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Inventory of Sand Borrow Sites along New York's Ocean Shoreline & their sustainable management

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Stony Brook University's COAST Institute

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Inventory of Sand Borrow Sites along New York's Ocean Shoreline & their sustainable management

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INTRODUCTION

This report is intended to provide inventory of existing sand borrow areas in state and federal waters, and to explore the sustainability of offshore sand resources for long-term use. Potential areas of interest for alternative energy development also will be identified, and accounted for in the plan for sustainable management of sand borrow areas. There are some 44 borrow sites that have been used in the past or are proposed for use now or in the future. All of these are in State waters. Although borrow sites have not been designated in Federal waters, sand resources extend far offshore. Williams (1976) divided the south shore from Atlantic Beach (on the west end of Long Beach) to Montauk Point into nine potential borrow areas. He estimated the volume of sand suitable for beach nourishment in individual borrow areas ranged from 259 million to 1.5 billion cubic yards.

Along the shoreline, the quality of the sand in a borrow area must be compatible with the nearby beaches, that is borrow areas are chosen in conformance to beach compatible zones. A preliminary screening suggests that about 30% of the total, natural sand reserves could be suitable for beach nourishment (Bokuniewicz and Huang 2015). The most suitable source of sand is considered to be found in the modern (Holocene) sand cover on the shelf. Deposits of Holocene sand are found in both State and federal waters. They are generally less than four meters thick with a grain size between about 0.25 and 0.7 mm. Much of the resource is found in obliquely shore-attached ridges (Appendix 1). Holocene-aged sand thickness has been mapped in detail by Foster et al. (1999) and Schwab et al. (2003). Although the details are not available, Finkl (2009 as reported by S. Keehn, electronic communication) apparently calculated sand volumes contained in sand ridges between Watch Hill and Fire Island Inlet, 18 miles to the west, which lie between about 8 and 15 miles offshore in water depths up to 130 feet (40 m). The ridges contain a total of 18 billion cubic yards of sand. The total ridge area was about 285,000 acres, corresponding to about 63,000 cubic yards per acre of ridge area.

IDENTIFIED BORROW SITES

HISTORICAL SITES IN STATE WATERS

In 2007, The US Army Corps of Engineers initiated the Long Island Sediment Needs Assessment. As part of this effort, an inventory of existing and historical borrow sites had been developed for the Atlantic coast of Long Island. Mapping had been completed to show where material has been dredged and placed historically between 1994 and 2007(URS Group and

Moffatt & Nichol 2009). Each borrow area has been spatially referenced in a GIS database and any relevant information pertaining to the borrow area (i.e. mean grain size, volume available, etc.) had been included in the database when available.

Historically, borrow areas are distributed along the south shore in state waters between about the 37-foot (11-m) contour and the 60-foot (18-m)contour or about 1.8 miles from shore (Appendices 2,3,4, and 5). Delineations for the borrow areas were obtained from previous work done by URS[1] in 2000, from historic reports provided by USACE-NAN, and by direct correspondence with USACE-NAN. Some of these borrow areas have been dredged multiple times and may no longer contain usable sediment. Others are active borrow areas that have been designated for future beach fill projects.

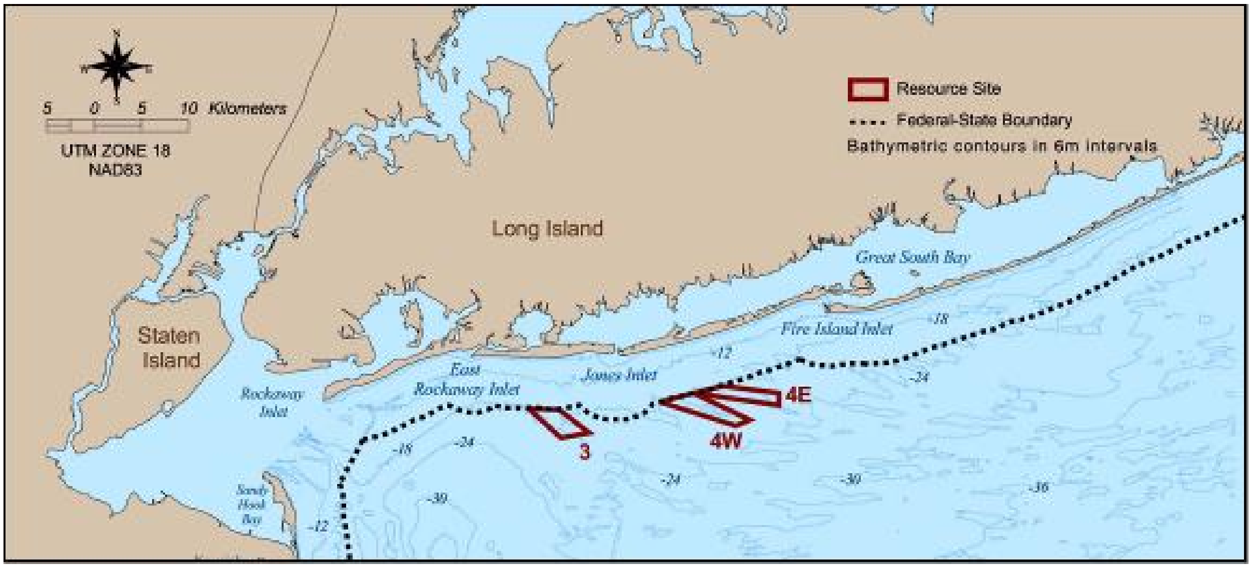

Figure 4. Potential borrow sites in Federal water (Byrnes et al. 2004).

FIMP SITES

The Fire-Island-to-Montauk-Point Reformulation Study (FIMP) of the New York District Corps of Engineers had identified eight (large rectangular) area in State waters along New York's ocean shoreline from Fire Island Inlet to Montauk Point within which borrow sites for individual nourishment projects were identified. Thirty-four borrow sites were delineated, although many have not been used.

POST-SANDY SITES

After "Superstorm" Sandy (October, 2012) beach renourishment projects and dune-building projects were implemented at Coney Island, Rockaway Beach, Long Beach, Jones Island, Fire Island , and Smith Point County Park. The 600,000 cubic yards of sand needed for restoration project at Coney Island was taken as a beneficial use from the Jamaica Bay Federal Navigation

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[1] http://www.urs.com/services/environmental/

Channel and from the Gravesend Bay shoreline at Sea Gate (Fall, 2013). There has been reconstruction work at Rockaway peninsula (3.5 million CY) and Long Beach. The Long Beach borrow area is shown in Figure 5. Jones Island received 1.9 million CY in 2013-14. The dune building on Fire Island is to be supplied from three offshore borrow areas in State waters (Figure 6a).Two offshore borrow sites a little over 0.5 n. miles offshore of Smith Point County Park were used for restoration efforts involving about 1.5 million CY in the Park. (Figure 6b). Quantities of sand that remain available in the identified borrow areas following these projects has not been determined.

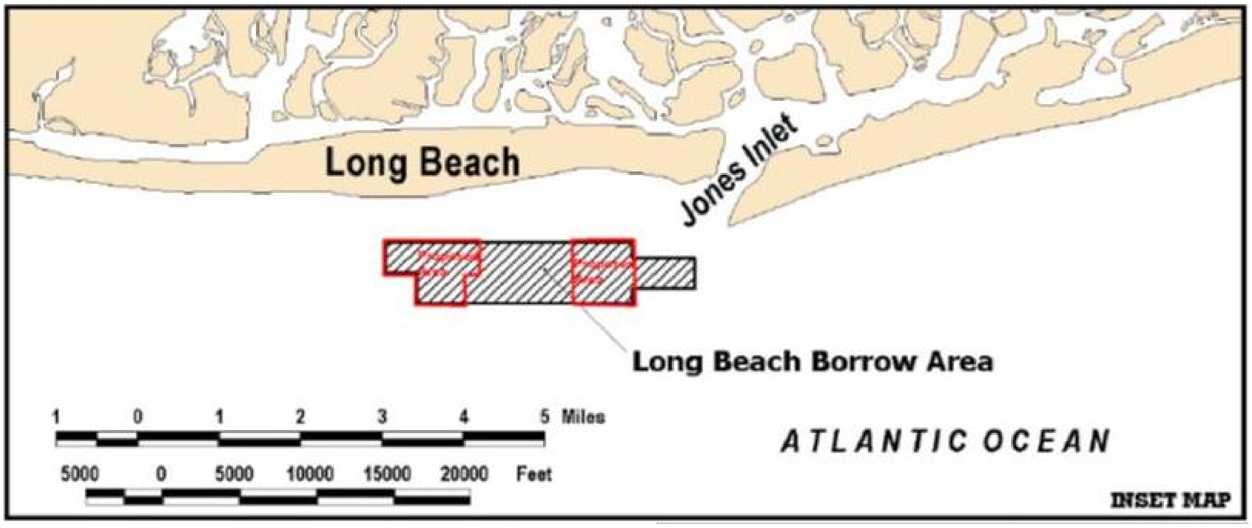


Figure 5. Borrow area for the restoration at Long Beach after Sandy. The borrow area is estimated to contain 36 million cubic yards (USACE 2014).

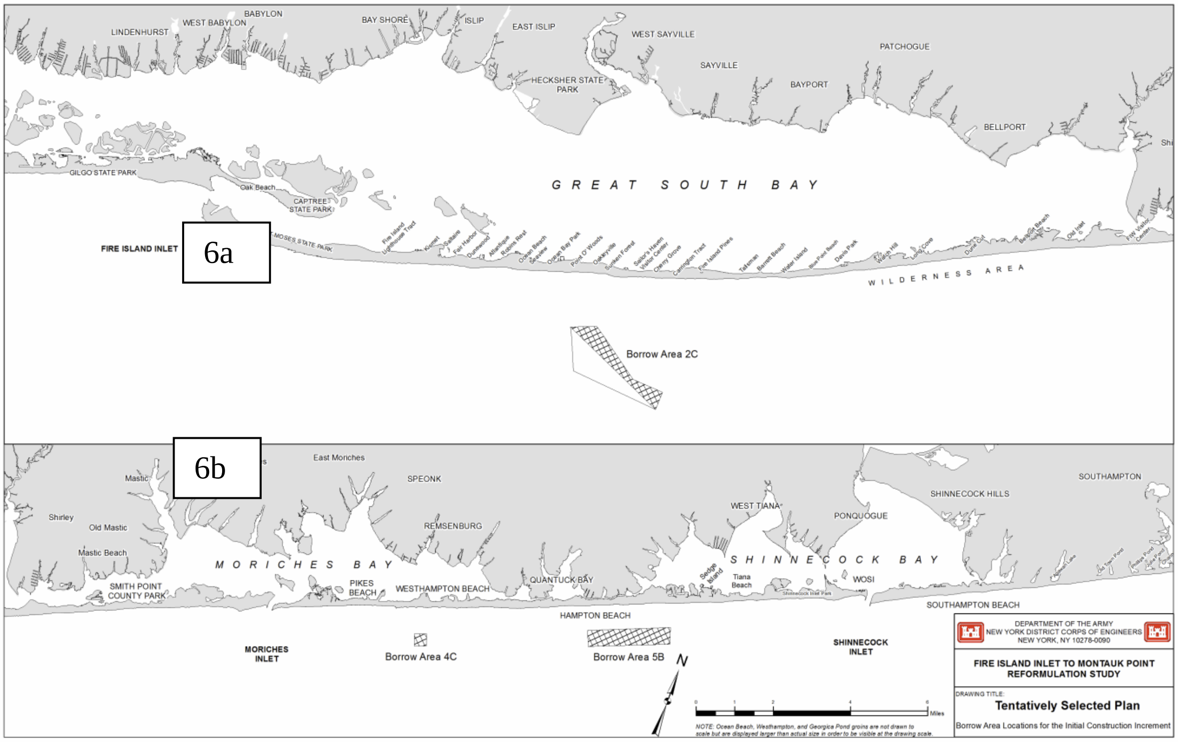


Figure 6a and b. Borrow areas for the post-Sandy restoration on Fire Island.

POTENTIAL SITES IN FEDERAL WATERS

As part of the Mineral Management Service (now the Bureau of Ocean Energy Management, or BOEM), effort Byrnes et al. (2004) examined the potential physical and environmental impacts of sand extraction from ridges and shoals at three potential sites in Federal waters south of Long Beach and Jones Beach on Long Island (Figure 4). The northern boundaries of the sites were three nautical miles offshore. Ridges in these areas range from 7 to 13 feet (2 to 4 meters) in height above the sea floor. Water depths over the ridges range from 55 to 66 feet (17 to 20 meters). In assessing physical and biological impacts of dredging, Byrnes et al. (2004) assumed ridges at the three sites would be excavated to the elevation of the ambient sea floor. Dredging these sites to a depth of 3.9 to 5.8 feet (1.2 to 1.8 meters) below the existing sea floor, depending on the specific site, would yield an approximate total volume of 62,300,000 cubic yards of sand and involve dredging a total area of 7,600 acres.

AVAILABLE SAND RESOURCES

Off the south shore of Long Island, unconsolidated sediments reach a maximum thickness of about 1.9 miles (3 kilometers) essentially giving a volume of material approaching eighty trillion cubic yards (sixty trillion cubic meters). Of course, not all this is sand, and only a fraction of the sand is both within the reach of dredging technology and suitable quality for beach nourishment. Bliss et al. (2009b) suggested the maximum practical limit for dredging is 130 feet (that is, 40 meters to the bottom of the sand resource to be extracted, as for example, 30m of water over 10m of suitable sand resource). Recovery of offshore sand is typically done with a trailing-suction hopper dredge and the digging depth is limited by the length of the dragarms. The U.S. dredging fleet has a maximum digging depth of 33 m (Randall et al. 2011; Bruun et al. 2005). European "jumbo" dredgers can reach to depths of 35 to 50 m (van Overhagen et al. 2004; Randall et al. 2011; Bruun et al. 2005), but the Jones Act requires that waterborne movement of commodities within the United States must take place on a U.S.-built, U.S.-owned, U.S.-flagged, and U.S.-crewed vessel.

Bliss et al. (2009a) used existing sedimentological data and probability statistics to model the amount of undiscovered Holocene-aged sand, presumably suitable for beach nourishment, contained in an area extending from a water depth of 33 feet (10 meters) to a depth of 131 feet (40 meters) off the south shore of Long Island between Long Beach and Montauk Point. Bliss et al. (2009a) believed offshore sand resources should only be considered if the borrow area is seaward of the active zone of significant nearshore sediment transport which they put at about 33 to 39 feet (10 to 12 meters) water depth, and in sufficiently shallow water so that sand can be extracted within U.S. dredging equipment limits. They estimated the mean volume of undiscovered Holocene sand in this 867,000 acres tract was 2.2 billion cubic yards or about 2,500 cubic yards per acre, although not all this sand would necessarily be available for extraction due to political, environmental, geographical, geological or other factors (Bliss et al., 2009a).

Based on an analysis of core samples and (widely spaced and relatively low resolution) seismic records taken along the stretch of coast between Tobay Beach and Montauk Point, Williams (1976) estimated that between 5.3 and 7.3 billion cubic yards) of sand was available for recovery with the dredging techniques available at that time in the area between the beach and a depth of 32 m. This area is approximately 369,000 acres giving an average of between 14,400 and 19,800 cubic yards per acre. These estimates include both the modern Holocene-aged and Pleistocene-aged sands. However, more specific estimates based on high-resolution mapping of the sea floor and shallow stratigraphy (Foster et al., 1999) indicated that the study area between Tobay Beach and Montauk covered 290,000 acres between a water depth of about 83 feet and a distance of about 6.2 miles from shore; this area was estimated to contain approximately 1.3 billion cubic yards (one billion cubic meters) of Holocene-age sand (Williams, electronic communication, 2007).

The Corps estimated the proposed "Fire Island Inlet to Montauk Point Storm Damage Reduction" (FIMP) project will require about 55 million cubic yards (44 million cubic meters) of sand for beach nourishment over its 50 year lifetime, or 1.1 million cubic yards (0.9 million cubic meters) per year. This was based on the assumption that sea level is rising at a rate of 0.1 inch per year (3 millimeter per year). Estimates of the volume of beach compatible sand found on the shelf less than 130 feet (40 meters) deep range from about 1.3 billion cubic yards (1.0 billion cubic meters) to 7.3 billion cubic yards (5.6 billion cubic meters) depending on the geographic area considered and the data used (Foster et al., 1999; Williams, 1976). The projected volume of sand required for federal beach nourishment under the FIMP project, therefore, represents less than 5 percent of the accessible beach-quality modern sands. This calculation does not reflect any constraints associated with protecting onshore or local sediment transport processes, or environmental or operational constraints.

One way to estimate the volume of sand available in each borrow area is to multiply the area by one meter (Table 1). This accounting in Table 1 gives a total of about 75 million cubic yards (57 million cubic meters). Alternatively, the USGS isopach map of the Holocene sand (Foster et al. 1999) can be used to calculate the total volume of Holocene sand in each borrow area. For each borrow site, the average thickness of the Holocene sand can be calculated and multiplied by the area of the site. Holocene sand quantity estimates, do not include potential non-Holocene deposits in the area that may include suitable sand for beach nourishment. This accounting gives a total of about 52 million cubic yards (40 million cubic meters)

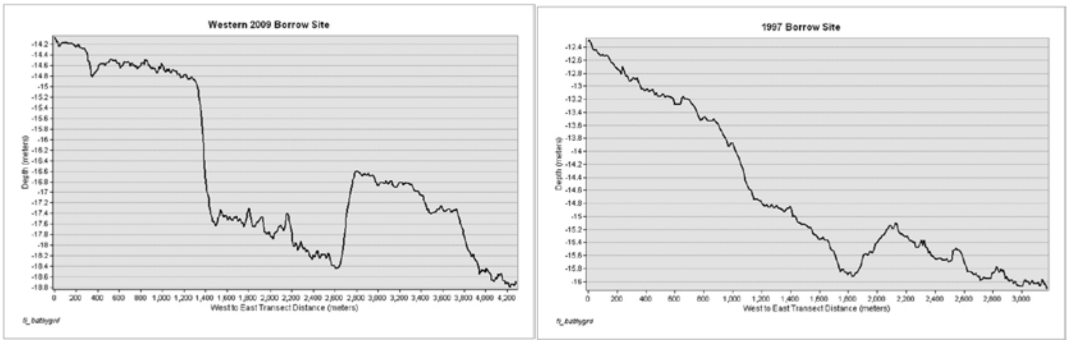
Table 1. Estimates of the volume of sand reserves (cubic meters) in designated borrow areas.

Borrow area	Appendix	Volume of Holocene sand	Sand volume assuming a one-meter layer	Differential*
1994 Saltaire/Fair Harbor/Dunewood Borrow Area	3	1,460,364	567,446	892,918
1997 Fire Island Pines Borrow Area	3	544,651	1,187,308	-642,656
1A	3	308,613	249,157	59,456
2A	3	1,633,180	1,148,402	484,778
2B	3	6,633,995	2,246,345	4,387,650
2C+2C expanded	3	11,262,288	5,405,601	5,856,687
2D	3	1,900,445	914,458	985,988
2F	3	660,410	248,832	411,577
2G	3	321,713	251,275	70,438
2H	3	73,941	244,080	-170,139
3A	3	1,994,471	3,692,438	-1,697,968
3B	3	194,501	247,584	-53,083
4A	4	39,270	283,204	-243,934
4B	4	805	343,103	-342,298
4C	4	176,938	253,897	-76,959
5A	4	101,768	618,995	-517,227
5B	4	711,655	2,339,261	-1,627,607
5B expanded	4	1,298,039	2,935,936	-1,637,897
6A	5	27,996	309,726	-281,730
6B	5	313,512	99,672	213,841
6C	5	60,272	442,859	-382,587
6E	5	226,759	258,038	-31,279
6F	5	68,017	242,587	-174,570
6G	5	66,153	239,456	-173,303
6H	5	71,640	239,343	-167,704
6I	5	17,314	248,177	-230,863
7A	5	51,123	852,131	-801,008
7B	5	4,333	246,105	-241,772
7C	5	924	252,848	-251,923
7D	5	92,460	251,230	-158,770
8A	5	293,810	2,428,643	-2,134,833
8B	5	373,698	252,415	121,283
8C	5	1,043,304	585,252	458,052
8D	5	21	242,668	-242,647
CI	2	0	1,555,587	-1,555,587
CP&E Western Borrow Area	3	847,084	845,740	1,344
CPE&E Eastern Borrow Area	3	1,995,657	629,864	1,365,793
Long Beach	2	0	6,417,025	-6,417,025
Shinnecock	4	4,802,941	13,327,953	-8,525,012
Westhampton Eastern Borrow Area	4	143,181	400,900	-257,719
Westhampton Western Borrow Area	4	35,794	422,232	-386,438
A-West	2	0	1,570,753	-1,570,753
A-East	2	0	1,599,536	-1,599,536
B-West	2	0	131,607	-131,607

* Values greater than zero indicate that more sand is found in the Holocene cover than would be recovered in the excavation of a uniform layer one-meter thick. A value less than zero means that the excavation of a uniform layer one-meter thick would provide more sand than is to be found in the Holocene layer alone.

BORROW SITE RECOVERY

Recovery and, subsequently, the potential reuse of designated borrow areas depends on the rate at which sand may be redistributed by natural processes on the sea floor, that is, excavated borrow areas may be naturally infilled with sand over time. The inner continental-shelf is a mobile sea bed; however, determining net sediment fluxes remains elusive. Even though there is a long history of interest in sand transport on the shelf, few specifics are known about these processes with confidence to allow forecasts. Ripples, megaripples and sand waves observed on the Long Island inner, middle and outer continental shelf, appeared to be formed by wind-forced currents (Swift et al. 1979a). Bottom currents to produce these features might be caused by the superposition of wave-orbital velocities and steady, unidirectional currents due to storm set-up or set-down (Bumpus 1973; Beardsley 1976, 1978; Boicourt and Hacker 1976; Csanday 1982). Numerical models of circulation and sediment transport have been used in the New York Bight to predict that winds from the northeast might generate currents strong enough to transport sediment in water depths between 20 and 50 m (Harris and Signell 1999; Butman et al. 2003) and that sand at the Historic Area Remediation Site (HARS) has been observed to be mobile (Butman et al. 2002). "Superstorm" Sandy mobilized sand on the lower shoreface and inner shelf of Fire Island. The storm conditions shifted large sand deposits many yards and caused deposition of layer of sand a foot or more thick in sections studied offshore of Fire Island (Goff et al. 2015). Rates of transport and regional patterns of pathways for mobile sand and the volumes and rates of transport are not well known. As a result, estimates of refilling cannot be made, but some excavated borrow sites appear to be recovering while others are not. Historical borrow areas were covered in the latest (2011) geophysical survey; evidence of infilling was recognized in borrow sites dredged in 1994 and 1996 (Schwab et al. 2013); "…the dredge sites (borrow sites) used for the 2009 beach nourishment projects can be identified easily on the bathymetric image collected in 2011, whereas older borrow sites show evidence of infilling, reformation of the sandridge system, or both…—additional evidence for the dynamic nature of the inner continental shelf" (Schwab et al. 2013). For example, a bathymetric profile across the CP&E Western Borrow Area clearly shows an area excavated in 2009 one to two meters below the ambient sea floor (Figure 7a) with no evidence of infilling. On the other hand, the Fire Island Pines Borrow Area excavated in 1997 is indistinct perhaps indicating that ambient sand transport has replenished the area (Figure 7b). The evidence is sparse, but infilling does seem to occur at some sites with recovery times on the order of decades.



a. b.

Figure 7. a. 2011 survey of the CP&E Western Borrow Area which had been dredged in 2009. b. 2011 survey of the Fire Island Pines Borrow Area which had been dredged in 1997.

RECOMMENDATIONS

Although the use of all these sites is described in permit condition, there is no comprehensive inventory keeping track of use. A continuing effort should be established to keep track of Corps' and State permits; such an inventory is needed to determine how previous uses affect the availability to use the borrow areas for the support of future demand.

Continued research is required in order to develop the scientific knowledge required to make fundamental decisions related to management of coastal resources. Quantifying the potential of offshore excavations to aggravate shore erosion, as has been done by Wilson and Hinrichs (2016), requires accurate mapping shelf bathymetry. In addition, better resolution will be needed of the shallow subsurface stratigraphy and sediment characteristics. The synthesis provided by Flood and Bokuniewicz (2015) presents the baseline from which the additional BOEM surveys and coring have been implemented. These new data now need to be synthesized and reinterpreted to better resolve potential sand resources.

The issue of infilling of previously excavated, offshore borrow areas will require additional research. Historical changes in the topography of the continental shelf of Long Island can provide a preliminary estimate of the resulting sediment mobility (e.g. Goff et al. 2015). Data is available for part of the study area, for example, between 1930 and 1975 (Gary A. Zarillo, 2015, SEA. Inc. and Florida Institute of Technology, Melbourne, Florida, personal communication). That any changes occur at all show that sand on the sea floor is undergoing active transport and sedimentation rates in the range of several centimeters per year are common. If the dredging removes a layer of sand a foot or so thick the recovery might occur in, say, a decade, assuming that the change in bathymetry does not itself alter any sedimentation rates. Comparisons should be made among surveys of the same area at different times to assemble such data.

Further quantification of shelf-sand transport will require the development of a physically-based numerical model using a coupled three-dimensional ocean and wave modeling system to predict the wind-driven waves, the regional ocean circulation patterns, the nearshore surf-zone wave-driven currents, and the resulting sediment transport due to bedload and suspended load processes. Numerical modeling of shelf-sediment transport might be developed as a three-dimensional coupled wave-ocean graphic-sediment numerical model following the work of Warner et al. (2008). This modeling will focus on two aspects: (1) understanding the existing wind-and wave-driven circulation and sediment transport of the region and (2) addressing the impact of the excavation of offshore sedimentary deposits on the circulation and sediment transport at the borrow site and onshore.

Results from numerical modeling then must be validated with data from an observational program before it can be used as a predictive tool. Data collection of wave-, tide-, and wind-driven currents, and sediment transport processes are required to provide practical values of the local conditions. Field measurements would need to focus on waves, currents, pressure, density, near-bed turbulence, and bed forms on the inner-shelf as well as and in the nearshore region and surf zone. Targeted experiments might consist of frame-mounted equipment deployed for several months in the offshore region and several weeks in the nearshore region to capture significant storm events. Bathymetric records including pre-excavation, post-excavation and long-term monitoring are needed to track behavior of borrow sites.

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APPENDICES: Inventory of New York's Sand Borrow

Appendix 1 : Sand-ridge formation and behavior.

In 2008, a two-day technical workshop on offshore sand resources south of Long Island was held to review what is known, or unknown, about the volume of offshore sand reserves, the potential for onshore transport, and the character of offshore sand ridges (Bokuniewicz, H. and J. Tanski. 2008. Long Island Offshore Sediment Resources: Workshop Summary, 42 pp. and Bocomazo, L., H.J. Bokuniewiz, and J.J. Tanski, 2011. Sand Resources offshore of Long Island (NY) Proceedings of the Coastal Sediments 2011(Volume 2): 1021-1033). Workshop attendees included researchers from federal agencies, academia and the private sector as well as federal, state and local agency representatives involved in coastal science or resource management. Part of that discussion involved the nature and role of shoreline-oblique sand ridges in nearshore sediment transport rates and pathways. The report concluded, among other things, that:

- Sand suitable for beach nourishment is found both in ridges and (more widely distributed) Pleistocene/glacial deposits.
- Accessible sand resources are found all along the coastline but are not uniformly distributed.
- There is geologic evidence that sand is being transported into the surf zone from beyond the surf zone.
- The strongest evidence of onshore transport of sediment is from along western Fire Island and points west.
- The published estimates of onshore transport range from 0% to 63% of the long shore transport estimates.
- There is active sand transport on sand ridges.
- These ridges are actively maintained by hydrodynamic processes in the coastal ocean. The types of hydrodynamic processes that might maintain these ridges have been postulated but their relative importance offshore of Long Island has not been quantified.

The relevant sections of the workshop report are reproduced in this appendix.

1. Sand suitable for beach nourishment is found both in ridges and (more widely distributed) Pleistocene/glacial deposits.

Sand deposits offshore of southern Long Island lie on a regional unconformity that truncates Cretaceous-aged coastal plain strata. In places, this Cretaceous-aged stratum is exposed at the sea floor and characterized by a gravelly, erosional lag deposit. This sediment deposit is composed of Pleistocene-aged glaciofluvial deposits, Holocene-aged reworked marine sand, and deposits filling an intricate paleochannel system cut into the Upper Pleistocene-aged surface, a ravinement surface formed during the last marine transgression (Foster et al., 1999). The Pleistocene-aged deposits are dominantly fine-grained to medium-grained sand but can include gravels (Schwab et al., 2000). The paleochannel fill can contain muddy sediment and peat layers. The Pleistocene-aged sediment is exposed at the seafloor or covered by a thin veneer, less than three feet, or one meter, of Holocene-aged fine sand which covers much of the inner shelf within 2.5 miles (4 km) of the shoreline west of Watch Hill. Holocene-aged or modern sediment is derived from the reworking of the underlying

Pleistocene-aged deposits and Early Holocene-aged, paleochannel fill deposits as well as of outcropping Cretaceous-aged strata.

The topography of the Middle Atlantic Continental Shelf both in New York and New Jersey is dominated by the shore-oblique ridges and swales, approximately northwest to southeast in orientation (e.g. Duane et al., 1972; Swift et al., 1984; Stubblefield et al., 1983; Swift et al., 1972). They are superimposed on large-scale, shoal-retreat massifs left by the Holocene transgression (Swift et al., 1973; Sanders and Kumar, 1975; Stubblefield and Swift, 1976). The oblique ridges south of Long Island are made up of sand reworked from these Pleistocene-aged deposits and Cretaceous-aged outcrops (Schwab et al., 2000).

In general, such features are classified as either inner shelf ridges, in water depths of less than 66 feet (20 meters), or middle shelf ridges 66 to 131 feet (in 20 to 40 meters) depth (Stubblefield et al., 1984; Swift et al., 1972; McKinney and Friedman, 1970; Rine et al., 1991)). Inner shelf ridges are oriented between about 15° and 30° to the shoreline (Duane et al., 1972), while middle shelf ridges are more nearly shoreparallel (Rine et al., 1991). The ridges are composed of very well to moderately sorted, medium to fine grain sand, compatible with beach type sand found along the south shore (Schwab et al., 1999; William, 1976). Inner shelf ridges in New Jersey show a nearly-uniform sediment texture vertically with the coarsest sand on the shoreward flank and the finest sand of the seaward flank (Stubblefield et al., 1984), while the middle shelf ridges tend to coarsen upward with the coarsest sand on the upper shoreward flank (Stubblefield et al., 1984).

The origin of these features has been the topic of considerable debate. Several lines of evidence that suggest the oblique sand ridges have relic origins, as (a) ridges from paleo (sub aerial) drainage (McKinney and Friedman, 1970), (b) abandoned ebb shoals (McBride and Moslow, 1991), (c) relic barrier islands (Stubblefield et al., 1984) or (d) drowned shorelines. Because sand ridges on the Long Island shelf paralleled the relict coastal plain stream drainage system visible on bathymetric charts, McKinney and Friedman (1970) suggested that the destruction of the drainage system had resulted in the ridge and swale topography by erosion of interfluve areas creating crests, and partial infilling of stream channels forming troughs. Based on radiocarbon dating of shells recovered in cores on the ridges, Stubblefield et al. (1983) suggested that shelf ridges evolved between 8,000 and 14,000 years BP during one of the sea level stillstands. Several stillstands had been identified by the occurrence of terraces on the outer shelf of Long Island (e. g. Veatch and Smith, 1939), and other evidence including the Block Island paleoshoreline at 79 feet (24 meters) below present sea level off Block Island (McMaster and Garrison, 1967) and the Atlantis paleoshoreline 131 feet (40 meters) below present sea level, south of Long Island (Dillon and Oldale, 1978). As such, these features would be relict of littoral processes which acted during lower stands in sea level. Ridges on the middle New Jersey shelf and Long Island shelf, for example, had been described as drowned, degraded barrier islands (Uchupi, 1970; Sanders and Kumar, 1975; Panageotou and Leatherman, 1986; Stubblefield et al., 1983, 1984). The absence of inlet filling sediments in cores between two and seven kilometers offshore of Fire Island was taken as indicative of overstepping and drowning of an inferred barrier island that existed seven kilometers seaward of Fire Island 8,500 to 9,000 years BP (Sanders and Kumar, 1975; Rampino, 1979; Rampino and Sanders, 1981b; Panageotou and Leatherman, 1986). Such evidence for the in-place drowning of the barrier island was contested by Leatherman and Allen (1985) and more recent, high-resolution mapping of the sea floor and shallow subsurface (Foster et al., 1999; Schwab et al., 2000) showed no evidence of an overstepped, drowned barrier island offshore of Long Island.

Another, speculation hypothesis for ridge origin was the drowning of shoreface-attached sand ridges forming parts of shoal-retreat massifs (Swift et al., 1979b, 1984). These sand ridges might be the result of the jet-like downwelling character of coastal geostrophic flow resulting from coastal storm set-up during sustained high energy winter winds (Stubblefield and Swift, 1976). Although Stubblefield et al. (1983) contended that such features on the inner shelf could not have survived the transgressing sea during sea level rise; it seems likely that the ridges off the south shore of Long Island were formed in response to the marine transgression.

2. Accessible sand resources are found all along the coastline but are not uniformly distributed.

While sand is relatively plentiful on along the Long Island coast compared to other areas of the eastern seaboard, supplies are not evenly distributed along the adjacent continental shelf. Williams (1976) divided the south shore from Atlantic Beach (on the west end of Long Beach) to Montauk Point into nine potential borrow areas. He estimated the volume of sand suitable for beach nourishment in individual borrow areas ranged from 259 million to 1.5 billion cubic yards (198 million to 1.1 billion cubic meters). Schwab et al., (2000) found a larger supply of Holocene-age sediments on the shelf west of Watch Hill, located in the central portion of Fire Island, than further to the east.

Although the details are not available, Finkl (2009 as reported by S. Keehn, electronic communication) apparently calculated sand volumes contained in sand ridges between Watch Hill and Fire Island Inlet, 18 miles (29 kilometers) to the west, which lie between about 8 and 15 miles (13 km and 24 km) offshore in water depths up to 130 feet (40 m). The ridges contain a total of 18 billion cubic yards (13.8 billion cubic meters) of sand. The total ridge area was about 285,000 acres (1154 km2), corresponding to about 63,000 cubic yards per acre (1.2 million cubic meters of sand per square kilometer) of ridge area.

3. There is geologic evidence that sand is being transported into the surf zone from beyond the surf zone.

Offshore sources of sand have long been hypothesized by various authors to account for the apparent increases in the longshore transport rates at Fire Island Inlet (Panuzio 1969, Taney 1961a, Williams 1976, McCormick and Toscano 1980, Kana 1995, Rosati et al., 1999, Bokuniewicz 1999, Schwab et al., 2000, Hapke et al., 2010). Other lines of evidence are provided by granulometry, mineralogical tracers, and acoustic images of sea floor texture; these will be discussed later. In this section, however, we will discuss (a) the various longshore sediment budgets that indicate an east-west deficit and (b) sand sources other than transport from beyond the surf zone that have been proposed to explain any deficit. It is to be noted that there is a good deal of uncertainty regarding the relative contribution of each of these sources to the littoral sediment system. Various sediment budgets have been constructed for the south shore of Long Island. These will not be examined in detail here but have been reviewed by Gravens et al., (1999) and more recently by URS Group and Moffat and Nichol (2009). Much of the basic data is the same for all these budgets although each adds refinement with any new information available at the time. Three points are noteworthy. First, there are inherently large uncertainties in the results. Discrepancies in long shore sediment transport estimates between studies can range from 262,000 to 392,000 cubic yards (200,000 to 300,000 cubic meters) per year. Not all the budgets are equally precise; some of the (earlier) budgets are semi-quantitative; and all must be examined and used with care. Second, existing sediment budgets usually cover the area from the dune to the depth of closure which is approximately 27 feet (8.2 meters) deep off the south shore, even though it is recognized that changes can occur beyond the depth of closure. (See the note on depth of closure at the end of this report). Third, the budgets cover different time intervals and periods making comparisons difficult. Differences in values derived from different time intervals may be due to actual changes or real variations in the transport rates over time or to uncertainties in the calculations.

The supply of sand from erosion of Montauk bluffs is an important starting point. Although a gradual decrease of angular grains coupled with an increase in rounded grains downdrift of Montauk Point was taken to show that bluff erosion is, at least, a partial source (Williams and Morgan 1988), several studies concluded that bluff erosion is not capable of supplying enough sand to beaches further west. Various estimates have been made, as discussed below, but all are substantially lower than longshore transport estimates for points further east.

Taney (1961a) estimated the supply rate of littoral sediments from headland erosion to be slightly less than 100,000 cubic yards per year (76,500 cubic meters per year). For the period between 1955 and 1979, Kana (1995) assumed a contribution of 144,000 cubic yards (110,000 cubic meters) per year by bluff erosion along Montauk, based on historical recession rates (Leatherman and Joneja 1980), bluff elevations, and subtidal volume changes. Rosati et al.(1999) used a reduced value of 43,000 cubic yards (33,000 cubic meters) per year for the 1979-1995 budget. Including very limited information on grain-size distributions, Bokuniewicz (1999) calculated that only between 8,000 and 27,000 cubic yards (6,100 and 21,000 cubic meters) per year of the total budget of beach quality sand could be delivered by bluff/headland erosion of the Montauk bluffs. A recent estimate based on profiles measured between 1995 and 2001 puts the total amount of sediment supply at 45,100 cubic yards (34,500 cubic meters per year) with 28,400 cubic yards (21,700 cubic meters) per year being beach-suitable sand (Buonaiuto and Bokuniewicz, 2005).

Estimates of the longshore transport rate in western Fire Island range between 254,000 cubic yards (194,000 cubic meters) (Gravens et al. 1999) and 600,000 cubic yards (460,000 cubic meters) (Panuzio 1969) per year to the west with an average of 415,000 cubic yards (317,000 cubic meters) per year (URS Group and Moffat and Nichol, 2009). Hapke et al., 2010 cite deficits of between 192,000 and 412,000 cubic yards (147,000 to 315,000 cubic meters) per year between Moriches Inlet and Fire Island Inlet for three published sediment budgets (Panuzio 1969, Kana 1995, Rosati et al., 1999). Beach sediments along Fire Island showed "marked" textural fluctuations, which supports contribution of sediments from a source other than Montauk (Williams and Morgan 1988). However, the deficits don't necessarily come from onshore transport of sand from the inner continental shelf. Panuzio (1969) and Rosati et al. (1999) indicated that the apparent deficit in their budgets could be explained by various factors including updrift beach nourishment and erosion as well as the uncertainty in the data. The reworking of glacial outwash sand, reworking of tidal ebb shoals, and onshore transport along shoreface attached sand ridges have been proposed. Taney (1961a) even originally suggested that streams may provide additional material to the south shore. However, Long Island's streams drain into bays behind the barrier islands and spits; therefore any amount of sediment discharged would likely be trapped in the bays. As expected, sediment analysis by Taney (1961b) showed these streams provide minimal, if any, contribution of sediments to the littoral zone.

Williams (1976) suggested offshore glacial outwash lobes as a source of littoral material. The excavation of the outwash plain, reworking of relic, glacial overwash lobes, however, could add sand to the littoral system over the long term, as the shoreline adjusts to rising sea level. In other areas, like North Carolina, the addition of sand from the reworking of pre-Holocene deposits is necessary to maintain existing barrier islands (McNinch et al., 1999). West of the Montauk bluff, the shoreface is cut directly into glacial outwash sands for distance of about 22 miles (35 kilometers) before the barrier islands are encountered. A comparison of grain-size distribution from subaerial outwash sand deposits with that of the Hamptons' beaches showed that about 45% of the outwash sand is suitable for the beach (Zimmerman, 1983). The outwash slope in the headland section averages 0.003 (Zimmerman, 1983). Beyond closure depth, the slope of the ramp is also 0.003. The ramp is parallel to the outwash surface but displaced downward an average of 44 feet (13.5 meters). The thickness of the reworked sediment (further to the west) has been estimated to be 16 feet (5 meters) (Rampino and Sanders, 1981b). Assuming an average-annual rate of sea-level rise of about one inch per decade (3 millimeters per year) (Hicks and Hickman, 1988), about 507,000 cubic yards (388,000 cubic meters) per year (Zimmerman, 1983) of glacial outwash sand would be mobilized over a 22-mile (35-kilometer) stretch of the shoreline between Montauk and Shinnecock Inlet, if this shoreface geometry is assumed to be constant as sea level rises. In principle, the incision of the shoreface into the outwash surface would liberate 228,000 cubic yards (174,000 cubic meters) per year of beach-compatible sand based on calculated long-term average recession rates.

Kana (1995), however, proposed hypothetical relict, ebb-tidal shoals contributed to the beach system, arguing an offshore source may be needed to support spit growth at the terminus of Fire Island (Democrat Point). As Fire Island migrated westward, trailing ebb shoals have been estimated to contain between 41 million cubic yards (31 million cubic meters) (URS Group and Moffat and Nichol, 2009) and 50 million cubic yards (38 million cubic meters) (Walton and Adams, 1976) of sand. The eventual stranding of ebb shoals, as inlets migrated westward in this case, and sea level rise have been postulated in other areas to be the origin of oblique ridges (McBride and Moslow, 1991). However, Schwab et al. (2000) found no evidence of such features and concluded they could not provide the amount of sand needed to balance the budgets. Alternatively, Schwab et al. (2000) proposed that the sediment source was derived from erosion of a Cretaceous-aged headland offshore of central Fire Island; this headland is now submerged but its bathymetric expression has been detected (Schwab et al., 2000).

Sand transported landward from the inner continental shelf is another potential source of material to the littoral system. Taney (1961a) believed that an offshore source would be minimal, and that updrift erosion of the headlands to the east, like that discussed above, was the probable source of additional sand required to meet the estimated longshore sand transport rates. Indeed, calculation of the volume of material that could result from headland erosion seems to show that this supply can account for much of the modern estimates of longshore transport along the Long Island Atlantic coast. Studies on Long Island and other areas have found that sand from the inner shelf contributes to beaches (Swift et al., 1985; Wright et al., 1991; Conley and Beach, 2003; Hinton and Nicholls, 2007). Cowell et al. (2000), for example, examined several sediment budgets compiled for the Netherlands, Australian, and southern Washington State coasts; their results indicated that a sand supply from the shoreface was needed to balance observed sediment gains. A similar conclusion has been reached recently along the west coast of Florida (Dean, 2009, personal communication) and along the northern coast of South Carolina (Gayes et al., 2003).

The sediment budget by Rosati et al. (1999) is the first to include estimates of uncertainties associated with the formulation of coastal sediment budgets along southern Long Island. Their estimates are likely the most accurate available although the time period for the analysis is limited to

16 years (1979 to 1995). Although a net sediment deficit is apparent in the values presented by Rosati et al. (1999), they suggest that this deficit can be accounted for by sediment contributions from erosion along the eastern portion of the barrier-island system and beach nourishment. Given this range of uncertainties, an offshore sediment source is not necessarily required. The range of uncertainties presented by Rosati et al. (1999), however, also allow for the possibility of a substantial offshore source. Rosati et al. (1999), however, calculated that onshore transport of 98,000 cubic yards (75,000 cubic meters) per year would be needed to support the maximum estimate of spit growth at Democrat Point of 311,000 cubic yards per year (238,000 cubic meters per year). To support Taney's "best" estimate of spit growth of 450,000 cubic yards per year or (344,000 cubic meters per year), onshore transport would have to be increased to 209,000 cubic yards per year (160,000 cubic meters per year) (Rosati et al., 1999).

More recent work by Batten (2003) described substantial volumetric gains to the coastal system based on an analysis of 3,136 beach profiles along the south shore of Long Island collected between 1995 and 2002 as part of the Atlantic Coast of New York Monitoring Program (ACNYMP). While the uncertainty is large, perhaps +80%, total residual volume change calculated for the south shore can be interpreted to represent an onshore transport rate of almost 785,000 cubic yards (600,000 cubic meters) per year between 1995 to 2001 (Batten, 2003). This was not uniformly distributed in space or time, however. Over the 6.25 years, the shoreline was calculated to have gained sand at a rate of about 929,000 cubic yards (710,000 cubic meters) per year updrift of Shinnecock. West of Shinnecock Inlet and on Fire Island east of Barrett Beach/Talisman, a net volume of about 400,000 cubic yards (306,000 cubic meters) per year were lost while the western stretch of Fire Island gained about 400,000 cubic yards (370,000 cubic meters) per year. Approximately 3.35 million cubic yards (2.56 million cubic meters) were lost from Jones Beach. The areas of gaining sand were associated with broad areas of relatively larger, Holocene-aged deposits on the inner shelf (Batten, 2003). The majority of these gains were observed to occur over the time period between Spring and Fall 1995, but not explained. Gains during this particular period could merely reflect temporal variations; although some systematic profile measurement error could not be completely ruled out. A visual check of individual profiles by Batten did not reveal any anomalies, so it seems that observed gains in sand are unlikely to be a result of profile measurement error.

Based on a field study of sediment transport of Long Island, Niedoroda et al. (1984) proposed that onshore/offshore transport was driven by wind-induced coastal upwelling. Storm events resulted in dominant shore parallel transport with a secondary, net offshore transport of sand from the littoral zone. While northeast winds would induce downwelling and offshore transport (Niedoroda et al., 1984) southwest winds along the coast would result in upwelling events inducing onshore sediment transport. Deposition was observed outside the surf zone on the middle to lower surface (<82 feet or 25 meters) and longer term equilibrium would be maintained by the gradual return of sand up the shoreface during non-storm conditions (Nierdoroda et al., 1984).

4. The strongest evidence of onshore transport of sediment is from along western Fire Island and points west.

Although the need to "balance" the sediment budgets is the strongest evidence of onshore transport, sedimentological and mineralogical evidence also have been reported (Williams and Morgan 1988). Such evidence for onshore transport of sand is strongest in the vicinity of Fire Island Inlet. Taney (1961b) found that the character of bottom nearshore and offshore sediments in depths up to 50 ft (15 m) were similar to material found along the beaches and nearshore bottom, noting that the transport mechanism “is not clear” but that it was “probable” that “some amounts” of the materials were transported into the littoral zone from offshore (Taney 1961b). Williams and Meisburger (1987) used glauconite grains from offshore source beds as a tracer of sediment transport. Glauconite grains, non-indigenous to terrestrial glacial deposits, were found in beach sands along Rockaway Beach, Long Beach, and Jones Beach and traced to offshore deposits via vibracore samples. Glauconite was not found onshore east of Jones Beach. The occurrence of euhedral quartz crystals linked sediments from offshore glacial outwash lobes to beach deposits along the western end of Fire Island, especially in the vicinity of Democrat Point. So, evidence for onshore transport of sand is strongest in the vicinity of Fire Island Inlet.

5. The published estimates of onshore transport range from 0% to 63% of the long shore transport estimates.

Using Kana’s sediment budget figures, Schwab et al. (2000) estimated a sediment flux of approximately 262,000 cubic yards (200,000 cubic meters) per year from offshore was necessary to balance the budget in this area. Similarly, URS Group and Moffat and Nichol (2009) reported that differences between potential net transport computed with the GENESIS one line shoreline change model and transport computed based on volume changes in central Fire Island indicated an onshore sediment flux of approximately 262,000 cubic yards (200,000 cubic meters) per year was needed to explain the well-documented relative shoreline stability in this area. Assuming this onshore transport rate and the average longshore transport rate of 415,000 cubic yards (317,000 cubic meters) per year (URS Group and Moffat and Nichol, 2009) the onshore component would comprise 63 percent of the longshore transport rate. On the other hand, Gravens et al. (1999) calculated a lower possible onshore transport rate of 98,000 cubic yards (75,000 cubic meters) per year, based on their own sediment budget and Fire Island spit growth estimates. This represents 24 per cent of the average estimated longshore transport rate at the inlet subject to the uncertainties and natural variability discussed earlier. Rosati et al. (1999) found an offshore sediment source was not required to balance the sediment budget but concluded an offshore sediment source could exist given the range of uncertainty in the data.

6. There is active sand transport on sand ridges.

Ripples, megaripples and sand waves observed on the Long Island inner, middle and outer continental shelf, appeared to be formed by wind-forced currents (Swift et al., 1979a). In response to unidirectional flow during peak storm-flow megaripples were most frequent on the inner shelf and are formed by storms from November through March. At times, megaripples were found to cover up to 15 percent of the Long Island shelf, but such fields are short-lived since fair weather conditions in summer tend to erase them (Swift et al., 1979a). Sand waves were generally found on the shallow inner shelf as solitary features, or less frequently, with megaripples (Swift et al., 1979a). They are oriented oblique to shore and are controlled by the near-bottom flow structure during storms (Swift et al., 1979a).

Bottom currents might be caused by the superposition of 6-12 second wave orbital velocities and steady, unidirectional currents due to storm set-up or set-down (Bumpus, 1973; Beardsley, 1976; Boicourt and Hacker, 1976; Beardsley, 1978; Csanday, 1982). McClennen (1973) measured peak geostrophic bottom currents of 1.3 feet per second (0.4 meter per second) on the New Jersey Shelf during a mild summer storm, and Butman et al., (1979) measured similar bottom current velocities during a winter storm. Lavelle et al., (1978) observed that bottom shear velocity exceeds the critical erosion velocity of fine sand-size particles intermittently during all seasons and critical shear velocity for coarser particles is exceeded mainly during sustained winter storms. Under normal, fair weather conditions on the continental shelf, wave orbitals can stir the bottom sediments to a water depth of 69 feet (21 meters; Sanders and Kumar, 1975; Lavelle et al., 1978); however, during mild storm conditions; there is a marked increase in the depth to which waves are able to transport sediment (Lavelle et al., 1978; Vincent, 1986). Combined-flow bottom current velocities as high as two feet per second (0.6 meter per second) were observed by Vincent (1986) in the Middle Atlantic Bight. Numerical models of circulation and sediment transport have been used in the New York Bight to predict that winds from the northeast might generate currents strong enough to transport sediment in water depths between 20 and 50m (Harris and Signell, 1999; Butman et al., 2003) and that sand at the Historic Area Remediation Site (HARS) has been observed to be mobile (Butman et al., 2002).

Breakdown of thermal stratification due to cold winter temperature also helps the winter storms to disturb the sea bed more easily than during summer storms (Swift et al., 1986; Rine et al., 1991). Hurricanes, although very effective at moving beach sands, are not thought to be of major importance in the long-term continental shelf sediment transport system (Swift et al., 1986). The inner continental-shelf is a mobile sea bed, however, determining net sediment fluxes remains elusive.

7. These ridges are actively maintained by hydrodynamic processes in the coastal ocean. The types of hydrodynamic processes that might maintain these ridges have been postulated but their relative importance offshore of Long Island has not been quantified.

It has been suggested that ridges might be maintained, in situ, by tidal convergence (Huthnance, 1982), infragravity waves (Boczar-Karakiewicz and Bona, 1986), storm currents (Trowbridge, 1995;Calvetle et al., 2001), surface wave convergence (Hayes and Nairn, 2004), or internal waves. Stubblefield et al., (1983) put forward the hypothesis that the topography of the sand ridges is at equilibrium with the shelf processes. Although, a steady, unidirectional flow would tend to smooth the topography that existed, the periodic lows associated with storms on the shelf coupled with storm waves might be sufficient to maintain the ridge and swale topography (Stubblefield et al., 1983). Stubblefield et al., (1983) envisioned ridge crest deposition primarily occurring during high energy winter storms and trough erosion persisting in the summer. In this way, ridges have net aggradations (Stubblefield et al., 1983) and would be expected to migrate along-coast to the south and offshore (Swift et al., 1973), although migration has not been documented.

A three-layer flow field is thought to exist on the shelf with the boundary layers mostly influenced by sustained, high energy winds and the middle layer being more steady, controlled by mean geostrophic flow (Stubblefield and Swift, 1976). Although never measured in the field, Csandnay and Scott (1974) and Stubblefield and Swift (1976) theorized that a combination of frictional force and Coriolis force act on the boundary layers might be able to produce hypothetical, helical cells which cause downwelling (and upwelling) currents that scour troughs and aggrade crests between the shoreface in order to create an offshore ridge field. The spacing and shape of shoreface ridges is then modified and maintained by the flow field after shoreface retreat during sea level rise (Stubblefield and Swift, 1976). According to this hypothesis, inner shelf ridges would be post-trangressive features which eventually become middle shelf and outer shelf ridges until submergence below a depth where currents can no longer move sand (Swift et al., 1976; Stubblefield et al., 1983).

Rine et al., (1991) supported the proposed method of inner shelf ridge formation by Stubblefield and Swift (1976) but provided a fourth explanation for middle shelf ridge development. They hypothesized that the sand ridges off the New Jersey coast were formed at or near their present day positions after complete or partial reworking of pre-trangressive structures. Inner shelf ridges originated on the shoreface as a result of strong winter storms, as proposed by Scott and Csanday (1974) and Stubblefield and Swift (1976), and are presently being modified by storm processes (Rine et al., 1991). Rine (University of South Carolina, personal communication, 1994) believed that they eventually became completely reworked by middle shelf hydrodynamics following drowning. Rine et al., (1991) suggested that middle shelf ridge development by explaining that middle shelf ridges were not relict features but they were predominantly formed in a middle shelf environment. During an early Holocene (8,000 to 14,000 BP) stillstand (Stubblefield et al., 1983), sand would have been concentrated into prograding or trangressive barriers at the present middle shelf position (Rine et al., 1991). As the rate of sea level increased, these barriers were drowned and altered by middle shelf processes to the point where they were completely or almost completely removed. Evidence of complete or partial excavation of the barriers came from the analyses of sedimentary structures and discriminant analysis of macrofaunal assemblages at various depths in vibracores obtained from inner shelf ridges and middle shelf ridges. Reworking and redeposition at or near present day sea level has produced middle shelf ridges above the inactive and depreciated roots of paleobarriers which may indicate a much more dynamic shelf environment of deposition than has been suggested by Stubblefield et al., (1983, 1984) and Swift et al., (1979b, 1984) (Rine et al., 1991). Presence of the ridges above the presumed paleobarrier roots was thought to be due to past abundance of sand in these positions, although sand deposits were not restricted to the paleobarrier positions (Rine, University of South Carolina, personal communication, 1994). Paleobarrier roots have been identified by vibracores from the ridges containing fossil assemblages of beach and littoral zone fauna (Rine et al., 1991).

More recently, Schwab et al., (2000) suggested that the shoreline-oblique ridges offshore of western Fire Island originated from erosion and subsequent reworking of sediments from a Cretaceous-aged outcrop of coastal plain strata off Watch Hill during the Holocene marine transgression. Schwab et al., (2000) had proposed that the sediment budget deficits at Fire Inlet could be balanced by onshore transport along the shoreface-attached sand ridges off of western Fire Island. Allen and Labash (1997) noted that shoreline changes along Fire Island between 1979 and 1994 differ east and west of Watch Hill; shoreline change along the western half of Fire Island shows an undulating pattern of erosion and accretion with a wavelength of six or seven kilometers, but any pattern is not clear east of Watch Hill. Schwab et al., (2000) speculated that the patterns observed by Allen and Labash (1997) might be explained either by refraction patterns of storm waves shoaling over shoreline-oblique ridges west of Watch Hill or by hypothetical interactions of the ridges with the nearshore bar allowing some segments of the bar to withstand storm waves better than others. Additional data by Hapke et al. (2010) suggest that these areas of erosion are relatively static and do not migrate in time.

As mentioned earlier, onshore transport might be attributed to wind-induced flows and identified as a long-term process often hidden by more rapid cyclical changes (Cowell et al., 1999).

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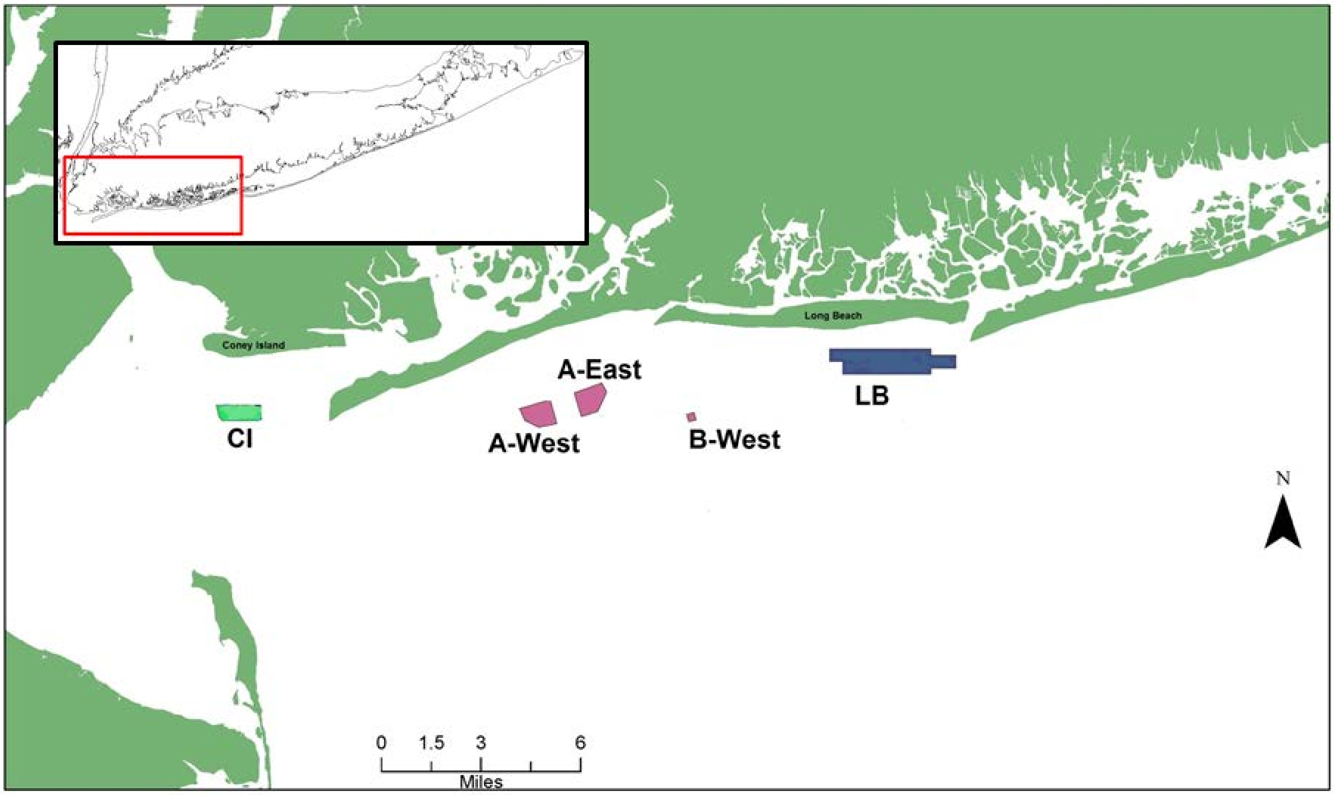
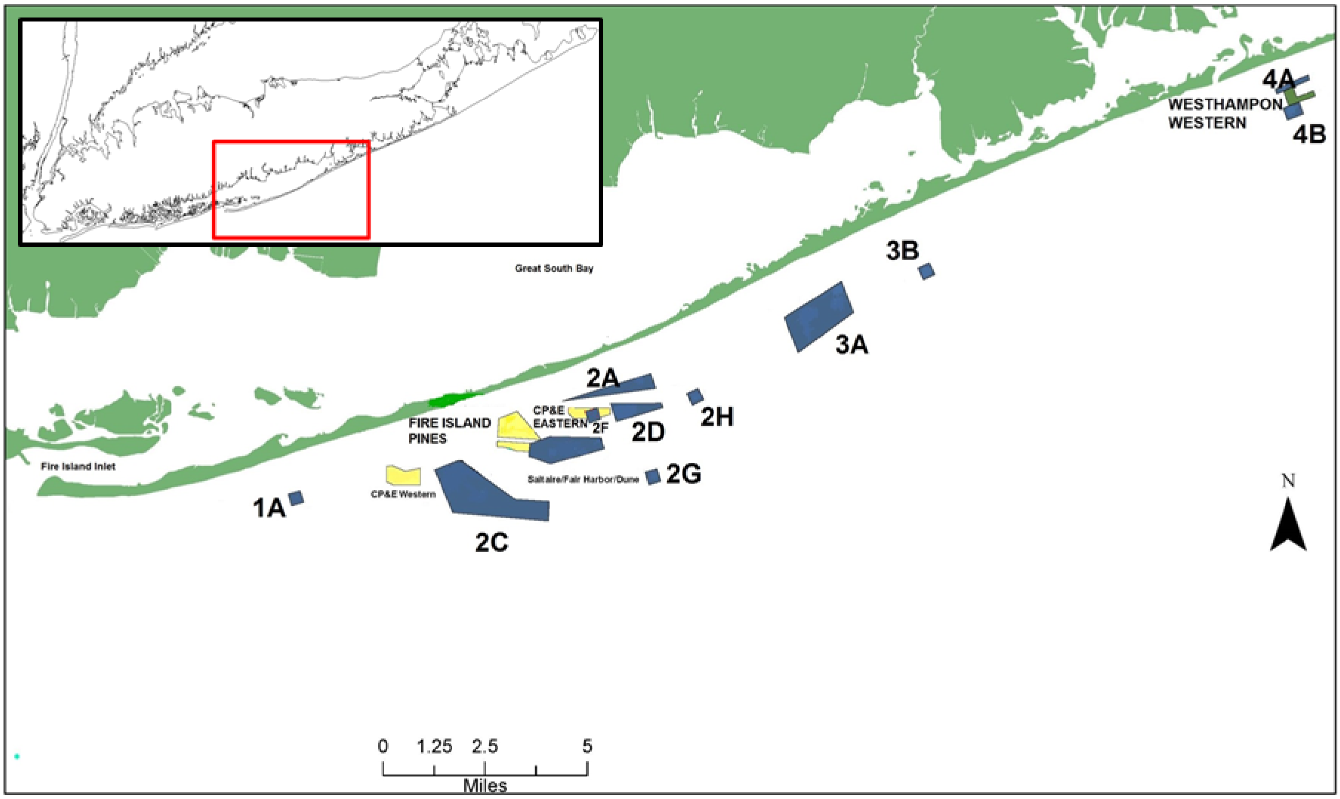
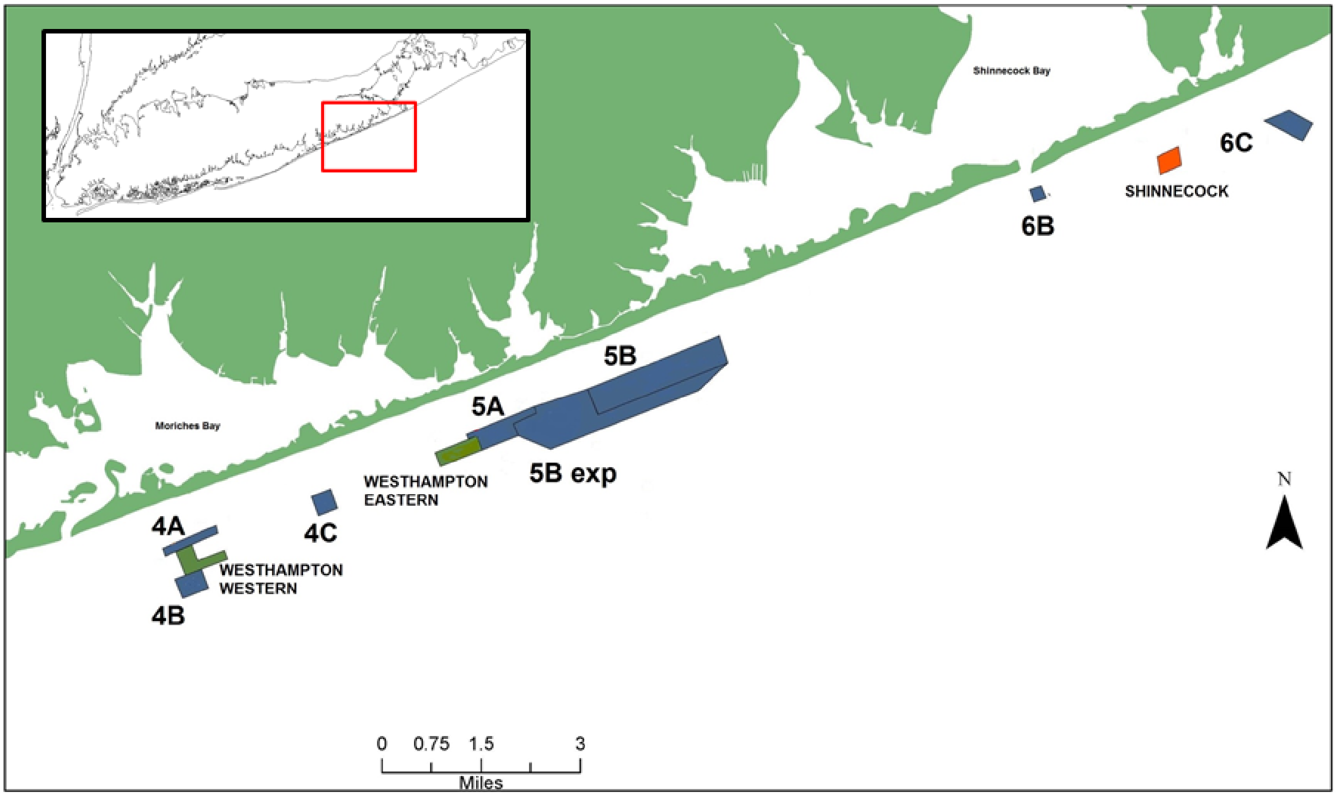
Appendix 2: Distribution of borrow areas 1994 to 2007 from Coney Island to Fire Island Inlet



Appendix 3: Distribution of borrow areas 1994 to 2007 from Fire Island Inlet to Shinnecock Inlet.



Appendix 4. Distribution of borrow areas 1994 to 2007 from Moriches Inlet to Shinnecock Inlet.



Appendix 5. Distribution of borrow areas 1994 to 2007 from Shinnecock Inlet to Montauk Point.