Southeast Atlantic Regional Sediment Management Plan for Florida

Final Report

July 2009

TAYLOR ENGINEERING INC

US Army Corps of Engineers®
Jacksonville District

Southeast Atlantic Regional Sediment Management Plan for Florida

Final Report

Prepared for

U.S. Army Corps of Engineers, Jacksonville District

by

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EXECUTIVE SUMMARY

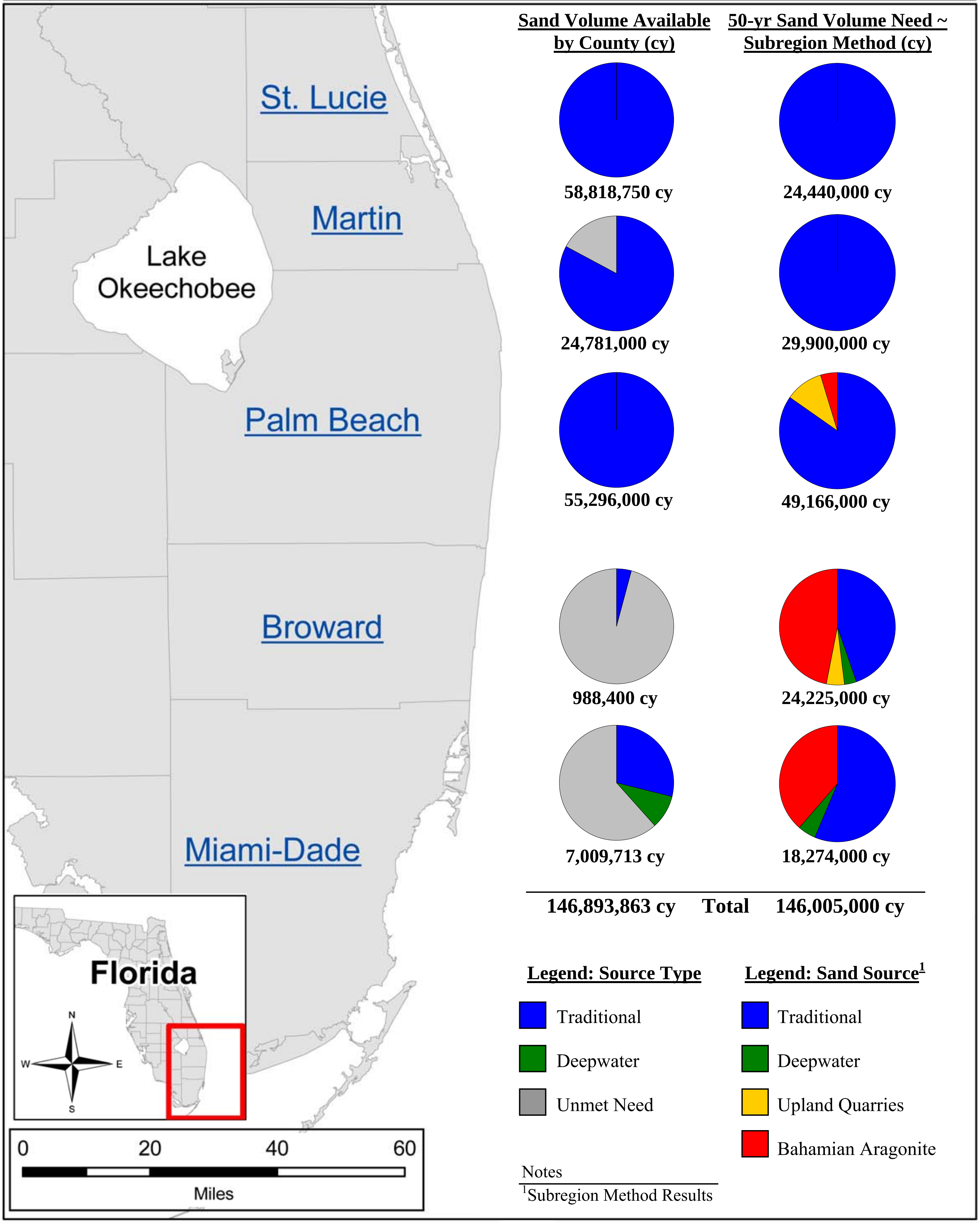
This Southeast Atlantic Regional Sediment Management (RSM) Plan for Florida updates and expands the *Southeast Atlantic Regional Sediment Source Study for Florida* (USACE, 2008). The RSM Plan study region comprises St. Lucie, Martin, Palm Beach, Broward, and Miami-Dade counties. These counties contain 11 active federal and 10 active non-federal beach nourishment projects. This RSM Plan synthesizes data from multiple sources to estimate the sand needs of these active projects over a 50-year analysis period (until the end of 2059). The study also evaluates management options for meeting these needs with recognition that storm damage reduction considerations provide the justification for all federally authorized projects.

Possible beach-quality sand sources include traditional offshore borrow areas and deepwater borrow areas (in water depths greater than 70 ft), as well as alternative sources — upland quarries, non-domestic sand, and sand from the Apalachicola River Delta.

The total 50-year sand volume need for the region equals approximately 146.0 million cubic yards (mcy) and the volume of verified beach-quality sand available offshore equals approximately 146.9 mcy. The figure on the following page summarizes the study results for each county and the entire region. The first column of charts summarizes the sustainability analysis and the second column summarizes the allocation of sand for the Subregion Method — one of four methods applied to allocate sediment resources in the study. For a 50-year analysis period, the sustainability analysis shows St. Lucie and Palm Beach counties have a surplus of offshore sand, while Martin, Broward, and Miami-Dade counties have a deficit. If current trends continue, Miami-Dade County will run out of offshore sand to nourish their beaches in less than 5 years and Broward County will do so in between 5 and 10 years.

A main premise for this RSM Plan assumes that every sand source has a "best use" project or projects based on economics. Given that all evaluated sources contain beach-quality sand, different sand sources will provide very similar project benefits. Therefore, from a National Economic Development (NED) and Regional Economic Development (RED) perspective, the cost to acquire, transport, and place material at a project area to achieve optimal benefit determines the best use project. With federal and non-federal beach nourishment projects and sediment sources located throughout the region, the best use of a source directly relates to the costs of acquisition and transport. This premise allows for development of a strategy that maximizes the economical use of sources and recognizes the need to maintain a holistic, regional management approach.

Sustainability Analysis by County



Such a strategy must also prove realistic and implementable with consideration given to: Environmental Quality (EQ), State of Florida legislation, maximizing benefits, current practices, ideology, and Other Social Effects (OSE). Such a strategy should also consider realistic future project needs, environmental trends such as sea level rise, and development of additional sources and improved methods of acquiring and transporting sand, which will lower associated costs. This Southeast Atlantic RSM Plan for Florida includes suggestions that consider these items.

Some results from the analysis methods used by this RSM Plan indicate the least-cost decisions may require additional considerations. For example, the sand from upland quarries, the Bahamas, and the Apalachicola River Delta costs significantly more per cubic yard than sand from traditional or deepwater borrow areas due to logistical expenses related to transporting material from the source to the project site. Using cost as the main parameter for analysis indicates that transporting sand from a borrow area offshore St. Lucie County to a project in Miami-Dade County proves more economical than using any of the alternative sand sources. However, a plan to manage sediment in a holistic, regional context must include other considerations such as:

- probable renourishment beyond the next 50 years of projects in closer proximity to the borrow areas offshore of St. Lucie County
- current State of Florida legislation that requires notification to counties when sand is under investigation for transport out of subregions
- possible improvement of dredging and transport methods that would lower costs of alternative sources closer to Miami-Dade project areas
- likely construction of additional projects throughout, and north of, the region, which would create additional demand for the sources in question
- long-distance, southerly mechanical transport of sediment across several counties would short-circuit the natural sediment transport pattern, which would provide protection to beaches between a northern project area and southern terminus as the sand moved south

The sustainability analysis required development of databases to quantify the beach nourishment needs and available sediment sources in the region. Application of four different management methods with the beach nourishment and borrow source databases allowed allocation of the known beach-quality sediment resources to the projects in the region. The four management alternatives allocate the material in different ways, but produce generally similar economic results with total costs near $3.5 billion over 50 years. All management strategies also apply non-domestic material at some point to minimize cost. This study uses least cost as a proxy for benefits in the economic evaluation. Analysis of the plan formulation results demonstrates the sensitivity of the plans to the material cost — a change to the delivery method for non-domestic sand or upland sources that removes the need to double-handle the material would significantly alter the distribution of material and total costs.

The sustainability analysis shows that sediment supplies will just meet the project needs in the study region. However, given realistic limitations in sediment distribution and the unbalanced location of the available material within the region, projects will need sand from alternative sand sources within the next 50 years as traditional offshore borrow areas become depleted. Non-domestic sand provides a viable option as an alternative source to provide material to the southern counties and to potentially minimize cost. Currently, the majority of sand and the largest unverified volumes occur in the northern portion of the region. To meet the region's volume need for the next 50 years and beyond, northern project areas should conduct additional reconnaissance studies to verify the quality of material in areas of limited, but promising, data. Projects in the southern portion of the region, especially those in Broward and Miami-Dade counties, should further investigate the use of deep-water and non-domestic sources such as Bahamian aragonite. The RSM Plan results suggest the immediate need to apply a regional sediment management plan for southeast Florida — a plan with foresight to evaluate the best means to allocate the available resources to the existing projects based on known borrow sources — traditional and alternative.

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1.0 INTRODUCTION

The practice of nourishing the beaches of southeast Florida with sand from offshore borrow sources began in the late 1950s and has steadily increased in scale to the present day. Miami Beach, for example, has received nearly 17 million cubic yards (mcy) of beach nourishment material since 1960. In recent years, finding appropriate offshore borrow areas to meet the long-term needs of many of Florida's beach nourishment projects has become increasingly difficult. This trend has arisen as the number of trusted offshore sources has started to dwindle. In addition, increased public concern for environmental issues has led to stricter permitting sanctions. As related to the allocation of offshore sand resources for beach nourishment, Regional Sediment Management (RSM) views projects at a regional scale and aims to manage sediment sources most efficiently to meet long-term sediment needs within that region.

The 2008 *Southeast Atlantic Regional Sediment Source Study for Florida* (completed by GEC, Inc. and Halcrow for the Jacksonville District, U.S. Army Corps of Engineers) drew on multiple sources to create an inventory of beach nourishment projects and domestic borrow areas in Palm Beach, Broward, and Miami-Dade counties, Florida. The study found the estimated volumes of sand within existing offshore borrow areas in these three counties insufficient to meet the counties' predicted beach nourishment needs over the next 50 years. Consequently, the USACE retained Taylor Engineering to expand this regional sediment source study to include St. Lucie and Martin counties and to consider upland, deepwater, and non-domestic sand sources.

Figure 1.1 shows the project area considered in this expanded study. The project area consists of the entire coastlines of St. Lucie, Martin, Palm Beach, Broward, and Miami-Dade counties (hereafter identified as "the region").

This Southeast Atlantic RSM Plan for Florida first predicts the long-term (50-year) sediment needs of all the active beach nourishment projects within the region, then evaluates the capability of traditional borrow areas, deepwater borrow areas, upland quarries, and non-domestic sources to meet these needs. Next, the study assesses the cost of using each of the available sand sources. The final step compares various management alternatives for distributing the sand and discusses relevant economic and political constraints.

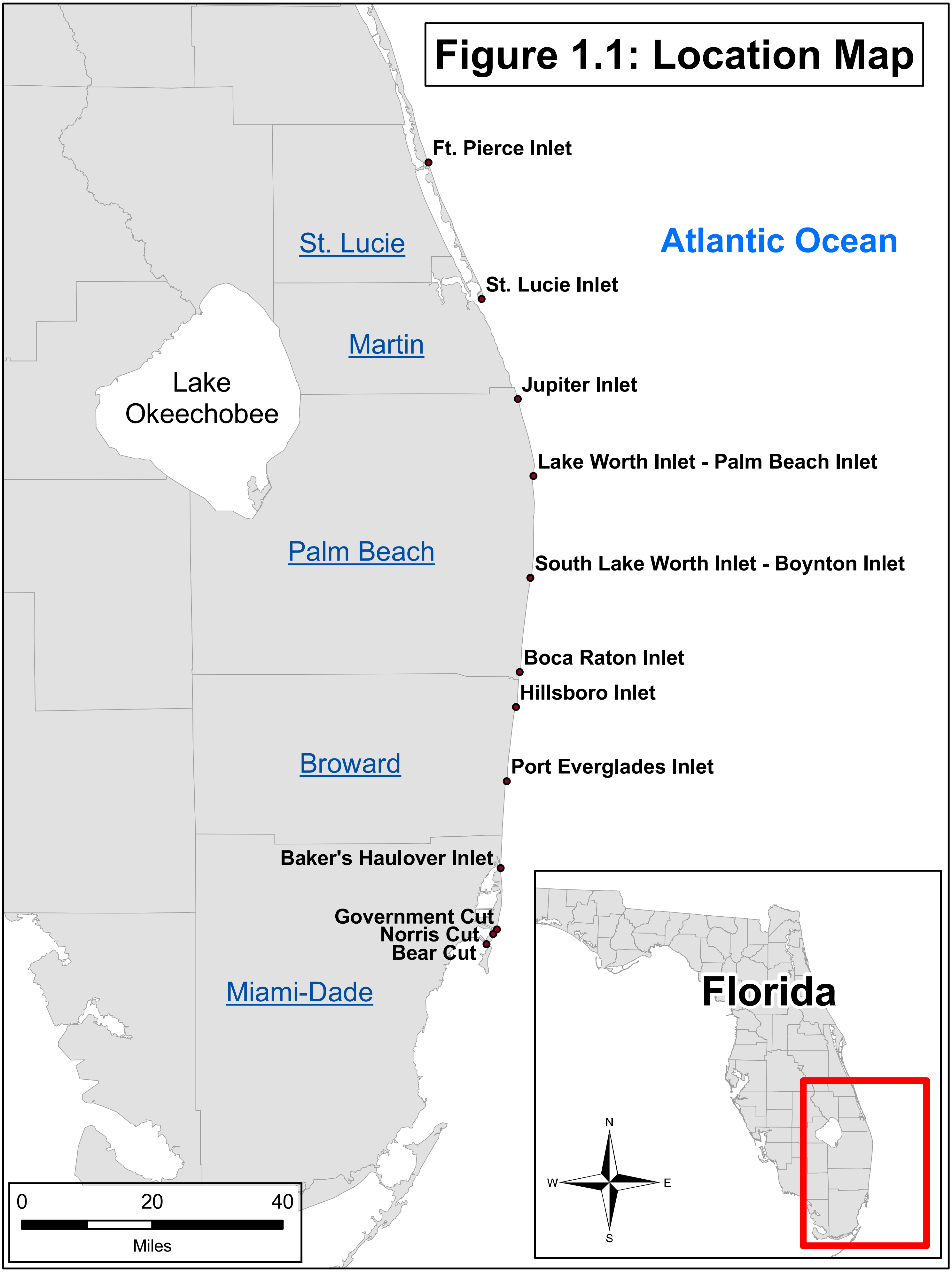
Figure 1.1: Location Map
Ft. Pierce Inlet
St. Lucie
Atlantic Ocean
St. Lucie Inlet
Martin
Lake
Okeechobee
Jupiter Inlet
Lake Worth Inlet - Palm Beach Inlet
Palm Beach
South Lake Worth Inlet - Boynton Inlet
Boca Raton Inlet
Hillsboro Inlet
Broward
Port Everglades Inlet
Baker's Haulover Inlet
Government Cut
Norris Cut
Bear Cut
Miami-Dade
Florida
N
W
E
S
0
20
40
Miles

2.0 SUSTAINABILITY ANALYSIS METHODOLOGY

2.1 Sources of Information

This study collected and synthesized the most recent information available from multiple reports and resources, but did not collect any new data. Table 2.1 contains a full list of sources applied in this study and the 2008 USACE report. The list maintains numbering system of the 2008 USACE report as far as reference number 33.

Table 2.1 Sources of Information

Ref	Title
1	Strategic Management Plan East Coast of Florida (Coast of Florida Erosion and Storm Effects Study). Appendix A Offshore Sand Source Information. USACE Jacksonville District, 1998.
2	Regional Sediment Budgets for Florida's Central Atlantic and Southeast Atlantic Coasts, USACE Jacksonville District, October 2006.
3	Offshore Sand Sources for Beach Nourishment in Florida: Atlantic Coast. Olsen Associates and USACE Jacksonville District, 1988.
4	Town of Palm Beach Reach 8 Beach Nourishment Project – Environmental Assessment. Coastal Planning & Engineering, December 2005.
5	Strategic Beach Management Plan for the Southeast Atlantic Coast Region. Florida Department of Environmental Protection, Bureau of Beaches and Coastal Systems, June 2007 (Draft).
6	Florida Southeast Coast Reconnaissance Offshore Sand Search (ROSS). URS (for FLDEP), August 2007.
7	usSEABED Atlantic Offshore Coastal Surficial Sediment Data Release. US Geological Survey Series 118, 2005.
8	Florida Beach Nourishment Projects Monitoring Database. S. Robert Wang, Mark E. Leadon, Todd L. Walton, Beaches and Shores Resource Center, Florida State University, 2004. http://beach15.beaches.fsu.edu. *(Web link no longer operational)*.
9	Intracoastal Waterway Maintenance Dredging. Placement of Dredge Material on Beaches. Florida Shore and Beach Preservation Association Conference. USACE Jacksonville District, September 2004.
10	Consultant's List of Beaches Controlled by Placements of Large Amounts of Sand. Unknown source or date.
11	Seabed Classification Based on Interpretation of Airborne Laser Bathymetry in Class II Waters off Southeast Florida. Submitted to International Coastal Systems Symposium, Iceland, 2005. Coastal Planning and Engineering, 2005.
12	DEP Beach Monitoring Index. Florida DEP, 2007. (ftp://ftp.dep.state.fl.us/pub/water/beaches/HSSD/unreviewdat/MONITORI NG%20INDEX.xls).
13	Florida Southeast Coast Reconnaissance Offshore Sand Search (ROSS) Data Dictionary and Database Schema. URS, 2004.
14	Using Geographic/Marine Information System (GIS/MIS) frameworks to determine spatial variability of beach sediments and nearshore geomorphology in subtropical southeast Florida. L Benedet and CW Finkl, Unknown date.
15	Detailed Design Report. Dade County Beach Erosion Control and Hurricane Protection Project – Bal Harbour Segment. USACE Jacksonville District, December 2005

Table 2.1 Sources of Information continued

Ref	Title
16 -19	*Numbers 16 to 19 were not used.*
20	Dade County Florida, Beach Erosion Control and Hurricane Protection Project. Evaluation Report. USACE Jacksonville, October 2001.
21	Palm Beach County, Florida Shore Protection Project. Ocean Ridge Segment. Project Information Report for the hurricane rehabilitation effort. USACE Jacksonville District, April 2005.
22	Number 22 was not used.
23	Ocean Ridge Shore Protection Project 1st Renourishment – Fact Sheet. Palm Beach County, 2005.
24	Delray Beach Erosion Control and Hurricane Protection Project, Palm Beach. Palm Beach, August 2006.
25	Project Information Report – Rehabilitation Effort for the Delray Beach Shore Protection Project. Palm Beach County, Florida. USACE Jacksonville, August 2006.
26	Palm Beach County Shore Protection Project (from Martin County line to Lake Worth Inlet and from South Lake Worth Inlet to South County Line) – for North Boca Raton second periodic renourishment. USACE Jacksonville District, September 2007.
27	Project Information Report. Rehabilitation Effort for the Dade County Beach Erosion Control and Hurricane Protection Project. USACE Jacksonville District, August 2006.
28	Project Information Report. Rehabilitation Effort for the Broward County, Segment II Hurricane/Shore Protection Project. USACE Jacksonville District, May 2005.
29	Project Information Report. Rehabilitation Effort for the Broward County, Segment III Hurricane/Shore Protection Project. USACE Jacksonville District, February 2005.
30	Town of Palm Beach Reach 8, Beach Nourishment Environmental Assessment. Coastal Planning and Engineering, Inc., December 2005.
31	Final Report Geotechnical Investigation Palm Beach County Singer Island Vibracores: 2005. SEA Inc., October 2005.
32	Town of Palm Beach Offshore Sand Source Investigation, Coastal Planning and Engineering, Inc., November 1999.
33	Seismic Profiling to Determine Sand Source Potential of Three Offshore Area. S.E.A., Inc., 2003.
34	A Geological Investigation of Sand Resources in the Offshore Area Along Florida's Central-East Coast. U.S. Department of Interior, Minerals Management Services, 2002.
35	Fort Pierce Shore Protection Project, Geotechnical and Borrow Area Investigation, Phase I: Reconnaissance Level. USACE, 1997.
36	Fort Pierce Shore Protection Project, Geotechnical and Borrow Area Investigation, Phase II: Plans and Specs. Level. USACE, 1997.
37	Fort Pierce Shore Protection Project; St. Lucie County, Florida; General Reevaluation Report with Revised Draft Environmental Assessment. USACE, 2008
38	Reconnaissance Offshore Sand Search (ROSS) Preliminary Inventory Report. URS, 2009.
39	St. Lucie County Geotechnical Investigation, Reconnaissance Level. Coastal Technology Corporation, 2007.
40	Martin County BEC Sand Search Investigations Offshore Drilling Report. USACE, 2008.
41	South St. Lucie County Hurricane and Storm Damage Reduction Project, Geotechnical Investigations. Coastal Planning and Engineering, 2006.
42	Martin County Shore Protection Project, 2006 Gilbert Shoal Analysis. Taylor Engineering, 2006.
43	Jupiter Island Beach Renourishment Program Sand Search. Gahagan and Bryant Associates, 1989.
44	Strategic Beach Management Plan for the Central Atlantic Coast Region. Florida Department of Environmental Protection, Bureau of Beaches and Coastal Systems, May 2008.

Table 2.1 Sources of Information continued

Ref	Title
45	Deep Water Geotechnical Investigation of Offshore Sand Deposits for Beach Nourishment in Dade County, Florida. Coastal Planning and Engineering, 2000 (revised 2002).

2.2 Ongoing Beach Nourishment Projects

The Florida Department of Environmental Protection (FDEP) publishes its *Strategic Beach Nourishment Plans* annually. The reports for the Central Atlantic Coast and Southeast Atlantic Coast Regions refer to all the ongoing beach nourishment projects in the region (References 5 and 44).

For the RSM Plan, the calculation of the predicted project needs within the region over the next 50 years considered all available historic beach nourishment data. The life cycle of a beach nourishment project usually begins when the FDEP designates a stretch of coastline "critically eroded." Some reaches of coastline — whether or not designated "critically eroded" — undergo federal study and can become a federally authorized project and receive federal funding for beach nourishment based on an evaluation of national benefits and costs. The initial nourishment of such a stretch of coastline typically restores the beach to a wide and healthy condition (termed the "design template") and adds additional sand to protect the design template from subsequent erosion (termed "advance fill"). The design template represents an optimally designed sand placement to provide storm damage reduction to coastal development and infrastructure, so the designers aim to maintain the template at all times. The advance fill acts as sacrificial material and will gradually disperse due to background erosion and longshore transport. Eventually the removal of the advance fill will expose the design template to erosion and the project will need renourishment to replace the advance fill. Thus, the historic beach nourishment data for a site commonly shows a large volume of sand placed initially followed by a smaller volume placed periodically. Beach designers investigate local rates of erosion and design the advance fill to last a specified length of time, but the unpredictable nature of weather and ocean conditions means that the shoreline may erode more quickly or more slowly than anticipated. Consequently, most beach nourishment projects include annual monitoring to determine project performance and renourishment interval.

For projects with a long nourishment history, monitoring data provides information on yearly shoreline and volume changes within the project and adjacent areas. Analysis of the monitoring data shows project performance under natural forcing conditions and allows development of yearly erosion rates and average renourishment intervals for projects with multiple nourishment events. For these projects with lengthy nourishment histories, the renourishment volume and period applied in the study came from the historic trend. For projects with insufficient historic data to form a trend, the renourishment volume and period came from the designer's predictions.

The region contains 11 federal and 10 non-federal active projects. Calculation of the volumetric needs of each project for the next 50 years requires multiplying the project's renourishment volume by the number of times the project would need renourishment before the end of 2059. This methodology assumes that all active projects in the region will receive complete renourishments throughout the next 50 years. With this assumption, the date of the next renourishment for each project becomes important. Consider a million-cubic-yard project that requires renourishment every seven years and a 50-year analysis period that begins in January 2010. If this project's next renourishment occurs in May 2010, then the project will need eight renourishments (8,000,000 cy) before the end of 2059. However, if its next renourishment occurs in May 2015, then the project will need only seven renourishments (7,000,000 cy) before the end of 2059. The calculation of total project volume requirement carries other assumptions, principally:

- The renourishment needs for all active projects will continue until the end of 2059.
- All active projects will continue to receive full funding at least until the end of 2059.
- The size of all active projects will remain constant for the next 50 years.
- No additional projects will begin in the region before the end of 2059.
- Local rates of erosion will not change significantly in the next 50 years.

These five methodological assumptions come in order of decreasing likelihood. Local rates of erosion will likely change in the next 50 years, especially with increasing sea levels. However, without sufficient data to predict future erosion rates, this study applies constant erosion rates for the next 50 years. Sea level rise, changes to erosion patterns, and other causes will likely create the need for additional projects in the region over the 50-year study period. These additional projects would increase the demand for existing sand sources and the need to locate additional sand sources.

2.3 Quality of Beach Nourishment Sand

Knowledge of the sediment characteristics of the beach requiring nourishment allows definition of acceptable quality characteristics for the project's sand source. Matching the nourishment sand to the pre-project native beach sand preserves the beach's integrity, appearance, erosion behavior, equilibrium shape, and suitability as habitat for local species. Specific sediment characteristics for comparison include mean grain size, sorting, silt content, carbonate content, organic content, and Munsell color. The beaches in the region generally contain a mixture of silicates and carbonates with negligible organic content and mean grain size between 0.25 and 0.35 mm. The beaches typically have low silt content (on the order of 1%) and appear light yellow or light grey in color (predominantly Munsell value 6 – 7 and chroma 1 – 2). However, although these broad generalizations provide a starting point for assessing the quality of nourishment material, each project's individual beach characteristics will refine the limits of acceptability of its sand source.

To determine the volume of beach-quality sediment in a sand source, the study methodology applies the broad definition of beach quality provided by the Florida Administrative Code, Rule 62B-41.007(2)(j) (Table 2.2). Thus, when this report uses the term "beach quality," it does not mean the sand automatically suits any beach in the region, but that the material could potentially suit some beaches in the region.

Table 2.2 Florida Administrative Code Characteristics of Sand Placed on Beaches

Sand Source Sediment Characteristic	**Absolute Limits for Placement in Florida**
Composite mean grain size	Composite between 0.12 mm and 0.80 mm
Composite Munsell color	Value between 4 and 8, any hue and chroma
Silt content (passing through sieve #230)	No more than 5% by weight in composite
Gravel content (passing through sieve #4)	No more than 5% by weight in composite
Coarse gravel (retained on ¾" sieve)	None in any sample
Construction debris, toxic material, foreign matter	None in any sample
Material resulting in beach cementation	None in any sample

The scope of this RSM Plan did not include individual grain size analysis of every nourishment project and sand source in the region. The reference documents listed in Table 2.1 generally provided summary sediment characteristics for the beach projects, but only for very few of the borrow areas. The reference documents often calculated a volume of beach-quality sand without stating a definition of beach quality. Consequently, this study created management options and estimated costs based on the assumption that any sand passing the broad benchmark of beach quality defined in Table 2.2 could nourish any beach in the region. However, this necessary operating assumption does not completely reflect reality, and a future study may need to refine the characteristics of the "beach-quality" sand in the sand sources.

2.4 Sand Sources

This RSM Plan considers all sand source types that have previously provided nourishment to beaches in the region, including inlets, traditional offshore borrow areas, upland quarries, and non-domestic sources (namely Bahamian aragonite; although significant quantities of aragonite exist near the Turks and Caicos Islands). The study also considers deepwater borrow areas (in depths greater than 70 ft) and dredged sand from the Apalachicola River, although these sources have never provided sand to the region's beaches before.

2.4.1 Inlets

Table 2.3 presents data on the 12 inlets in the region. The federal government maintains 6 of the 10 man-made inlets and local authorities maintain the remaining 4. Only two of the inlets in Table 2.3 have fixed sand-bypassing pumps (Lake Worth Inlet and Boynton Inlet). Five of the remaining inlets benefit from a certain volume of natural bypassing including St. Lucie Inlet, Jupiter Inlet, and Hillsboro Inlet, which have features to bypass material not directly related to the navigation channel. All 10 of the man-made inlets require regular dredging, which typically places the accumulated sand back into the beach system, either updrift or downdrift of the inlet. This dredging activity does not reduce the volumetric requirements of the projects in the region, because the project performance accounts for the material already. However, ebb shoals have formed outside some of the inlets, and these provide potential borrow areas that accrete sand over time. The accumulating sand in these ebb shoals likely comes directly from neighboring beaches and therefore makes ideal beach fill. Thus, values in the "Inlet Dredging Activity" column of Table 2.3 do not feature in the sustainability analysis in Section 3.0, but values in the "Ebb Shoal" column do contribute.

2.4.2 Traditional Borrow Areas

Traditional borrow areas lie offshore in both state and federal waters (landward and seaward of the three-mile jurisdictional boundary on the east coast of Florida). The term *traditional* applies because the vast majority of beach nourishment projects in the region have taken sand from these areas. The United States' dredging industry has significant experience dredging in water depths up to 70 ft, but lacks the equipment to dredge any deeper (USACE, 2001). Thus, traditional borrow areas occur in water depths up to 70 ft and deepwater borrow areas occur in water depths greater than 70 ft.

Table 2.3 Inlets in the Region

Inlet Name	County	Responsibility	Annual Bypass Volume (cy)	Bypassing Force	Inlet Dredging Activity	Ebb Shoal
Fort Pierce Inlet	St. Lucie	Federal	0	-	10,000cy/yr dumped offshore - too coarse for local beaches	Erodes at 11,000 cy/yr onto downdrift beaches
St. Lucie Inlet	Martin	Federal	20,000	Natural	19,000cy/yr placed upland, 40,000cy/yr placed on downdrift beaches	Accretes at 6,000cy/yr, too small to dredge
Jupiter Inlet	Palm Beach	Jupiter Inlet District	154,000	Natural	85,300cy/yr placed upland	Accretes at 10,000cy/yr, not currently used
Lake Worth Inlet	Palm Beach	Channel - Federal, Bypass Plant - PBC	164,000	Pumped	80,000cy/yr placed on downdrift beaches	None
Boynton Inlet	Palm Beach	Palm Beach County	80,000	Pumped	3,000cy/yr placed on downdrift beaches	Accretes at 13,000cy/yr, not currently used
Boca Raton Inlet	Palm Beach	City of Boca Raton	75,000	Natural	42,000cy/yr (inlet) and 14,000cy/yr (ebb shoal) placed on downdrift beaches	Accretes at 19,000cy/yr after dredging
Hillsboro Inlet	Broward	Hillsboro Inlet District	48,000	Natural	64,000cy/yr placed on downdrift beaches	Accretes at 4,000cy/yr, too small to dredge
Port Everglades Inlet	Broward	Federal	0	-	7,000cy/yr placed upland	None
Haulover Inlet	Dade	Federal	21,000	Natural	9,000cy/yr placed bach on updrift beaches	Accretes at 32,000cy/yr, not currently used
Government Cut	Dade	Federal	0	-	15,000 dumped offshore	None
Norris Cut	Dade	None (natural inlet)	-	-	-	-
Bear Cut	Dade	None (natural inlet)	-	-	-	-

Almost all the traditional borrow areas identified in this study occur within the boundaries of the five counties in the region. The RSM Plan included several unverified areas in federal waters in Brevard and Indian River counties, north of the region, to illustrate the existence of other possible sources. Notably, additional federal and non-federal beach nourishment projects exist north of the region.

Vibracores represent the primary source of offshore sand quality data. They can provide information on the stratification, grain sizes, colors, and chemical compositions of the offshore sediments at a spot location to a depth of approximately 20 ft. However, a single vibracore does not provide much information on its own; a full understanding of the subsurface sediment requires a grid of vibracores at 1,000-ft spacing, preferably complemented by seismic data. Both dense grids of vibracores and isolated reconnaissance vibracores are available for certain areas in the region, so the study adopted a slightly modified version of the USACE (2008) borrow area categorization system (Table 2.4).

Table 2.4 Borrow Area Categories

Category	Description
1: Proven	Sufficient vibracore data to prove quality and quantity of sand (not necessarily 1,000-ft centers). Laboratory testing throughout full three-dimensional geometry of the borrow area.
2: Potential	Strong evidence to suggest a beach-quality sand source, including laboratory testing of samples from at least three vibracores (more for large areas). Might include additional information, such as geomorphic evidence, remote sensing, etc.
3: Unverified	Some evidence to suggest a beach-quality sand source, such as a single vibracore (with or without laboratory testing), geomorphic evidence, or remote sensing. Anecdotal evidence, such as grab samples, usually sufficient.
0: Depleted or Unusable	Cannot extract any beach-quality sand from the borrow area because the material occurs in small quantities, or in close proximity to hardbottom, historical artifacts, submerged pipelines, etc.

Various sources provided borrow area information (Table 2.1), and in some cases borrow areas from different sources overlapped. When this occurred, borrow areas with more vibracore data superseded areas with less geotechnical information (category 1 data more reliable than category 3), unless the more recent source provided updated information on an area. Where possible, the study combined vibracore data from different sources to create a more complete record.

This study adopted the following rules for unsuitable sand source areas (USACE, 2008).

- Areas shallower than the 18-ft depth of nearshore closure, except for inlets, shoals, and beaches currently serving as sand sources
- Areas covered by protected natural resources such as sea grasses
- Areas within 400 ft of natural hardbottom, artificial reefs, cables, pipelines, navigation channels, etc.

- Restricted access areas, such as the U.S. Navy's permitted crossings area south of Port Everglades, Broward County
- Artificial reef permit areas

The FDEP does not have a standard buffer between hardbottom and dredging activity, but assesses each project individually. The value of 400 ft applied in this study represents the most likely requirement, but in certain circumstances the buffer could increase to 600 ft or more (Seeling, 2009). This study did not eliminate a borrow area that broke one or more of the USACE report (2008) rules, but reduced the area to avoid conflict.

For most of the proven and potential borrow areas (categories 1 and 2), the reference that provided the vibracore data and delineated the borrow area also calculated the volume of beach-quality sand. Some borrow areas required a decrease in size due to the conflicts described above; the volumes of these sources decreased proportionately. This study calculated the volume of beach-quality sand for one borrow area: Borrow Area C in St. Lucie County. The calculation involved identifying samples containing beach-quality sand, determining the maximum depth of good sand, subtracting the 2 ft overdredge buffer, establishing the overall dredge elevation (-50 ft-NAVD88), and computing the cut volume with digital terrain modeling.

References for category 3 borrow areas do not indicate associated volumes. In addition, because these areas contain so few vibracores, the calculation outlined above does not apply. The USACE (2008) report provided the procedure to estimate the volume available for the category 3 borrow area — volume estimates equaled the surface area (after reduction due to conflicts) multiplied by a 6-ft depth. The 6-ft depth corresponds to the median depth used in the ROSS database (Ref. 6, Table 2.1). This calculation produces uncertain results because the beach-quality sediment depth has no basis in site-specific data, or even bathymetry. Category 3 (unverified) borrow areas did not contribute any sand volume to the sustainability analysis or management alternatives presented in this report.

2.4.3 Deepwater Borrow Areas

Deepwater borrow areas occur in water depths greater than 70 ft. Otherwise, deepwater borrow areas are identical to traditional borrow areas and all methodology described in Section 2.4.2 applies to them. The United States' dredging industry currently has no equipment capable of dredging in water depths greater than 70 ft. Dredging deepwater borrow areas requires a jumbo dredge capable of dredging in water depths up to 300 ft (USACE, 2001). To meet the need for a deepwater dredge within the region would require modification of an existing U.S. flagged vessel to include larger pumps and a longer drag arm. This method results in a high equipment mobilization and demobilization cost, as Section 4.1 describes.

2.4.4 Upland Quarries

Upland quarries have provided sand to at least five small-scale beach nourishment projects in Miami-Dade County (USACE, 2001). These projects have demonstrated the viability of upland quarries as beach-quality sand sources, but have also revealed a number of challenges. The differences between taking sand from a quarry and from a traditional borrow area include the following. Unless otherwise noted, page numbers refer to Coastal Planning and Engineering (CPE), 1997.

- Sand travels from the quarry by truck or train. The material can go directly to the beach, or to a port, from which barges take the material to the project area (p.16).

- Both truck-haul options have associated drawbacks. Truck haul through cities creates noise, pollution, traffic congestion, road damage, spilled sand along roadways, and numerous other safety and aesthetic concerns. In response to one of its truck haul beach nourishment projects, the city of Miami Beach set a limit on the amount of sand that trucks may bring through the city. A typical street-legal dump truck carries approximately 9 cy of sand, so a small 10,000 cy project requires over 1,100 truck loads (USACE, 2001). Taking the sand to a port and transferring the material onto a barge avoids these problems, but includes increased cost of double-handling. Although some infrastructure exists to make this transfer, a large project would strain or overwhelm existing equipment and facilities.

- Some upland quarries manufacture aggregate by crushing limestone, while other quarries mine quartz sand directly from pits. The method of crushing limestone produces predictable and uniform sediment, but the manufacturing process can create a high-strength fill with angular grains that give the material a tendency to compact over time (p.17). The FDEP currently does not allow placement of manufactured sand on Florida beaches. The mining method produces less predictable results and requires a stringent quality control procedure.

- Traditional borrow area dredging can transfer between 3,000 and 30,000 cy of offshore sand per day. In contrast, upland quarries typically produce less than 2,000 cy per day, most of which goes to primary customers. This much slower rate would greatly extend a beach nourishment project's construction schedule and increase associated costs (p.18).

- Traditional borrow area dredging contractors receive payment based on the volume of sand placed on the beach, while upland quarries sell sand by the ton. Sand from the dredging process arrives saturated with water and compacted by the pressure of the pumps; however, sand from a quarry arrives in a less compacted state and with moisture content between 5% and 9%. The design engineer must account for these differences in order to place the correct volume of sand on the beach (pp. 19 and 29).

The smallest active project in the region (Key Biscayne) has a renourishment volume of 121,000 cy. This project would require more than 13,400 truckloads of sand, or 42 truckloads every working hour for 8 weeks. This study did not consider the option of using trucks to haul sand directly to a beach nourishment site in this study due to unacceptable social effects. Social effects include noise, pollution, traffic congestion, road damage, spilled sand along roadways, and numerous other safety and aesthetic concerns. The alternative method of transporting the quarried sand to a port and transferring the material onto a barge keeps the trucks on major roads along routes designed for heavy truck traffic (near major port facilities). This method avoids many of the undesirable social effects associated with bringing the quarry material directly to the beach through beachfront areas. Therefore, transporting the quarried sand to a port and transferring the material onto a barge provides a more desirable method as long as the additional work involved does not make the operation cost-prohibitive. Only three ports in the region have the potential to develop the bulk handling capacity necessary to transfer large volumes of sand from trucks onto barges: the Port of Palm Beach, Port Everglades, and the Port of Miami. In addition, each of these port facilities has actively maintained channel depths necessary for loaded hopper dredges to navigate safely to and from the port. Given the infrastructural limitations of these ports, the study methodology limits the volume of sand truck-hauled into them to 750,000 cy in a 6-month period. This volume would require over 83,000 road-legal dump trucks with a capacity of 9 cy. The Port of Miami, for example, receives approximately 6,000 trucks per day. Hauling 750,000 cy of sand via truck to a port in a 6-month period (183 days) would add 455 dump trucks per day to port traffic. Such an undertaking would require enhancements to existing port infrastructure. Furthermore, hauling a volume greater than 750,000 cy by truck seems unrealizable within the 50-year analysis period.

The rate at which quarries can produce sand also limits their usefulness to beach nourishment projects. In some areas of the state, turtle-nesting season limits the time that beaches can receive nourishment to about six months of the year. A quarry with a 2,000 cy/day undesignated output would produce 365,000 cy of sand in this period, enough for only 3 of the 21 ongoing nourishment projects in the region. Multiple quarries could serve one project, but this raises beach-compatibility issues. Overall, upland quarries suit small emergency nourishments. For full-sized beach nourishment projects, quarries currently cannot compete with traditional borrow areas as long as the latter remain available. For the purposes of this RSM Plan, the study included upland quarries and assumed that an increased need for large quantities of sand would motivate providers to improve their infrastructure and resolve the production rate and processing issues.

Table 2.5 contains information on the three upland sources most suitable — based on material specifications, location, and infrastructure — to satisfy the needs of the large beach nourishment projects in the study area. Figure 2.1 shows the locations of these three quarries.

Table 2.5 List of Upland Quarries

Quarry Name	Address	County	Suppliers	Beach-Quality Sand (cy)
Stewart Mine (Indrio Pit)	13575 Indrio Road, Fort Pierce, 34945	St. Lucie	Dickerson Aggregates, Inc., Wild Brothers, Stewart Mining Industries	9,807,700
Dickerson's Indrio Pit	14885 W. Indrio Road, Fort Pierce, 34945	St. Lucie	Eastman Aggregate Enterprises, LLC	9,423,000
Witherspoon Sand Plant	11655 W SR 78, Moore Haven, 33471	Glades	Eastman Aggregate Enterprises, LLC	61,538,000

2.4.5 Apalachicola River Delta

This study considered use of the sand stockpiles on the banks of the Apalachicola River Delta (Figure 2.2). The Apalachicola reserves contain approximately 2,000,000 cy of beach-quality sand already dredged from the riverbed (only transportation-related costs to place in the region). Transportation would require a river barge within the river delta, an ocean-going barge around the Florida peninsula to a port, and a barge with hydraulic pump-out capacity from the port to a project in the region. Despite the extensive transport distance, this option has significant practical advantages over upland quarries, and avoids most of the problems outlined in the previous section.

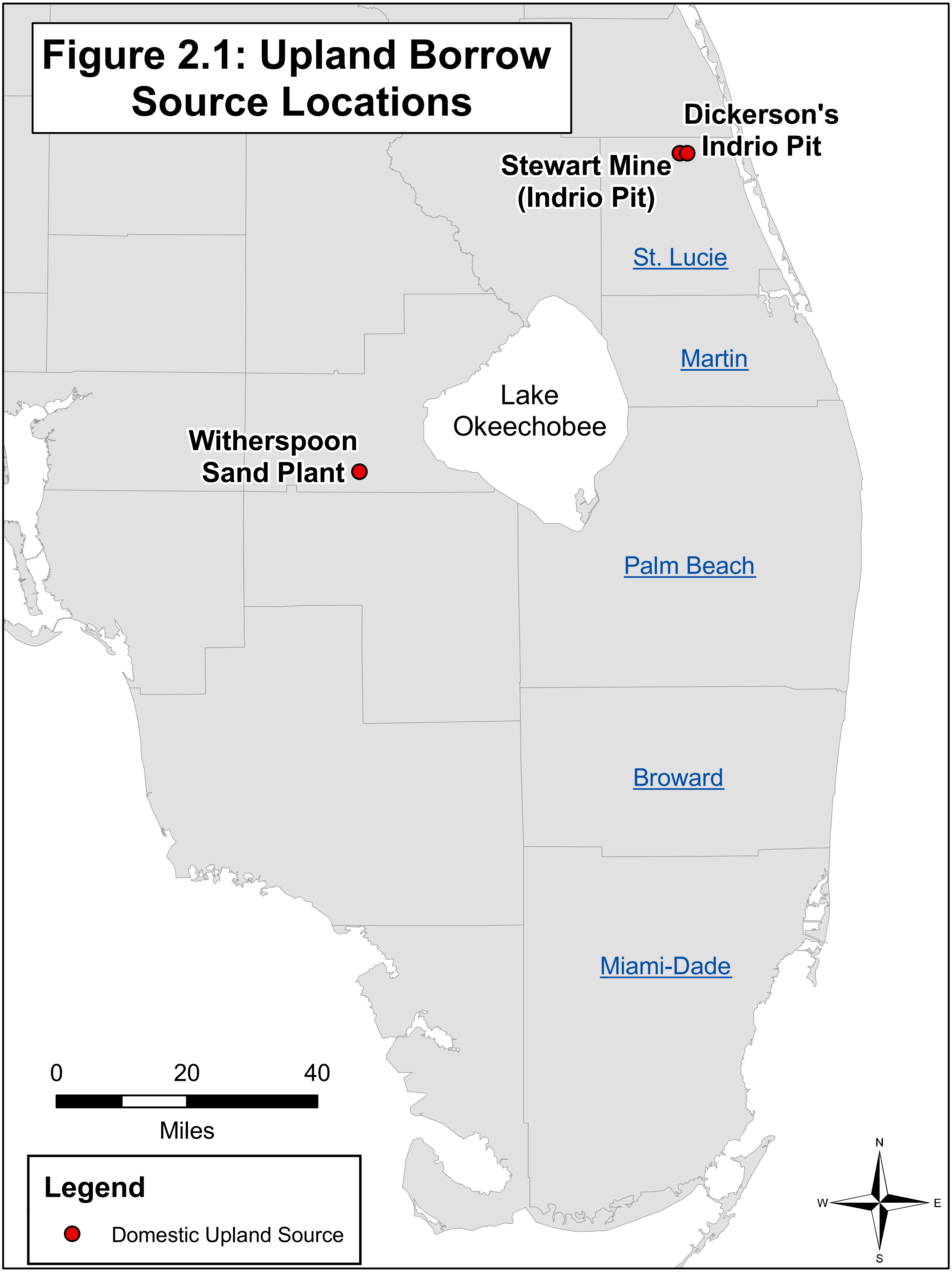
Figure 2.1: Upland Borrow Source Locations
Dickerson's Indrio Pit
Stewart Mine (Indrio Pit)
St. Lucie
Martin
Lake Okeechobee
Witherspoon Sand Plant
Palm Beach
Broward
Miami-Dade
0
20
40
Miles
Legend
Domestic Upland Source
N
W
E
S

Figure 2.2: Apalachicola and Non-Domestic Source Locations

2.4.6 Non-Domestic Sources

Although several sources of non-domestic beach-quality sediment exist, Bahamian aragonite represents the only non-domestic source evaluated in this RSM Plan due to limited cost and logistical data. Bahamian aragonite sources considered in this study include Ocean Cay and Freeport (Figure 2.2). The Turks and Caicos Islands also export aragonite, but lie too far from the region (approximately 500 miles) to provide an economically viable sand source. Aragonite consists of spherical grains of pure calcium carbonate (oolites) that precipitate out of agitated saline waters around a nucleus. Conditions near the Bahamas provide the ideal environment for aragonite to form, and aragonite exists there in almost limitless quantities (USACE, 2001). Although Florida's subtropical beaches do contain aragonite and other calcareous oolites, they do not naturally predominate (Thorp, 1939, as cited in CPE, 1997). Bahamian aragonite represents a known large volume of beach-quality material in close proximity to much of the region. Existing U.S. dredge equipment and methods could collect and transport aragonite.

Several qualities of aragonite make it an attractive beach fill option (from Thomson et al., 2004).

- **Grain Size** — the grain size of Bahama Bank oolite (0.3 mm) compares favorably with the sand currently on the beaches in the region.
- **Grain Sphericity** — the higher sphericity of aragonite reduces grain movement in turbulent waters, but may also reduce the slope stability of the material.
- **Specific Gravity** — the greater relative density of aragonite (2.88) compared to quartz sand (2.65) produces faster fall velocities and greater resistance to motion in currents.
- **Natural Adhesion** — aragonite sands have a natural adhesive quality that provides greater resistance to erosion.
- **Gradation** — aragonite sands typically have fine sorting with no pebbles or silt.
- **Color** — white-colored aragonite sand appeals aesthetically to beach users. Aragonite does not absorb as much solar radiation as darker quartz sand, and therefore has a consistently lower temperature. (However, the color and temperature properties of aragonite present turtle-nesting implications — see Table 2.6)
- **Availability** — the Bahama Banks contain 30 – 50 billion tons of oolite.

To date, aragonite has provided beach fill to only one nourishment project in Florida: a 1991 private project at Fisher Island (Olsen and Bodge, 1991). Because this project also included construction of six groins, it offers limited data on the erosion rate of aragonite. The Fisher Island Community Association (FICA) is considering a second beach nourishment project, which could occur in the next 3 years. This would equate to a 21-year renourishment interval, the highest of all active projects in the region. The extended renourishment interval might reflect well on the performance of aragonite, but more likely reflects well on the design of the groins. Public response to the placement of aragonite on Fisher Island in 1991 seemed generally positive. Locals enjoyed the fine, white appearance of the sand, and the FICA would use aragonite again if economically viable (Politis, 2009). Wind and wave action have largely replaced the aragonite with the darker native material, but digging below the beach surface will still uncover pockets of white aragonite.

The Fisher Island project, together with several scientific studies, have allayed most of the initial concerns of the engineering and environmental communities over the use of aragonite as beach fill in southeast Florida. Table 2.6 presents the salient issues.

Table 2.6 Concerns and Responses Regarding Aragonite as Beach Fill in SE Florida

Concern	Response
Would aragonite form a stable beach?	Still not clearly observed in the field, but settling tube analysis indicates that aragonite would behave as a sand 1.26 – 1.36 times coarser, and would therefore form a more stable beach than quartz sand (Olsen and Bodge, 1991). Observations of the Fisher Island project do not discredit this theory.
Does the spherical grain shape lead to less interlocking and lower stability?	This remains uncertain. The longevity of the Fisher Island project is at least partially due to groins, and native sand has now largely replaced the aragonite. The initial results of a small beach test at Pepper Park Beach by Cunningham (1966) indicated that aragonite formed a slightly more stable beach than native sand (CPE, 1997).
Does aragonite fill increase turbidity?	Monitoring observations for two years after construction at Fisher Island suggest that aragonite does not increase turbidity (Olsen Associates, Inc., 1993).
Does harder quartz sand abrade, dissolve, and cement aragonite on mixed beaches?	The USACE observed no significant difference in the abrasion of aragonite between mixed and aragonite-only beaches in wave tank tests in 1985. Monitoring of the Fisher Island project seems to discount this concern (CPE, 1997).
Does the lighter-colored aragonite change the temperature of the beach?	Yes. White aragonite beaches typically have a temperature 1.25 – 1.50°C cooler than darker carbonate beaches during summer days (Blair et al., 1998).
Does this temperature difference affect the survival of sea turtle hatchlings?	No. The survival of sea turtles hatched in aragonite does not differ much from their survival in darker carbonate sand. However, the cooler aragonite causes a longer incubation time (Blair et al., 1998).
Does the temperature difference affect the gender balance of sea turtle hatchlings?	Experiments have shown that warmer incubation conditions increase the proportion of female hatchlings. However, weather conditions and the proximity of the eggs to the surface likely have a far greater effect than sand type (Nelson et al., 1996).

Presently the Bahamian authorities will not allow U.S. vessels to enter their waters to dredge aragonite directly (USACE, 2001). Therefore, projects wishing to use aragonite must currently pay Bahamian shipping companies to transport the material to a port in Florida. After customs has approved the cargo, U.S. barges can pick up the aragonite and deliver the material to the project. This double-handling adds to the expense of the project. If, in the future, the Bahamian authorities allowed U.S. vessels to dredge aragonite directly, then this would lower the material cost considerably, as Section 4.1 describes.

3.0 SUSTAINABILITY ANALYSIS DEVELOPMENT

An analysis of the sustainability of current and likely future beach nourishment practices provided the starting point for the RSM Plan. Projects in the region typically use traditional borrow sources as a main sand source. The volume requirements of some projects can allow construction with upland material but these are of very small volume compared to projects that employ traditional offshore sites. The RSM Plan sustainability analysis seeks to determine whether using only traditional borrow sources to nourish beaches within the region will prove sustainable or whether the region's 50-year needs demand the use of alternative sources to augment the traditional source volume.

3.1 Beach Nourishment Projects

The region contains 21 active beach nourishment projects and 3 inactive projects (Table 3.1). For each of the projects, Table 3.1 presents the project location and 50-year volume requirement. The 50-year volume requirement equals the renourishment volume per event times the number of renourishment events in the 50-year analysis period. The number of renourishment events depends on the renourishment interval and the date of next nourishment for that project. Appendix A contains location maps and relevant data for all projects considered in the RSM Plan.

3.2 Offshore Borrow Areas

The RSM Plan identified 107 traditional offshore borrow areas in the region (including areas offshore of Indian River and Brevard counties), 30 of which contain verified beach-quality sand. Tables 3.2 – 3.7 contain summary data for all of these borrow areas, presented by county from north to south. The tables also include data for the nine deepwater borrow areas in the region and Miami South Beach. The nine deepwater borrow areas occur offshore Miami-Dade County and have names beginning with "DDW Zone." Only one of these areas contains verified beach-quality sand. Notably, FDEP and National Oceanographic and Atmospheric Administration (NOAA) data sets provided the bathymetry applied in the study; some of the depth values — especially in Broward and Miami-Dade counties — do not match those published in some other references. Figures 3.1 – 3.7 (located at the end of Section 3.0) plot the location of each borrow area by county from north to south. Appendix B contains location maps and relevant data for all borrow areas considered in the RSM Plan.

Table 3.1 Beach Nourishment Projects

Project Name (* = non-federal)	County	Monument Range	Volume (cy/event)	Interval (yr)	Next Event	No. Events	50-year Volume (cy)
Ft Pierce SPP	St. Lucie	R034 - R041	550,000	2	5/2009	26	14,300,000
South St. Lucie Project	St. Lucie	R088.5 - R090.3, R098 - MCo line	780,000	4	5/2011	13	10,140,000
						County Total:	**24,440,000**
Martin County SPP	Martin	R001 - R025	800,000	4	5/2011	13	10,400,000
Jupiter Island*	Martin	R075 - R116	1,500,000	4	3/2011	13	19,500,000
						County Total:	**29,900,000**
Jupiter/Carlin	Palm Beach	R013.5 - R019	625,000	7	3/2010	8	5,000,000
Juno Beach*	Palm Beach	R026 - R038	700,000	7	3/2015	7	4,900,000
Lake Worth Inlet (Rch 2)	Palm Beach	R078 - R090	*Project Cancelled*				
Midtown Beach*	Palm Beach	R090.4 - R101.4	1,000,000	7	2/2013	7	7,000,000
South of Midtown Beach (Rch 5)	Palm Beach	R100 - R110	*Project Cancelled*				
Phipps Ocean Park Beach (ch 7)*	Palm Beach	R119 - R126	1,100,000	6	5/2012	8	8,800,000
Palm Beach (Rch 8)*	Palm Beach	R126 - R134	500,000	5	11/2012	10	5,000,000
Ocean Ridge Beach	Palm Beach	R153 - R159	558,000	7	11/2012	7	3,906,000
Delray Beach	Palm Beach	R175 - R188.5	1,140,000	10	4/2012	5	5,700,000
Boca Raton - North Beach	Palm Beach	R205 - R212	680,000	8	4/2016	6	4,080,000
Boca Raton - Central Beach	Palm Beach	R216 - R222	340,000	8	3/2011	7	2,380,000
Boca Raton - South Beach*	Palm Beach	R223 - R228	300,000	6	12/2014	8	2,400,000
						County Total:	**49,166,000**
Hillsboro/Deerfield Beach*	Broward	R006 - R012	555,000	10	3/2009	6	3,330,000
Pompano Beach to Ft Lauderdale	Broward	R025 - R053	935,000	6	4/2010	9	8,415,000
John U. Lloyd Park Project	Broward	R086 - R094	780,000	6	5/2012	8	6,240,000
Hollywood/Hallandale	Broward	R101 - R128	780,000	6	5/2012	8	6,240,000
						County Total:	**24,225,000**
Miami Dade	Miami-Dade	R020 - R026	686,000	2	4/2009	26	17,836,000
Fisher Island*	Miami-Dade	R075 - R078	25,000	21	4/2012	3	75,000
Virginia Key*	Miami-Dade	R079 - R088	*One-Time Event: No Future Nourishments Planned*				
Key Biscayne*	Miami-Dade	R101 - R113.7	121,000	15	8/2017	3	363,000
						County Total:	**18,274,000**
						Overall Total:	**146,005,000**

Table 3.2 Borrow Areas Offshore Brevard and Indian River Counties

Borrow Area Name	Monument Range	Distance Offshore (mi)	Max Depth (ft)	Number of Vibracores	Category	Estimated Volume (cy)	Annual Accretion (cy)
MMS-1	V162 – R022	7.4	67.9	1	3: Unverified	115,000,000	0
MMS-2	R038 – R071	8.3	66.2	2	3: Unverified	49,500,000	0
MMS-3	R165 – R023	6.3	70.1	4	3: Unverified	260,000,000	0
MMS-4	R014 – R041	5.7	58.2	4	3: Unverified	100,000,000	0
MMS-5	R030 – R066	7.8	63.6	1	3: Unverified	0	0
					Category 3 (Unverified) Total:	**524,500,000**	**0**

Table 3.3 Borrow Areas Offshore St. Lucie County

Borrow Area Name	Monument Range	Distance Offshore (mi)	Max Depth (ft)	Number of Vibracores	Category	Estimated Volume (cy)	Annual Accretion (cy)
Area AB	R032 – R037	3.7	45.6	3	1: Proven	1,570,000	0
Area C	R039 – R057	2.8	40.1	38	1: Proven	7,760,000	0
Area D	R008 – R013	2.6	39.3	3	1: Proven	1,540,000	0
Area F	R020 – R027	1.7	37.6	4	1: Proven	1,230,000	0
CPE BA-5	R103 – R111	3.1	53.1	14	1: Proven	5,118,750	0
					Category 1 (Proven) Total:	**17,218,750**	**0**
MMS Area A	R074 – R089	5.5	56.6	19	2: Potential	23,000,000	0
Borrow Area "C"	R094 – R108	3.7	60.2	7	2: Potential	18,600,000	0
					Category 2 (Potential) Total:	**41,600,000**	**0**
					Total Volume in Categories 1 and 2:	**58,818,750**	**0**
Unnamed Shoal #1	R003 – R014	3.9	51.4	1	3: Unverified	6,349,077	0
Area E	R010 – R013	3.7	41.0	1	3: Unverified	640,000	0
Shoal A	R004 –R040	5.2	44.2	1	3: Unverified	26,237,852	0
MMS-6	R033 – R093	6.3	71.5	3	3: Unverified	92,213,323	0
SL-5	R045 –R075	4.6	44.2	2	3: Unverified	32,711,040	0
St. Lucie #2	R081 – R090	4.7	58.0	0	3: Unverified	3,065,315	0
St. Lucie #3	R068 – R080	6.2	56.6	1	3: Unverified	14,048,838	0
St. Lucie #4	R065 – R076	5.5	47.0	1	3: Unverified	9,107,758	0
CPE BA-1	R084 – R086	1.7	35.9	2	3: Unverified	919,940	0
CPE BA-2	R088 – R091	1.2	42.3	5	3: Unverified	915,550	0
CPE BA-3	R093 –R096	1.2	44.9	6	3: Unverified	1,752,750	0
CPE BA-4	R097 – R104	0.8	41.5	19	3: Unverified	620,970	0
					Category 3 (Unverified) Total:	**188,582,413**	**0**
SL-1	R006 – R047	4.7	42.9	1	0: Depleted	0	0
SL-2	R025 – R065	3.0	51.3	7	0: Unusable	0	0
SL-3	R075 – R102	0.9	45.7	0	Overlapped	0	0
SL-4	R068 – R086	2.1	49.2	0	Overlapped	0	0
Borrow Area "A"	R076 – R090	5.5	54.8	0	Overlapped	0	0
St. Lucie #1	R092 – R106	4.3	58.4	0	Overlapped	0	0

Table 3.4 Borrow Areas Offshore Martin County

Borrow Area Name	Monument Range	Distance Offshore (mi)	Max Depth (ft)	Number of Vibracores	Category	Estimated Volume (cy)	Annual Accretion (cy)
Borrow Area "B"	R099 – R112	6.6	64.7	49	1: Proven	17,000,000	0
Site A	R079 – R087	2.3	47.5	2	1: Proven	367,000	0
Site B	R107 – R116	2.2	60.4	6	1: Proven	7,414,000	0
					Category 1 (Proven) Total:	**24,781,000**	**0**
					Total Volume in Categories 1 and 2:	**24,781,000**	**0**
MMS-7	R086 – R002	6.0	114.9	7	3: Unverified	252,900,000	0
MI-1	R002 – R015	1.9	56.1	0	3: Unverified	6,539,551	0
MI-3	R054 – R070	2.5	47.2	1	3: Unverified	11,472,029	0
MI-4	R078 – R090	2.2	60.9	4	3: Unverified	6,076,647	0
MI-6	R040 – R060	3.5	44.7	3	3: Unverified	5,745,356	0
					Category 3 (Unverified) Total:	**282,733,583**	**0**
Gilbert Shoal	R020 – R031	1.1	42.6	25	0: Depleted	0	0
St. Lucie Inlet Ebb Shoal	R042 – R043	0.4	15.1	0	0: Unusable	0	6,000
MI-2	R016 – R031	1.1	43.7	12	Overlapped	0	0
MI-5	R105 – R114	3.0	56.4	0	Overlapped	0	0

Table 3.5 Borrow Areas Offshore Palm Beach County

Borrow Area Name	Monument Range	Distance Offshore (mi)	Max Depth (ft)	Number of Vibracores	Category	Estimated Volume (cy)	Annual Accretion (cy)
Jupiter/Carlin	R125	2.4	72.7	46	1: Proven	1,250,000	0
Ocean Ridge	R152 – R165	0.4	47.1	10	1: Proven	3,670,000	0
Delray Beach	R175 – R190	0.5	48.4	24	1: Proven	3,800,000	0
Boca Raton	R204 – R214	0.5	50.6	39	1: Proven	3,300,000	0
South Boca Raton	R222 – R224	0.2	19.1	21	1: Proven	19,000	19,000
					Category 1 (Proven) Total:	**12,039,000**	**950,000**

Table 3.5 Borrow Areas Offshore Palm Beach County Continued

Borrow Area Name	Monument Range	Distance Offshore (mi)	Max Depth (ft)	Number of Vibracores	Category	Estimated Volume (cy)	Annual Accretion (cy)
Singer Island	R055 – R070	0.7	52.3	38	2: Potential	2,000,000	0
Lake Worth Inlet	R072 – R075	0.3	30.2	1	2: Potential	80,000	0
Lake Worth Inlet North	R072 – R076	0.5	43.6	8	2: Potential	3,500,000	0
Lake Worth Inlet South	R076 – R083	0.4	34.9	38	2: Potential	5,270,000	0
Palm Beach North	R091 – R094	0.6	41.5	11	2: Potential	2,700,000	0
Palm Beach South	R098 – R105	0.6	56.9	30	2: Potential	15,212,000	0
Palm Beach Area III	R128 – R130	0.6	72.2	5	2: Potential	545,000	0
Briny Breezes	R165 – R175	0.3	35.8	10	2: Potential	7,666,667	0
Highland Beach	R194 – R217	0.4	63.9	20	2: Potential	5,333,333	0
Category 2 (Potential) Total:						**42,307,000**	**0**
Total Volume in Categories 1 and 2:						**54,346,000**	**950,000**
Area 4	R121 – R126	3.2	72.8	32	3: Unverified	2,400,000	0
PB (Juno to Jupiter)	R013 – R052	1.0	61.5	23	3: Unverified	20,000,000	0
PB-2	R094 – R105	0.4	39.0	1	3: Unverified	1,033,101	0
PB-3	R136 – R145	0.3	46.6	2	3: Unverified	3,401,028	0
PB-5	R194 – R217	0.3	18.0	0	3: Unverified	1,973,890	0
Boynton Inlet Ebb Shoal	R151 – R152	0.1	15.4	0	3: Unverified	0	13,000
ROSS Area-1	R001 – R072	0.6	41.8	20	3: Unverified	28,487,854	0
ROSS Area-10	R085 – R091	0.6	39.9	8	3: Unverified	824,051	0
ROSS Area-12, 17	R152 – R167	0.5	77.4	15	3: Unverified	2,738,578	0
ROSS Area-28	R179 – R182	0.5	39.3	0	3: Unverified	198,422	0
ROSS Area-36	R181 – R190	0.4	36.0	2	3: Unverified	408,959	0
ROSS Area-44	R182 – R185	0.5	39.4	1	3: Unverified	112,701	0
ROSS Area-54	R204 – R208	0.5	58.6	0	3: Unverified	580,700	0
ROSS Area-59	R206 – R216	0.4	41.1	7	3: Unverified	610,792	0
ROSS Area-73	R217 – R222	0.5	46.8	5	3: Unverified	520,316	0
ROSS Area-79	R224 – R228	0.7	67.8	3	3: Unverified	661,434	0
Category 3 (Unverified) Total:						**63,951,826**	**650,000**
Area 3	R121 – R126	2.2	65.6	18	0: Depleted	0	0
Jupiter Shoal	R012 – R013	0.3	20.0	15	0: Unusable	0	10,000
Palm Beach Area IV	R132 – R135	0.5	74.0	8	0: Unusable	2,000,000	0
Palm Beach Area V	R129 – R136	0.4	40.3	0	0: Unusable	0	0
Palm Beach Area VI	R122 – R127	0.4	40.5	0	0: Unusable	0	0

Table 3.6 Borrow Areas Offshore Broward County

Borrow Area Name	Monument Range	Distance Offshore (mi)	Max Depth (ft)	Number of Vibracores	Category	Estimated Volume (cy)	Annual Accretion (cy)
BA-I	R001	0.4	28.4	9	1: Proven	988,400	0
					Category 1 (Proven) Total:	**988,400**	**0**
					Total Volume in Categories 1 and 2:	**988,400**	**0**
Pomp 1983	R028 – R032	0.8	92.3	1	3: Unverified	212,186	0
BO-1	R011 – R027	0.7	116.9	8	3: Unverified	2,340,482	0
BO-3	R057 – R086	1.2	128.1	0	3: Unverified	1,238,917	0
BO-4	R105 – R112	1.0	51.0	0	3: Unverified	235,106	0
1977 BA	R077 – R082	1.1	113.9	3	3: Unverified	1,090,000	0
					Category 3 (Unverified) Total:	**5,116,691**	**0**
BA-II	R011 – R021	0.3	44.0	12	0: Depleted	0	0
BA-III	R016 – R019	0.8	96.0	7	0: Depleted	0	0
BA-IV	R031 – R032	0.6	37.9	1	0: Depleted	0	0
BA-V	R041 – R044	1.015	77.5	0	0: Unusable	0	0
BA-VI	R046 – R049	0.8	63.9	3	0: Depleted	0	0
BA-VII	R046 – R049	1.105	88.1	1	0: Unusable	0	0
1972 BA	R006 – R011	0.5	82.0	1	0: Unusable	0	0
Hillsboro Inlet Ebb Shoal	R024 – R025	0.1	13.3	0	0: Unusable	0	4,000
1979 BA	R103 – R125	1.365	116.0	0	0: Unusable	0	0

Table 3.7 includes Miami South Beach as a borrow area although the area does not fit any of the sand source categories defined in Section 2.4. Sand accretes on the South Beach and past renourishment projects in Miami-Dade County have relocated a portion of this accreted volume northward to more eroded stretches of the coast. This study applies the hydraulic dredge cost equation to estimate the cost of relocation.

A Minerals Management Service report (Hoenstine et al., 2002) provided information on the five traditional borrow areas outside the region (Table 3.2). All five of the areas occur seaward of the 3-mile jurisdictional boundary and do not have a dedicated project. Thus, they could provide sand to the region. However, the quality of the sand in these areas remains unverified and they do not contribute to the sustainability analysis in Section 3.3.

Table 3.7 Borrow Areas Offshore Miami-Dade County

Borrow Area Name	Monument Range	Distance Offshore (miles)	Max Depth (ft)	Number of Vibracores	Category	Estimated Volume (cy)	Annual Accretion (cy)
Miami South Beach	R063 – R070	0.0	0.0	0	1: Proven	400,000	50,000
SGC Ext 1S	R106 – R110	3.9	79.5	0	1: Proven	500,000	0
Category 1 (Proven) Total:						**900,000**	**2,500,000**
Sunny Isles	R007 – R010	1.8	111.8	0	2: Potential	94,753	0
Haulover Shoal	R025 – R026	0.4	12.4	0	2: Potential	0	32,000
Miami Channel	R070 – R074	2.5	86.5	0	2: Potential	204,960	0
DDW Zone 3B	R084 – R113	4.9	230.5	7	2: Potential	1,710,000	0
Category 2 (Potential) Total:						**2,009,713**	**1,600,000**
Total Volume in Categories 1 and 2:						**2,909,713**	**4,100,000**
Borrow Area #1	R004 – R007	1.7	99.0	3	3: Unverified	150,000	0
Borrow Area #2	R009 – R016	1.8	120.7	11	3: Unverified	150,000	0
DA-1	R004 – R032	1.5	89.9	6	3: Unverified	2,752,065	0
DA-3	R055 – R063	2.0	85.6	1	3: Unverified	1,020,848	0
DA-4	R030 – R033	1.1	90.0	0	3: Unverified	410,694	0
Borrow Area A	R020 – R022	0.6	120.8	0	3: Unverified	24,027	0
Borrow Area B	R036 – R039	1.5	62.4	0	3: Unverified	38,086	0
Borrow Area C	R032 – R036	1.9	102.1	0	3: Unverified	150,000	0
Borrow Area D	R051	1.5	54.5	0	3: Unverified	26,264	0
Borrow Area E	R042 – R051	1.8	111.0	9	3: Unverified	150,000	0
DDW Zone 2C	R031 – R073	2.9	375.7	2	3: Unverified	9,900,000	0
Category 3 (Unverified) Total:						**14,771,984**	**0**
DA-2	R064 – R098	1.5	26.8	3	0: Unusable	0	0
DDW Zone 1A	R004 – R021	2.5	240.5	1	0: Unusable	0	0
DDW Zone 1B	R004 – R022	2.9	377.4	1	0: Unusable	0	0
DDW Zone 2A	R033 – R061	2.8	296.3	3	0: Unusable	0	0
DDW Zone 2B	R061 – R072	3.2	265.3	2	0: Unusable	0	0
DDW Zone 3A	R091 – R113	4.6	142.2	2	0: Unusable	0	0
DDW Zone 3C	R082 – R096	5.0	344.6	1	0: Unusable	0	0
DDW Zone 3D	R105 – R113	5.7	340.3	1	0: Unusable	0	0
SGC (ROSS)	R093 – R095	3.2	52.4	0	0: Unusable	284,164	0
SGC B/A	R085 – R105	3.2	67.5	1	0: Unusable	0	0
SGC-2 B/A	R096 – R099	3.5	51.3	6	0: Depleted	0	0
SGC Ext 1N	R103 – R106	3.9	64.5	6	0: Depleted	0	0
Deep Water	R114 – R115	4.4	104.1	0	0: Depleted	0	0

3.3 Sustainability Analysis Results

Table 3.8 summarizes the data from Sections 3.1 and 3.2 that outline the material requirements and availability in the region. St. Lucie and Palm Beach counties have sufficient offshore sand in categories 1 and 2 to meet their 50-year project needs. Martin, Broward, and Miami-Dade counties cannot meet their project needs with verified beach-quality offshore sand. Overall, the surplus material in St. Lucie and Palm Beach counties makes up for the deficit in the other three counties and provides an excess of 0.9 mcy. The region contains large volumes of unverified (Category 3) sand, particularly in Martin County, but these areas cannot contribute to the sustainability analysis without further investigation.

Table 3.8 Regional Sustainability Analysis

County	50-Year Volume Need (cy)	Borrow Area Beach Quality Sand Volumes (cy)					Volume Balance (cy)
		Category 1 (Proven)	Category 2 (Potential)	Category 3 (Unverified)	Renewable	County Total	
Brevard	-	0	0	424,500,000	0	0	-
Indian River	-	0	0	100,000,000	0	0	-
St. Lucie	24,440,000	17,218,750	41,600,000	188,582,413	0	58,818,750	34,378,750
Martin	29,900,000	24,781,000	0	282,733,583	0	24,781,000	(5,119,000)
Palm Beach	49,166,000	12,039,000	42,307,000	63,951,826	950,000	55,296,000	6,130,000
Broward	24,225,000	988,400	0	5,116,691	0	988,400	(23,236,600)
Miami-Dade	18,274,000	900,000	2,009,713	14,771,984	4,100,000	7,009,713	(11,264,287)
Totals	**146,005,000**	**55,927,150**	**85,916,713**	**1,079,656,497**	**5,050,000**	**146,893,863**	**888,863**

NOTES:

Sand sources in this table include all known borrow areas in state waters, federal waters, and deep water (>70 ft).

All Brevard and Indian River borrow areas occur in federal waters.

Project 50-year volumes assume placement of scheduled full-sized projects until the end of 2059.

Renewable volumes include Category 1 and 2 sources, but exclude Category 3 sources.

County totals ignore Category 3 contributions and include renewable contributions.

The sustainability analysis results show that known offshore sand resources in the region barely meet the region's 50-year beach nourishment needs, although Category 3 material could potentially provide substantially more sand. The analysis does not take into account future increases in the region's sand requirements due to the construction of new projects or increasing rates of erosion. Given current trends of increased storm activity and sea level rise, the region's future need will likely exceed that predicted by this analysis. Even allowing for the sharing of traditional offshore sources throughout the region, the analysis predicts almost complete depletion of known sources within 50 years. The beach nourishment projects in the region will likely continue to need sand after the depletion of known offshore sources. Beach nourishment projects in the region do not currently practice long distance sand “sharing” due to high transportation costs and significant political and social opposition. Such opposition shows no sign of changing, especially as project needs increase and sand sources diminish. From this realistic viewpoint, Miami-Dade and Broward Counties will experience a significant sand deficit in the near future. The results of this sustainability analysis indicate that investigation and development of alternative sources should begin in order to properly plan and meet sand needs of the region during the next 50 years and beyond.

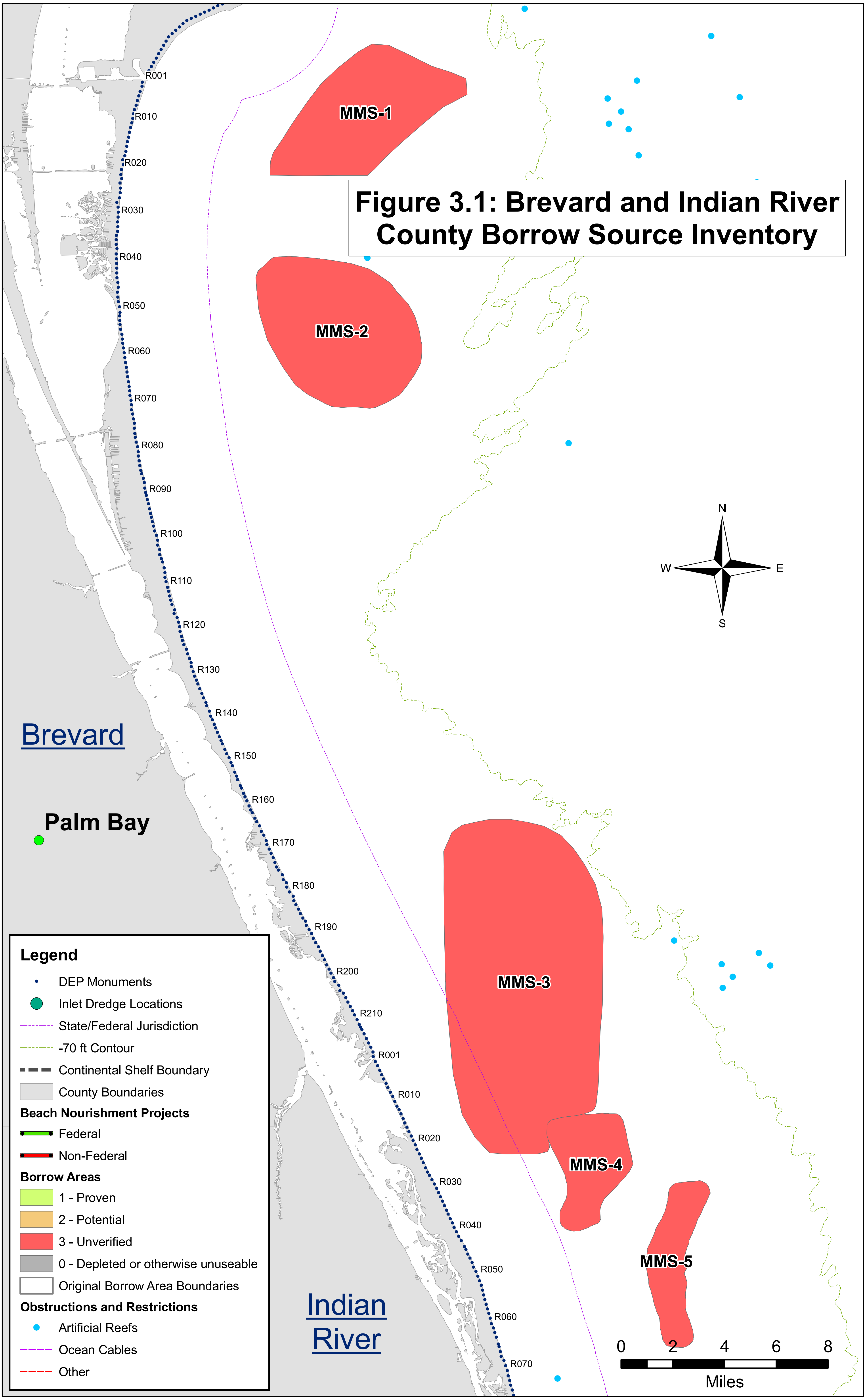

Figure 3.1: Brevard and Indian River County Borrow Source Inventory

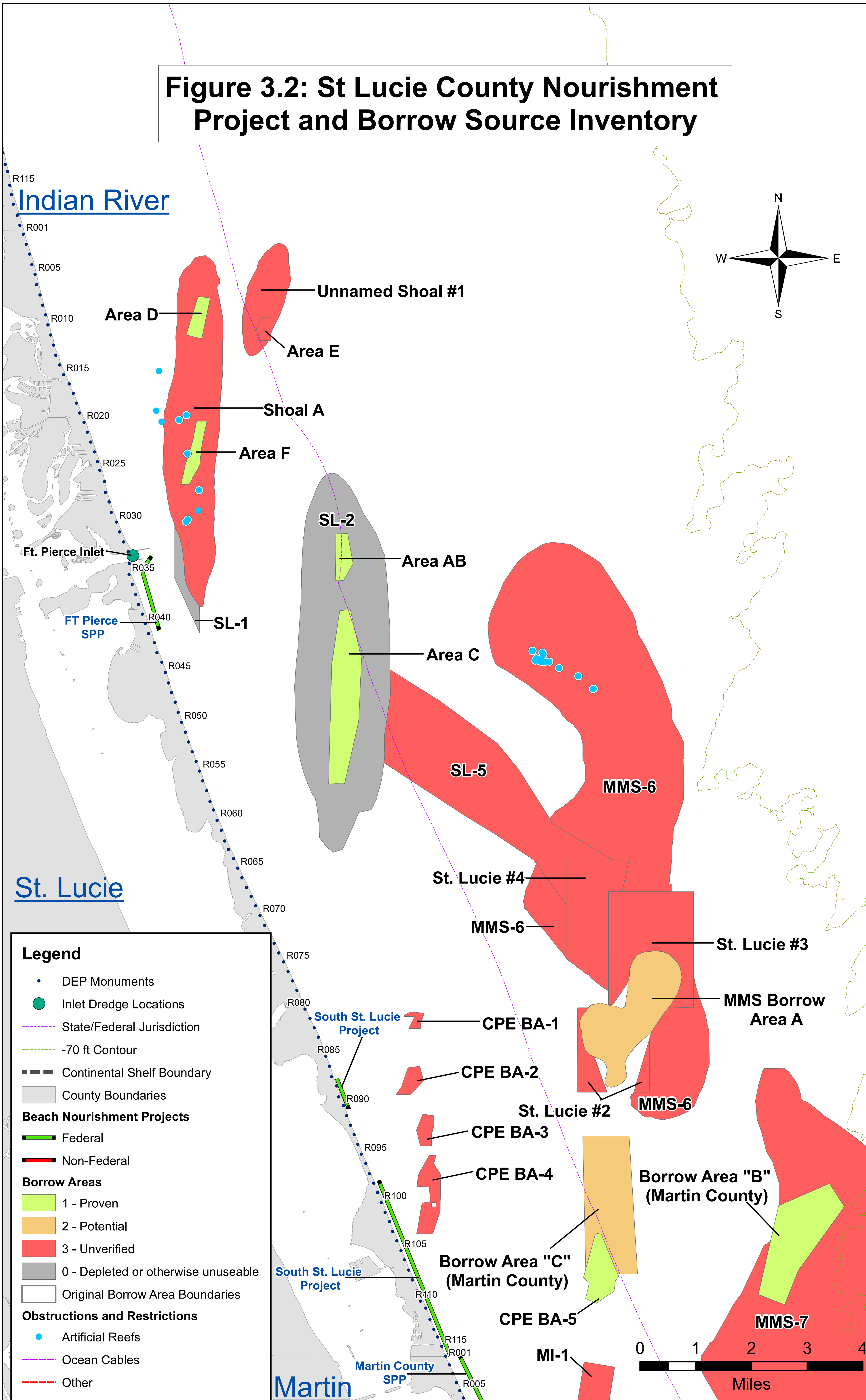

Figure 3.2: St Lucie County Nourishment Project and Borrow Source Inventory

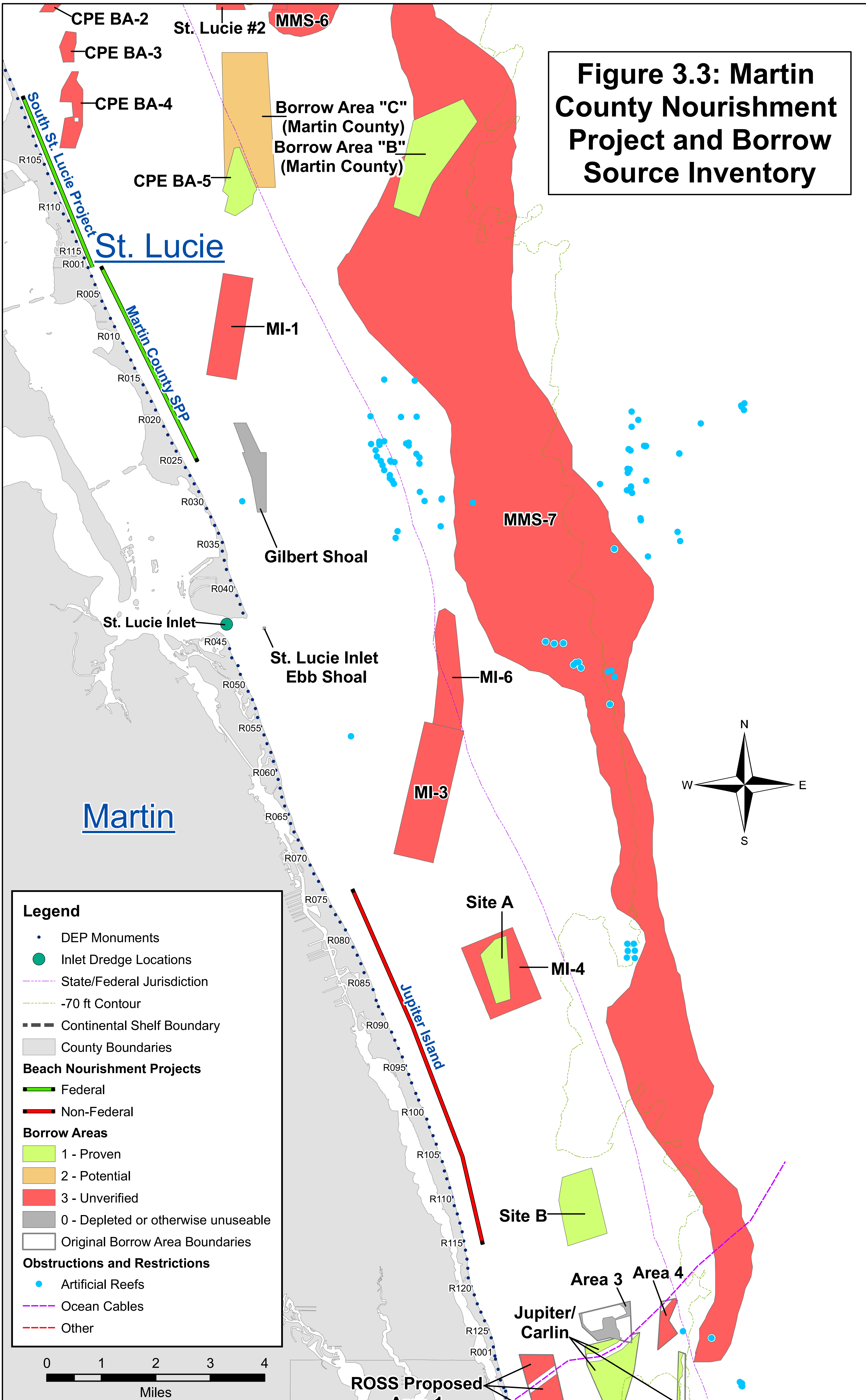

Figure 3.3: Martin County Nourishment Project and Borrow Source Inventory

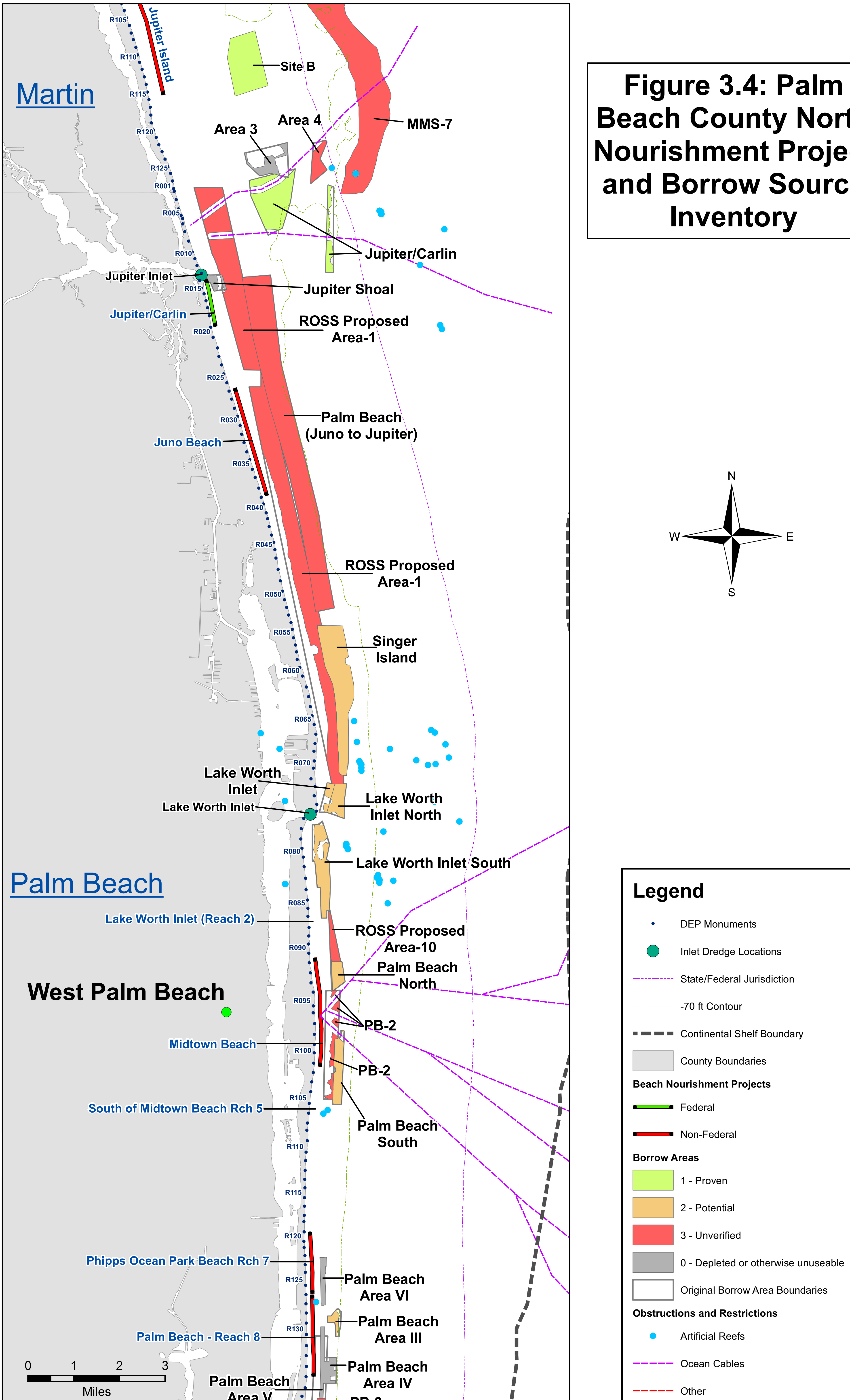

Figure 3.4: Palm Beach County North Nourishment Project and Borrow Source Inventory

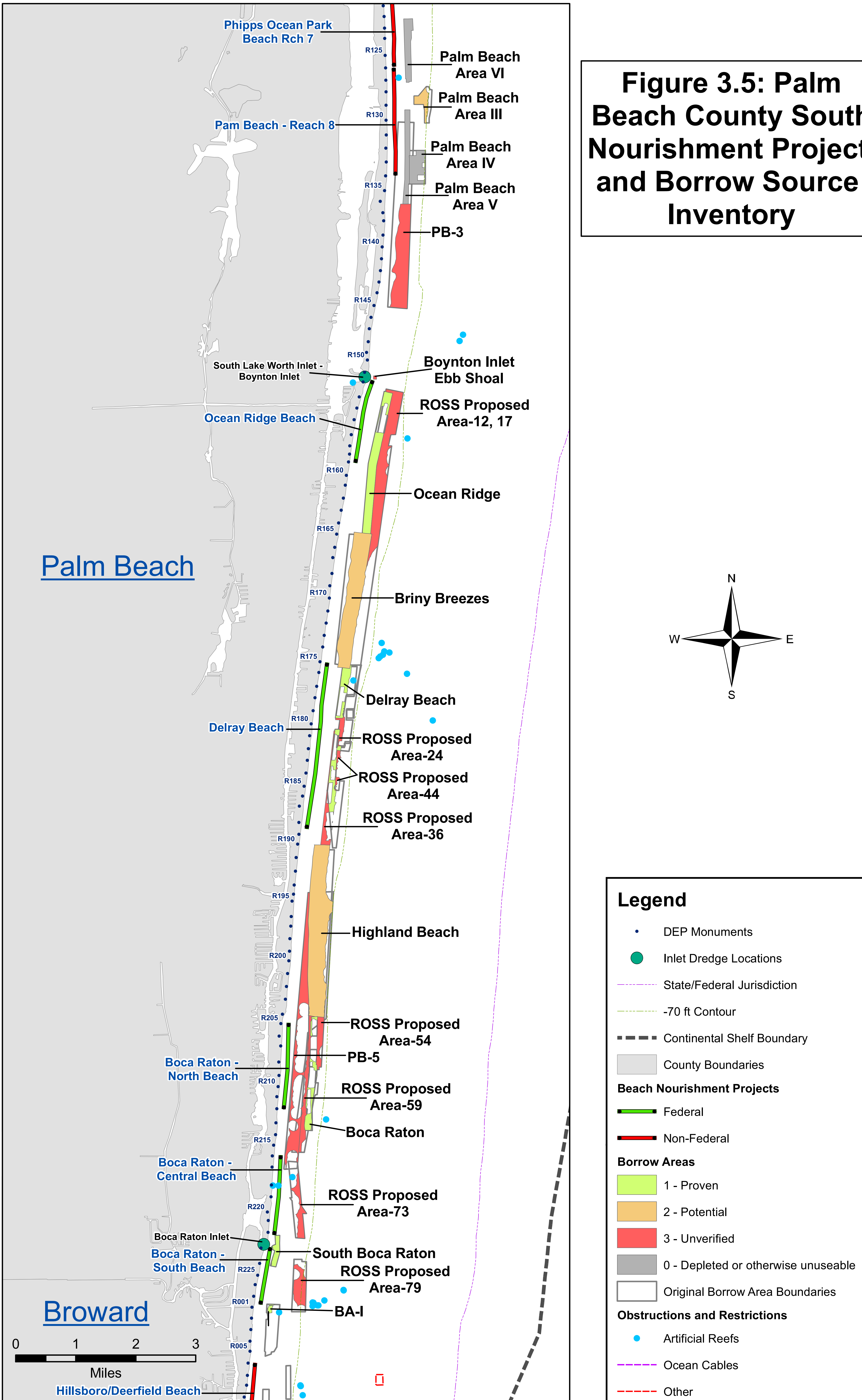

Figure 3.5: Palm Beach County South Nourishment Project and Borrow Source Inventory

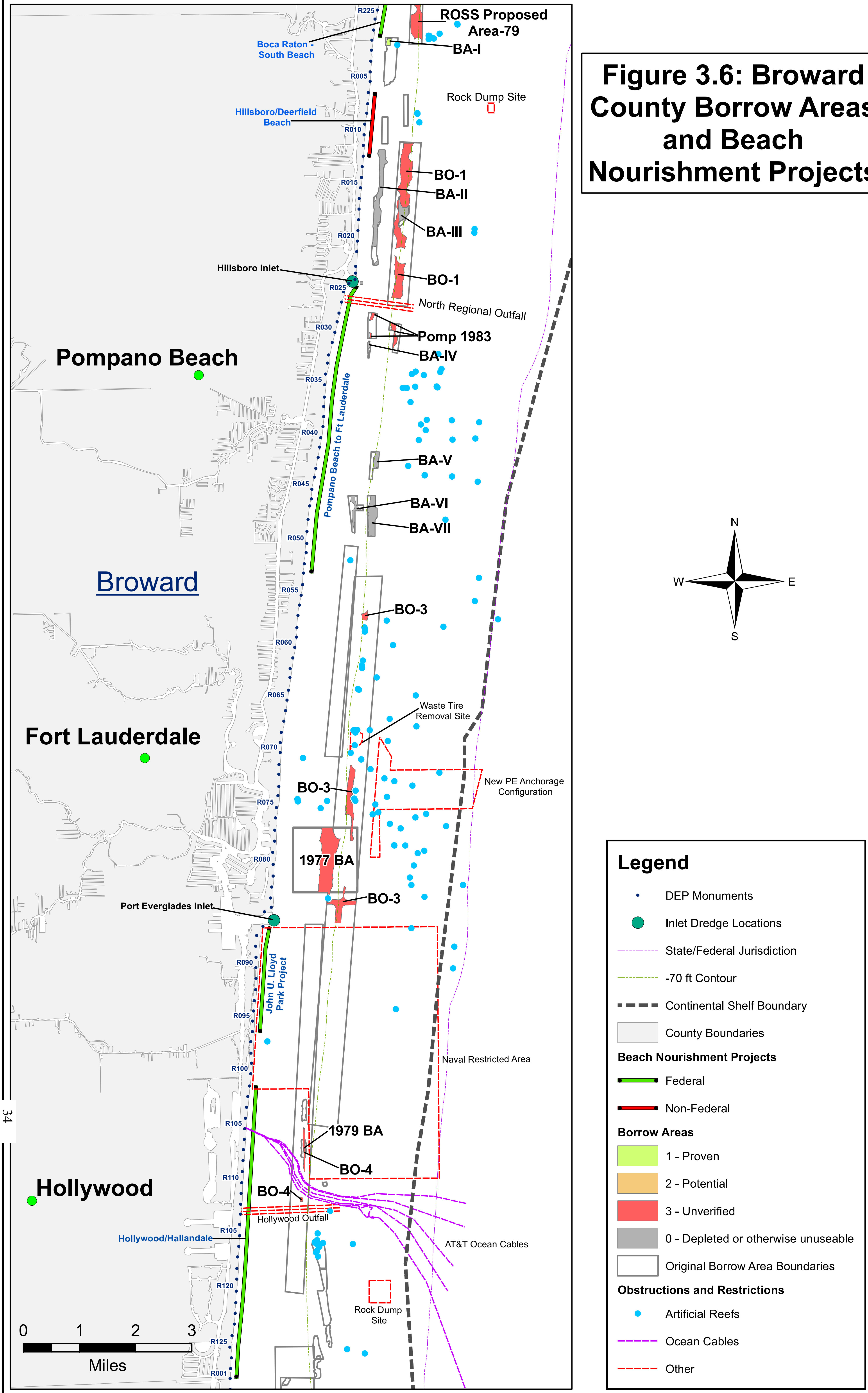

Figure 3.6: Broward County Borrow Areas and Beach Nourishment Projects

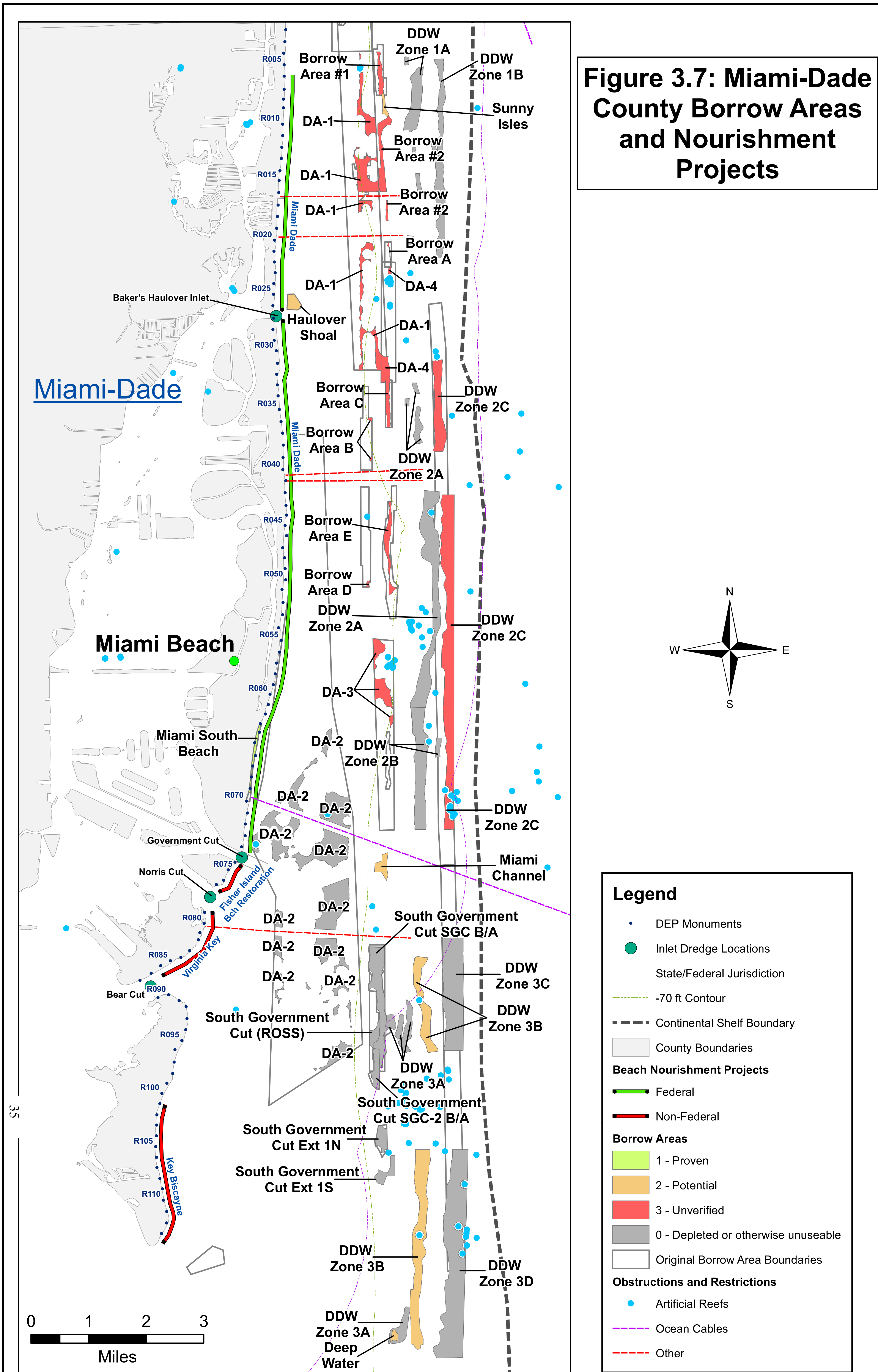

Figure 3.7: Miami-Dade County Borrow Areas and Nourishment Projects

4.0 COST ANALYSIS METHODOLOGY

4.1 Quantifying Beach Nourishment Project Costs

The RSM Plan applied cost information primarily from the *Dade County Beach Erosion Control and Hurricane Protection Project Evaluation Report* (USACE, 2001). The 2001 USACE report applied the USACE Micro Computer-Aided Cost Estimating System (MCACES) to predict the costs of various beach fill options. A 2009 USACE analysis updated the costs to reflect October 2008 (FY09) prices (Appendix C). Table 4.1 contains a summary of MCACES costs for specific sand delivery alternatives.

Table 4.1 Results from MCACES

Item	Volume (cy)	Distance (miles)	MCACES Cost FY09	Cost per Cubic Yard	Cost per Cubic Yard per Mile
Hydraulic Cutterhead Dredge					
Mobilization/Demobilization	-	-	$ 1,074,313.00	-	-
Extraction and Placement of Beach Fill	500,000	5	$ 8,137,312.00	-	$ 3.255
Endangered Species Observation	500,000	5	$ 96,999.00	$ 0.19	$ 0.039
Hopper Dredge					
Average Mobilization/Demobilization	-	-	$ 1,403,283.50	-	-
Extraction and Placement of Beach Fill	500,000	110	$ 20,715,537.00	-	$ 0.377
Extraction and Placement of Beach Fill	500,000	45	$ 18,364,448.00	-	$ 0.816
Extraction and Placement of Beach Fill	500,000	5	$ 7,119,370.00	-	$ 2.848
Extraction and Placement of Beach Fill	500,000	13	$ 9,191,708.00	-	$ 1.414
Endangered Species Observation	500,000	110	$ 149,136.00	-	$ 0.003
Endangered Species Observation	500,000	45	$ 132,646.00	-	$ 0.006
Endangered Species Observation	500,000	5	$ 72,749.00	-	$ 0.029
Endangered Species Observation	500,000	13	$ 94,817.00	-	$ 0.015
Deepwater Jumbo Dredge					
Mobilization/Demobilization	-	-	$ 3,720,046.00	-	-
Extraction and Placement of Beach Fill	500,000	6	$ 5,681,361.00	-	$ 1.894
Endangered Species Observation	500,000	-	$ 24,250.00	$ 0.05	-
Upland Quarry (Sand Trucked to Port and then Barged to Site)					
Barge Mobilization/Demobilization	-	-	$ 1,328,549.00	-	-
Extraction and Placement of Beach Fill	500,000	40	$ 32,032,827.00	-	$ 1.602
Endangered Species Observation	500,000	-	$ 71,537.00	$ 0.14	-
Non-Domestic (Aragonite Shipped to Port and then Barged to Site)					
Purchase and Delivery of Aragonite	500,000	-	$ 14,973,057.00	$ 29.95	-
Barge Mobilization/Demobilization	-	-	$ 1,328,549.00	-	-
Hopper Dredging	500,000	10	$ 8,250,666.00	-	$ 1.650
Endangered Species Observation	500,000	-	$ 71,537.00	$ 0.14	-
Costs Common to All Sand Delivery Methods					
Beach Tilling	500,000	-	$ 14,573.00	$ 0.03	-

To compare the costs of using different borrow areas for a beach nourishment project, the study applied cost equations that described the MCACES scenarios, one for each of the six sand delivery alternatives:

(i) **Hydraulic Cutterhead Dredge —** dredges sand in shallow water and pumps the sand directly to the beach placement site. This provides an ideal option for relocating sand from inlets and inlet ebb shoals to adjacent beaches within a 5-mile radius. The scope of this study and the limited data available required the reasonable limitation that cutterhead dredges could not dredge borrow areas further than 2 miles (mi) offshore. The inclusion of booster pumps could increase this distance limits imposed for this study.

(ii) **Hopper Dredge —** dredges sand from the ocean floor in water depths up to 70 ft, fills up its hopper, travels to the beach placement site, moors offshore, and pumps sand slurry onto the beach. This represents the best option for borrow areas further than 2 mi offshore and in water depths less than 70 ft.

(iii) **Deepwater Jumbo Dredge —** operates in the same way as a hopper dredge, but with capacity to dredge in water depths up to 300 ft. This provides the only option for offshore borrow areas in water depths greater than 70 ft, although no U.S. companies possess the equipment necessary to extract material in over 70 ft of water. Completing several projects in the region with a single mobilization could offset the costs associated with modifying an existing U.S. flagged vessel to perform deepwater dredging.

(iv) **Upland Quarry —** a standard dump truck delivers sand to a port, where bulk-handling equipment transfers the sand onto a hopper dredge. The dredge transports the material to the beach placement site, moors offshore, and pumps a sand slurry onto the beach. This represents the most practical option for sand from upland quarries. Hauling sand via trucks directly to the beach placement site causes significant negative social effects. In addition, the quarries do not possess the infrastructure to transport sand to a port by train.

(v) **Barges from Apalachicola —** a river barge collects sand from a spoil heap in the Apalachicola River Delta, transports the sand to the open ocean, and delivers the sand to an ocean-going barge. This ocean-going barge transports the sand around the Florida peninsula to a port in the region. Finally, bulk-handling equipment transfers the material onto a hopper dredge, which transports the material to the beach placement site, moors offshore, and pumps a sand slurry onto the beach. The Dade County MCASES report (USACE, 2001 updated to FY09 values did not address the Apalachicola sand source.

(vi) **Non-Domestic —** a Bahamian barge delivers aragonite to a port, where bulk-handling equipment transfers the material onto a hopper dredge. The dredge transports the material to the beach placement site, moors offshore, and pumps a sand slurry onto the beach. This method currently represents the only alternative for using aragonite on Florida's beaches.

Each of the six cost equations has a fixed cost component, a component that varies only with volume, and a component that varies with volume and distance. The fixed cost component (A, in dollars) includes mobilization and demobilization. The component that varies only with volume (B, in dollars per cubic yard) includes dredging, handling, pumping, sand processing (such as spinning out silt), and beach tilling costs. The component that varies with volume and distance (C, in dollars per cubic yard per mile) includes travel costs. The cost estimate for each sand delivery alternative includes species observation costs based on the updated MCACES values. The resultant equations provide the total cost of any project:

$$\text{Total cost} = A + B^*(\text{Project Volume Requirement}) + C^*(\text{Volume})^*(\text{Distance})$$

For projects using an offshore borrow area, the distance in the equation above equals the line-of-sight distance between the centroid of the borrow area and the centroid of the project. For projects using a port, the distance equals the one-way traveling distance between the port and the project.

MCACES does not separate project costs into fixed, volume-variant and distance-variant components, so the cost analysis required the following assumptions to generate cost calculations:

- **Costs vary linearly with both volume and distance.** This assumption ignores economies of scale. The Dade County MCASES report (USACE, 2001 updated to FY09 values) presents costs for four hopper dredge projects with the same placement volume, but different travel distances. The cost analysis divided the total cost of each project by the volume (500,000 cy) and plotted cost per cubic yard against travel distance on a graph (Figure 4.1). With the assumption of linearity, a least-squares linear trend line drawn through these four points then yielded the hopper dredge volume-variant cost component (the y-intercept of the trend line, equal to $16.96/cy including $0.03 tilling costs) and distance-variant component (the slope of the trend line, equal to $0.25/cy/mi). Figure 4.1 presents the analysis to develop the cost components for the hopper dredge sand placement alternative. The four data points come from the USACE (2001, Revised 2009) analysis and represent borrow sources in St. Lucie/Martin County, Palm Beach County, and two in Dade County.

- **The deepwater dredge has the same distance-variant component as the hopper dredge.** With this assumption, the MCACES data fixes the volume-variant component at $9.92/cy. The greater efficiency of this larger dredge accounts for its lower cost per cubic yard compared to the hopper dredge — discussed in *Dade County Beach Erosion Control and Hurricane Protection Project Evaluation Report* (USACE, 2001).

- **A hopper dredge to pick up sand at a port and transport the sand to a project site would cost the same whether the dredge collected quarry sand, Bahamian aragonite, or sand from Apalachicola.** This allows for the separation of MCACES costs into the material cost and transportation components for these three sources. Because a hopper dredge takes the material from the port to the project, the distance-variant cost of such a barge equals $0.25/cy/mi.

- **Trucks carrying sand from upland quarries will take the material to the same port every time.** This assumption simplifies the complex cost calculation arising from two variable distances — the truck-hauling distance from the quarry to the port and the hopper dredge-hauling distance from the port to the project site. Fixing the quarry-to-port distance incorporates the quarrying, transport, and unloading costs into a single volume-variant component, and leaves the port-to-project distance as the only variable in the distance-variant component. In the cost equations, all sand from the Stewart Mine went to the Port of Palm Beach (65.9 mi by road), all sand from Dickerson's Indrio Pit went to Port Everglades (116.5 mi), and all sand from the Witherspoon Mine went to the Port of Miami (123.0 mi).

- **Barging aragonite from Freeport to Palm Beach will cost the same as barging the material from Ocean Cay to Miami.** The distance from the Port of Ocean Cay to the Port of Miami equals approximately 60 mi. By comparison, the distance from Freeport Container Port to the Port of Palm Beach equals approximately 80 mi. Thus, the costs should not differ significantly. The distance between the Port of Ocean Cay and Port Everglades slightly exceeds 70 mi, so the operation should cost about the same to deliver aragonite to any of the three ports in the region with bulk handling capacity.

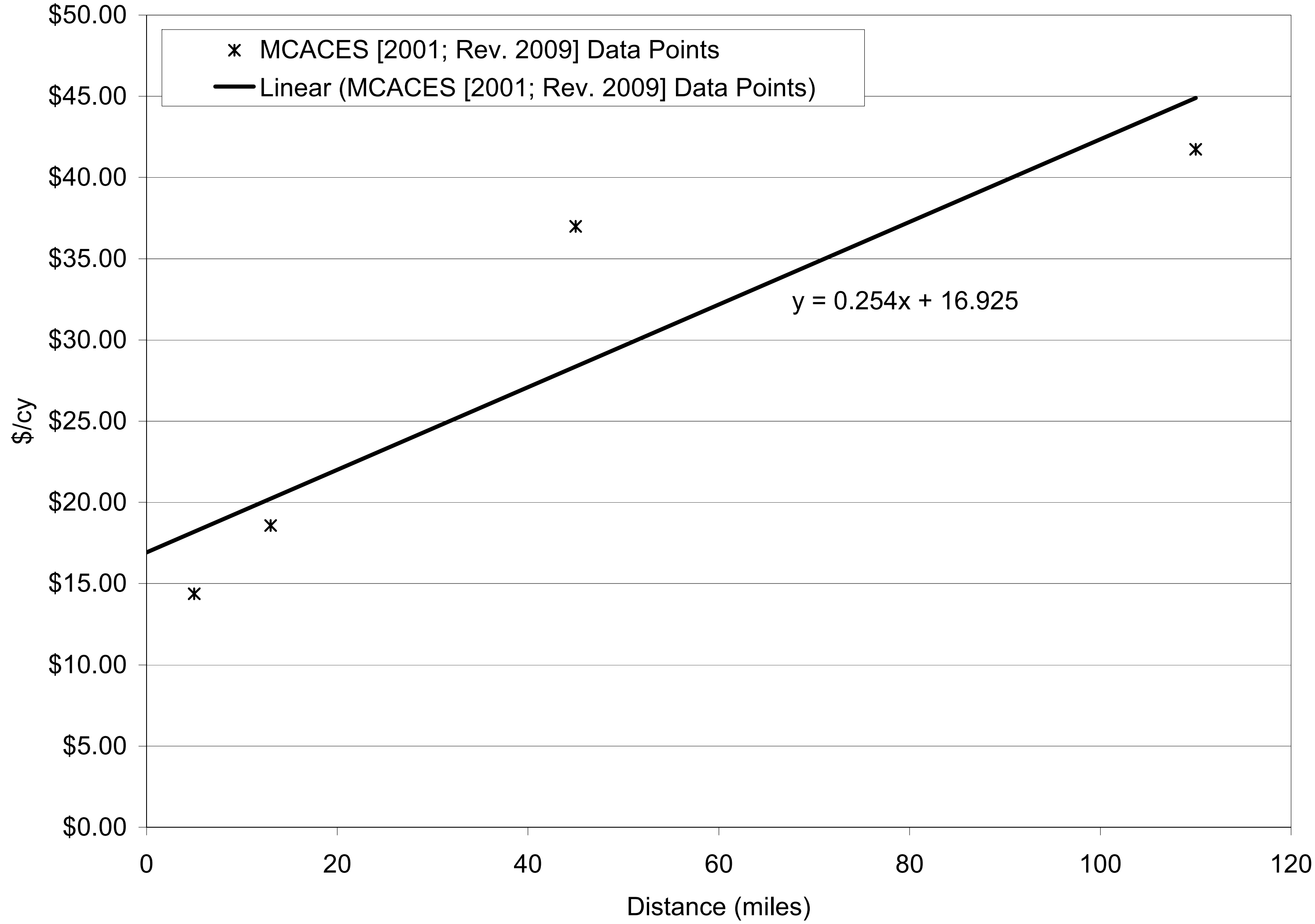

Figure 4.1 Analysis to Develop the Cost Components for Hopper Dredge Sand Placement

These assumptions allow the computation of the volume-variant and distance-variant components of the MCACES costs. Additional information applied includes data received from quarries in St. Lucie, Glades, and Palm Beach counties on truck-hauling costs and estimates of barge-hauling costs from Apalachicola. Table 4.2 summarizes all the cost results.

Table 4.2 Cost Calculation Components from MCACES

Sand Delivery Alternative	Fixed Cost (A)		Volume-Variant Cost (B)		Distance-Variant Cost (C)	
	$	Includes	$/cy	Includes	$/cy/mi	Includes
Cutterhead Dredge	$1,074,313	Dredge Mob/Demob	$ 0.03	Tilling	$ 3.29	Material, Hydraulic Transport, Species Observation
Hopper Dredge	$1,403,284	Dredge Mob/Demob	$ 16.96	Loading, Unloading, Species Observation, Tilling	$ 0.25	Dredge Transport
Deepwater Dredge	$3,720,046	Dredge Mob/Demob	$ 9.92	Loading, Unloading, Species Observation, Tilling	$ 0.25	Dredge Transport
Truck/Barge from Quarry	$1,328,549	Barge Mob/Demob	$ 24.72 + 0.21*d1	Transport from Quarry, Loading, Unloading, Species Observation, Tilling	$ 0.25	Barge Transport
Long-Distance Barge: Apalachicola	$1,328,549	Barge Mob/Demob	$ 44.69 + 0.03*d2	Transport from River, Loading, Unloading, Species Observation, Tilling	$ 0.25	Barge Transport
Double-Barged Aragonite	$1,328,549	Barge Mob/Demob	$ 44.08	Delivery to Port, Loading, Unloading, Species Observation, Tilling	$ 0.25	Barge Transport

NOTES:
d1 equals the driving distance between a quarry and its assigned port.
d2 equals the distance between the Port of Miami and the port of delivery.

4.2 Management Strategies

This RSM Plan considers three main strategies developed by the USACE for apportioning sand resources — the Timeline Method, the Total Quantity Method, and the Subregion Method. All three methods model the distribution of sand resources to the projects in the region based on a simple set of rules. Each method produces a total cost of beach nourishment in the region until the end of 2059 (a 50-year analysis period). The method with the lowest cost also likely possesses the most benefits from National Economic Development (NED) and Regional Economic Development (RED) standpoints. However, the lowest cost method may not prove acceptable on Environmental Quality (EQ) or Other

Social Effects (OSE) accounts and a combination of several methods may provide a better means of managing the region's active beach nourishment projects adequately.

4.2.1 Current Method Practiced Throughout the Region

Currently, designers locate a prospective borrow area likely to contain beach-quality sand during the planning phase of a beach nourishment project. Federal projects identify potential areas with 50-year capacity while non-federal projects may identify sources with one nourishment capacity. Agencies issue permits to dredge sand from borrow sources based on environmental, geotechnical, and other investigations. The investigation and permitting process represents time and cost borne by an individual project that typically uses the same source for its design life. In nearly every case, prospective borrow sources lie offshore of the Florida county in which the project resides. A close proximity between source and project lowers cost and reduces potential conflict with other counties that may want the sand. The development of borrow sources located offshore of St. Lucie County that both Martin and St. Lucie counties are currently targeting for use presents a current situation with two counties working in the same immediate area.

Some RSM strategy is involved on various projects that use ebb shoals as borrow areas to mimic natural bypassing, bypass sand from areas of accretion north of inlets to areas of erosion south, or backpass sand and "recycle" it into the longshore sediment transport mechanism. With the exception of these localized examples, current practices employ little large-scale strategy due to time and cost required to develop borrow sites. In general, once the project owner develops a borrow source, the project owner would prefer to continue to use one source for cost and permitting reasons.

4.2.2 Timeline Method

The Timeline Method seeks to mimic the renourishment timing of active projects, but makes all sources available to all projects throughout the region. This method determines whether allowing all projects access to all sources would generate significant benefits.

The Timeline Method considers the region's sand requirements in chronological order for a period of 50 years beginning in 2009. Each active project in the region has an associated renourishment volume, renourishment interval, and date of next renourishment. Figure 4.2 illustrates the logical procedure of the Timeline Method. The procedure applies simple calculations to allocate sand to the individual projects and track borrow area volumes; the procedure does not include simulation of physical processes.

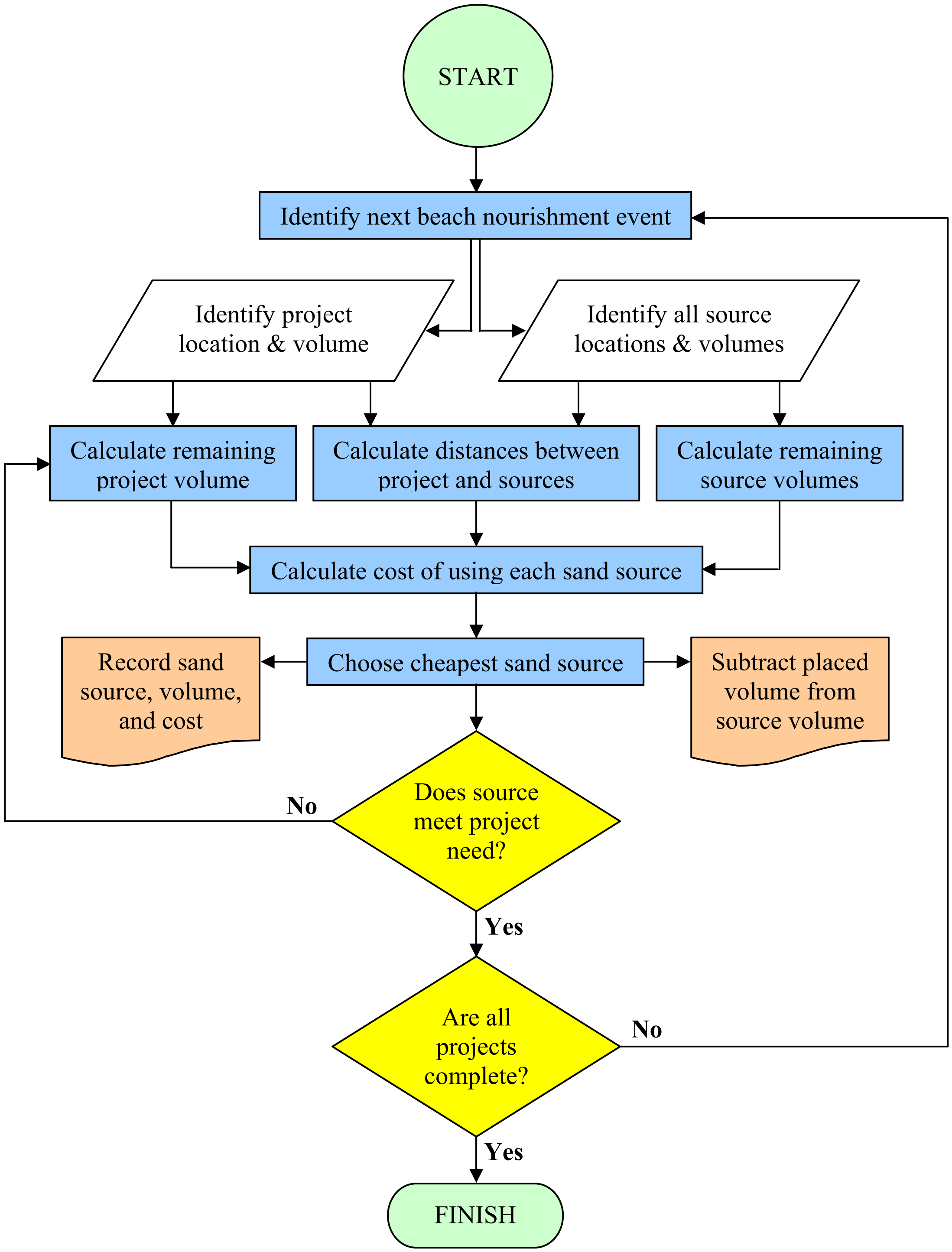

Figure 4.2 Flow Chart to Illustrate the Logical Procedure of the Timeline Method

The procedure for apportioning sand resources by the Timeline Method involves determining the next project in need of renourishment, identifying its volume requirement, computing the costs of nourishing the project with every sand source in the region, choosing the least expensive sand source, and subtracting the project's volume requirement from the volume available in that sand source. If the sand source volume exceeds the project requirement then the project takes all the sand it needs from that source. If the project requirement exceeds the sand source volume then the project empties that source and looks for the next cheapest sand source. The Timeline Method repeats this procedure to satisfy the needs of every active project in the region until the end of 2059.

In some cases, the least expensive sand source did not contain sufficient beach-quality sand to nourish the whole project. In these cases, the Timeline Method uses all the material available in the least expensive source, and then looks for the next lowest cost source to meet the remaining project need. If the second source uses the same equipment as the first (e.g., a hopper dredge) then the project did not require another mobilization and demobilization cost. A dredge or barge would make multiple trips between the sand source and the project site as part of normal operation, so moving to a different port or borrow area would have little effect on the overall operation. The Timeline Method applies this cost saving when choosing the second sand source. Therefore, continuing the same delivery method from a different source is more economically attractive than switching to a new delivery method. The mobilization and demobilization saving does not apply to hydraulic dredges, because they do not travel back and forth between source and project as part of normal operation. The calculation method allows each project to use up to five sources during a single nourishment, although in practice very few projects use more than two sources.

The Timeline Method allows sand to travel any distance and move freely across county boundaries. The method does not consider long-term strategy, but considers each project requirement in turn. Thus, the Timeline Method applies little strategy in managing the region's sand resources.

4.2.3 Total Quantity Method

The Total Quantity Method also makes all sources available to all projects in the region. However, it reserves the cheapest sand sources for the projects with the largest sand need. A number of political and social disputes might arise against such a method that favors larger projects. However, this method determines whether reserving the cheapest sources for the largest projects would generate significant benefits overall.

The Total Quantity Method considers the region's sand requirements based on total 50-year project need — by individual project — in order of largest 50-year need to smallest. Martin County's Jupiter Island project requires the largest total volume over the next 50 years — 19,500,000 cy in 13 renourishments. The Total Quantity Method determines the least expensive method to provide material for this total need before considering the second largest project. Thus, the Total Quantity Method exactly follows the procedure of the Timeline Method, except for the order in which project needs arise. The methodology for the Total Quantity Method allows for the larger projects to "reserve" borrow sources well into the future (up to 49 years in advance) with smaller projects having access only to those sources not applied to the larger projects.

4.2.4 Subregion Method

The Subregion Method resembles current and likely future practices. It mimics the renourishment timing of current projects as done in current practices and limits each project's prospective borrow sources to those within the project's local subregion. The Subregion Method differs from current practices by allowing a project to borrow sand from numerous sources rather than relying on just one source. This method evaluates benefits generated by slightly modified current and likely future practices and provides the most realistic benchmark against which to assess the other methods.

The Subregion Method divides the projects and offshore sand sources into three subregions (Figure 4.3) and then follows the chronological renourishment procedure of the Timeline Method. The North Subregion contains the nourishment projects in St. Lucie and Martin counties and all of the borrow areas north of Lake Worth Inlet in Palm Beach County. The Central Subregion contains the projects in Palm Beach County and all the borrow areas between St Lucie Inlet (Martin County) and Hillsboro Inlet (Broward County). The South Subregion contains the projects in Broward and Miami-Dade counties and all the borrow areas south of Boynton Inlet in Palm Beach County. Many of the offshore borrow areas fall into two of the subregions. The Subregion Method follows the procedure of the Timeline Method, with the difference that sand cannot cross the boundaries of the subregions. The Subregion Method most closely resembles current practice where nourishment projects may obtain material from borrow sources close to their border in a neighboring county, but not from non-adjacent counties.

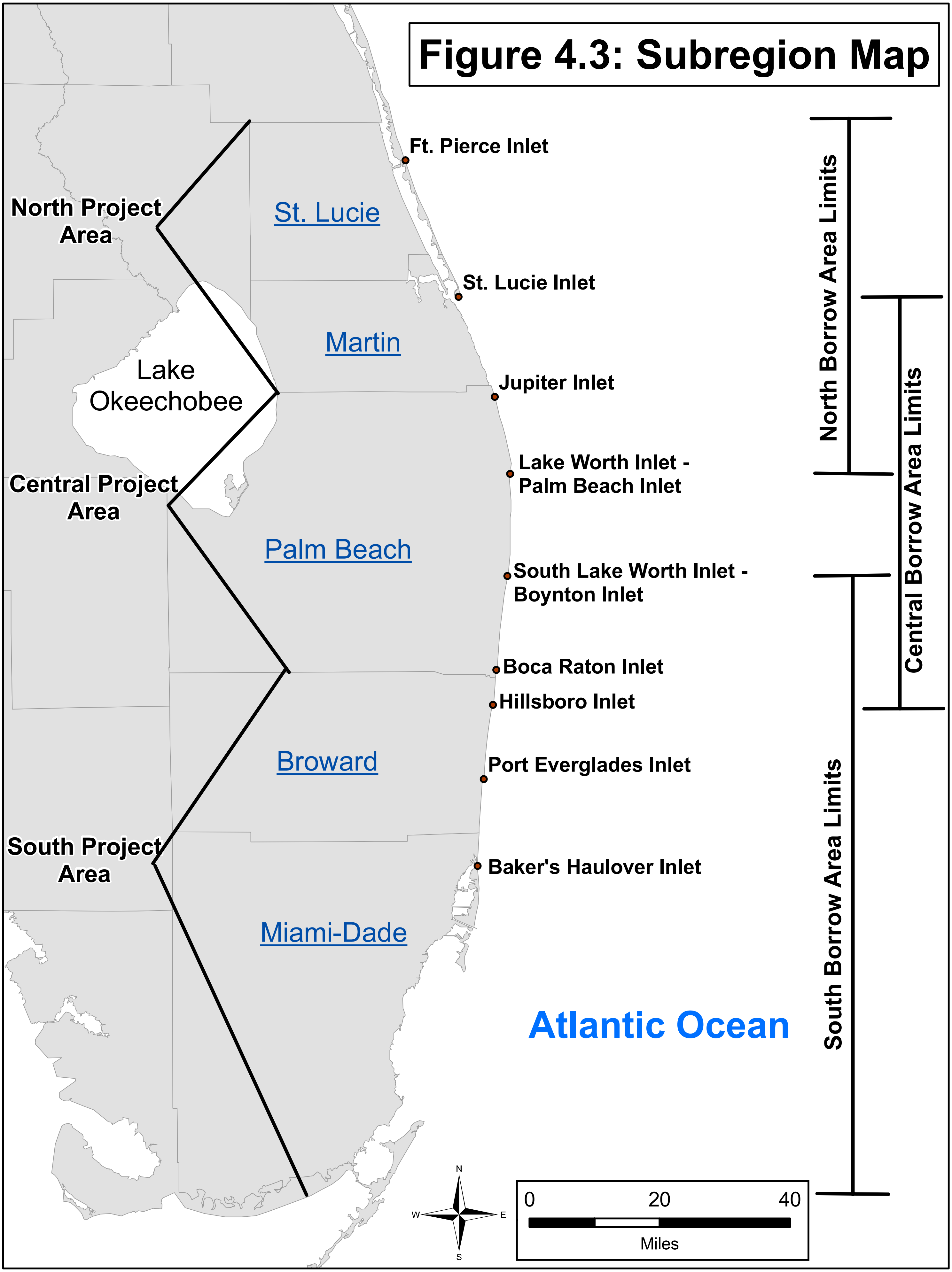
Figure 4.3: Subregion Map
Ft. Pierce Inlet
North Project Area
St. Lucie
St. Lucie Inlet
Martin
Lake Okeechobee
Jupiter Inlet
Lake Worth Inlet - Palm Beach Inlet
Central Project Area
Palm Beach
South Lake Worth Inlet - Boynton Inlet
Boca Raton Inlet
Hillsboro Inlet
Broward
Port Everglades Inlet
South Project Area
Baker's Haulover Inlet
Miami-Dade
Atlantic Ocean
North Borrow Area Limits
Central Borrow Area Limits
South Borrow Area Limits
N
W
E
S
0
20
40
Miles

4.2.5 Alternative Method

The three methods described in Sections 4.2.2 – 4.2.4 possess certain similarities to one another. All three methods consider one project need at a time and find the least expensive source to meet the need. The only differences between the three methods are the order in which the project needs occur and the list of sources each project may draw from. The three methods consider which sand source to use for a project without regard to future sand allocation decisions required within the analysis period. For example, the three methods do not have the foresight to evaluate whether a future project (or a combination of projects) could use the material at a lower cost. With application of the Alternative Method, this study investigates whether a broader and more long-sighted approach to apportioning sand resources might reduce costs over the next 50 years.

The Alternative Method creates a matrix of costs per cubic yard to nourish each project with each sand source. The method then proceeds to match sources to projects, beginning with the cheapest and working in order of increasing cost per cubic yard until the method has satisfied all the projects' needs. The Alternative Method presents a different beach management paradigm to the other three methods. Instead of considering a project need and finding the least expensive sand source to meet the need, the Alternative Method considers a sand source and identifies the project(s) that can use the sand for the lowest cost.

5.0 COST ANALYSIS RESULTS

In the following analysis, cost serves as a proxy for benefits. All methods include two calculations, one with non-domestic material (Bahamian aragonite), and one without non-domestic material. These two analyses provide a means to evaluate of the effect of using non-domestic material on the overall cost and sediment allocation. Each method begins with applicable assumptions and limitations.

5.1 Timeline Method

Assumptions

- Projects can use any source available to the region.
- Projects receive renourishment chronologically according to design renourishment intervals.

Limitations

- Method ignores significant political and social opposition to sharing sand across county boundaries.
- Method does not account for likely future construction of additional beach nourishment projects.
- Method assumes that erosion rates for projects will remain constant.
- Method assumes additional reconnaissance geotechnical activity locates no new offshore sediment resources in the region.

Table 5.1 presents the results of the 50-year regional beach nourishment cost analysis using the Timeline Method including all sand sources. Table 5.2 presents the results of the same analysis, but without aragonite. The results show that only Miami-Dade County receives sand from any alternative sources. The exclusion of aragonite has negligible effect on the overall cost because aragonite contributes only 0.1% of the total volume. In Table 5.2, sand from Apalachicola replaces the aragonite at an extra cost of $0.62/cy.

Table 5.1 Timeline Method with All Sand Sources Included

County	50-Year Volume (cy)	Volume Transferred in 50 Years (cy)					
		Hydraulic Dredge	Hopper Dredge	Deepwater Dredge	Upland Quarries	Barge from Apalachicola	Bahamian Aragonite
St. Lucie	24,440,000	1,230,000	23,210,000	0	0	0	0
Martin	29,900,000	0	29,900,000	0	0	0	0
Palm Beach	49,166,000	18,094,521	31,071,479	0	0	0	0
Broward	24,225,000	555,000	22,890,000	780,000	0	0	0
Miami-Dade	18,274,000	4,509,435	12,809,565	930,000	0	0	25,000
Total Volume (cy)	**146,005,000**	**24,388,956**	**119,881,044**	**1,710,000**	**0**	**0**	**25,000**
Volume Percentage	**100.0%**	**16.7%**	**82.1%**	**1.2%**	**0.0%**	**0.0%**	**0.0%**
Total Cost (millions)	**$3,388.187**	**$261.944**	**$3,089.121**	**$34.669**	**$0.000**	**$0.000**	**$2.453**
Cost Percentage	**100.0%**	**7.7%**	**91.2%**	**1.0%**	**0.0%**	**0.0%**	**0.1%**
Average $/cy	**$23.21**	**$10.74**	**$25.77**	**$20.27**	**-**	**-**	**$98.13**

Table 5.2 Timeline Method with Non-Domestic Sources (Aragonite) Excluded

County	50-Year Volume (cy)	Volume Transferred in 50 Years (cy)					
		Hydraulic Dredge	Hopper Dredge	Deepwater Dredge	Upland Quarries	Barge from Apalachicola	Bahamian Aragonite
St. Lucie	24,440,000	1,230,000	23,210,000	0	0	0	0
Martin	29,900,000	0	29,900,000	0	0	0	0
Palm Beach	49,166,000	18,094,521	31,071,479	0	0	0	0
Broward	24,225,000	555,000	22,890,000	780,000	0	0	0
Miami-Dade	18,274,000	4,509,435	12,809,565	930,000	0	25,000	0
Total Volume (cy)	**146,005,000**	**24,388,956**	**119,881,044**	**1,710,000**	**0**	**25,000**	**0**
Volume Percentage	**100.0%**	**16.7%**	**82.1%**	**1.2%**	**0.0%**	**0.0%**	**0.0%**
Total Cost (millions)	**$3,388.202**	**$261.944**	**$3,089.121**	**$34.669**	**$0.000**	**$2.469**	**$0.000**
Cost Percentage	**100.0%**	**7.7%**	**91.2%**	**1.0%**	**0.0%**	**0.1%**	**0.0%**
Average $/cy	**$23.21**	**$10.74**	**$25.77**	**$20.27**	**-**	**$98.75**	**-**

5.2 Total Quantity Method

Assumptions

- Projects can use any source available to the region.
- Projects with the largest sand need reserve lowest-cost sources.

Limitations

- Method ignores significant political and social opposition to sharing sand across county boundaries.
- Method does not account for likely future construction of additional beach nourishment projects.
- Method assumes that erosion rates for projects will remain as designed.
- Method assumes additional reconnaissance geotechnical activity locates no new offshore sediment resources in the region.
- Method ignores likely political and social opposition to dedicating cheapest sand to the largest projects.

Table 5.3 and 5.4 contain the results of the cost analysis using the Total Quantity Method, with and without aragonite. The Total Quantity Method increases the volume of aragonite Miami-Dade County receives. Over the 50-year analysis period, the Total Quantity Method costs approximately $39.5 million more than the Timeline Method. The exclusion of aragonite increases contributions from offshore hopper dredging and from Apalachicola, but has little effect on the overall cost.

Table 5.3 Total Quantity Method with All Sand Sources Included

County	50-Year Volume (cy)	Volume Transferred in 50 Years (cy)					
		Hydraulic Dredge	Hopper Dredge	Deepwater Dredge	Upland Quarries	Barge from Apalachicola	Bahamian Aragonite
St. Lucie	24,440,000	1,230,000	23,210,000	0	0	0	0
Martin	29,900,000	0	29,900,000	0	0	0	0
Palm Beach	49,166,000	16,714,082	32,451,918	0	0	0	0
Broward	24,225,000	55,543	24,086,602	82,855	0	0	0
Miami-Dade	18,274,000	4,509,435	11,699,420	1,627,145	0	0	438,000
Total Volume (cy)	**146,005,000**	**22,509,060**	**121,347,940**	**1,710,000**	**0**	**0**	**438,000**
Volume Percentage	**100.0%**	**15.4%**	**83.1%**	**1.2%**	**0.0%**	**0.0%**	**0.3%**
Total Cost (millions)	**$3,427.682**	**$267.343**	**$3,096.222**	**$35.958**	**$0.000**	**$0.000**	**$28.158**
Cost Percentage	**101.2%**	**7.9%**	**91.4%**	**1.1%**	**0.0%**	**0.0%**	**0.8%**
Average $/cy	**$23.48**	**$11.88**	**$25.52**	**$21.03**	**-**	**-**	**$64.29**

Table 5.4 Total Quantity Method with Non-Domestic Sources (Aragonite) Excluded

County	50-Year Volume (cy)	Volume Transferred in 50 Years (cy)					
		Hydraulic Dredge	Hopper Dredge	Deepwater Dredge	Upland Quarries	Barge from Apalachicola	Bahamian Aragonite
St. Lucie	24,440,000	1,230,000	23,210,000	0	0	0	0
Martin	29,900,000	0	29,900,000	0	0	0	0
Palm Beach	49,166,000	16,714,082	32,451,918	0	0	0	0
Broward	24,225,000	55,543	24,086,602	82,855	0	0	0
Miami-Dade	18,274,000	4,509,435	12,062,420	1,627,145	0	75,000	0
Total Volume (cy)	**146,005,000**	**22,509,060**	**121,710,940**	**1,710,000**	**0**	**75,000**	**0**
Volume Percentage	**100.0%**	**15.4%**	**83.4%**	**1.2%**	**0.0%**	**0.1%**	**0.0%**
Total Cost (millions)	**$3,427.896**	**$267.343**	**$3,117.188**	**$35.958**	**$0.000**	**$7.406**	**$0.000**
Cost Percentage	**101.2%**	**7.9%**	**92.0%**	**1.1%**	**0.0%**	**0.2%**	**0.0%**
Average $/cy	**$23.48**	**$11.88**	**$25.61**	**$21.03**	**-**	**$98.75**	**-**

5.3 Subregion Method

Assumptions

- Projects can only use sources within their local subregion.
- Projects receive renourishment chronologically according to design renourishment intervals.
- Method reflects current and likely future practices.

Limitations

- Method ignores significant political and social opposition to sharing sand across county boundaries.
- Method does not account for likely future construction of additional beach nourishment projects.
- Method assumes that erosion rates for projects will remain as designed.
- Method assumes additional reconnaissance geotechnical activity locates no new offshore sediment resources in the region.

Table 5.5 and 5.6 contain the results of the cost analysis using the Subregion Method, with and without aragonite. The North Subregion (containing St. Lucie and Martin counties) uses only offshore sand, while the Central and South Subregions receive sand from upland quarries (6.4 mcy total) and aragonite from the Bahamas (20.7 mcy total). Over the 50-year analysis period, the Subregion Method costs approximately $235 million more than the previous two methods. Preventing sand from moving between the subregions makes aragonite a necessary sand source within the 50-year analysis period.

Table 5.5 Subregion Method with All Sand Sources Included

County	50-Year Volume (cy)	Volume Transferred in 50 Years (cy)					
		Hydraulic Dredge	Hopper Dredge	Deepwater Dredge	Upland Quarry	Barge from Apalachicola	Bahamian Aragonite
St. Lucie	24,440,000	1,230,000	23,210,000	0	0	0	0
Martin	29,900,000	0	29,900,000	0	0	0	0
Palm Beach	49,166,000	20,194,521	21,478,282	0	5,203,545	0	2,289,652
Broward	24,225,000	555,000	10,310,000	780,000	1,235,000	0	11,345,000
Miami-Dade	18,274,000	4,509,435	5,796,883	930,000	0	0	7,037,682
Total Volume (cy)	**146,005,000**	**26,488,956**	**90,695,165**	**1,710,000**	**6,438,545**	**0**	**20,672,334**
Volume Percentage	**100.0%**	**18.1%**	**62.1%**	**1.2%**	**4.4%**	**0.0%**	**14.2%**
Total Cost (millions)	**$3,622.817**	**$283.144**	**$1,996.515**	**$34.669**	**$298.908**	**$0.000**	**$1,009.581**
Cost Percentage	**106.9%**	**8.4%**	**58.9%**	**1.0%**	**8.8%**	**0.0%**	**29.8%**
Average $/cy	**$24.81**	**$10.69**	**$22.01**	**$20.27**	**$46.42**	**-**	**$48.84**

Table 5.6 shows insufficient available sand quantities without aragonite. Notably, the quarries still contain sediment reserves; however, the number of projects that require quarry material invokes the limitation of 750,000 cy/yr from each quarry and the quarries cannot process enough sand. Appendix D contains summaries for each nourishment project and tables that detail the allocation of sediment resources to elucidate the results presented in Table 5.5.

Table 5.6 Subregion Method with Non-Domestic Sources (Aragonite) Excluded: Insufficient Supply

County	50-Year Volume (cy)	Volume Transferred in 50 Years (cy)					
		Hydraulic Dredge	Hopper Dredge	Deepwater Dredge	Upland Quarry	Barge from Apalachicola	Bahamian Aragonite
St. Lucie	24,440,000	1,230,000	19,450,000	0	0	0	0
Martin	29,900,000	0	25,300,000	0	0	0	0
Palm Beach	49,166,000	19,957,575	21,478,282	0	1,427,143	0	0
Broward	24,225,000	555,000	10,310,000	780,000	8,046,886	1,370,971	0
Miami-Dade	18,274,000	3,852,986	5,796,883	930,000	4,296,102	629,029	0
Total Volume (cy)	**125,410,857**	**25,595,561**	**82,335,165**	**1,710,000**	**13,770,131**	**2,000,000**	**0**
Volume Percentage	**85.9%**	**17.5%**	**56.4%**	**1.2%**	**9.4%**	**1.4%**	**0.0%**
Total Cost (millions)	**$2,960.227**	**$265.840**	**$1,817.971**	**$34.669**	**$740.021**	**$101.726**	**$0.000**
Cost Percentage	**87.4%**	**7.8%**	**53.7%**	**1.0%**	**21.8%**	**3.0%**	**0.0%**
Average $/cy	**$23.60**	**$10.39**	**$22.08**	**$20.27**	**$53.74**	**$50.86**	**-**

5.4 Alternative Method

Assumptions

- Projects can use any source throughout the region.
- Projects can reserve sources on the basis of using them at least cost.

Limitations

- Method ignores significant political and social opposition to sharing sand across county boundaries.
- Method does not account for likely future construction of additional beach nourishment projects.
- Method assumes that erosion rates for projects will remain as designed.
- Method assumes additional reconnaissance geotechnical activity locates no new offshore sediment resources in the region.
- Method ignores likely political and social opposition to allowing reservation of sources.

Table 5.7 and 5.8 contain the results of the cost analysis using the Alternative Method, with and without aragonite. St. Lucie, Martin, Palm Beach, and Broward counties use offshore sand exclusively; only Miami-Dade County receives sand from alternative sources. Over the 50-year analysis period, the Alternative Method saves over $140 million compared to the Timeline Method and almost $375 million compared to the Subregion Method. This saving arises from increased use of hydraulic dredges (27.4% of the total volume) with a low average delivery cost of $9.52/cy.

Table 5.7 Alternative Method with All Sand Sources Included

County	50-year Volume (cy)	Volume Transferred in 50 Years (cy)					
		Hydraulic Dredge	Hopper Dredge	Deepwater Dredge	Upland Quarry	Barge from Apalachicola	Bahamian Aragonite
St. Lucie	24,440,000	1,230,000	23,210,000	0	0	0	0
Martin	29,900,000	0	29,900,000	0	0	0	0
Palm Beach	49,166,000	34,281,132	14,884,868	0	0	0	0
Broward	24,225,000	0	24,225,000	0	0	0	0
Dade	18,274,000	4,509,435	11,699,420	1,627,145	0	0	438,000
Total Volume (cy)	**146,005,000**	**40,020,567**	**103,919,288**	**1,627,145**	**0**	**0**	**438,000**
Volume Percentage	**100.0%**	**27.4%**	**71.2%**	**1.1%**	**0.0%**	**0.0%**	**0.3%**
Total Cost (millions)	**$3,247.892**	**$380.924**	**$2,807.969**	**$30.842**	**$0.000**	**$0.000**	**$28.158**
Cost Percentage	**95.9%**	**11.2%**	**82.9%**	**0.9%**	**0.0%**	**0.0%**	**0.8%**
Average $/cy	**$22.25**	**$9.52**	**$27.02**	**$18.95**	**-**	**-**	**$64.29**

Table 5.8 Alternative Method with Non-Domestic Sources (Aragonite) Excluded

County	50-Year Volume (cy)	Volume Transferred in 50 Years (cy)					
		Hydraulic Dredge	Hopper Dredge	Deepwater Dredge	Upland Quarry	Barge from Apalachicola	Bahamian Aragonite
St. Lucie	24,440,000	1,230,000	23,210,000	0	0	0	0
Martin	29,900,000	0	29,900,000	0	0	0	0
Palm Beach	49,166,000	34,281,132	14,884,868	0	0	0	0
Broward	24,225,000	0	24,225,000	0	0	0	0
Dade	18,274,000	4,509,435	11,699,420	1,627,145	363,000	75,000	0
Total Volume (cy)	**146,005,000**	**40,020,567**	**103,919,288**	**1,627,145**	**363,000**	**75,000**	**0**
Volume Percentage	**100.0%**	**27.4%**	**71.2%**	**1.1%**	**0.2%**	**0.1%**	**0.0%**
Total Cost (millions)	**$3,250.287**	**$380.924**	**$2,807.969**	**$30.842**	**$23.147**	**$7.406**	**$0.000**
Cost Percentage	**95.9%**	**11.2%**	**82.9%**	**0.9%**	**0.7%**	**0.2%**	**0.0%**
Average $/cy	**$22.26**	**$9.52**	**$27.02**	**$18.95**	**$63.77**	**$98.75**	**-**

5.5 Sensitivity Analysis: Traditional Borrow Sources

The total 50-year project need for the region equals approximately 146.0 mcy and the volume of beach-quality sand available in traditional offshore borrow sources equals approximately 146.9 mcy. Consequently, the cost analysis results in Sections 5.1 – 5.4 indicate relatively little need for alternative sand sources. This section explores the effect of a realistic reduction in the volume of beach-quality sand available in traditional offshore sources. Reducing the offshore volume increases the need for alternative sources, and should therefore increase the total 50-year cost of beach nourishment in the region. Notably, the scope of the RSM Plan did not include the analyses necessary to evaluate overfill values and beach nourishment project construction losses in the project volume requirements; both of these factors would increase the total amount of material required by the projects for the 50-year analysis period. However, additional geotechnical investigations in many of the category 3 borrow areas may lead to increased volumes for the beach-quality resources in the region.

Table 5.9 contains the results of the Subregion Method with all sources included, but with the volume contained in the offshore sources reduced by 10% to 132.7 mcy. After this reduction, the volume of sand that alternative sources must contribute increases significantly — from 27.1 to 33.2 mcy. The total cost of nourishing the region's projects with reduced offshore areas reaches over $3.8 billion — a 5% increase in cost from Table 5.5. This sensitivity analysis reveals that replacing traditional offshore sources with alternative sources causes a significant increase in cost.

Table 5.9 Subregion Method with Reduced Offshore Sources

County	50-year Volume (cy)	Volume Transferred in 50 Years (cy)					
		Hydraulic Dredge	Hopper Dredge	Deepwater Dredge	Upland Quarry	Barge from Apalachicola	Bahamian Aragonite
St. Lucie	24,440,000	1,100,000	23,340,000	0	0	0	0
Martin	29,900,000	0	29,900,000	0	0	0	0
Palm Beach	49,166,000	16,946,521	19,404,937	0	7,992,896	0	4,821,646
Broward	24,225,000	555,000	10,137,000	953,000	1,235,000	0	11,345,000
Dade	18,274,000	4,469,435	5,430,717	586,000	0	0	7,787,848
Total Volume (cy)	**146,005,000**	**23,070,956**	**88,212,654**	**1,539,000**	**9,227,896**	**0**	**23,954,494**
Volume Percentage	**100.0%**	**15.8%**	**60.4%**	**1.1%**	**6.3%**	**0.0%**	**16.4%**
Total Cost (millions)	**$3,819.385**	**$246.295**	**$1,942.013**	**$33.423**	**$426.119**	**$0.000**	**$1,171.535**
Cost Percentage	**112.7%**	**7.3%**	**57.3%**	**1.0%**	**12.6%**	**0.0%**	**34.6%**
Average $/cy	**$26.16**	**$10.68**	**$22.02**	**$21.72**	**$46.18**	**-**	**$48.91**

5.6 Sensitivity Analysis: Alternative Delivery of Aragonite

The management options in Sections 5.1 – 5.4 make limited use of aragonite. The double-handling delivery method of aragonite makes it more expensive than traditional borrow areas, even when sand from the traditional sources travels a long distance. However, policy changes may allow U.S. dredges access to aragonite in the future, which would affect the cost estimates significantly.

If the Bahamian authorities allowed U.S. vessels access to aragonite directly then the cost equations could treat Ocean Cay and possibly other Bahamian locations as a traditional borrow area. A hopper dredge would excavate the aragonite, transport it straight to the project site, moor offshore, and pump a sand slurry onto the beach. This method would eliminate the need to go through a port and would reduce costs. However, the issue of how to get clearance from U.S. customs would need resolution.

The cost equations for the alternative aragonite delivery method resemble those of a hopper dredge. The mobilization and demobilization would cost approximately $1,400,000, the volume-variant cost would equal $16.95/cy and the distance-variant cost would equal $0.25/cy/mi. The line-of-sight distance between Ocean Cay and the project site would provide the distance variable. In addition to these costs, the Bahamian government would receive payment for the aragonite, probably per cubic yard. Within the cost assumptions and values applied for this study, a sensitivity test reveals that a fee of more than $12/cy would make the aragonite uneconomical compared with sand from upland quarries. Table

5.10 shows the results of the Subregion Method including the alternative aragonite delivery method with a fee of $5/cy paid to the Bahamian government. In comparison with Table 5.5, the alternative aragonite delivery method uses approximately 3.3 mcy more aragonite and saves more than $148 million.

Table 5.10 Subregion Method with Alternative Aragonite Delivery Method

County	50-year Volume (cy)	Volume Transferred in 50 Years (cy)					
		Hydraulic Dredge	Hopper Dredge	Deepwater Dredge	Upland Quarry	Barge from Apalachicola	Bahamian Aragonite
St. Lucie	24,440,000	1,230,000	23,210,000	0	0	0	0
Martin	29,900,000	0	29,900,000	0	0	0	0
Palm Beach	49,166,000	20,194,521	21,478,282	0	3,112,143	0	4,381,054
Broward	24,225,000	555,000	10,310,000	780,000	0	0	12,580,000
Dade	18,274,000	4,509,435	5,796,883	930,000	0	0	7,037,682
Total Volume (cy)	**146,005,000**	**26,488,956**	**90,695,165**	**1,710,000**	**3,112,143**	**0**	**23,998,736**
Volume Percentage	**100.0%**	**18.1%**	**62.1%**	**1.2%**	**2.1%**	**0.0%**	**16.4%**
Total Cost (millions)	**$3,474.336**	**$283.144**	**$1,996.515**	**$34.669**	**$135.984**	**$0.000**	**$1,024.024**
Cost Percentage	**102.5%**	**8.4%**	**58.9%**	**1.0%**	**4.0%**	**0.0%**	**30.2%**
Average $/cy	**$23.80**	**$10.69**	**$22.01**	**$20.27**	**$43.69**	**-**	**$42.67**

5.7 Cost Analysis Findings Incorporating Sensitivity Analyses

The sensitivity analyses in Sections 5.5 and 5.6 provide realistic checks on the four cost analysis methods. Three of the four methods indicate a relatively small need for alternative sand sources. However, the need still exists. The sensitivity analysis in Section 5.5 suggests that once the region's beach nourishment projects have depleted traditional offshore sources, Bahamian aragonite provides the most economical source of additional sand. Should the cost of delivering Bahamian aragonite decrease, as described in Section 5.6, significant benefits (represented as cost savings) could result.

Recognizing similarities in results of the four methods can provide the means to formulate steps toward sediment management in the region. Similarities and cost comparisons across every method include the following.

- Depletion of traditional offshore sources requires use of alternative sources.
- Upland quarries represent the most cost effective alternative source for the northern counties (St. Lucie, Martin, and Palm Beach).

- Bahamian aragonite — or Apalachicola if the analysis does not include aragonite — represents the most cost effective alternative source for the southern counties (Broward and Miami-Dade).
- Each method must access either Bahamian aragonite or Apalachicola sand.
- The Subregion Method has the highest cost: approximately $235 million more than the Timeline Method for a 50-yr analysis period. This represents about 7% of the estimated total 50-year cost.
- The Alternative Method creates approximately $140 million in cost savings compared to the Timeline Method and almost $375 million compared to the Subregion Method.
- Bahamian aragonite costs slightly less than Apalachicola sand.

These similarities underscore the conclusion reached in the sustainability analysis — that further investigation and development of alternative sources should begin in order to properly plan for and meet sand needs of the region over the next 50 years and beyond. The northern counties would benefit from reconnaissance of category 3 (unverified) reserves and development of methods to lower costs and overcome logistical concerns associated with upland sources. The two southern counties would benefit from further investigation of deepwater sources and means to decrease the cost of providing Bahamian aragonite to project areas. The delivery of all 2 mcy of Apalachicola sand to a storage location in the region could prove beneficial, but Apalachicola represents a relatively small amount of available material while upland quarries, deepwater borrow areas, and Bahamian aragonite represent potentially large volumes usable over the next 50 years and beyond.

6.0 DISCUSSION OF MANAGEMENT ALTERNATIVES

6.1 No Action

The option to take no action makes no changes to existing policy or strategy and allows beach nourishment projects in the region to continue as they have in recent years. Each project would operate independently of others in the region and search for its own sand sources. Projects would deplete known sand sources and develop additional offshore borrow areas. Little (if any) sand would move across county boundaries.

Based on the sustainability analysis results in Section 3.3, St. Lucie and Palm Beach counties could maintain their projects with only sand resources within their county limits. The sustainability analysis shows that St. Lucie County has an abundance of beach-quality offshore sand — enough to nourish the county's beaches for 120 years. Similarly, Palm Beach County has enough beach-quality offshore sand to supply its project needs for more than 50 years, however the county may start running short in the longer term (beyond 50 years) if its unverified sources prove unusable. Although Martin County only has enough verified beach-quality offshore sand for about 41 years, the county has the largest volume of unverified offshore material in the region and could likely meet its long-term project needs with more offshore investigation.

However, Broward and Miami-Dade counties would quickly encounter difficulty in meeting the material requirements for their projects. Broward County has a little over 2 years' worth of verified beach-quality offshore sand and only about another 10 years' worth in unverified sources. Miami-Dade County has less than 4 years' worth of verified beach-quality sand in water depths less than 70 ft, although the potential deepwater borrow area could provide another 4 years' worth of material. Past beach nourishment projects in Miami-Dade County have repeatedly scoured the submerged lands for beach-quality sand, so the county's unverified sources likely hold very little usable material. Therefore, the option to take no action would leave Broward and Miami-Dade counties with a difficult decision in the next 10 – 20 years; the counties would have to either abandon their beach-nourishment programs or use alternative sources and see large increases in project costs. Most, if not all, beach nourishment programs in the region will stop once the costs of maintaining the beaches outweigh the benefits.

6.2 Manage Distribution of Existing Sand Resources

The option to manage the distribution of sand would apply one of the methods outlined in Section 4.0 to apportion existing offshore resources. Sand would move across county boundaries as necessary to meet project needs in the region. The surplus of beach-quality sand in the north of the region would alleviate the deficit in the south. This southerly flow of sand would give Broward and Miami-Dade counties access to inexpensive offshore beach nourishment material for most of the 50-year analysis period and delay the transition to alternative sources. Managing the distribution of offshore sand within the region would save federal money over the course of the 50-year analysis period, with only minor additional cost to St. Lucie, Martin, and Palm Beach counties. However, by the end of the 50-year analysis period, the region's projects would have exhausted the entire inventory of currently verified offshore borrow areas in the region.

6.3 Evaluation of Aragonite as Alternative Sediment Source

The research cited in Section 2.4.6 suggests that aragonite makes acceptable beach fill in southeast Florida. Ocean Cay, only 60 miles offshore Miami-Dade County, contains an almost unlimited source of aragonite. The Bahamian aragonite occurs in water depths and at distances where known extraction, transport, and placement methods can obtain and deliver the material to the projects in the region. The high cost of nourishing Florida's beaches with aragonite arises from the double handling necessitated by existing policies. If the Bahamian government were to allow U.S. vessels to collect aragonite directly from Ocean Cay or other Bahamian locations, the cost reduction would in some instances make aragonite more economically attractive to the beaches in Miami-Dade County than either deepwater borrow areas or traditional borrow areas offshore of other counties. Notably, significant aragonite deposits also occur in other Caribbean locations such as the Turks and Caicos Islands and the economics of obtaining the aragonite — transport costs, permitting costs, and royalties — will dictate the most economically viable sources.

6.4 Investigate Unverified Borrow Areas

The sustainability analysis results in Section 3.3 suggest that the volume of unverified offshore beach-quality sand in the region could exceed 1 billion cubic yards. This figure includes a large margin of error and indicates the need for additional reconnaissance in the form of vibracore collection and seismic analysis. Although this reconnaissance involves significant cost, development of nearshore borrow areas would result in lower costs by reducing the need for more expensive material from alternative sources. The discovery of additional offshore borrow areas within the region would reduce the costs presented in Section 5 and eliminate the need to use expensive alternative sources within the 50-year analysis period.

Martin County has the largest volume of unverified offshore sand of any county in the region. Therefore, Martin County would likely yield the largest volume of beach-quality sand after further investigation of these unverified areas. In particular, MI-3, MI-6, and MMS-7 might reward additional reconnaissance. St. Lucie County also has several promising areas. The broad continental shelf offshore of these two counties produces a large area landward of the -70 ft contour where borrow areas might occur. In contrast, the much narrower continental shelf offshore of Palm Beach, Broward, and Miami-Dade counties limits the area landward of the -70 ft contour. Past beach nourishment projects in the southern counties have investigated the submerged lands more thoroughly than in the north, thus leaving the unverified areas less likely to yield large volumes of beach-quality sand.

6.5 Invest in Deepwater Dredging

No beach nourishment project in the region has ever taken sand from a deepwater borrow area. However, the cost analysis in Section 5.0 suggests that deepwater borrow areas can compete economically with traditional borrow areas, despite the high mobilization and demobilization cost of retrofitting a U.S. flagged vessel to reach the necessary depths. Deepwater borrow areas appear favorable to Miami-Dade County, which has almost exhausted the sand in traditional borrow areas. However, prior investigations of deepwater areas in Miami-Dade County have not found significant volumes of sand that meets FDEP sand requirements.

Initial reconnaissance of deepwater areas offshore Miami-Dade County (CPE, 1997) suggests the presence of a thin layer of beach-quality sand extending over large areas. Deepwater borrow areas warrant further investigation, but this initial reconnaissance indicates that deepwater dredging might raise problems in addition to the need for special equipment. For example, the higher pressure of the deeper water causes partial lithification of the sand into rock fragments. A beach project dredging operation would need to screen out these rock fragments as the equipment dredged the sand from a deepwater borrow area.

Investment in deepwater dredging would begin with additional reconnaissance of potential borrow areas in water depths greater than 70 ft. If the reconnaissance effort uncovered substantial quantities of beach-quality sand in deepwater areas, then this alternative could provide the most economical solution to Miami-Dade County’s sand source problem. If a need for deepwater dredging in Florida arose, dredging companies would likely expand their fleets to include jumbo dredges, which would lower the mobilization and demobilization cost in Table 4.2.

6.6 Invest in Infrastructural Improvements to Upland Quarries

Table 2.5 shows that upland quarries in the region contain large quantities of beach-quality sand. Presently two major physical factors limit the usefulness of upland quarries to beach nourishment projects: the rate at which the quarries can extract sand (about 2,000 cy per day) and the bulk-handling capacities of the major ports in the region. In consideration of these two limitations, the cost analysis in

Section 5.0 capped the volume of sand a quarry could provide to local beach projects at 750,000 cy in a 6-month period. Capital investment to improve the sand extraction equipment at the quarries and the bulk-handling equipment at the ports could raise the 750,000 cy cap. However, such infrastructural improvements would not eliminate the problem of quality inconsistency; the sand arriving from upland quarries would still require rigorous (and expensive) quality control. Because traditional borrow areas in the region still contain almost 50 years' worth of beach-quality sand, investment in infrastructural improvements to upland quarries seems unlikely to prove economical at present.

6.7 Miscellaneous Considerations

This section contains miscellaneous considerations that fall outside the scope of this study, but relate tangentially to regional sediment management. This RSM Plan has assumed that rates of beach erosion in the region will not change during the 50-year analysis period. Sea level rise will likely increase erosion rates over the next 50 years. Conversely, the placement of shore protection structures along the coast could reduce erosion rates in some areas. If the rates of beach erosion in the region were to change, then the rate of depletion for the existing offshore sand sources would also change. As low-cost traditional borrow areas start to dwindle and sea levels continue to rise, the placement of structures might become more economically attractive than placement of material from distant locations.

Additionally, this RSM Plan has evaluated all known sources of beach-quality sand that projects in the region might practically and economically use. However, the plan has not investigated methods of manufacturing sand, such as from glass cullet (Makowski et al., 2007). As research into such methods progresses, they might prove economical alternatives to those presented here pending FDEP approval.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This RSM Plan for southeast Florida evaluated the sediment needs of all the active federal and non-federal beach nourishment projects in St. Lucie, Martin, Palm Beach, Broward, and Miami-Dade counties. These counties contain 21 active projects — 11 federal and 10 non-federal— that will require a total sediment volume of approximately 146.0 mcy over the next 50 years.

The region contains approximately 140.1 mcy of beach-quality sand in proven and potential offshore borrow areas and another 5.1 mcy will accrete during the 50-year analysis period. A potential deepwater borrow area (in water depths greater than 70 ft) offshore Miami-Dade County contains another 1.7 mcy. The total volume in the offshore borrow areas (146.9 mcy) exceeds the 50-year project need (146.0 mcy) by approximately 0.9 mcy.

The RSM Plan evaluated the quality of alternative sand sources, including upland quarries, sand from the Apalachicola River Delta, and aragonite from the Bahamas. All three of these sources contained sand of acceptable quality for use as beach fill in southeast Florida.

The USACE software MCACES provided cost estimates for nourishing beaches in the region with sand for different sand delivery methods. The delivery method for all three of the alternative sources involves the transfer of material from one carrier to another at a port in the region. Three ports have sufficient bulk-handling capacity to transfer large volumes of sand — the Port of Palm Beach, Port Everglades, and the Port of Miami. The double-handling of the material makes the cost of using alternative sources approximately double the cost of using traditional borrow areas.

The RSM Plan evaluated three main management options (based on costs) for distributing sand resources between projects in the region. The Timeline Method considered each renourishment event in the region in chronological order and chose the least expensive sand source for each in turn. The Total Quantity Method considered the renourishment events in order of largest total project need to smallest. The Subregion Method divided the region into three subregions and followed the procedure of the Timeline Method. The Timeline Method returned the lowest cost result, approximately $3.39 billion over 50 years. The Subregion Method returned the highest cost result, approximately $3.62 billion over 50 years.

An additional management option — Alternative Method — distributed the sand after first considering the sand source and then identifying the project(s) that could use the sand for the lowest cost. This method results in cost savings of approximately $140 million compared to the Timeline Method and almost $375 million compared to the Subregion Method.

Despite resulting in the highest overall cost, the methodology of the Subregion Method most closely follows current practice and recognizes the social and political implications of allocating sand within the region. Therefore, of the methods evaluated in this study, the Subregion Method provides the best mechanism to allocate sand resources in the study region over the next 50 years.

If current trends continue, Miami-Dade County will run out of offshore sand to nourish its beaches in less than 5 years and Broward County will run out of sand in 5 – 10 years. Following the depletion of offshore borrow areas, these counties will need to obtain sand from elsewhere to protect their shorefront property and infrastructure from coastal erosion. Upland quarries, sand from the Apalachicola River Delta, and non-domestic sources such as Bahamian aragonite all require substantial handling in the delivery of the material, which results in high costs. Current economics would direct Miami-Dade and Broward counties to take sand from offshore Palm Beach, Martin, or St. Lucie counties. However, transfer of offshore sand across county boundaries has met political and social opposition, so investigation of deepwater dredging and changes to non-domestic delivery methods provide more politically acceptable and sustainable solutions. Changes to the mechanics of obtaining material from upland quarries or non-domestic sources that limit the handling (and reduce costs) would remove the need to draw on available sediment resources offshore of other counties.

The management strategies applied in the study do not account for some existing constraints on beach nourishment activities. At present, certain borrow areas are permitted for specific projects and the movement of sand resources across county boundaries can meet opposition. The plans as developed provide a theoretical framework to distribute known sand resources within four different management scenarios. Certainly, new projects will start and sand search investigations will reveal new borrow sources. This new information will affect the data sets and analyses developed in the RSM Plan. Updates of the project and borrow source inventories should occur as new information and projects become available.

Despite the limitations of the theoretical framework applied, the RSM Plan demonstrates that with careful management, the active projects in the region will use the region's valuable offshore sand sources more strategically and economically. Further efforts — including cooperation and coordination between the State of Florida, Florida counties, USACE, and others — must reconcile differences between the theoretical framework applied for the RSM Plan and the realities of existing and future beach nourishment practices.

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