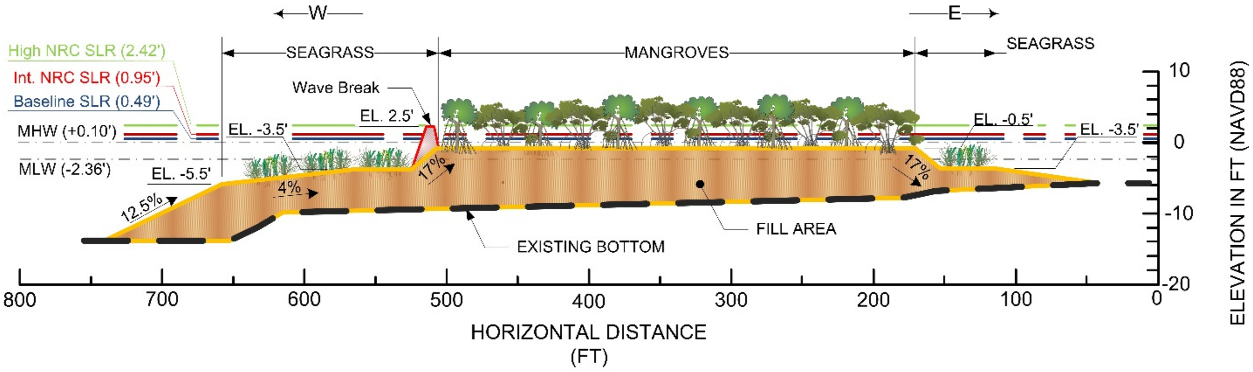

Figure 5-3 – Bonefish Conceptual Plan with Sea Level Rise Scenarios

5.5.2 Adaptive Management Plan

The Adaptive Management plan for the project will involve seagrass transect sampling, mangrove monitoring, and oyster monitoring.

5.5.3 Climate Change Analysis

The Climate Change analysis conducted per USACE requirements is included as Attachment G to this appendix.