PUERTO RICO COASTAL STUDY

DRAFT INTEGRATED FEASIBILITY REPORT AND ENVIRONMENTAL ASSESSMENT

APPENDIX D
Geotechnical

November 2020

US Army Corps
of Engineers
Jacksonville District

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The Coastal Storm Risk Management Integrated Feasibility Study and Environmental Assessment for Puerto Rico includes two coastal study areas: San Juan, and Rincon as depicted in **Figure 1-1** below.

Figure 1-1. San Juan Beach Sampling Profile Lines Locations

2 GEOLOGY

2.1 REGIONAL GEOLOGY

Puerto Rico is a volcanic island located within the boundaries of the Caribbean and North American tectonic plates and part of the clustered islands of the Greater Antilles which are in the Atlantic Ocean. The island is predominantly composed of volcanic and plutonic rock of Jurassic to Eocene age overlain by limestone and other sedimentary deposits of Oligocene to recent age. Since the island is wedged between two active tectonic plates seismic activity is prevalent resulting in earthquakes, tsunamis and landslides.

2.2 LOCAL GEOLOGY

San Juan is located within the shallow marine shelf that surrounds the Commonwealth of Puerto Rico. Recent beach sand composed of quartz and carbonate is deposited in pocket beaches formed between reef outcrops along the shoreline. Sand dunes originally present along on the land-ward side of the beaches were harvested to build roads and buildings along San Juan's shoreline and no longer exist. Below the recent coastal deposits, localized occurrences of Pleistocene eolianite and reef rock is present. But largely the quaternary sediments are underlain by thick-bedded, dense limestone which is found at depths varying

from 25 feet to more than 100 feet. The Limestone unit is of early Miocene age and up to 950 feet thick. Periods of fluctuating sea levels occurred during the glacial periods at the end of the Neogene period exposing the limestone, allowing for weathering and erosion to occur. Sea levels rose to its current position during the Miocene age after the end of the last glacial period.

The coastal geology at Rincon is comprised of Quaternary age sandy beaches and reef out crops along the shore, and a narrow strip of alluvial deposits on the landward side of the coast. The Quaternary sediments are underlain unconformably by a complex, deformed series of sedimentary and igneous rocks.

3 EXISTING BEACH

The project includes several beaches along the San Juan and Rincon coastline of Puerto Rico. The sand from San Juan beaches and dunes was mined for construction aggregate in the past and left the beaches altered from their natural state. Beach nourishments, to date, have not been conducted at any of the beaches.

The existing beach was characterized through a beach sampling program conducted in March 2019. Beach samples were collected at the beach locations listed in **Table 1** and depicted in **Figure 3-1** and **Figure 3-2** below. The individually named beaches at San Juan are pocket beaches and separated by reef outcrops. The beaches at Rincon seamlessly blend into each other.

Table 1: Beach Sampling Locations

Study Area	Beach Locations	NAD83 State Plane, PR/V	
		Easting	Northing
San Juan	San Juan - Cangrejo	805200	878762
	San Juan - Isla Verde	781330	882912
	San Juan - Ocean Park	797908	878127
	San Juan - Parque	789768	881167
	San Juan - Condado	785938	881875
Rincon	Rincon - Conserga	374611	834611
	Rincon - Stella	371461	839810
	Rincon - Dona Lala	373482	834560

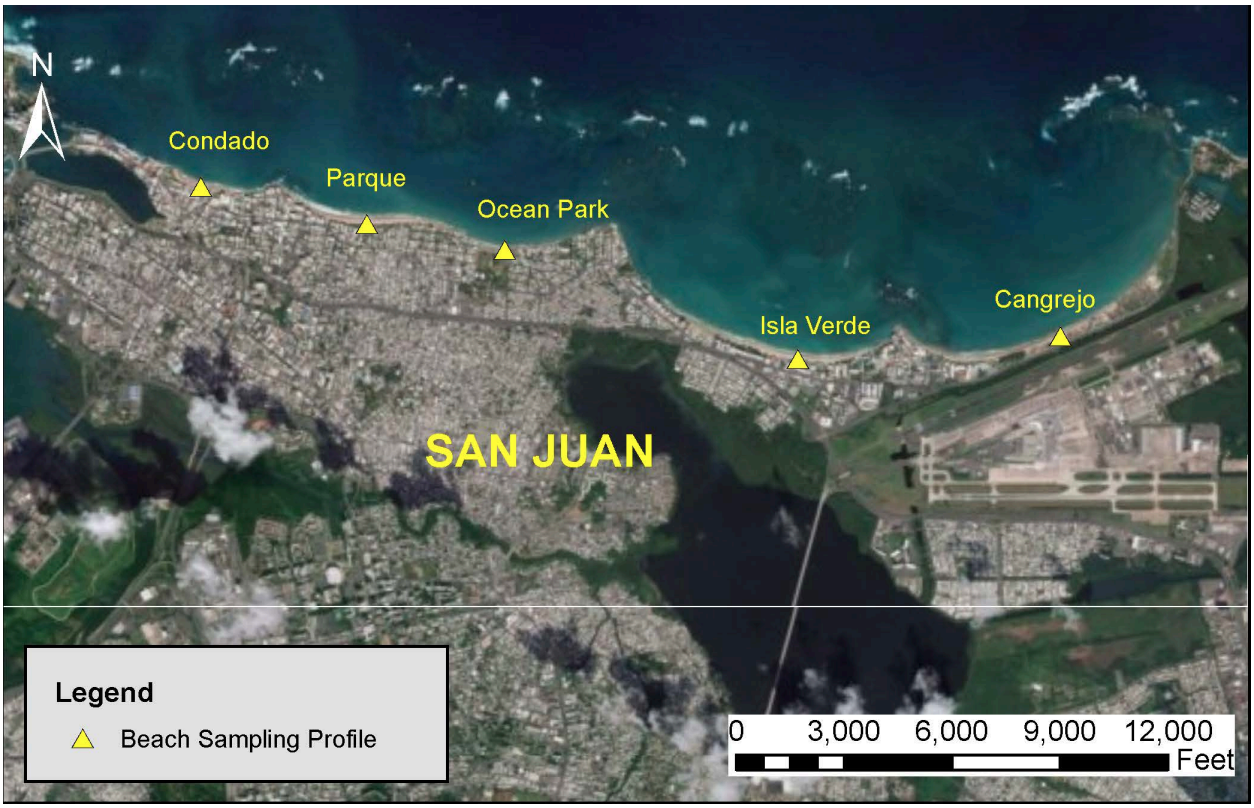

Figure 3-1. San Juan Beach Sampling Profile Lines Locations

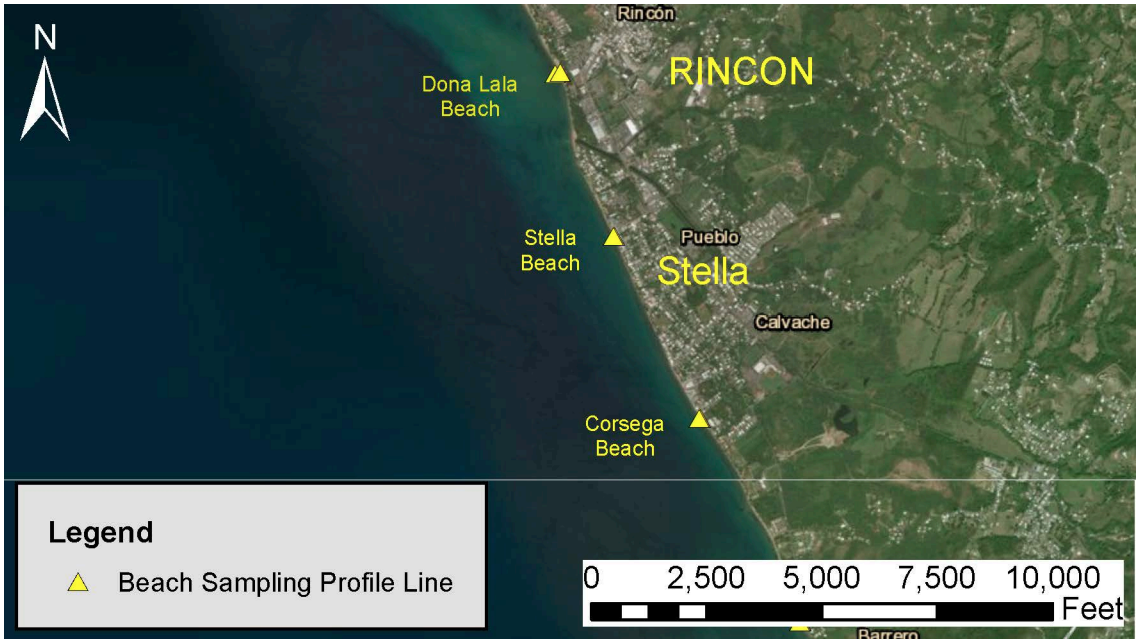

Figure 3-2. Rincon Beach Sampling Profile Lines Locations

Beach samples were collected at the following beach profile locations: berm, mid-tide, -3 ft., -5 ft. below Mean Sea Level as shown in the diagram in **Figure 3-3**. The samples were collected from a depth of approximately 6-12 inches below ground surface. The Puerto Rico beaches have a lower gradient than that shown in Figure 2 and buildings and roads were constructed at the location of the original dune. Therefore, dune samples could not be collected at any locations.

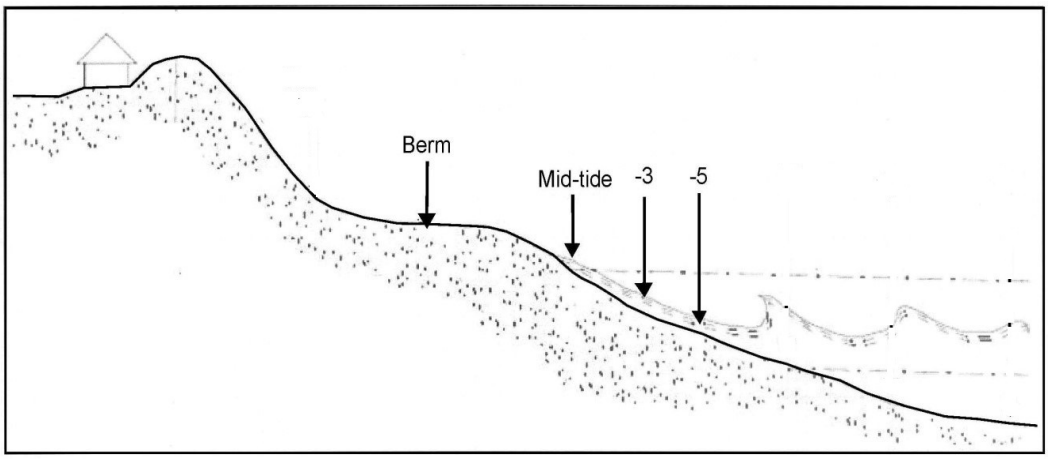

Figure 3-3. Idealized Beach Transect with Sampling Locations

Grain size and visual shell analyses were performed on all thirty-two (32) samples and carbonate analyses were performed on seven (7) representative samples. Gradation curves and granularmetric reports are attached in **Paragraph 8.1.1**.

A representative arithmetic composite sample was calculated for each study area using all samples. The granularmetric results using the method of moments for each sample and for the composite sample are summarized in **Table 2** for Sand Juan beaches and in **Table 3** for Rincon beaches.

Table 2: San Juan Beach Sampling Results

Beach Designation	Location	USCS*	Mean (mmi)	Sorting (phi)	Retain. on # 4 Sieve %	Silt Pass. #230 Sieve %	Visual Shell in %*	$CaCO_3$* in %	Moist Munsell Color
San Juan - Condado	Berm	SP	0.28	0.57	0.00	0.90	11.1		10YR 7/3
San Juan - Condado	Mid-Tide	SP	0.27	0.59	0.00	1.22	21.1		10YR 6/3
San Juan - Condado	-3	SP	0.46	0.85	0.00	1.95	16.4		10YR 6/3
San Juan - Condado	-5	SP	0.19	0.63	0.00	2.04	39.5	46.56	10YR 6/3
San Juan - Isla Verde	Berm	SP	0.23	0.91	1.27	0.42	25.8	29.41	10YR 7/2
San Juan - Isla Verde	Mid-Tide	SP	0.25	0.74	0.00	0.83	17.2		10YR 6/3
San Juan - Isla Verde	-3	SP	0.14	0.48	0.00	1.62	8.7		2.5Y 6/3
San Juan - Isla Verde	-5	SP-SM	0.12	0.40	0.00	3.02	13.0		2.5Y 5/2
San Juan - Ocean Park	Berm	SP	0.28	0.68	0.00	0.63	12.5		2.5Y 6/3

Beach Designation	Location	USCS*	Mean (mmi)	Sorting (phi)	Retain. on # 4 Sieve %	Silt Pass. #230 Sieve %	Visual Shell in %*	$CaCO_3$* in %	Moist Munsell Color
San Juan - Ocean Park	Mid-Tide	SP	0.37	0.67	0.00	1.31	43.8	47.24	10YR 6/2
San Juan - Ocean Park	-3	SP	0.16	0.49	0.00	2.02	11.1		2.5Y 5/2
San Juan - Ocean Park	-5	SP	0.16	0.51	0.00	2.06	12.3		2.5Y 6/2
San Juan - Parque	Berm	SP	0.31	0.62	0.00	0.49	17.0		10YR 7/2
San Juan - Parque	Mid-Tide	SP	0.25	0.55	0.00	1.09	18.6		10YR 6/3
San Juan - Parque	-3	SP	0.19	0.71	0.08	1.76	40.0	46.88	10YR 6/2
San Juan - Parque	-5	SP	0.22	1.02	1.73	1.65	24.3		2.5Y 6/2
San Juan - Cangrejo	Berm	SP	0.22	0.70	0.00	0.51	17.9		10YR 6/2
San Juan - Cangrejo	Mid-Tide	SP	0.19	0.70	0.00	1.14	16.7		10YR 5/2
San Juan - Cangrejo	-3	SP-SM	0.12	0.67	0.00	6.29	15.8		10YR 5/2
San Juan - Cangrejo	-5	SM	0.10	0.63	0.22	14.78	19.3		2.5Y 5/1
BEACH COMPOSITE SAN JUAN		**SP**	**0.21**	**0.86**	**0.16**	**2.29**	**20.11**	**42.52**	**Value 6**

*USCS = US Soil Classification System, $CaCO_3$ = Calcium Carbonate

Table 3: Rincon Beach Sampling Results

Beach Designation	Location	USCS*	Mean (mmi)	Sorting (phi)	Retain. on # 4 Sieve %	Silt Pass. #230 Sieve %	Visual Shell in %*	$CaCO_3$* in %	Moist Munsell Color
Rincon - Conserga	Berm	SP	0.35	0.68	0.00	0.45	8.7		2.5Y 6/6
Rincon - Conserga	Mid-Tide	SP	0.39	0.60	0.00	0.89	18.1		2.5Y 6/3
Rincon - Conserga	-3	SP	0.76	1.09	1.54	1.30	33.9		2.5Y 5/2
Rincon - Conserga	-5	SP	0.23	0.54	0.00	1.03	34.2	24.55	10YR 5/3
Rincon - Dona Lala	Berm	SP	0.32	0.64	0.00	0.10	16.7		2.5Y 6/3
Rincon - Dona Lala	Mid-Tide	SP	0.33	0.76	0.00	0.97	33.6	36.11	10YR 4/3
Rincon - Dona Lala	-3	SP	0.45	0.87	0.00	0.86	38.0		2.5Y 5/3
Rincon - Dona Lala	-5	SP	0.18	0.39	0.00	1.25	23.9		2.5Y 5/3
Rincon - Stella	Berm	SP	0.33	0.64	0.00	0.26	33.1		10YR 5/3
Rincon - Stella	Mid-Tide	SP	0.30	0.62	0.00	1.04	35.6		10YR 5/2
Rincon - Stella	-3	SP	0.66	1.28	3.43	1.00	36.1	33.62	10YR 4/3
Rincon - Stella	-5	SP	0.17	0.37	0.00	1.05	18.6		2.5Y 5/3
BEACH COMPOSITE RINCON		**SP**	**0.34**	**0.97**	**0.41**	**0.85**	**27.54**	**31.43**	**Value 5**

*USCS = US Soil Classification System, $CaCO_3$ = Calcium Carbonate

The beach composite sample for San Juan Beaches was classified as clean, poorly-graded, fine-grained quartz sand (SP) with a mean grain size of or 0.21 mm, and a standard deviation of 0.86

phi. The average percentage of fines passing the #230 sieve is 2.29. The average visual shell percentage is 20 %, with a range from 8.7 % through 43.8 %. The typical moist Munsell Color value is 6 and color is described as light brownish gray. The graph with the composite sample for each of the various San Juan Beaches is shown in **Figure 3-4**. The graphs and granularmetric reports for each composite sample is attached in **Paragraph 8.1.4.**

The beach composite sample for Rincon Beaches was classified as clean, poorly-graded, fine-grained quartz sand (SP) with a mean grain size of or 0.34 mm, and a standard deviation of 0.97 phi. The average percentage of fines passing the #230 sieve is 0.85. The average visual shell percentage is 27 %, with a range from 8.7 % through 38 %. The typical moist Munsell Color value is 5 and color is described as grayish brown. The graph with the composite sample for each of the various Rincon is shown in **Figure 3-5**. The graphs and granularmetric reports for each composite sample is attached in **Paragraph 8.2.3.**

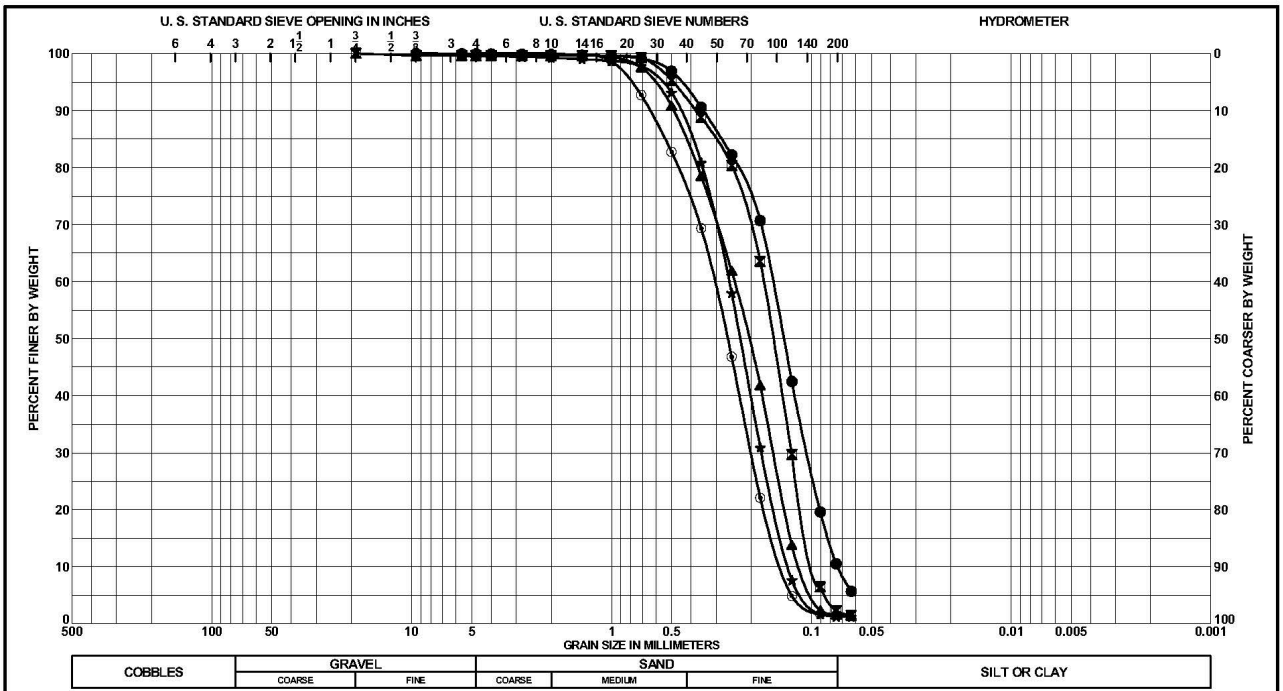

Figure 3-4. Composite Gradation Graphs for San Juan Beach Transects

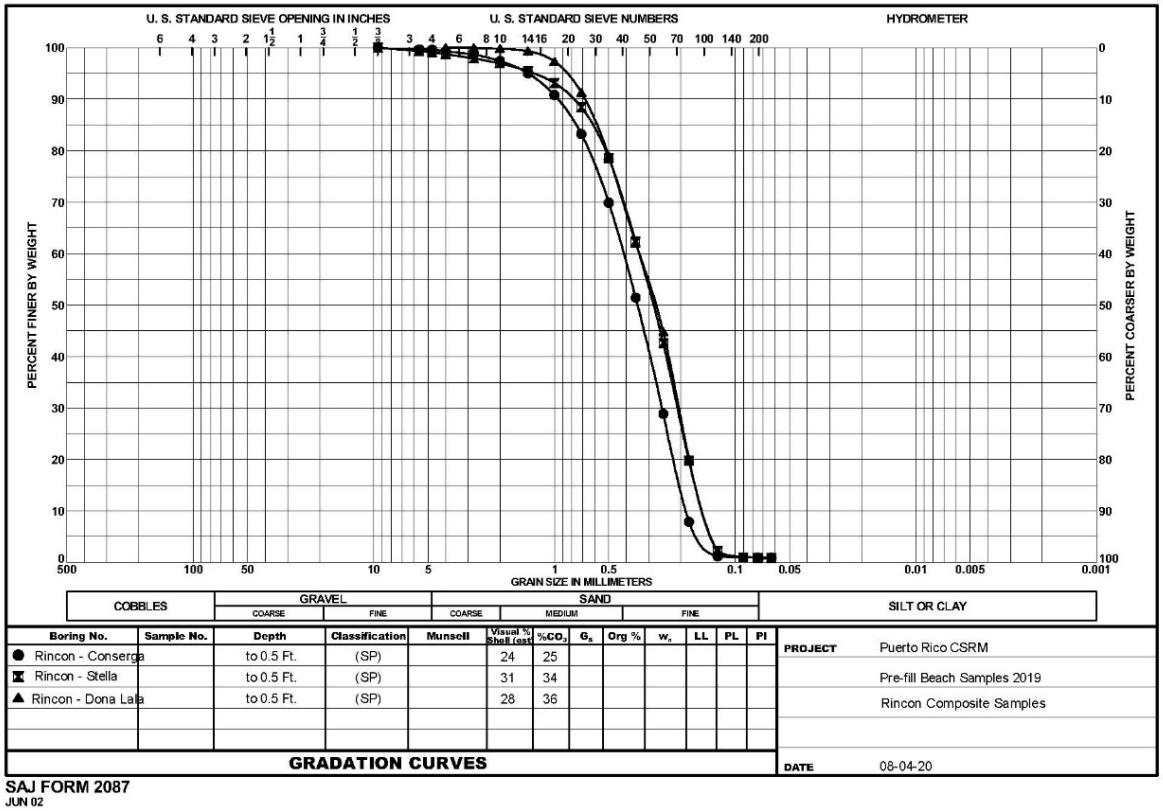

Figure 3-5. Composite Gradation Graphs for Rincon Beach Transects

4 SAND SOURCES

Nearshore, and offshore sand sources, and upland sand mines were identified for both study areas and are discussed in the paragraphs below. Puerto Rico has no specific requirements for the beach fill quality. However, from an environmental and sustainability point of view the sand placed on the beach should be similar to the sand of the existing beach and free of foreign matter, like rock, debris, and toxic material.

4.1 SAN JUAN NEARSHORE AND OFFSHORE SAND SOURCES

The evaluation of offshore sand sources are based on existing data from other federal and non-federal agencies only. Boring data are not available for this project, the only physical samples for the nearshore are push cores collected 2014, and for the offshore sand sources surficial samples collected by USGS in 1992 in the context of a geophysical investigation.

The following four offshore and nearshore sand sources were explored for San Juan.

- La Esperanza (near shore)
- Sand deposits within the nearshore of the San Juan study area
- Loiza unverified offshore sand sources
- Luquillo potential offshore sand sources

La Esperanza is approximately 5-10 Miles away from the San Juan Beaches. The San Juan nearshore deposits are located approximately 1-3 miles from the receiving beaches. The off-shore sand sources Loiza 1&2 are located approximately 15 miles east of San Juan, and Luquillo 1&2 approximately 25 miles east.

An overview map for the sand sources is included in **Figure 4-1** below and the available information for each sand source is summarized in the chapters below.

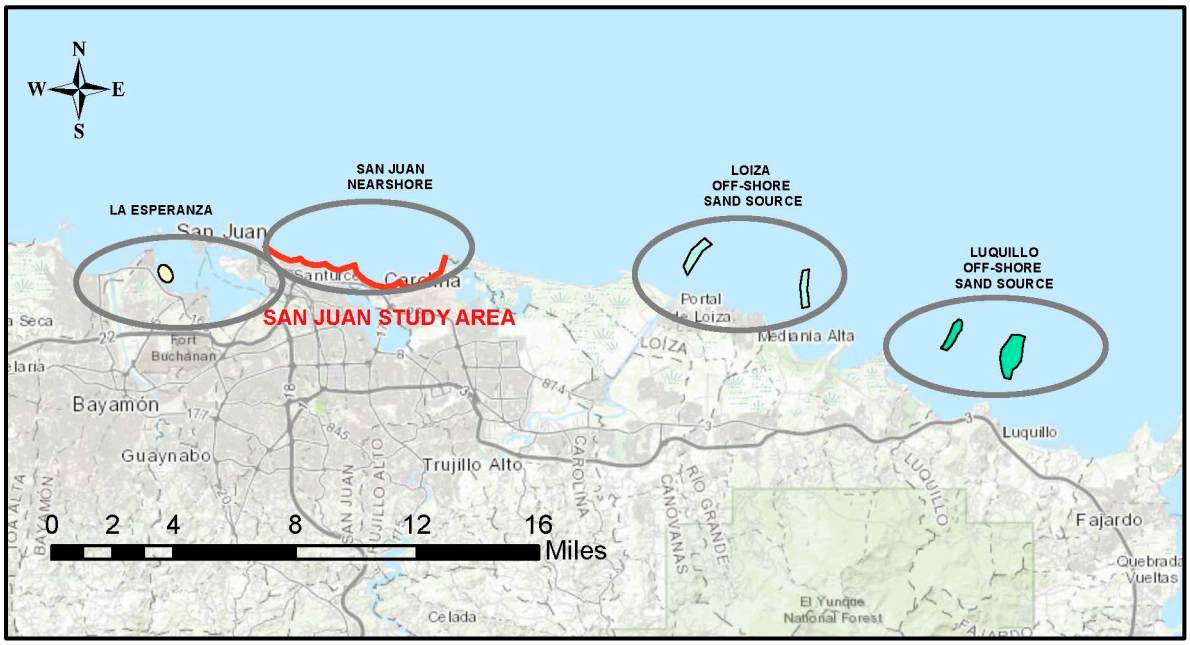

Figure 4-1. San Juan Offshore Sand Sources Overview

4.1.1 LA ESPERANZA

La Esperanza is an Ecosystem Restoration project (Environmental Assessment USACE 2015) and a Regional Sediment Management (RSM) sand source. The La Esperanza Peninsula is located in the northwestern side of the San Juan Harbor. The island is manmade and was initiated through the placement of dredged material from San Juan Harbor construction dredging 1962 - 1965. The placed dredged material has been migrating and changing in shape since placement due to prevailing winds, tides, wave action, and formed the shape and size of today's La Esperanza Peninsular. The long hook shape significantly impairs water circulation inside a shallow embayment by trapping and concentrating nutrients and sediment-laden water discharged by the Malaria Canal. In 2005, the La Esperanza Peninsula was dredged by the USACE, to restore water quality. However, due to the littoral drift and wave action, the La Esperanza Peninsula shoaled in quickly and is in need to be dredged again.

The material consists of poorly graded fine grained quartz sand and shell beds with a mean grainsize of 0.36mm and would be suitable for beach placement. The USACE, Jacksonville District collected fifteen push cores, each 2-5 feet deep in 2014 and lab analysis was performed on selected samples. The push core locations are depicted in **Figure 4-2** and listed in **Table 4. La Esperanza Push Core Sample LocationsTable 4**. Laboratory testing results are summarized in **Table 5**. Logs and gradation graphs of the samples are attached in **Paragraph 8.1.3**.

A specific dredge template cannot be designed at this time since the peninsular is ever changing and the dredge area must be configured considering the ecosystem restoration of the La Esperanza area. However, it is estimated that a minimum of 200,000 cuyd could be dredged and used for San Juan beach nourishment.

Figure 4-2. La Esperanza Potential Dredge Area

Table 4. La Esperanza Push Core Sample Locations

Sand Source Designation	Sample	PR/VI State Plane NAD83 (US feet)		Hole Depth (US Feet)
		X	Y	
La Esperanza	SJH-HA-1	760121	881499	2.8
La Esperanza	SJH-HA-2	760347	881035	3.2
La Esperanza	SJH-HA-3	760590	880872	3.0
La Esperanza	SJH-LE-1	760284	881658	3.7
La Esperanza	SJH-LE-10	760619	880645	4.0
La Esperanza	SJH-LE-13A	759927	879462	1.5
La Esperanza	SJH-LE-15A	759896	879371	4.0
La Esperanza	SJH-LE-17	759927	879280	2.0
La Esperanza	SJH-LE-2	760715	881251	2.3
La Esperanza	SJH-LE-3	760255	881426	2.5
La Esperanza	SJH-LE-4	760464	881187	1.5
La Esperanza	SJH-LE-5	760245	881208	5.0
La Esperanza	SJH-LE-5A	760264	881220	5.0
La Esperanza	SJH-LE-6	760714	880918	5.0
La Esperanza	SJH-LE-7	760500	880973	5.0
La Esperanza	SJH-LE-8A	760354	880945	1.5
La Esperanza	SJH-LE-9	760780	880730	5.0

Table 5. La Esperanza Push Core Sample Grain-size Analysis Results

Core Designation	Sample Name	USCS	Mean (mm)	Sorting (phi)	Retain. on # 4 Sieve %	Silt Pass. #200 Sieve %	CaCo3* in %	Moist Munsell Color
SJH-LE-1	1	SP	0.38	1.59	8.3	1.5	61.5	2.5Y 5/2
SJH-LE-1	2	SP	0.41	1.90	9.6	3.3		2.5Y 4/2
SJH-LE-1	3	SP	0.42	1.25	0.5	3.1		2.5Y 5/1
SJH-LE-1	4	SP-SM	0.34	1.16	0.3	7.7		2.5Y 5/2
SJH-LE-2	1	SP	0.17	0.58	0.0	2.4		10YR 4/2
SJH-LE-2	2	SM	0.21	0.74	0.0	39.6		2.5Y 4/1
SJH-LE-2	3	MH						2.5Y 4/1
SJH-LE-3	1	SP	0.82	1.49	6.4	0.3		10YR 6/4
SJH-LE-3	2	SP	2.28	1.21	16.3	1.3	96.1	10YR 6/6
SJH-LE-3	3	SP	0.24	1.80	6.4	3.3		2.5Y 5/2
SJH-LE-4	1	SP	0.69	1.93	10.3	0.6	73.4	10YR 5/2
SJH-LE-4	2	SP	0.22	1.32	1.8	3.0		2.5Y 5/2
SJH-LE-5	1	SP	0.30	1.06	1.3	4.3		2.5Y 7/2
SJH-LE-5	2	SP	0.62	1.54	9.0	1.1	69.9	2.5Y 6/4

Core Designation	Sample Name	USCS	Mean (mm)	Sorting (phi)	Retain. on # 4 Sieve %	Silt Pass. #200 Sieve %	CaCo3* in %	Moist Munsell Color
SJH-LE-5	3	SP	0.66	1.57	6.1	1.6		2.5Y 5/2
SJH-LE-5	4	SP	0.21	0.98	0.6	2.9		2.5Y 5/2
SJH-LE-5A	1	SP	0.24	0.81	1.0	0.3		2.5Y 6/3
SJH-LE-5A	2	SP	0.46	1.34	2.7	0.6		2.5Y 6/3
SJH-LE-5A	3	SP	0.21	0.64	0.0	2.3		2.5Y 5/3
SJH-LE-5A	4	SP	0.24	0.94	0.3	1.9		2.5Y 5/3
SJH-LE-5A	5	SP-SM	0.16	0.77	0.0	7.7		2.5Y 5/2
SJH-LE-5A	6	SP-SM	0.15	0.80	0.0	10.3		2.5Y 5/2
SJH-LE-6	1	SP	0.24	0.69	0.6	0.4		2.5Y 5/3
SJH-LE-6	2	SP	0.55	1.89	8.2	1.5	77.4	10YR 5/2
SJH-LE-6	3	SP	0.95	1.58	12.1	0.9		2.5Y 5/3
SJH-LE-6	4	SP-SM	0.17	1.46	2.4	7.5		2.5Y 5/2
SJH-LE-6	5	SP-SM	0.33	1.19	0.6	11.4		2.5Y 5/2
SJH-LE-7	1	SP	0.34	1.36	2.8	0.1	59.2	2.5Y 7/2
SJH-LE-7	2	SP	0.73	2.13	18.3	0.9		2.5Y 6/3
SJH-LE-7	3	SP	0.36	1.52	5.8	0.6	62.4	2.5Y 5/3
SJH-LE-7	4	SW	1.60	1.85	26.6	0.9		2.5Y 5/3
SJH-LE-7	5	SP	0.82	1.69	20.2	1.6		2.5Y 5/2
SJH-LE-8A	1	SM	0.28	1.62	3.5	14.2		2.5Y 4/2
SJH-LE-8A	2	SP-SM	0.19	1.66	3.8	10.8	65.1	2.5Y 5/2
SJH-LE-9	1	SP	0.28	1.41	3.7	0.6		2.5Y 5/3
SJH-LE-9	2	SP	0.15	0.45	0.0	1.3	68.4	2.5Y 5/2
SJH-LE-9	3	SP	0.59	1.95	11.2	1.2		2.5Y 5/3
SJH-LE-10	1	SP	0.24	0.72	0.3	0.7		2.5Y 5/2
SJH-LE-10	2	SP	0.29	1.20	2.6	1.2	59.7	2.5Y 5/2
SJH-LE-10	3	SP	0.24	0.89	0.0	2.3		2.5Y 4/3
SJH-LE-13A	1	SP	0.32	1.42	5.4	2.9		2.5Y 5/2
SJH-LE-15A	1	SP	0.25	1.28	3.3	1.0		2.5Y 6/3
SJH-LE-15A	2	SP	0.29	1.29	2.4	2.0	68.5	2.5Y 5/2
SJH-LE-15A	3	SP	0.29	1.29	2.4	2.0		2.5Y 5/2
SJH-LE-17	1	SP	1.09	1.46	9.7	1.0		2.5Y 6/3
SJH-LE-17	2	SP	0.40	1.30	3.7	2.0		2.5Y 5/2
La Esperanza Composite		**SP**	**0.36**	**1.62**	**5.13**	**3.73**	**69.3**	**Light brown**

4.1.2 SAN JUAN NEARSHORE

The Coastal and Hydraulics Laboratory (CHL) of the USACE Engineer Research and Development Center (ERDC) collected sub bottom profiling data in the nearshore of San Juan in 2017. The purpose of the data collection was to study the sediment transport. The study team developed an isopach map showing the sand thicknesses over hard bottom (**Figure 4-3**).

The sand deposits are located between the outer San Juan longitudinal reef complex and the mainland which also has multiple reef outcrops at the ends each pocket beach. The maximum sand thicknesses are as follows:

- Condado: max. 5 feet
- Carolina: max. 35 feet
- Isla Verde: max. 15 feet
- Ocean Park: max 18 feet

The seafloor slopes gently toward the reefs and the maximum water depth is approximately 30 feet at the landward boundary of the longitudinal reefs.

Figure 4-3. San Juan Nearshore Sand Thickness

The landward portions of the sand deposits are part of the submerged beach. Even though there seem to be an abundance of sand, these sand deposits are unlike offshore shoals, they are located beneath the gently sloped seafloor. Dredging those sand deposits would leave a dredge hole in the sediment starved coastal system of San Juan that may trigger erosion at the nearby beaches.

In summary, using the nearshore sand deposits as sand source for San Juan beaches is not recommended since it may not only trigger erosion at the nearby beaches, but also jeopardize the environmental resources in the immediate vicinity.

4.1.3 LOIZA UNVERIFIED OFFSHORE SAND SOURCES

The Loiza unverified offshore sand sources are located approximately 15 miles east of San Juan in water depths of 20-40 feet. They were identified based on flow vector models and laboratory testing results of surficial samples collected by USGS (Schwab et Al, 1996 and Cross et al, 1998). The flow vector model suggests the location of the local river beds (Loiza Rio Grande, Rio Grande, and Rio Espiritu Sancto) extending into the ocean. The shoreline of Puerto Rico extended further into the present ocean before the sea level rise associated with the end of the last glacial period. Therefore, relict river channels, typically filled with sand, are now submerged and referred to as paleochannels. Typically, the terrestrial coarser sediments are overlain by finer marine sediments. Paleochannels are commonly sought after in the context of sand source investigations and are typically identified through geophysical surveys. **Figure 4-4** depicts the Loiza 1&2 sand sources, likely paleochannel locations, the flow vector model, the surficial sample locations, and the sand source design. The coordinates of the sample locations are listed in **Table 6**.

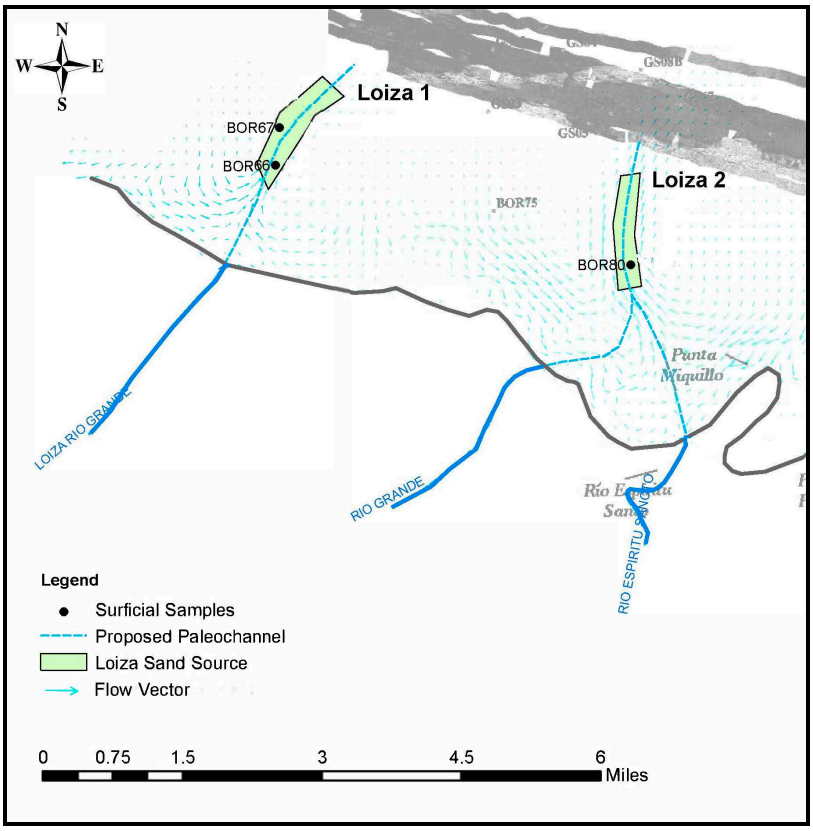

Figure 4-4. Loiza Unverified Sand Sources

Table 6. Loiza Surficial Sample Locations

Sand Source Designation	Sample Designation	NAD83 / UTM Zone 20N (Meters)	
		X	Y
Loiza 1	BOR66	196,751	2,042,829
Loiza 1	BOR67	196,835	2,043,473
Loiza 2	BOR80	202,876	2,040,997

The granularmetric data of the samples are summarized in **Table 7**. All sample data is derived directly from the USGS study (Schwab et al, 1996 and Cross et al, 1998). Sieve data, gradation curves and granularmetric reports are not available. There are only three surficial samples available for Loiza 1&2 unverified sand sources. The samples are classified as poorly graded sand (SP), poorly graded sand with silt (SP-SM), and silty sand (SM) with a mean grain size of 0.07-0.15mm, and percentage fines of 2.48, 11.04, and 29.89%, respectively. Thus, the surficial sediment samples are classified as very fine-grained sand and are not representative of beach compatible sand. Therefore, at this time Loiza 1&2 are not considered to be compatible sand sources for this project. However, the evaluation is based on only three surficial samples. Geophysical surveys and vibracores would be required to properly characterize this potential sand source.

Table 7. Grain Size Analysis Results for Loiza 1&2 Sand Sources

Sand Source Designation	Sample ID	USCS	%Gravel	%Sand	%Silt	%Clay	Mean (mm)	Standard Deviation (phi)
Loiza 1	BOR66	SP	0.23	97.29	1.58	0.90	0.15	0.91
	BOR67	SP-SM	0.00	88.96	4.67	6.37	0.09	1.77
Loiza 2	BOR80	SM	0.52	69.61	26.36	3.50	0.07	0.79

1 Grain size analysis results are directly derived from Schwab et al, 1996 publication

4.1.4 LUQUILLO POTENTIAL OFFSHORE SAND SOURCES

The Luquillo 1&2 potential offshore sand sources are located approximately 25 miles east of San Juan in water depths of 40-60 feet. They were identified based on geophysical data and laboratory testing results of surficial samples collected by USGS (Schwab et al, 1996 and Cross et al, 1998). The side scan image suggests the location of the local river channels (Rio Mameyes, Rio Pitahaya) extending into the ocean as paleochannels as depicted in **Figure 4-5**. The geophysical survey results revealed low backscatter sand, which indicates relatively fine-grained material, at the Luquillo 1 sand source, and high backscatter sand, which indicates coarse grained material, at Luquillo 2. A detailed map showing the potential sand source and

the sample numbers is included as **Figure 4-6**. The coordinates of the sample locations are listed in **Table 8**.

Sand volume estimates are included in **Paragraph 5**. A conservative estimate of 5-foot sand thickness is used for the volume estimates since borings are not available for the sand sources and the vertical extent of the sand cannot be verified at this time. The granularmetric data of the samples are summarized in **Table 9**. All sample data is derived directly from the USGS study (Schwab et al, 1996 and Cross et al, 1998). Sieve data, gradation curves and granularmetric reports are not available.

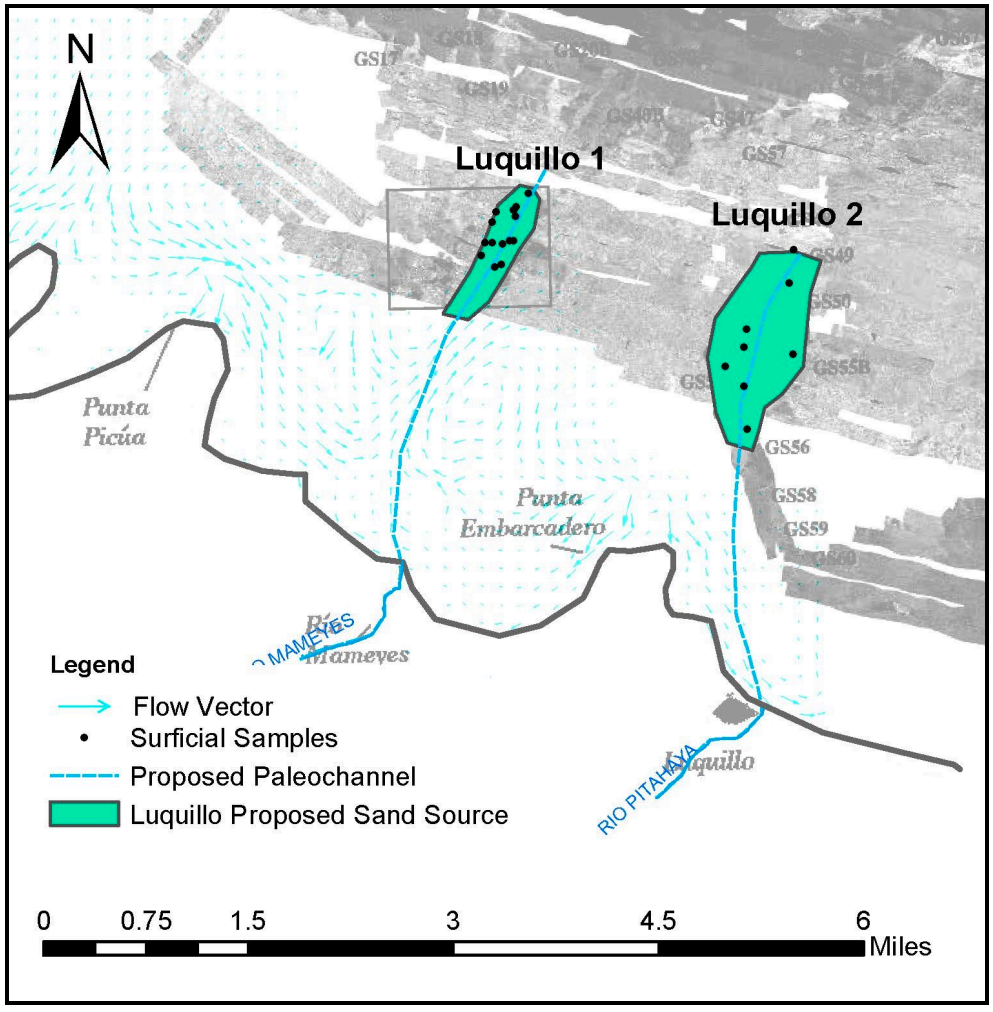

Figure 4-5. Luquillo Potential Sand Sources with side scan image

Table 8. Luquillo Surficial Sample Locations

Sand Source Designation	Sample Designation	NAD83 / UTM Zone 20N (Meters)	
		X	Y
Luquillo-1	BOR09	210,446	2,038,956

Sand Source Designation	Sample Designation	NAD83 / UTM Zone 20N (Meters)	
		X	Y
Luquillo-1	BOR13	210,835	2,039,490
Luquillo-1	BOR17	210,579	2,039,347
Luquillo-1	BOR34	210,867	2,039,526
Luquillo-1	BOR35	210,845	2,039,490
Luquillo-1	BOR38	210,677	2,038,847
Luquillo-1	BOR43	210,787	2,039,122
Luquillo-1	BOR44	210,702	2,039,086
Luquillo-1	BOR45	210,575	2,039,107
Luquillo-1	BOR46	210,491	2,039,108
Luquillo-1	GS34	210,603	2,038,818
Luquillo-1	GS35	210,829	2,039,125
Luquillo-1	GS36	210,855	2,039,412
Luquillo-1	GS37	210,634	2,039,471
Luquillo-1	GS38	211,018	2,039,687
Luquillo-2	GS49	214,125	2,038,953
Luquillo-2	GS50	214,067	2,038,556
Luquillo-2	GS51	213,551	2,038,021
Luquillo-2	GS52	213,516	2,037,811
Luquillo-2	GS53	213,291	2,037,581
Luquillo-2	GS54	213,509	2,037,346
Luquillo-2	GS55B	214,096	2,037,713
Luquillo-2	GS56	213,533	2,036,836

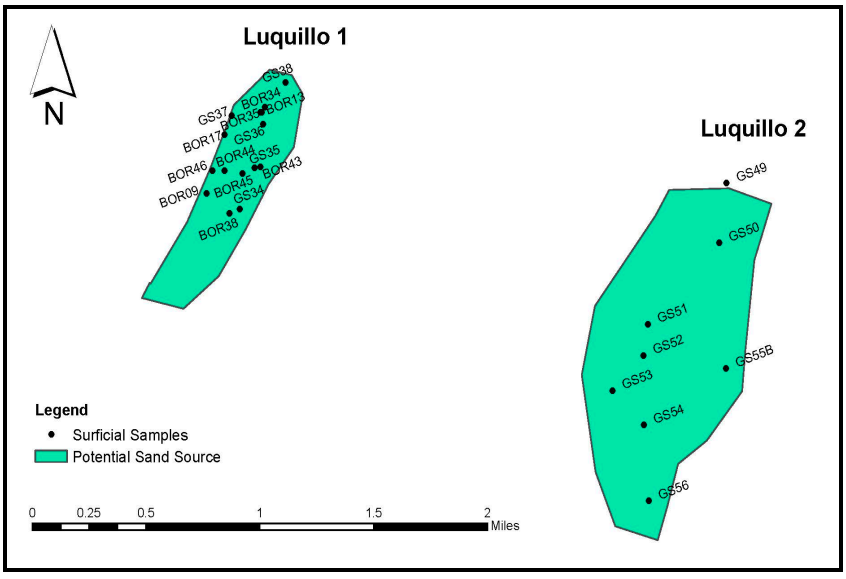

Figure 4-6. Luquillo Potential Sand Sources Sample Locations

There are fifteen (15) surficial samples available for Luquillo 1. An arithmetic composite sample was created using the 15 samples. The composite sample classifies as poorly graded medium grained sand (SP) with a mean grain size of 0.58 mm, and 1.58 percent fines (silt and clay fractions).

There are eight (8) surficial samples available for Luquillo 2. An arithmetic composite sample was created using the 8 samples. The composite sample classifies as poorly graded medium grained sand (SP) with a mean grain size of 0.59 mm, and 0.08 percent fines (silt and clay fractions).

In summary, the geophysical survey and laboratory test results indicate the presence of beach compatible sand in Luquillo 1 & 2 potential sand sources. The vertical extent of the beach compatible sand deposits needs to be determined through vibracore borings.

Table 9. Grain Size Analysis Results for Luquillo 1&2 Sand Sources

Sand Source Designation	Sample ID	USCS	% Gravel	% Sand	% Silt	%Clay	Mean (mm)	Standard Deviation (phi)
Luquillo 1	GS34	SP	0.10	99.75	0.15	-	0.18	0.72
	GS35	SP	9.74	90.26	-	-	0.65	1.14
	GS36	SP	1.28	95.24	3.47	-	0.18	1.19
	GS38	SP	0.29	99.71	-	-	0.53	0.57
	BOR13	SP	7.17	91.02	0.56	1.25	0.79	1.41
	BOR34	SP	1.95	96.22	0.58	1.25	0.62	1.26
	BOR35	SP	23.26	75.19	0.48	1.06	1.11	1.49
	BOR38	SP	0.12	98.30	0.94	0.65	0.43	1.00
	BOR43	SP	2.02	95.68	1.60	0.69	0.55	1.30
	BOR44	SP	0.47	97.16	1.69	0.69	0.48	1.15
	BOR45	SP	1.01	96.95	0.55	1.49	0.55	1.34
	GS37	SP	4.80	95.14	0.06	-	0.73	0.84
	BOR09	SP	5.45	91.94	0.82	1.78	0.54	1.57
	BOR17	SP	5.12	93.60	0.45	0.83	0.80	1.16
	BOR46	SP	1.20	96.16	1.33	1.31	0.52	1.35
Luquillo 2	GS49	SP	1.30	98.47	0.23	-	0.35	0.75
	GS50	SP	2.82	97.18	-	-	0.80	0.68
	GS51	SP	6.13	93.87	-	-	0.79	0.78
	GS52	SP	10.64	89.36	-	-	0.71	1.13
	GS53	SP	2.18	97.82	-	-	0.50	0.80
	GS54	SP	5.16	94.84	-	-	0.68	0.90

Sand Source Designation	Sample ID	USCS	% Gravel	% Sand	% Silt	%Clay	Mean (mm)	Standard Deviation (phi)
	GS55B	SP	0.25	99.49	0.26	-	0.34	0.87
	GS56	SP	1.89	97.97	0.13	-	0.52	0.90
COMPOSITE Luquillo 1		**SP**	**4.27**	**94.15**	**0.85**	**0.73**	**0.58**	**1.17**
COMPOSITE Luquillo 2		**SP**	**3.80**	**96.13**	**0.08**	**-**	**0.59**	**0.85**

1 Grain size analysis results are directly derived from Schwab et Al, 1996 publication

4.2 RINCON OFFSHORE SAND SOURCES

The evaluation of the Rincon offshore sand source is based on existing data collected by the University of Puerto Rico - Mayaguez Campus which collected geophysical data and surficial samples at the Bajo Blanco (Canals M. Ph et al, 2018; Rojas Vázquez C.A., 2016). The Bajo Blanco is an approximately 5,000-foot long sand shoal located less than 500 feet offshore the northern part of the Rincon project and immediately south of the Tres Palmas Marine Preserve (**Figure 4-7**). The water depths of the shoal are 0 to 5 feet. This is the only offshore sand source in the proximity of the Rincon project area.

Boring data are not available for the Bajo Blanco sand source. The only available grain-size analysis data is from the eighteen (18) surficial samples collected in the context of the geophysical investigation (Rojas Vázquez C.A., 2016). The sample locations are depicted in **Figure 4-7** and listed in **Table 10**.

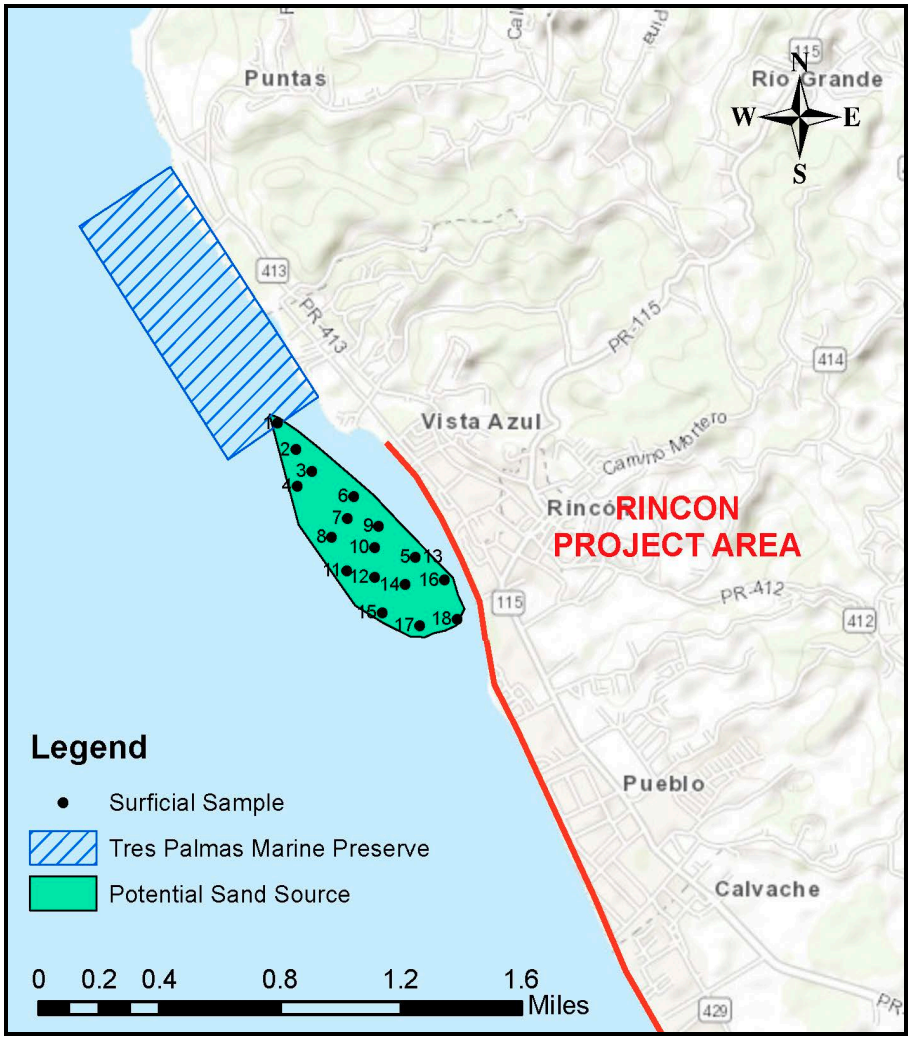

Figure 4-7. Bajo Blanco Potential Sand Source, Rincon

Table 10. Rincon Surficial Sample Locations (Rojas Vázquez C.A., 2016)

Samples Designation	Latitude	Longitude
1	18.344550	-67.263767
2	18.343300	-67.262850
3	18.342267	-67.262050
4	18.341567	-67.262767
5	18.338233	-67.256783
6	18.341100	-67.259933
7	18.340050	-67.260233
8	18.339167	-67.261017
9	18.339700	-67.258650
10	18.338680	-67.258860
11	18.337567	-67.260250
12	18.337283	-67.258833
13	18.338233	-67.256783
14	18.336933	-67.257317
15	18.335583	-67.258450
16	18.337150	-67.255317
17	18.334983	-67.256550
18	18.335300	-67.254670

Grain size analyses were performed on all 18 samples. The available granularmetric data of the samples are summarized in **Table 11**. All sample data is derived directly from Rojas Vázquez C.A., 2016. Sieve data, gradation curves and granularmetric reports are not available for the dataset. The available granularmetric data of the individual samples shows that the Bajo Blanco sand deposit is very homogeneous. The arithmetic composite sample created using all 18 samples characterizes the material as poorly graded fine-grained sand (SP) with a mean grain size of 0.24 mm. Color data was not available.

Table 11. Rincon Surficial Sample Grain-sizes (Rojas Vázquez C.A., 2016)

Sample Designation	Mean Grain-size (phi)	Mean Grain-size (mm)	Standard Deviation (phi)
Sample#/1	2.18	0.22	0.49
Sample#/2	2.05	0.24	0.62
Sample#/3	2.13	0.23	0.65
Sample#/4	2.17	0.22	0.49
Sample#/5	2.05	0.24	0.58
Sample#/6	1.49	0.36	1.04
Sample#/7	2.10	0.23	0.58
Sample#/8	2.02	0.25	0.61
Sample#/9	2.12	0.23	0.53

Sample Designation	Mean Grain-size (phi)	Mean Grain-size (mm)	Standard Deviation (phi)
Sample#l0	2.07	0.24	0.68
Sample#/11	2.20	0.22	0.51
Sample#/12	2.19	0.22	0.47
Sample#/13	2.16	0.22	0.49
Sample #/14	2.08	0.24	0.55
Sample#/15	2.00	0.25	0.62
Sample#/16	2.13	0.23	0.52
Sample#/17	2.12	0.23	0.55
Sample#/18	2.22	0.22	0.58
COMPOSITE	**2.08**	**0.24**	**0.59**

Even though the available data shows that the sand deposits from Bajo Blanco is beach compatible, its use as sand source may be limited due to its close proximity to the shoreline and the Tres Palmas Marine preserve.

4.3 UPLAND SAND MINES

There are upland sand mines available for both project areas, which are described in the paragraphs below.

4.3.1 SAND JUAN UPLAND SAND MINE- CONCRETOS DE PUERTO RICO, INC.

The only currently known sand mine close to the San Juan project site is the Concretos De Puerto Rico, Inc. sand mine located in Juncos, approximately 30 Miles south of San Juan (**Figure 4-8**). The sand mine is located in the immediate vicinity of the river Rio Valenciano and the sand is derived from the alluvial flood plain. The sand mine has a sand washing and sorting plant to customize the grain-size distribution.

The USACE visited the sand mine and collected three representative sand samples. Two samples, Concretos 1 and Concretos 2 were collected from the mined land and were in unprocessed condition. One sample was collected from a stockpile after it was processed (washed). The samples were collected approximately 0.5 to1.0 foot below ground surface. The location of the sand samples are listed in **Table 12** and depicted in **Figure 4-9**.

Table 12. Concretos Sand Mine, Juncos, Sample Locations

Sample Designation	PR VI State Plane NAD83 US Foot	
	X	Y
Concretos 1	836501	803791
Concretos 2	834870	801163
Stockpile 3	836703	800362

Figure 4-8. Concretos Upland Sand Mine Location

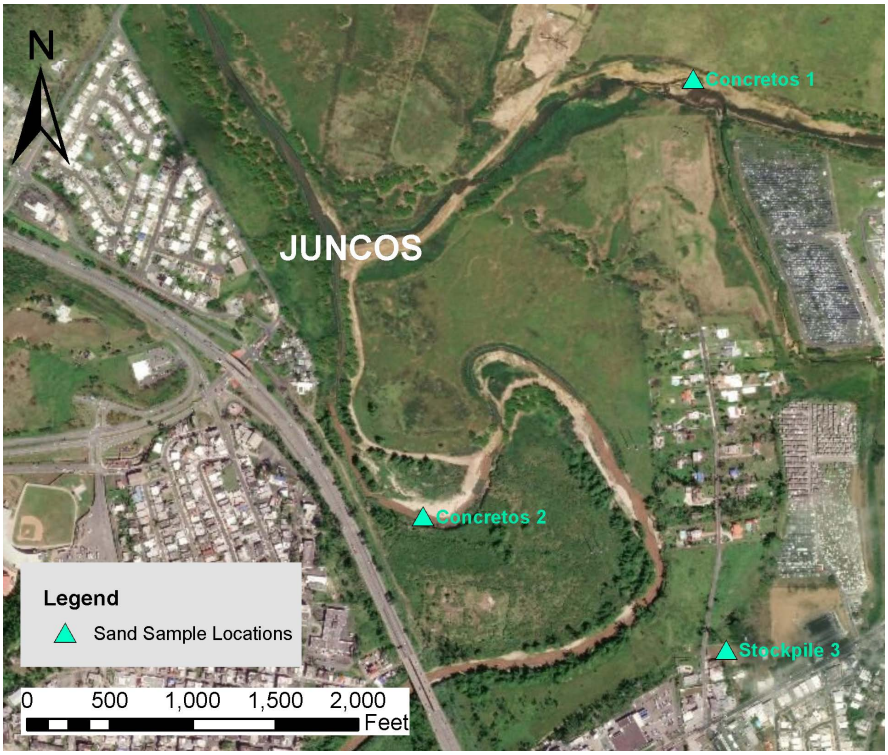

Figure 4-9. Sample Locations Concretos Sand Mine

Grain size analyses were performed on all three (3) samples. The granularmetric data of the samples are summarized in **Table 13**. Gradation curves or granularmetric reports are attached in **Paragraph 8.1.2**. The unprocessed samples Concretos 1 and Concretos 2 are characterized as poorly-graded, fine-grained sand with silt (SP-SM) with a mean grain size of or 0.37mm and 0.30mm respectively, 6% percent fines (or less) passing the #230 sieve, and brown in color. The processed sample, Stockpile 3, is classified as poorly graded medium-grained sand (SP) with a mean grain size of 0.58mm, 4.5 percent of fines passing the #230 sieve, and pale brown in color.

Table 13. Concretos Sand Mine Grain-size Analysis Results

Designation	USCS*	Mean (mm)	Sorting (phi)	Retain. on # 4 Sieve %	Silt Pass. #230 Sieve %	Visual Shell in %*	CaCo3* in %	Moist Munsell Color
Concretos 1	SP-SM	0.37	0.99	0.86	5.97	2.70	0.00	10YR 4/3
Concretos 2	SP-SM	0.30	0.92	0.37	5.75		0.00	10YR 5/3
Stockpile 3	SP	0.58	1.08	1.15	4.51	2.40	0.00	10YR 6/3
Composite	**SP**	**0.40**	**1.07**	**0.79**	**5.41**	**2.55**	**0.00**	**brown**

4.3.2 RINCON UPLAND SAND MINE

An upland sand mine is located approximately 2 Miles south of Rincon (**Figure 4-10**). The sand mine was visited by USACE personnel in fall 2019. The mine was not actively operated at the time. Therefore, two samples were collected from the old quarry site (M-3) and a sand mine parcel (M-2). Three additional samples (Sample 1 through 3) were collected during a second visit in November 2019 from a property on the southern boundary of the mine, assuming that the material would be similar to the material in the mine since it is geologically from the same unit. The location of the sand samples is listed in **Table 14**, and depicted in **Figure 4-10**.

Table 14. Rincon Sand Mine Sample Locations

Mine	Sample Designation	PR VI State Plane NAD83 US Foot	
		X	Y
Rincon Sand Mine	Rincon M-1	377560	830857
	Rincon M-2	376711	830548
Rincon Private Property	Sample 1	376195	831387
	Sample 2	376194	831185
	Sample 3	376193	830983

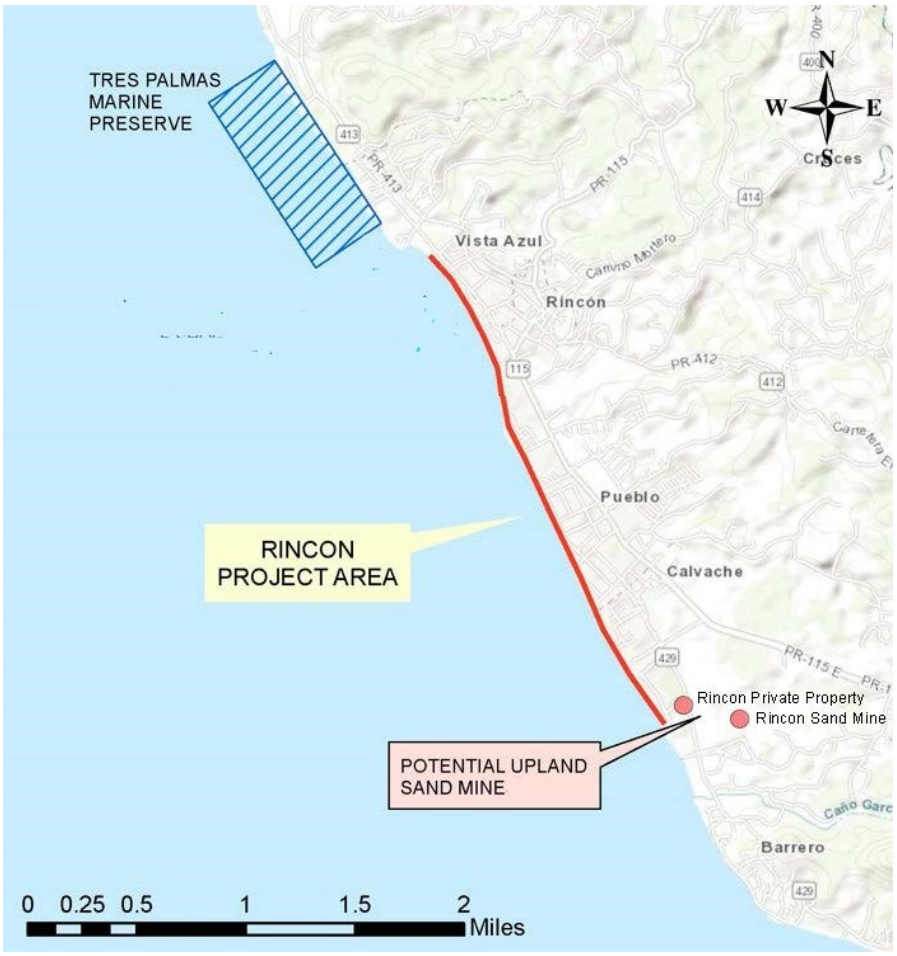

Figure 4-10. Rincon Upland Sand Mine Sample Location

Grain size analyses were performed on all five (5) samples. The granularmetric data of the samples are summarized in **Table 15**. Gradation curves and granularmetric reports are attached in **Paragraph 8.2.2**.

Table 15. Sample Locations Rincon Sand Mine

Location	Sample Name	USCS	Mean (mm)	Sorting (phi)	Retain. on # 4 Sieve %	Silt Pass. #230 Sieve %	Visual Shell in %*	CaCo3* in %	Moist Munsell Color
Rincon Mine	M-2	SP	0.52	0.67	0.46	0.0	19.2	25.3	10YR 4/2
Rincon Mine	M-3	SP	0.38	0.75	0.00	1.62	0.0	14.7	10YR 5/1
Rincon Private Property	1	SP	0.43	0.72	0.00	2.38	20.8	1.8	10YR 5/6
Rincon Private Property	2	SP	0.44	0.85	0.29	3.25	0.0	11.9	10YR 6/3
Rincon Private Property	3	SP	0.47	0.73	0.00	2.62	31.0	8.5	10YR 5/4
RINCON UPLAND COMPOSITE		**SP**	**0.45**	**0.75**	**0.15**	**2.47**	**12.44**	**23.67**	**Grayish Brown**

The samples from the mine, M-1 and M-2, are characterized as poorly-graded, fine to medium grained sand (SP) with a mean grain size of 0.52 and 0.38mm, respectively, less than 2% percent

fines passing the #230 sieve, and brown and gray in color, respectively. The three samples (Sample 1 through 3) from the private property outside the mine are very similar and are characterized as poorly-graded medium-grained sand (SP) with a mean grain size of or 0.43, 0.44, and 0.47mm, respectively, with 3.25 percent (or less) of fines passing the #230 sieve, and grayish brown in color.

5 SAND SOURCE COMPATIBILITY AND VOLUMES

The compatibility of the San Juan and Rincon beaches with the sand sources and the respective volume estimates are summarized in the paragraphs below. Gradation graphs and granularmetric tables for the composite samples are included in **Paragraph 8.1.4** for San Juan and **Paragraph 8.2.3** for Rincon.

5.1 SAN JUAN SAND SOURCE COMPATIBILITY

Beach compatible sand for San Juan Beaches is available from one proposed nearshore sand source, La Esperanza, two proposed offshore sand sources, Luquillo 1&2, and one upland sand mine (**Figure 5-1**).

Figure 5-1. San Juan Project Area and Sand Sources Locations

Arithmetic composite calculations were completed for the beach, nearshore, offshore, and upland sand deposits. The arithmetic composite sample granularmetric parameters are summarized in **Table 16**.

Table 16: San Juan Grain Size Summary Beaches and Sand Sources

SOURCE	USCS[1]	Gravel[2] %	Silt[3] %	Mean (mm)	Standard Deviation (phi)
BEACH					
San Juan Beaches	SP	0.16	2.29	0.21	0.86
NEARSHORE SAND SOURCES					
La Esperanza	SP	5.13	3.73	0.36	1.62
POTENTIAL OFFSHORE SAND SOURCE					
Luquillo 1	SP	4.27	1.58	0.58	1.17
Luquillo 2	SP	3.80	0.08	0.59	0.85
UPLAND SAND SOURCE					
Concretos Sand Mine	SP	0.79	5.41	0.40	1.07

[1] *United Soil Classification System*

[2] *Gravel % = Percent Retained #4 Sieve*

[3] *Silt % = Percent Passing #200/230 Sieve*

The composite gradation graphs of the La Esperanza material and the of San Juan beaches is depicted in **Figure 5-2**. The composite gradation graphs of the upland mine Concretos material and the of San Juan beaches is depicted in **Figure 5-3**. A gradation graph for the offshore sand sources could not be created since individual sieve data was not available.

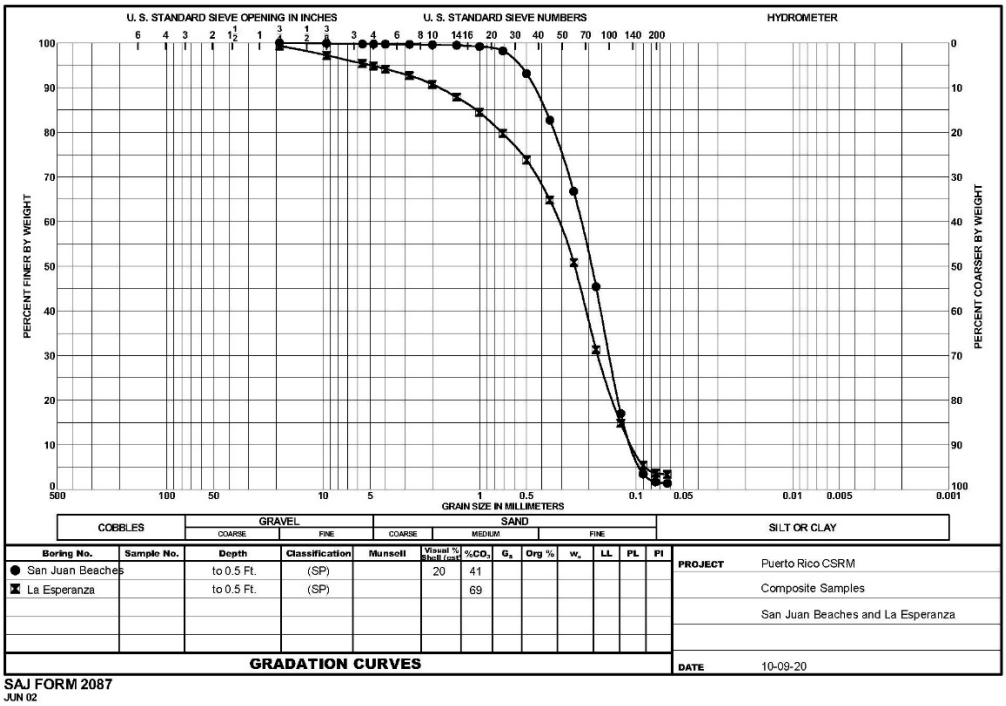

Figure 5-2. Composite Samples Graphs of San Juan Beaches and Nearshore Sand Source

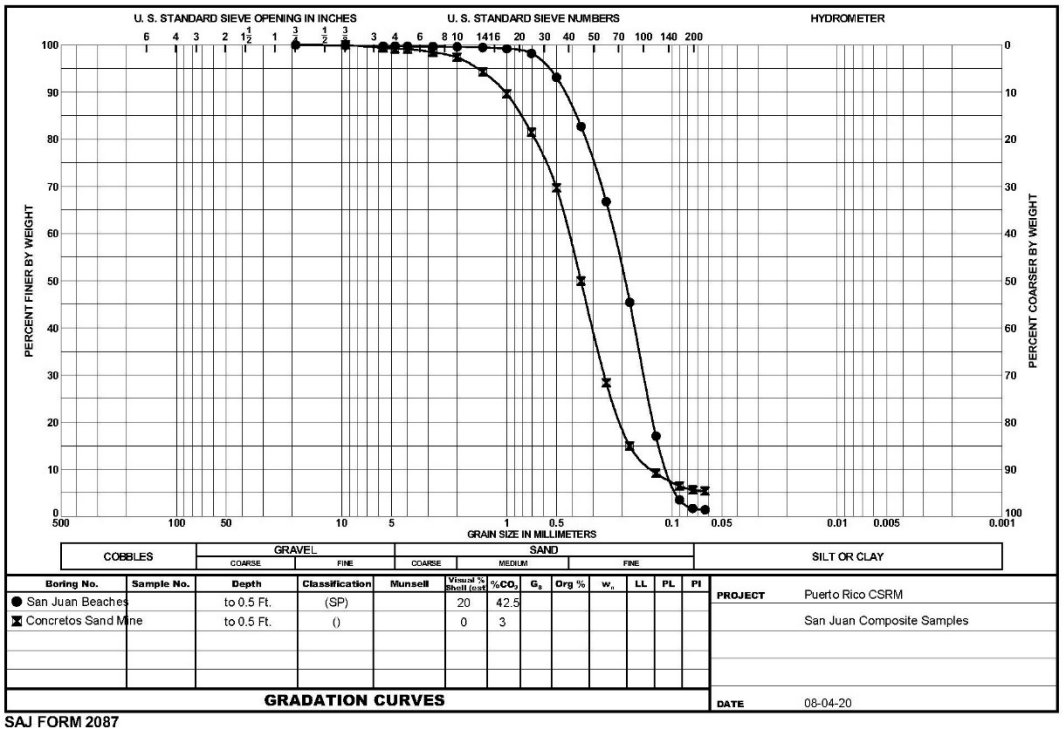

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Figure 5-3. Composite Samples Graphs of San Juan Beaches and Upland Sand Sources

The beach deposits consist of poorly graded fine-grained sand with a mean grain size of 0.21mm. The material from the nearshore, offshore, and upland sand sources is coarser than the existing beach sediments and consists of poorly graded fine to medium grained sand with a mean grain size of 0.36, 0.58, 0.59, and 40 mm, respectively. The coarser grain-size of the offshore sediments is due to the gravel sized shell content.

In summary, the La Esperanza nearshore sand source, the Luquillo offshore sand sources and the Concretos upland mine sediments are beach compatible and are similar to the sediments of the existing San Juan beaches.

<u>Sand volumes are estimated as follows:</u>

- La Esperanza is a Regional Sediment Management sand source with an estimated sand volume of 200,000 cubic yards of sand.
- Luquillo 1 is approximately 170 acres in size. The sand thickness is conservatively estimated to be 5 feet, resulting in approximately 1.2 Million cubic yards of sand.
- Luquillo 2 is approximately 480 acres in size. The sand thickness is conservatively estimated to be 5 feet, resulting in approximately 3.5 Million cubic yards of sand.
- The Concretos sand mine has several million cubic yards of sand available to be mined.

5.2 RINCON SAND SOURCE COMPATIBILITY

Beach compatible sand for Rincon Beaches is available from an upland sand mine and potentially from an offshore sand source, Bajo Blanco (**Figure 5-4**).

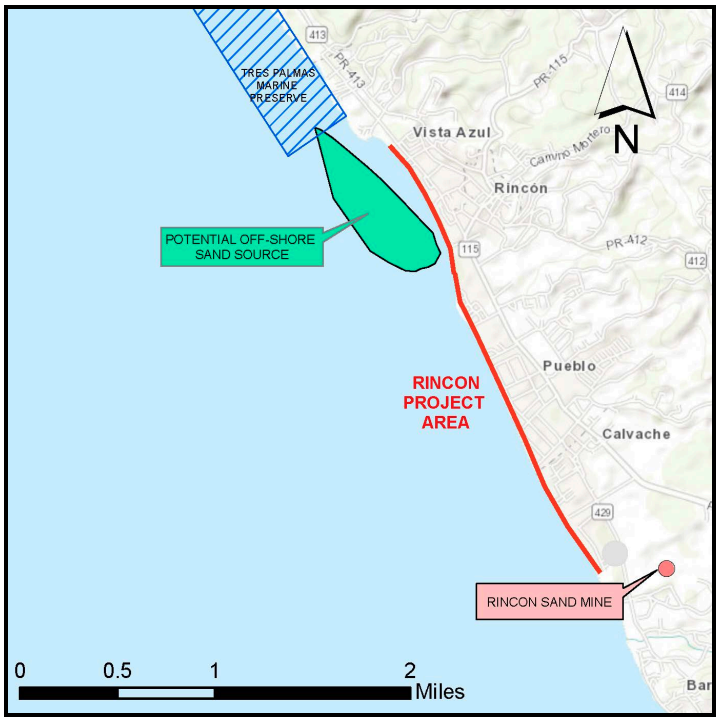

Figure 5-4. Rincon Project Area with Upland and Offshore Sand Source Locations

Arithmetic composite samples were created for the beach, the offshore, and the upland sand sources. The arithmetic composite sample's granularmetric parameters are summarized in **Table 17**.

Table 17: Rincon Grain Size Summary for Beaches and Sand Sources

SOURCE	USGS[1]	Gravel[2] %	Silt[3] %	Mean (mm)	Standard Deviation (phi)
BEACH					
Rincon Beaches	SP	0.41	0.85	0.34	0.97
POTENTIAL OFFSHORE SAND SOURCE					
Bajo Blanco	SP	n/a	n/a	0.24	0.59
UPLAND SAND SOURCE					
Rincon Sand Mines	SP	0.15	2.47	0.45	0.75

[1] *United Soil Classification System*

[2] *Gravel % = Percent Retained #4 Sieve*

[3] *Silt % = Percent Passing #200/230 Sieve*

The composite gradation graphs of the Rincon upland mine and the Rincon beaches, is depicted in **Figure 5-5**. A gradation graph for the offshore sand sources could not be created since individual sieve data was not available.

The material from the beach and the offshore sand source are similar and consist of poorly graded fine-grained sand with a mean grain size of 0.34 and 0.24mm, respectively. The material of the upland sand mine is coarser than the beach sediments and consists of poorly graded fine to medium grained sand with a mean grain size of 0.45mm.

In summary, the offshore and upland sand source sediments are beach compatible and are similar to the sediments of the existing Rincon beaches.

<u>Sand volumes are estimated as follows:</u>

- Only very limited volumes of sand should be considered for dredging from the Bajo Blanco to maintain the integrity of the shoal so as not to cause erosion at the nearby beaches. The Bajo Blanco is approximately 120 acres in size and, as a rough estimate, no more than 300,000 cubic yards should be dredged from the shoal.
- The volumes available from the Rincon sand mine are unknown but estimated to be at a minimum 300,000 cubic yards.

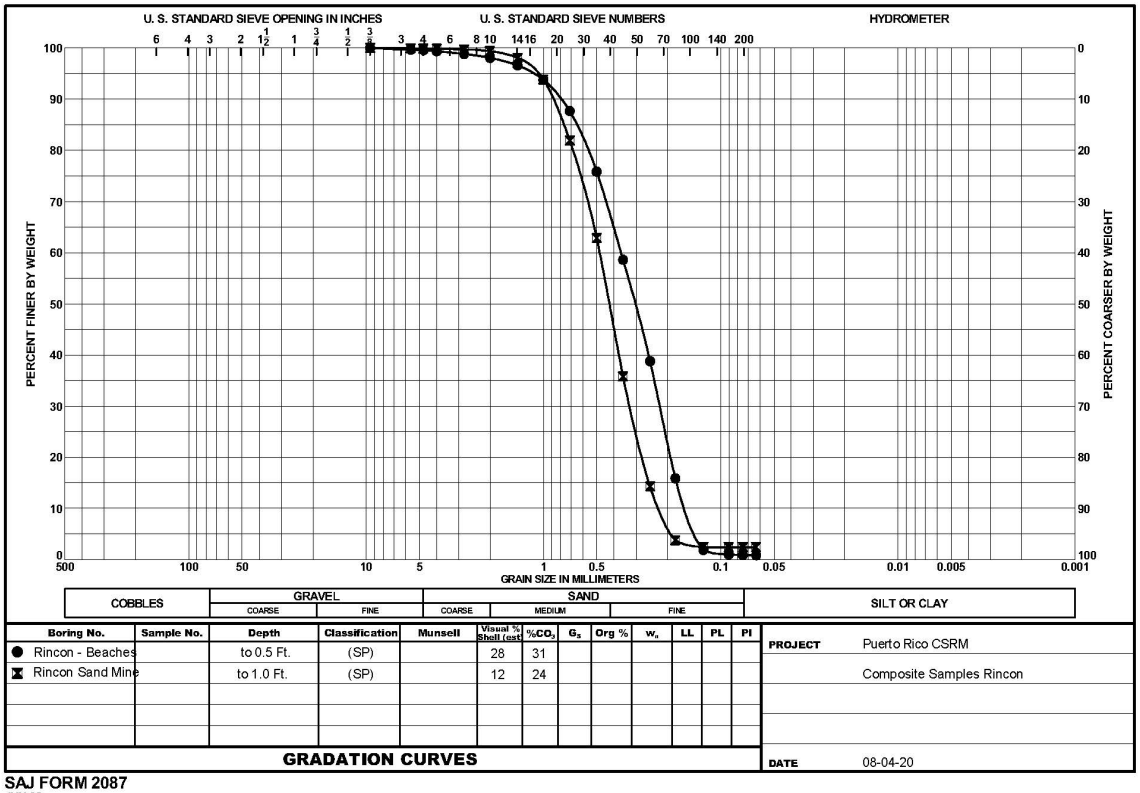

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Figure 5-5. Composite Samples Graphs of Rincon Beaches and Upland Sand Sources

6 ARMOR STONE

Armor stone for revetments is available for the San Juan and Rincon project areas from the armor stone quarries listed below and depicted in **Figure 6-1**. The quarries listed were either used or are being considered for use in other USACE projects in Puerto Rico. The distance to project sites is 25-35 miles.

- Cantera La Montana, Cadena
- Cantera Carraizo, Trujillo Alto
- Empresas Ortiz Brunet, Guaynabo

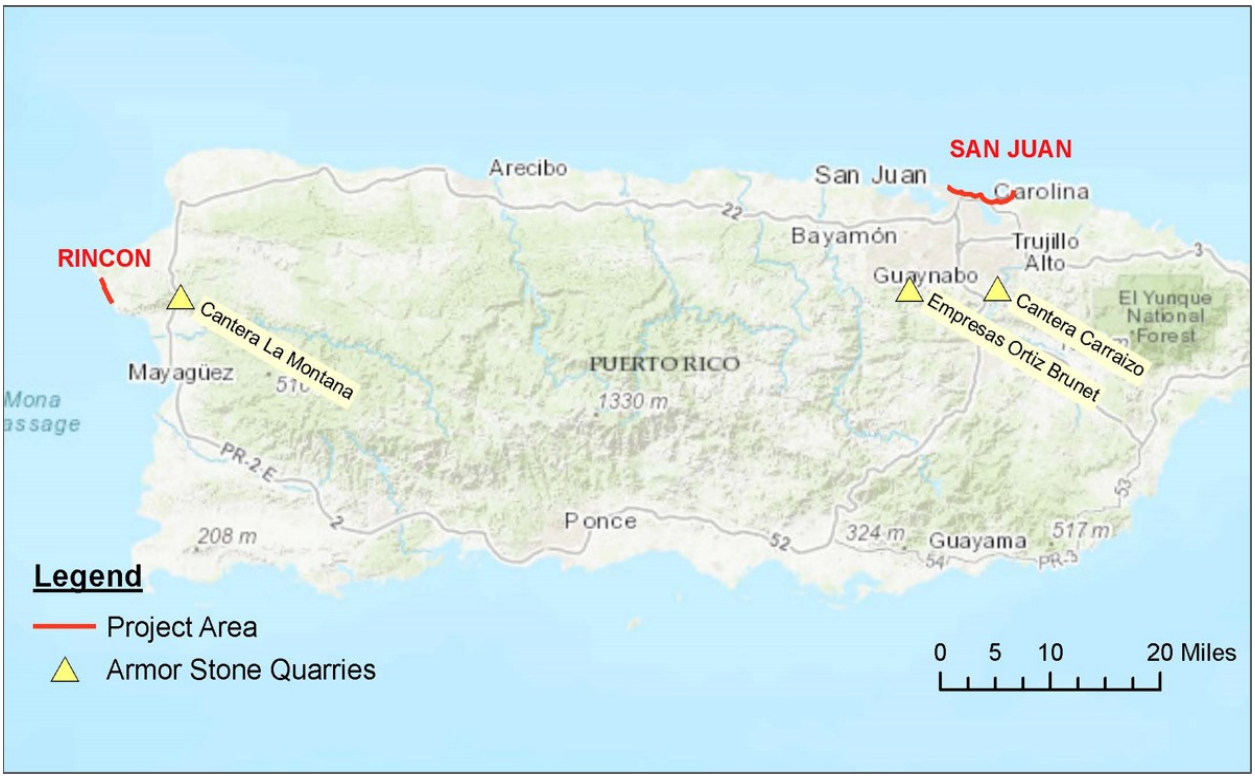

Figure 6-1. Armor Stone Quarry Locations

7 REFERENCES

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8 GRADATION GRAPHES AND GRANULARMERIC REPORTS

8.1 SAN JUAN

8.1.1 SAN JUAN BEACH

- Gradation Graphs
- Granularmetric Reports

8.1.2 SAN JUAN UPLAND MINE: CONCRETOS

- Gradation Graphs
- Granularmetric Reports

8.1.3 SAN JUAN: LA ESPERANZA POTENTIAL SAND SOURCE

- Boring Logs
- Gradation Graphs

8.1.4 SAN JUAN COMPOSITE SAMPLES

- Gradation Graphs
- Granularmetric Reports

8.2 RINCON

8.2.1 RINCON BEACH

- Gradation Graphs
- Granularmetric Reports

8.2.2 RINCON UPLAND MINE

- Gradation Graphs
- Granularmetric Reports

8.2.3 RINCON COMPOSITE SAMPLES

- Gradation Graphs
- Granularmetric Reports