Carteret County North Carolina

carteret county Shore protection office
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BOGUE BANKS MASTER BEACH NOURISHMENT PLAN

DRAFT REPORT | FEBRUARY 7, 2014

moffatt & nichol

COASTAL TECH
COASTAL TECHNOLOGY CORPORATION

BOGUE BANKS MASTER BEACH NOURISHMENT PLAN
CARTERET COUNTY, NC

DRAFT ENGINEERING REPORT

Prepared For:

carteret county Shore protection office
protectthebeach.com

Prepared By:

moffatt & nichol

February 7, 2014

PROJECT ABSTRACT

Carteret County, the Carteret County Beach Commission, and the Shore Protection Office (SPO) seek to provide long-term, sustaining management of Bogue Banks beaches. In 2001, by state legislation, the Carteret County Beach Commission was established, and a room occupancy tax (ROT) for funding beach nourishment and related functions was put in place mainly as a response to the hurricanes of the 1990's (Bertha, Fran and Floyd) and subsequent storms. Carteret County intends to maintain Bogue Banks beaches via implementation of this proposed Master Beach Nourishment Plan (MBNP) with guidance from the SPO and oversight by the Beach Commission.

Carteret County is specifically seeking federal and state permits to allow implementation of this MBNP as a non-federal shoreline protection and inlet management project over a multi-decadal period to preserve Bogue Banks' tax base, infrastructure, and tourist oriented economy. An inter-local agreement was developed and executed by each municipality on Bogue Banks creating an effective and efficient approach for a long-term and sustainable implementation of this MBNP.

The proposed program incorporates actions within multiple oceanfront municipalities to nourish recipient beaches, via use of multiple sand sources, over a multi-decadal timeline with revolving nourishment-project events. This document identifies MBNP engineering design elements including: sand volumes required to yield the desired level of protection throughout Bogue Banks; triggers expected to prompt future nourishment events; sand borrow sources, volumes, quality, and viability; the expected capacity of the recipient beaches for nourishment; and the projected timing of nourishment events. A primary MBNP goal is to offset natural and anthropogenic erosion effects by optimizing use of existing high quality borrow sources to nourish prioritized recipient beaches to provide a spatially-equivalent level of protection to upland property on Bogue Banks.

Analysis of historical survey data indicates annual background erosion losses along Bogue Banks (without Fort Macon) of roughly 452,200 cubic yards per year (cy/yr); based on these historical losses, the future nourishment need just to maintain existing beaches over 50 years is estimated at 22.6 Mcy. It is expected that losses for a significant hurricane or storm event may range between 1.4 – 1.7 Mcy; given that such storms have historically occurred once every three years or so, storm losses over 50 years are estimated to range between 22.4 – 27.2 Mcy, which is comparable to the background erosion losses. For purposes of this report, to account for both background erosion and future storm impacts, sand losses over the future 50 year planning horizon are conservatively estimated to be between 45.0 and 49.8 Mcy. Including USACE guidelines accounting for potential sea level changes, these future losses over 50 years increase to 46.8 to 51.6 Mcy.

The existing beach and dune system – per the June 2011 survey – provides a level of protection along all of the Bogue Banks to withstand a 25-year return period design storm event. Existing erosion hotspots will likely require more frequent nourishments to maintain an equal level of protection as compared to more stable reaches. Wave transformation

model results indicate a significant gradient in wave energy along Bogue Banks, which may, in addition to localized bathymetric/geologic features, be responsible for the hotspots.

In the late 1990's through early 2000's, Bogue Inlet shifted toward the Point at Emerald Isle and seriously threatened homes and infrastructure. The inlet was successfully relocated in early 2005 with excavated material used to nourish the adjacent beaches; the adjacent inlet area has been relatively stable ever since. The historical locations of the main Bogue Inlet ebb channel and numerical modeling point to a proposed area, or "safe box," within which the subsequent channel migration did not threaten adjacent inlet shorelines/infrastructure by erosion within 3 years (to provide adequate time for an inlet relocation project to occur).

It is inherently assumed that beach fill is the fundamental element of the MBNP. For beach fill, the level of protection (LoP) afforded to infrastructure is expressed by the design return interval storm event that will cause appreciable damage. Volume requirements were estimated for a 25-yr return period event and for a 50-yr return period event LoP. The alternative design for a 50-yr event is not economically feasible, and therefore a 25-yr return period event LoP is proposed. To provide a basis for post-storm FEMA funding, triggers for nourishment are proposed at an overall average of 233 cy/ft above the -12 foot NAVD contour and seaward of the dune crest (ranging from 211 cy/ft to 266 cy/ft). A summary table of triggers by reach is provided below.

Reach	Reach Length (ft)	50-yr, -12 ft Trigger (cy)	25-yr, -12 ft Trigger (cy)	Adjusted 25-yr, -12 ft Trigger (cy)	Preliminary -12 ft Trigger (cy)	-12 ft 2011 Volume (cy)
Bogue Inlet (1-8)	7,432	238	103	238	235	389
Emerald Isle West - A (9-11)	4,056	282	230	230		277
Emerald Isle West - B (12-22)	14,283	319	272	272	266	295
Emerald Isle West - C (23-25)	4,005	323	242	242		303
Emerald Isle Central - A (26-32)	10,428	237	213	213	211	292
Emerald Isle Central - B (33-36)	5,374	277	207	207		262
Emerald Isle East - A (37-44)	8,814	268	214	214	221	242
Emerald Isle East - B (45-48)	4,406	299	235	235		264
Indian Beach/Salter Path - West (49-52)	5,275	243	216	216	224	263
Indian Beach/Salter Path - East (53-58)	7,575	241	229	229		298
Pine Knoll Shores - West (59-65)	9,063	235	196	196	211	253
Pine Knoll Shores - East - A (66-70)	6,564	271	218	218		240
Pine Knoll Shores East - B (71-76)	8,251	287	222	222		262
Atlantic Beach - West (77-81)	5,388	269	225	225	254	281
Atlantic Beach - Central (82-89, 91-96)	13,771	375	248	248		291
Atlantic Beach - Circle (90)	1,006	408	364	364		330
Atlantic Beach - East (97-102)	6,011	318	276	276		384
TOTAL	**121,702**					
AVERAGE		**288**	**230**	**238**	**233**	**290**
					Weighted	

Multiple alternatives were considered, screened, and eliminated from further consideration due to their inability to meet the Project Purpose, and/or their lack of economic or regulatory feasibility. The remaining Alternatives were evaluated in detail to meet the Project Purpose including: No Action (Status Quo), Relocation/Abandonment, the USACE 50-yr project, Beach Nourishment Only (With Various Sources), and Beach Nourishment with Inlet Management (Non-structural and Structural). Only Beach Nourishment with

Inlet Management meets the Project purpose and need; this alternative is the Preferred Alternative.

The MBNP and Preferred Alternative include the following elements:

- Sand from offshore sources (1st priority), inlet sources (2nd priority) and upland sources (3rd priority) is proposed to be excavated and placed on the beach. These primary sand sources are sufficient to maintain the design beach at a 25-year LoP with advance fill varying from 25 to 50 cubic yards per foot – depending upon actual future erosion rates and available funding.

- Renourishment events are expected to be required at 3, 6, and 9 year intervals starting in 2019 - based upon average background erosion rates. Actual renourishment events will be dependent upon actual erosion, and available funding – including FEMA funding in response to future storms for which the timing and severity cannot be reasonably predicted.

- Sand obtained from the USACE maintenance dredging of the Morehead City Harbor Channel and Bogue Inlet AIWW "crossings" is proposed to be used as part of the primary sand sources; maintenance dredging is proposed to be performed by the USACE under their permit authority, but USACE dredging and beach-fill placement are assumed to continue and are an integral part of the MBNP.

- If the main channel at Bogue Inlet migrates outside the "safe box", the main channel is proposed to be relocated by the Applicant, Carteret County, to the location constructed in 2005 with the excavated material used to nourish the beach as part of the primary sand sources.

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1.0 EXECUTIVE SUMMARY

Carteret County, the Carteret County Beach Commission, and the Shore Protection Office (SPO) seek to provide long-term, sustaining management of Bogue Banks beaches. In 2001, by state legislation, the Carteret County Beach Commission was established, and a room occupancy tax (ROT) for funding beach nourishment and related functions was put in place mainly as a response to the hurricanes of the 1990's (Bertha, Fran and Floyd) and subsequent storms. Carteret County intends to maintain Bogue Banks beaches via implementation of this proposed Master Beach Nourishment Plan (MBNP) with guidance from the SPO and oversight by the Beach Commission.

Carteret County is specifically seeking federal and state permits to allow implementation of this MBNP as a non-federal shoreline protection and inlet management project over a multi-decadal period to preserve Bogue Banks' tax base, infrastructure, and tourist oriented economy. An inter-local agreement was developed and executed by each municipality on Bogue Banks creating an effective and efficient approach for a long-term and sustainable implementation of this MBNP.

The proposed program incorporates actions within multiple oceanfront municipalities to nourish recipient beaches, via use of multiple sand sources, over a multi-decadal timeline with revolving nourishment-project events. This MBNP identifies engineering design elements including: sand volumes required to yield the desired level of protection throughout Bogue Banks; sand volume triggers to initiate nourishment events; sand borrow source locations, volumes, quality, and viability; the expected capacity of the recipient beaches for nourishment; and the projected timing of nourishment events. A primary MBNP goal is to offset natural and anthropogenic erosion effects by optimizing use of existing high quality borrow sources to nourish prioritized recipient beaches to provide a spatially-equivalent level of protection to upland property along Bogue Banks.

In the process of completing past projects and monitoring, Bogue Banks has developed a large and impressive dataset that was the underpinning of all the analyses. Major findings of these datasets and analyses completed for the MBNP are listed below.

<u>Volume Need</u>

The analysis shows an overall annual background erosion loss along Bogue Banks (without Fort Macon) of roughly 452,200 cy with a 50-yr nourishment need of 22.6 Mcy just to keep up with historical erosion patterns. Again, the estimate compares favorably to the USACE estimate of approximately 356,247 cy/yr and a 50 year need of 17.8 Mcy.

To estimate storm losses, the overall dataset was restricted to the three years which covered Hurricanes Isabel, Ophelia, and Irene to estimate potential hurricane storm losses. Based on the results, it is expected that the need for a given storm may range between 1.4 – 1.7 Mcy. Given that storms have occurred once every three years or so, the storm need over

50 years may range between 22.4 – 27.2 Mcy, which is equivalent to the background erosion loss/need.

The overall (background and storm) sediment need over the 50 year planning horizon based on the analytical/empirical analysis is between 45.0 and 49.8 Mcy. Accounting for USACE guidelines for sea level change, the value increases to 46.8 to 51.6 Mcy.

As for the existing beach profiles, numerical modeling was completed to determine that the beach and dune system are considered to provide a sufficient level of protection along all of the Bogue Banks reaches for a 25-year return period design storm event, or its equivalent.

Hotspots Investigation

It is important to understand the existing hotspots and why they may be present given that these are areas that will likely require more frequent nourishments to maintain an equal level of protection as compared to more stable reaches. A primary hotspot under investigation has been historically observed approximately between survey Transects 37 and 52 in Emerald Isle-East and Indian Beach/Salter Path-West. An additional potential hotspot can also be observed in beach profile monitoring data from 2008 – 2012 in Pine Knoll Shores-East (between Transects 66 and 76).

The wave transformation model results indicate a significant gradient in mean annual wave energy along Bogue Banks, with wave energy increasing from west to east. This result alone would indicate that gradients in sediment transport-causing wave energy may be responsible for the increased erosion seen in the middle portions of Bogue Banks.

The sediment transport component of the model results further indicates gradients in net accumulated alongshore transport that would result in greater removal of sediment from these hotspot areas than is supplied by the updrift reaches.

The alongshore transport gradient observed in the local model results is believed to be primarily due to the increased wave energy affecting the shoreline in the western reaches. This increased wave energy at both hotspots is believed to be due to a combination of wave sheltering effects of Cape Lookout as well as localized bathymetric/geologic features.

Bogue Inlet

Bogue Inlet has been the subject of local project efforts in the past. Bogue Inlet is considered a shallow draft inlet with authorized dimensions of 150 ft wide and 8 ft deep which has historically been dredged by sidecaster dredges. In the late 1990's through early 2000's, the inlet shifted toward the Point at Emerald Isle and seriously threatened homes and infrastructure at that location. The inlet was successfully relocated in early 2005 and the adjacent inlet area has been relatively stable ever since.

An analytical study of Bogue Inlet channel morphology was conducted using historical aerial imagery from 1938 – 2011. The study was conducted by defining and then measuring a small set of geometric parameters such as the position and alignment of the main ebb channel and the two landward channels connecting Bogue Inlet with Bogue Sound and the White Oak River.

A product of the initial analytical study is a proposed area, or "safe box," within which the main channel of Bogue Inlet would be allowed move, without triggering engineering intervention. The limits of the "safe box" were set so that subsequent channel migration did not threaten adjacent inlet shorelines/infrastructure by erosion within 3 years (in order to provide adequate time for an inlet relocation project to occur).

A program of numerical model simulations was then envisioned to confirm or revise (i.e. potentially narrow) the limits of the proposed "safe box". The dynamically coupled wave, flow, sediment transport, and bathymetry change (morphodynamic) model simulations were run for several idealized (schematized) inlet channel configurations. The model simulations were intended to provide an indication of whether there is a certain (approximate) lateral position, channel orientation, or combinations of both which, once reached, may speed up (or inhibit recovery from) migration of the channel to unacceptable positions near Bogue Banks or Bear Island.

The numerical model results do not indicate a channel position, rotation, or combination of parameters that suggest that proposed "safe box" should be refined.

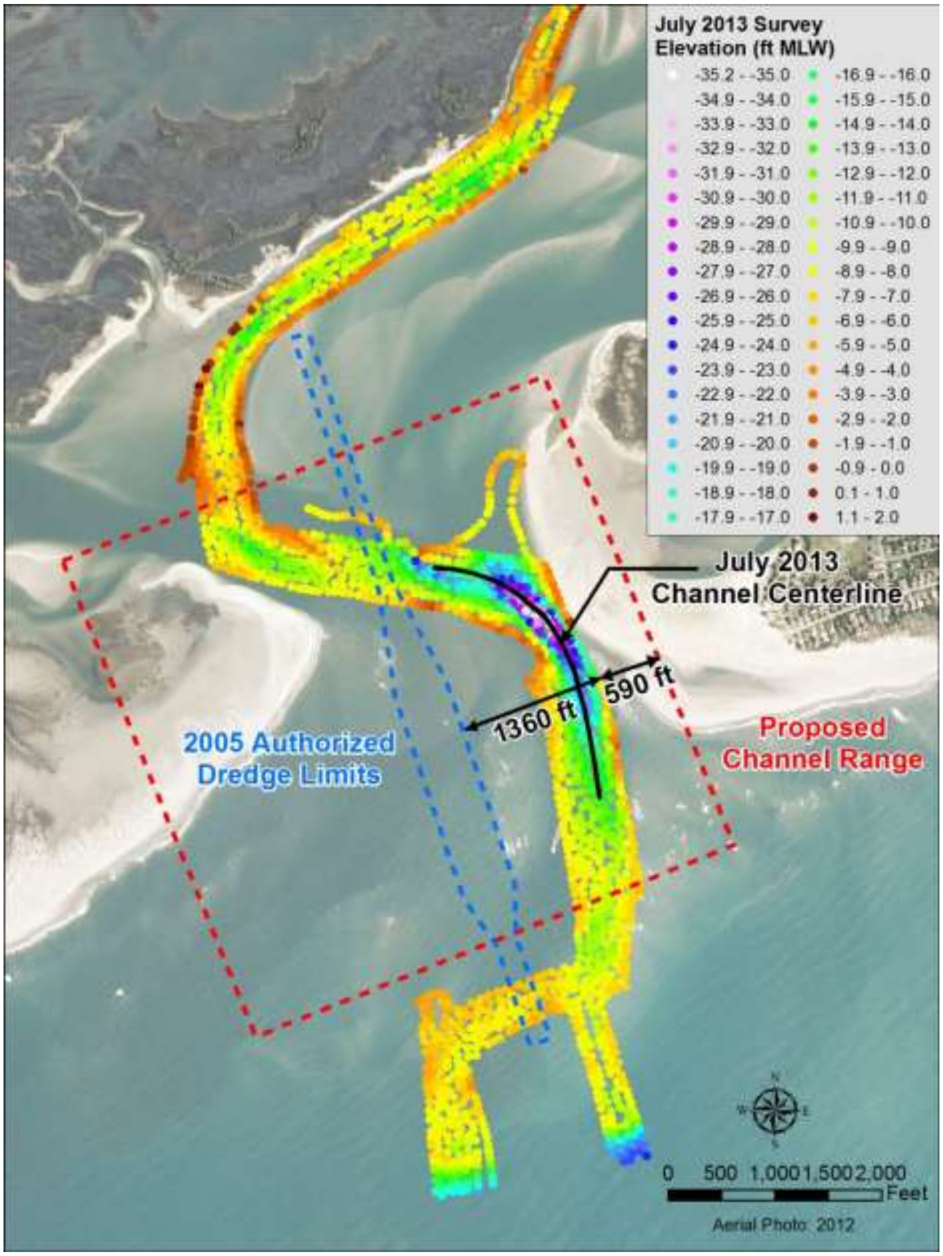

Figure 1-1: Bogue Inlet Current Channel Alignment

Level of Protection and Nourishment Trigger Determination

In addition to the study of Bogue Inlet to determine an optimal solution for protection of infrastructure adjacent to the inlet, the overall beach nourishment need to provide adequate protection for infrastructure along Bogue Banks was also needed.

As outlined previously, the current beach profiles are adequate to provide protection for a 25-yr event, while some targeted dune building in various reaches would be required to provide protection for a 50-yr event. A project of approximately 2.2 Mcy would be needed to provide this 50-yr event level of protection.

Since current funding streams are needed to meet the overall maintenance requirements, providing a LoP for a 50-yr event across the entire island was determined to not be feasible, and therefore a 25-yr event LoP was selected.

With the 25-yr event selected as the finalized level of protection, the development of nourishment triggers was completed. Again, it is important to note that the potential of triggers at all of the computation elevations was considered, but ultimately the elevation of -12 ft NAVD was selected.

The resulting overall average is 238 cy/ft (see Table 1-1). This result makes sense in the fact that the 225 cy/ft original trigger was based on profile volumes in Atlantic Beach (which had weathered the hurricanes well) AFTER the hurricanes. It would only make sense that the PRE-storm volume would be higher and given that the past hurricanes over the last decade have had roughly 1.2 -1.5 Mcy this would mean that the prestorm volume was approximately 10-13 cy/ft higher than the 225 cy/ft after the event. Therefore, the overall average of 238 cy/ft for the entire island was determined to be very reasonable.

Table 1-1: Revised Calculated Trigger Volumes Above -12 ft NAVD88 for Various RP Events

Reach	Reach Length (ft)	50-yr, -12 ft Trigger (cy)	25-yr, -12 ft Trigger (cy)	Adjusted 25-yr, -12 ft Trigger (cy)	Preliminary -12 ft Trigger (cy)	-12 ft 2011 Volume (cy)
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TOTAL	**121,702**					
AVERAGE		**288**	**230**	**238**	**233**	**290**
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Engineering Alternatives Considered

Multiple alternatives were considered to meet the project need including, No Action (Status Quo), Relocation/Abandonment, the USACE 50-yr project, Beach Nourishment Only (With Various Sources), and Beach Nourishment with Inlet Management (Non-structural and Structural).

With the exception of Beach Nourishment with Inlet Management, none of the other alternatives could meet the projects purpose and need.

In summary, non-structural inlet management is needed at both Beaufort Inlet and Bogue Inlet to meet the overall project needs. Management of these inlets will provide needed protection to the adjacent inlet shoulder volumes and infrastructure while providing the secondary benefit of a needed sand source to meet the 50-yr project sediment needs.

If all examined sand sources are incorporated (upland, AIWW, offshore, and inlets) approximately 50,253,057 cy of material would be available and would meet the 50-year sediment need (background and storm based erosion) of 45 Mcy to 49.8 Mcy (46.8 to 51.6 Mcy for moderate sea level change). The total volume available when the renewable (Bogue and Beaufort Inlets) and non-renewable (upland, AIWW, and offshore) sources are combined is tabulated in Table 1-2.

Table 1-2: Total Volume Available

Source	50-Yr Total Volume (cy)
Renewable	25,130,000
Non-Renewable	25,123,057
TOTAL	**50,253,057**

Preferred Alternative

Therefore, based on the above analyses, the preferred alternative is Beach Nourishment with Non-structural Inlet Management. This is the only option that provides adequate sand sources for to provide a 25-yr event LoP for all of Bogue Banks as well as provide adequate infrastructure and habitat protection along the shoreline surrounding Bogue Inlet (inlet "shoulders"). Revised triggers for -12 ft NAVD shall be utilized as shown in Table 1-1. The resulting reaches are on average 2-3 miles long with the exception of the Pine Knoll Shores and Atlantic Beach reaches which are somewhat longer and cover the entire Town in each case. For the proposed reaches, the weighted trigger is 233 cy/ft with triggers varying from 211 cy/ft for Emerald Isle Central to 266 cy/ft for portions of Emerald Isle West (Table 1-1). Through additional analysis, it was determined that renourishment intervals for various reaches would be needed at 3, 6, and 9 year intervals starting in 2019 (see Table 1-3). Please note that the nourishment volume approximates the need for background erosion only. It is expected that named storm losses will be handled separately through FEMA reimbursement projects.

Again, it is VERY IMPORTANT to note that the results are based upon average background erosion rates across the island. Storm effects and other factors could DRASTICALLY alter future nourishment requirements. The plan will nourish areas as they reach the nourishment triggers via gradual erosion or in response to future storms which of course cannot be predicted. It is also expected that the current funding streams would be sufficient for at least the next 20 years and possibly even longer.

Table 1-3: Renourishment Intervals and Preliminary Projects Based on Detailed Subreach and Management Reach Approaches

Year	Detailed Subreach Nourishment Volume (cy)	Management Reach Nourishment Volume (cy)	Nourishment Project (Yr)
2019	640,332	686,067	3
2022	1,686,018	1,839,351	6
2025	1,163,781	967,920	9
2028	1,686,018	1,839,351	6
2031	640,332	686,067	3
2034	2,209,467	2,121,204	6,9
2037	640,332	686,067	3
2040	1,686,018	1,839,351	6
2043	1,163,781	967,920	9
2046	1,686,018	1,839,351	6
2049	640,332	686,067	3
2052	2,209,467	2,121,204	6,9
2055	640,332	686,067	3
2058	1,686,018	1,839,351	6
2061	1,163,781	967,920	9
2064	1,686,018	1,839,351	6
TOTAL	**21,228,045**	**21,612,609**	

The MBNP and Preferred Alternative include the following elements:

- Sand from <u>offshore sources</u> (1st priority), <u>inlet sources</u> (2nd priority) and <u>upland sources</u> (3rd priority) is proposed to be excavated and placed on the beach. These <u>primary sand sources</u> are sufficient to maintain the design beach at a 25-year LoP with advance fill varying from 25 to 50 cubic yards per foot – depending upon actual future erosion rates and available funding.

- Renourishment events are expected to be required at 3, 6, and 9 year intervals starting in 2019 - based upon average background erosion rates. Actual renourishment events will be dependent upon actual erosion, and available funding

– including FEMA funding in response to future storms for which the timing and severity cannot be reasonably predicted.

- Sand obtained from the USACE maintenance dredging of the Morehead City Harbor Channel and Bogue Inlet AIWW "crossings" is proposed to be used as part of the primary sand sources; maintenance dredging is proposed to be performed by the USACE under their permit authority, but USACE dredging and beach-fill placement are assumed to continue and are an integral part of the MBNP.

- If the main channel at Bogue Inlet migrates outside the "safe box", the main channel is proposed to be relocated by the Applicant, Carteret County, to the location constructed in 2005 with the excavated material used to nourish the beach as part of the primary sand sources.

2.0 PROJECT PURPOSE AND NEED

2.1 Project Purpose

The Bogue Banks Master Beach Nourishment Plan (MBNP) project purpose is:

- to establish a regional programmatic plan to facilitate authorization and implementation of shoreline nourishment/maintenance events on Bogue Banks including management of Bogue Inlet;

- to provide long-term shoreline stabilization on Bogue Banks to:
  - provide an equivalent level of storm protection to upland property along Bogue Banks and the associated local, state, and federal tax bases;
  - to provide long-term protection to Bogue Banks tourism industry, State and local infrastructure, and oceanfront or inlet adjacent structures
  - maintain natural resources and associated recreational uses while avoiding and minimizing adverse environmental impacts to the extent feasible;

- to consolidate community resources to financially and logistically manage beaches on Bogue Banks and manage Bogue Inlet in an effective manner by reducing/eliminating the time and need for individual authorizations.

2.2 Project Need

After pronounced hurricane activity in the 1990's (Hurricanes Bertha, Fran, and Floyd), Carteret County leadership began to take formal steps to address erosion concerns along the ~25-mile long island of Bogue Banks. Figure 2-1 shows some of the damage from these hurricanes.

Figure 2-1: 1990's Hurricane Damage

In 1984, the U.S. Army Corps of Engineers (USACE) conducted a *Reconnaissance Study* relative to Coastal Storm Damage Reduction (CSDR) for Bogue Banks, but none of the analyzed coastal storm damage reduction plans were found to be economically feasible at that time (USACE, 2013). A USACE *Feasibility Study* was authorized by congressional resolution in 1998 and a *Feasibility Study Agreement* was executed in February 2001 after which federal funding became available; the *Feasibility Study* culminated in the August 2013 report - "Integrated Feasibility Report and Draft Environmental Impact Statement" for the USACE CSDR project for Bogue Banks. Congressional authorization and federal funding for this project are unlikely and remain uncertain due to lack of financial support by the present and prior administrations relative to the Shore Protection Program for ultimate implementation of the project.

In 1994, a USACE Section 111 Study was requested by Pine Knoll Shores to determine if damages to the beach can be directly attributable to the Federal Navigation Project (SPO website). In 2001, the USACE completed a Section 111 Study that addressed the impacts of dredging Morehead City Harbor upon the beaches of Bogue Banks. The study found no direct evidence that the harbor project has had a negative impact on any of the shorelines in the vicinity, including Pine Knoll Shores. However, the report suggested that alternative sand management practices in conjunction with harbor maintenance may be beneficial with regard to long-term stability of the shoreline (USACE, 2001).

However, with the advent of the hurricanes in the 1990's, County and Town leaders determined that action was needed. Occupancy tax legislation was developed to create a beach nourishment reserve fund and a County-wide Beach Commission was formed to manage the funds and make decisions regarding engineering intervention (i.e. nourishment) along Bogue Banks.

Consultants were retained by the Beach Commission to develop and implement the previous locally-funded Bogue Banks Restoration Project which placed material, in three phases, along Bogue Banks: Phase I) Indian Beach/Salter Path and Pine Knoll Shores (1.73 Mcy, 2002), Phase II) Emerald Isle Central and Emerald Isle East (1.87 Mcy, 2003), and Phase III) Emerald Isle West (0.69 Mcy, 2005) (see Figure 2-2).

In 2003, the USACE completed a 933 study investigating the beneficial placement of beach fill to be obtained by maintenance dredging of the Morehead City Harbor navigation project and by recycling previously dredged material from the adjacent Brandt Island confined disposal area (USACE, 2013). Phase I of the Section 933 project (2004) placed approximately 700,000 cy of material in Indian Beach/Salter Path while Phase II (2007) placed approximately 508,000 cy of material in Pine Knoll Shores (see Figure 2-2).

In 2004 and 2007, two FEMA-funded restoration efforts were undertaken due to storm damage from Hurricanes Isabel and Ophelia, respectively. These efforts resulted in the placement of about 1.4 Mcy of sand along Bogue Banks. Most recently, in 2013, a post-Irene restoration project, partially funded by FEMA, was constructed, placing approximately 965,000 cy of sand along Bogue Banks (see Figure 2-2).

In 2010, the USACE completed a "Dredged Material Management Plan" for the Morehead City Harbor navigation project. The base plan includes periodic placement of material on Fort Macon, Atlantic Beach, and west through Pine Knoll Shores at regular intervals to ameliorate the losses of material that would normally have been provided through natural sand bypassing currently interrupted by the navigation project" (USACE, 2010).

Since 1978 roughly 11 million cubic yards of sand have been placed upon the beaches of Bogue Banks – as illustrated in Figure 2-2 - at a total cost of about $95 million. While the Corps of Engineers' Dredged Material Management Plan and Interim Operation Plan for the Morehead City Harbor Federal Navigation Project hold some promise for eastern Bogue Banks, long-term beach nourishment for the entire island is needed to provide for pro-active management of County beaches.

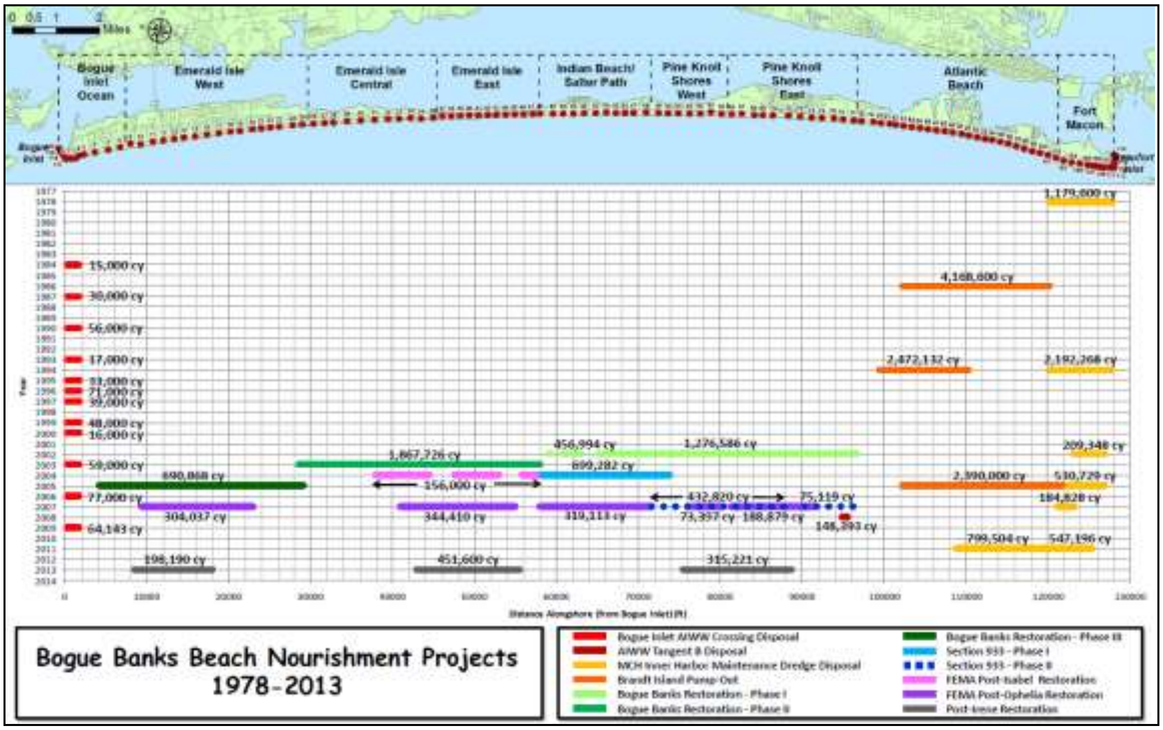


Figure 2-2: Beach Nourishment Project Completed Since 1978 Along Bogue Banks

2.3 Scope of Study

This comprehensive Engineering Report is to review present-day beach conditions, review and reassess the effectiveness of the County's previous beach nourishment projects over the past decade, and develop a new nourishment plan based on volumetric/beach elevation thresholds for Atlantic Beach, Pine Knoll Shores, Indian Beach/Salter Path, and Emerald Isle. It is assumed that a majority of Atlantic Beach's and Ft. Macon's nourishment needs will be met by utilizing dredged material emanating from the Morehead City Harbor Project.

A NEPA coordination document – in the form of an Environmental Impact Statement (EIS) - is also being prepared to supplement this engineering report to address short-term, long-term, and cumulative effects, and appropriate offsetting mitigation measures to avoid, minimize, or mitigate any significant adverse impacts. The Engineering Report and NEPA document are intended to address all anticipated beach nourishment activities to be incorporated into the Master Beach Nourishment Plan (MBNP). These activities could include AIWW dredging with concurrent beach disposal, beneficial use dredging projects/opportunities, FEMA reimbursement projects, and other potential sand placement activities. The Engineering Report and EIS are herein proposed to become a programmatic instrument whereby any activities detailed in the documents will be included in comprehensive permits rather than several individual permits. The planning horizon is 50 years – consistent with the federal planning process.

The final MBNP is intended to:

(1) establish the parameters for future beach nourishment and management,

(2) conform to North Carolina's rules concerning static line exceptions as related to 30-year nourishment plans (document past projects, nourishment need, sediment sources, and funding streams to implement project), and

(3) provide a basis for the municipalities of Bogue Banks to continue qualifying for FEMA reimbursement of replacing the volume of sand lost during a federally-declared disaster.

The overall Study Area primarily entails the ~25 mile long barrier island of Bogue Banks - which includes Fort Macon State Park, the Towns of Atlantic Beach, Pine Knoll Shores, Indian Beach, Salter Path, and Emerald Isle. Additional areas considered include Bogue and Beaufort Inlets, and the immediately adjacent portions of the adjacent barrier islands and tidal waters from Shackleford Banks (~9 mile uninhabited island owned by National Park Service) eastward to Bear Island (~3.5 mile uninhabited island owned by the State of North Carolina) westward (as related to management of the inlets), including portions of Bogue Sound and the nearshore waters to a depth of approximately -50 to -60 ft NAVD88. The Study Area is illustrated in Figure 2-3.

Figure 2-3: Study Area of Bogue Banks and Bogue Inlet, Carteret County, NC

Unless otherwise noted, all units in this report are in the English system, and all elevations are referenced to the North American Vertical Datum of 1988 (NAVD88). All horizontal coordinates are referenced to State Plane US Survey Feet, NAD 83 horizontal datum.

An overall goal of this project is to formulate and implement a long-term sustainable shore protection program for the beaches of Bogue Banks. The scope of this study consists of two major tasks (see Figure 2-4):

(1) this comprehensive Engineering Report that will determine the beach nourishment needs (volumes, placement areas, and intervals) and sand sources, and

(2) a separate programmatic NEPA-compliant EIS document with state and federal permits that will allow placement activities to be carried out over a multi-decadal (up to 50 year) time frame.

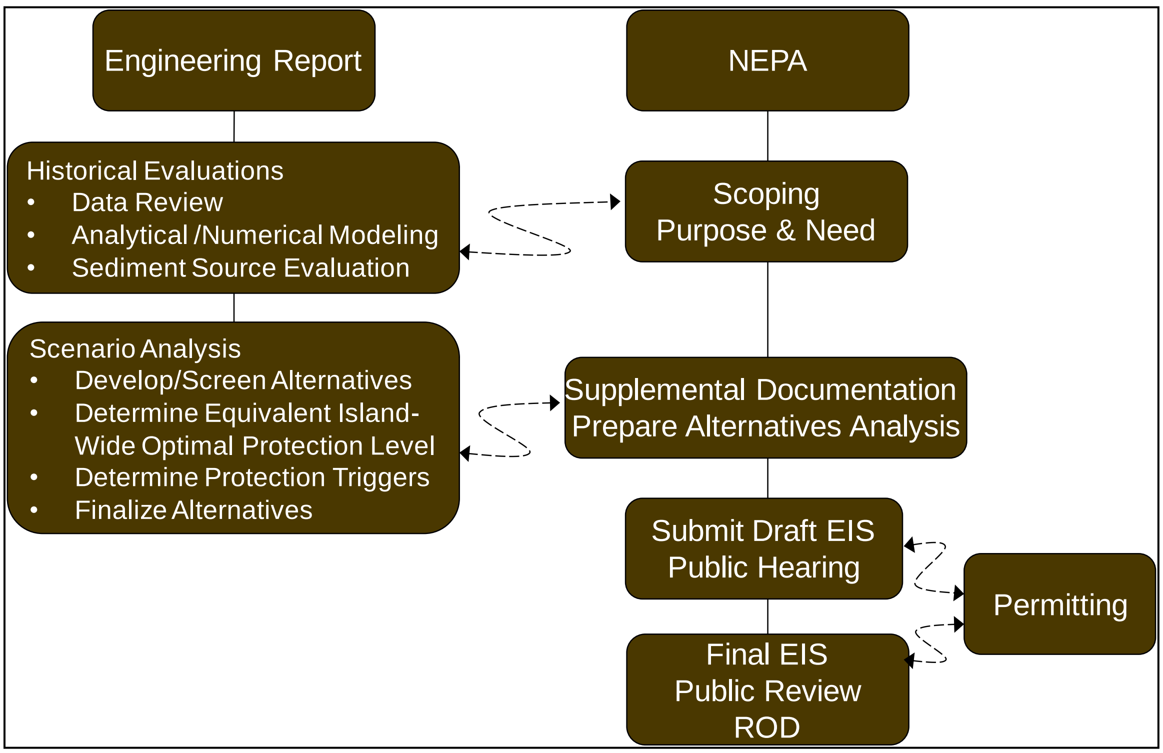


Figure 2-4: Engineering Report and Interaction with Environmental Document Process

While two separate efforts, the engineering and environmental components are being integrated throughout the project's development and the project team members have distinct and separate roles on the project. Moffatt & Nichol (M&N) is responsible for the overall project management and completion of the Engineering Report and analyses. Coastal Tech is assisting M&N with overall project QA/QC and the sand source/geological assessment. Dial Cordy and Associates (DC&A) is responsible for the NEPA/SEPA process, EIS document (with QA/QC by Coastal Tech), and NC Coastal

Management/USACE permitting. Jones Consulting (JC) is assisting Dial Cordy in the NEPA/SEPA EIS process and coastal permitting. The project team and the responsibilities for completing the overall scope is shown in Figure 2-5.

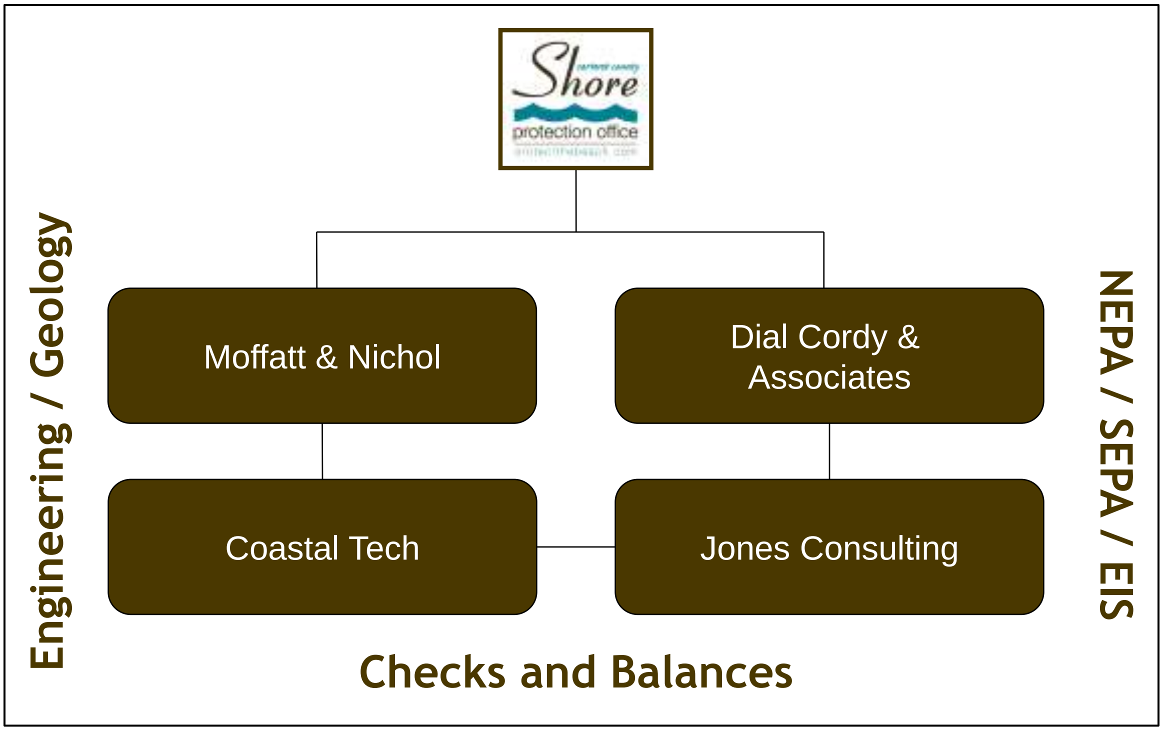


Figure 2-5: Project Roles and Responsibilities

2.4 Scope of Engineering Report

The main purpose of the Engineering Report is to determine the beach nourishment needs (volumes, placement areas, and intervals) for the next 50 years along with the sand sources that should be permitted to meet that need. Key elements of this Engineering Report include:

(1) determination of the historical regional sediment losses/gains including the responses to natural long-term and storm-induced erosion and man-made (dredging and beach nourishment) forcing functions,

(2) assessment of the historical behavior of Bogue Inlet and identification of the optimal channel orientation to promote inlet stability and protection of infrastructure adjacent to the inlet, and

(3) determination of the overall desired level of protection to be provided across the island and the associated appropriate nourishment volumes, sand sources, and nourishment triggers to be used for the sub-reaches of Bogue Banks, and costs to maintain beaches.

This Engineering Report is also intended to (a) consider and incorporate potential USACE short and long term local navigation dredged material management plan strategies as well as current work efforts being completed by the USACE as part of its long-term project study (currently at Draft EIS stage), (b) meet FEMA requirements for post-storm reimbursement, and (c) meet the individual Town's static line exception plans.

Figure 2-6 shows the approximate workflow required for the engineering report portion of the Master Plan.

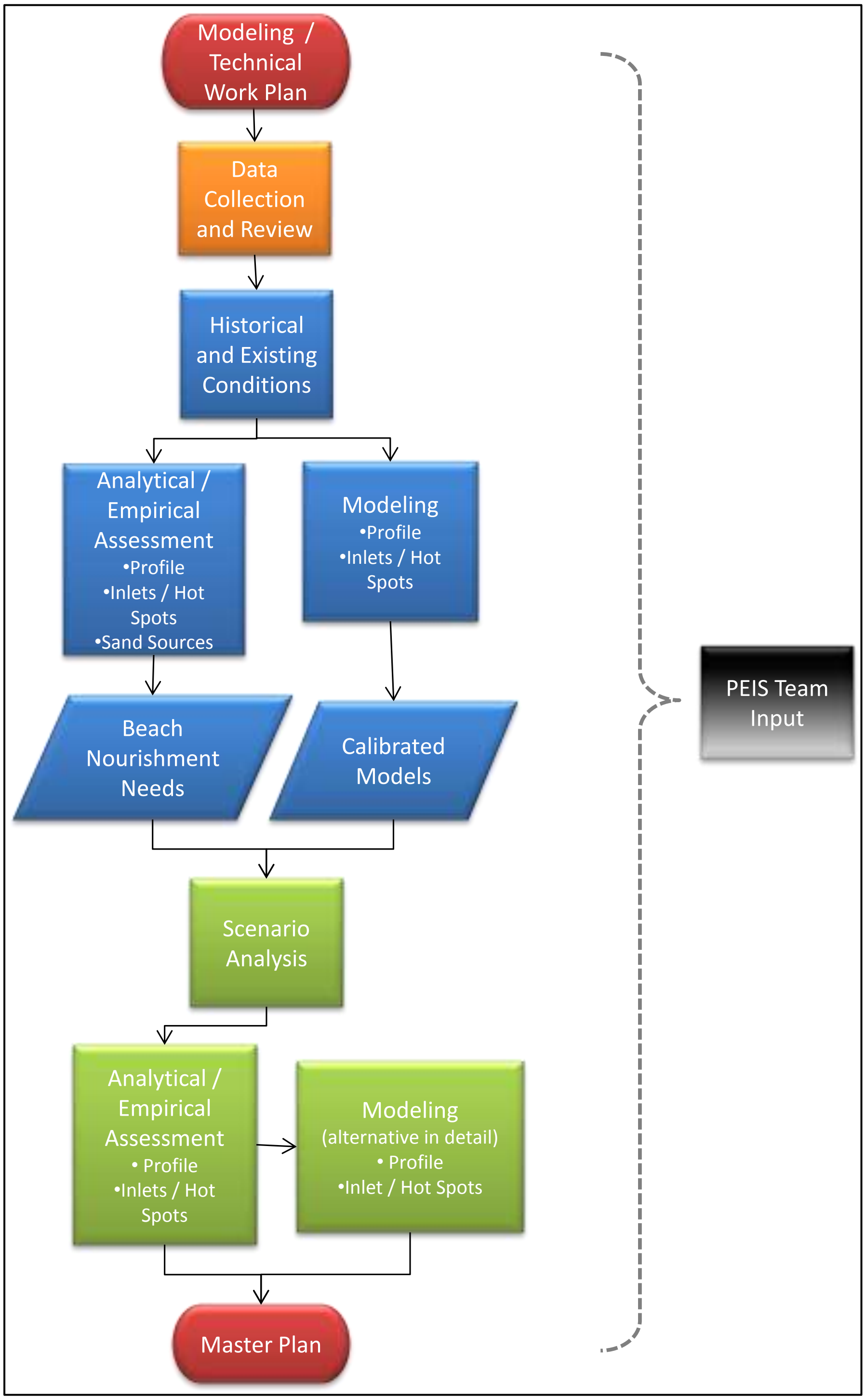


Figure 2-6: Workflow Diagram for Master Plan Engineering Report

2.5 Scope of Environmental Documents/Permits

The Programmatic Draft and Final Environmental Impact Statement (EIS) is intended to provide a basis (a) for issuance of a federal Record of Decision (ROD), an Administrative Record (AR), and associated supplemental documentation as required to meet the National Environmental Policy Act (NEPA) of 1969 as amended, found in the 42 United States Code § 4321, and (b) fulfillment of the State Environmental Policy Act (SEPA) procedures found in North Carolina General Statute 133A-1 through -12. The programmatic EIS efforts include significant and proactive public involvement; formal and informal coordination with local, state, and federal resource agencies; and preparation, coordination, and acquisition of specific local, state, and federal environmental authorizations for implementation of the MBNP.

3.0 REVIEW OF AVAILABLE DATA

Data from various sources were compiled during the course of this study. The primary types of data include historical measured water levels and flow velocities / discharges; historical measured and hindcast wave conditions; historical shoreline positions, beach profiles, and nearshore bathymetry; aerial photography; sediment characteristics both on the Bogue Banks beaches and within potential borrow areas; logs and records of historical coastal engineering works along Bogue Banks; and a collection of previous studies by others relative to coastal processes in the project area. This chapter documents the most significant data utilized for the coastal engineering analyzes of this study.

3.1 Wave Climate

Relevant wave data in the Study Area consist of three directional wave buoys that have been operated at various times by the National Data Buoy Center (NDBC) and the USACE Wave Information Studies (WIS) wave hindcast simulation archive. The NDBC measurements include wave height, period, and direction at approximately hourly intervals (with gaps) over various periods of time since 2003, as described below. The WIS archive contains simulated wave height, period, and direction at three-hour intervals over a period of 20 years from 1980 to 1999 (inclusive). The publicly available historical water level and wave data sources considered this study are shown in Figure 3-1.

This section of the report provides a brief summary of the offshore wave data sources relevant to determining the wave climate at Bogue Banks. Appendix A provides a more detailed presentation and discussion of the offshore wave data sources and wave transformation model simulations to generate nearshore wave climates for various components of this master plan.

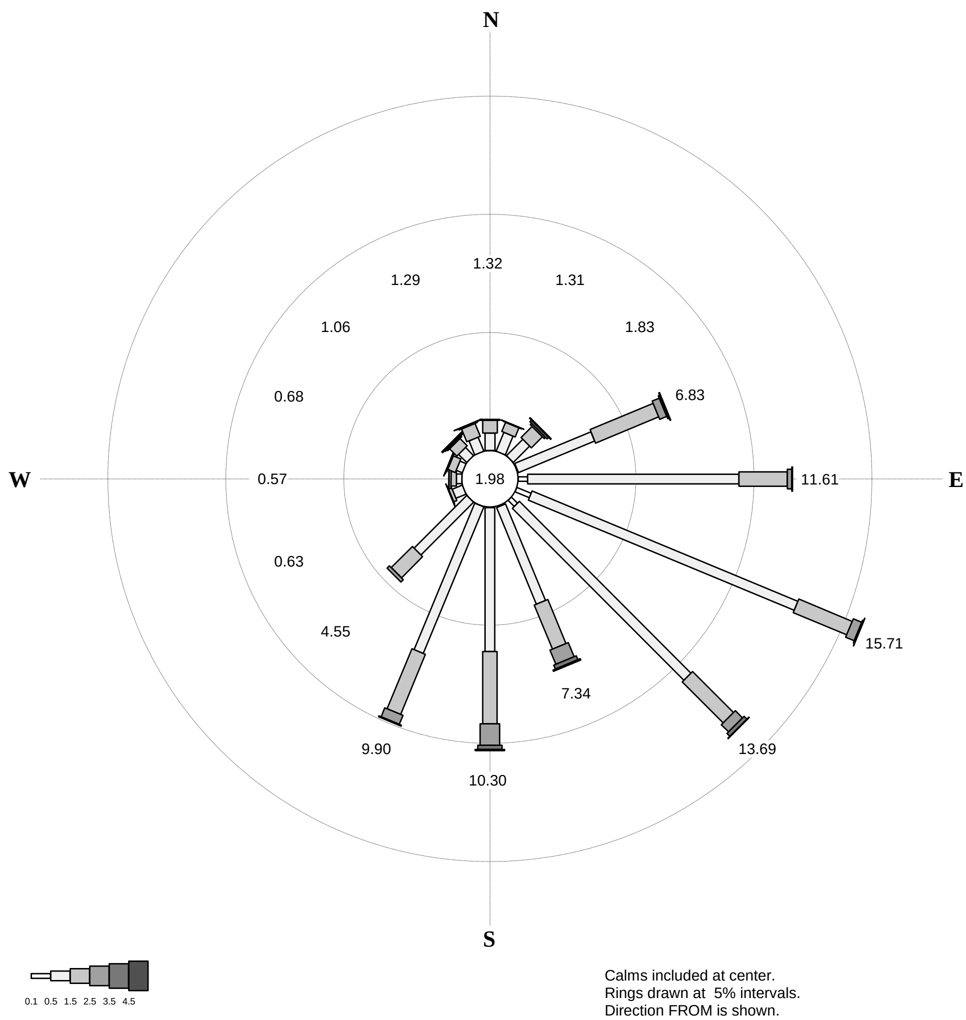
Figure 3-1: Wave and Water Level Data Locations

NDBC buoy #41036 (Onslow Bay Outer) is located approximately 32.5 miles south-southwest of Bogue Inlet and in a water depth of approximately 31 meters (101.7 ft). The data record spans July 2006 – September 2011, with significant gaps in coverage. Figure 3-2 shows a rose plot of wave heights by direction at this location. The rose indicates that, offshore of Bogue Banks, waves are predominantly from the southeast through the east-northeast sectors, with measured significant wave heights predominantly between 0.5 m (1.6 ft) and 2.5 m (8.2 ft). Measured significant wave heights exceed 2.5 m (8.2 ft) approximately 7.3% of the time, and they exceed 3.5 m (11.5 ft) approximately 2.4% of the time.

A second offshore data source at NDBC buoy #41013 (Frying Pan Shoals) was used to fill gaps in and extend the record available from buoy #41036. The data record at his gage spans November 2003 – September 2011. At the Frying Pan Shoals buoy, waves are predominantly from the southeast through the northeast sectors, with measured significant wave heights predominantly between 0.5 and 2.5 m (8.2 ft). Measured significant wave heights exceed 2.5 m (8.2 ft) approximately 5.7% of the time, and they exceed 3.5 m (11.5 ft) approximately 1.0% of the time. The recorded waves at the Frying Pan Shoals buoy are, in general, very similar in directional distribution (% occurrence) and in range of significant wave heights to those at Onslow Bay Outer.

The NDBC buoy data was used to establish the overall wave climate offshore of Bogue Banks. However, the NDBC record is not sufficiently long or complete to confidently establish high return-period extreme wave heights at this location. The longer-term hindcast wind and wave time series available from USACE Wave Information Studies (WIS) Atlantic hindcast station #63287 was used for establishing extreme wave heights offshore of Bogue Banks, for use in developing synthetic design storm data sets. The WIS hindcast program simulated operational and storm waves over 20 years from 1980 to 1999.

Joint Frequency Distribution (Annual)
Station 41036 - Onslow Bay (NC) Outer
Period of observations 2006-2011



PERCENT OCCURRENCE: Significant Wave Height (Meters)
LOWER BOUND OF CATEGORY

DIR	0.1	0.5	1.5	2.5	3.5	4.5
N	0.01	0.73	0.54	0.04	0.00	0.00
NNE	0.00	0.86	0.42	0.02	0.01	0.00
NE	0.00	0.98	0.66	0.08	0.09	0.03
ENE	0.03	3.49	2.89	0.32	0.07	0.03
E	0.40	8.94	2.05	0.19	0.03	0.00
ESE	0.66	12.17	2.44	0.38	0.05	0.01
SE	0.36	10.27	2.44	0.42	0.17	0.02
SSE	0.04	4.41	2.01	0.65	0.18	0.06

TOTAL OBS = 72034 MISSING OBS = 8199

PERCENT OCCURRENCE: Significant Wave Height (Meters)
LOWER BOUND OF CATEGORY

DIR	0.1	0.5	1.5	2.5	3.5	4.5
S	0.02	6.08	3.05	0.91	0.18	0.05
SSW	0.01	6.69	2.74	0.41	0.04	0.00
SW	0.00	3.15	1.26	0.14	0.00	0.00
WSW	0.00	0.46	0.14	0.02	0.01	0.00
W	0.00	0.23	0.23	0.09	0.01	0.00
WNW	0.00	0.28	0.34	0.03	0.02	0.01
NW	0.00	0.49	0.43	0.05	0.04	0.05
NNW	0.00	0.64	0.59	0.04	0.01	0.01

CALM OBS = 1429 PERCENT CALM = 1.98

Figure 3-2: Onslow Bay Outer Wave Rose (July 2006 – September 2011)

3.2 Water Levels and Currents

3.2.1 NOAA Tide Gauge #8656483 – Beaufort

The only presently-operating NOAA tide gauge in the immediate Study Area is located at Beaufort, NC (see Figure 3-1); the gauge is located inside the inlet just south of Highway 70 and north of Front Street. Verified six-minute and hourly water level measurements, with associated predicted tidal water levels, are readily available from NOAA's CO-OPS program website for the time period December 1995 – present.

NOAA's published tidal datum sheet indicates a range of 1.078 m (3.54 ft) between MHHW and MLLW, with a range of 0.948 m (3.11 ft) between MHW and MLW. The Beaufort tide station is located well within the harbor at Beaufort Inlet, and as such does not accurately represent tidal water levels along the open Atlantic coast of Bogue Banks or at the Bouge Inlet channel and ebb shoal. However, the Beaufort tide gauge data provides an applicable data set for inferring the effects of coastal storms (e.g. surge over predicted astronomical tides).

3.2.2 NOAA Tide Gauge #8656590 – Atlantic Beach Triple-S Pier

The only open-coast NOAA tide gauge listed by NOAA's CO-OPS program in the immediate Study Area was located in Atlantic Beach at the Triple-S Pier (see Figure 3-1). Verified hourly water level measurements are readily available from NOAA's CO-OPS program website for the time period December 1975 – June 2000; however, no data exists in the record between December 1983 and September 1998. Thus, the Atlantic Beach tide gauge is not available for directly analyzing water levels from recent tropical and extratropical storms of interest.

NOAA's published tidal datum sheet indicates a range of 1.264 m (4.14 ft) between MHHW and MLLW, with a range of 1.113 m (3.65 ft) between MHW and MLW. The Atlantic Beach Triple-S Pier tide station was located along the open Atlantic coast of Bogue Banks, and is useful for inferring the effects of coastal storms during its limited recent history of operation. Figure 3-3 shows the relationships of tidal datums MHHW, MLLW, and MSL in feet relative to NAVD88 at the Beaufort and Atlantic Beach Triple-S Pier tide stations based on NOAA's 1983-2001 tidal epoch.

The mean tide range at the Atlantic Beach Triple-S Pier tide gauge is approximately 117% of the mean tide range at the Beaufort tide gauge. The ratio of measured water levels at Atlantic Beach compared to those at Beaufort increases to just over 120% (in general) for very high tides and storm surge events.

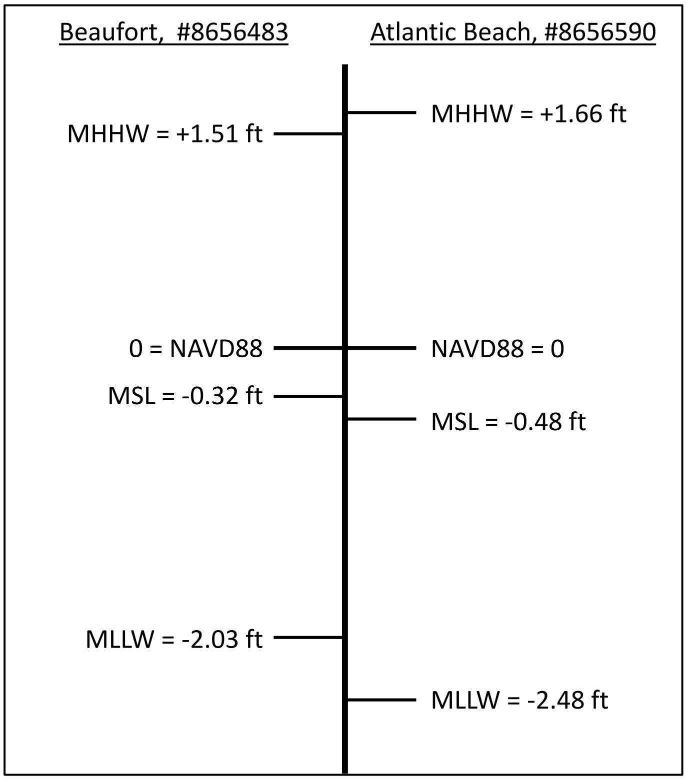


Figure 3-3: Selected Tidal Elevation Datums With Respect to NAVD88 at Beaufort and Atlantic Beach Triple-S Pier

3.2.3 Bogue Inlet Field Measurements

Coastal Science & Engineering (CSE) conducted field flow measurements on a transect across the Bogue Inlet main ebb channel using a digital Marsh-McBirney Model 201 flowmeter on June 27, 2005. The transect spanned both the "old" and "new" inlet channels existing at the time. Tidal water surface elevations were read from a tide staff (reference elevation leveled in using RTK-GPS) at The Point on Emerald Isle.

The measurements were conducted over a full tide cycle, from low tide at 6:40 a.m. to high tide at 12:52 p.m. to low tide at 6:50 p.m. (times approximated). A tide range of approximately 1.22 m (4 ft) was measured by CSE during the flow measurement period. Peak depth-average current velocities in the center of the new (relocated main) channel were approximately 1.0 m/sec (3.3 ft/sec) during ebb and 0.4 m/sec (1.3 ft/sec) during flood. Peak discharges of between approximately 850 m^3/sec (30,000 ft^3/sec) during flood tide and 1,200 m^3/sec (42,400 ft^3/sec) during ebb tide were reported across the transect.

3.2.4 Storm Surge

Significant variations from astronomical tidal water levels along Bogue Banks are generated by wind and pressure fields associated, primarily, with nor'easters, tropical storms, and hurricanes passing within approximately 100 nautical miles (nm). Storm surge is included in the historical water level measurements at Beaufort and Atlantic Beach Triple-S Pier NOAA tide gauges. The top 20 highest water level events at the Beaufort tide gauge since 1980, and the respective surge components, are summarized in Table 3-1.

Table 3-1: Twenty Highest Monthly Maximum Water Levels at Beaufort[1]

Date	Total Water Level (feet NAVD88)	Predicted Tide Level (feet NAVD88)	Storm Surge (feet)
2005-09-14	4.52	1.84	2.68
1999-09-16	4.26	-0.92	5.18
2011-08-27	4.22	1.22	3.00
1996-09-06	4.09	-1.19	5.27
1987-01-01	3.75	-0.96	4.71
2009-11-14	3.73	1.85	1.88
1996-07-12	3.72	1.41	2.31
2003-09-18	3.72	1.25	2.47
1986-12-02	3.67	-0.51	4.18
2006-10-09	3.58	2.32	1.26
2008-09-25	3.57	1.61	1.95
1998-08-27	3.35	1.14	2.21
2012-10-29	3.35	1.80	1.54
1985-09-26	3.34	-0.33	3.67
1993-03-13	3.32	0.39	2.93
1991-11-02	3.29	-0.35	3.64
2009-10-19	3.29	2.13	1.16

Date	Total Water Level (feet NAVD88)	Predicted Tide Level (feet NAVD88)	Storm Surge (feet)
2012-06-06	3.29	2.04	1.25
1998-02-04	3.26	1.08	2.18
2009-06-23	3.26	2.08	1.18

[1]Within NOAA monthly extremes data set starting in 1973.

3.2.5 Sea Level Change

Relative mean sea level at the Beaufort NOAA tide gauge has been rising at a long-term average rate of approximately 0.1012 inch/year (2.57 mm/year), as computed by NOAA (2013) from monthly mean sea level data between 1953 and 2006. Over a 50-year future planning period, the continuance of this trend would result in a relative mean sea level increase of approximately 0.42 feet.

It is recognized that the actual rate of relative sea level change experienced by Bogue Banks, including any potential acceleration of this rate, is not known with certainty. It is therefore necessary to consider how resilient and/or adaptable the forward-looking plans and design generated by this study are.

USACE guidance on inclusion of sea level rise in federal planning and design studies (USACE, 2011) indicates that USACE projects in tidal waters must include potential relative sea-level change in planning and design. The guidance specifies that planning and design must consider the sensitivity and adaptability of projects to relative sea level change. The uncertainty in the rate of sea level change to be applied is accounted for by considering three scenarios described by “low,” “intermediate,” and “high” sea level change rate curves.

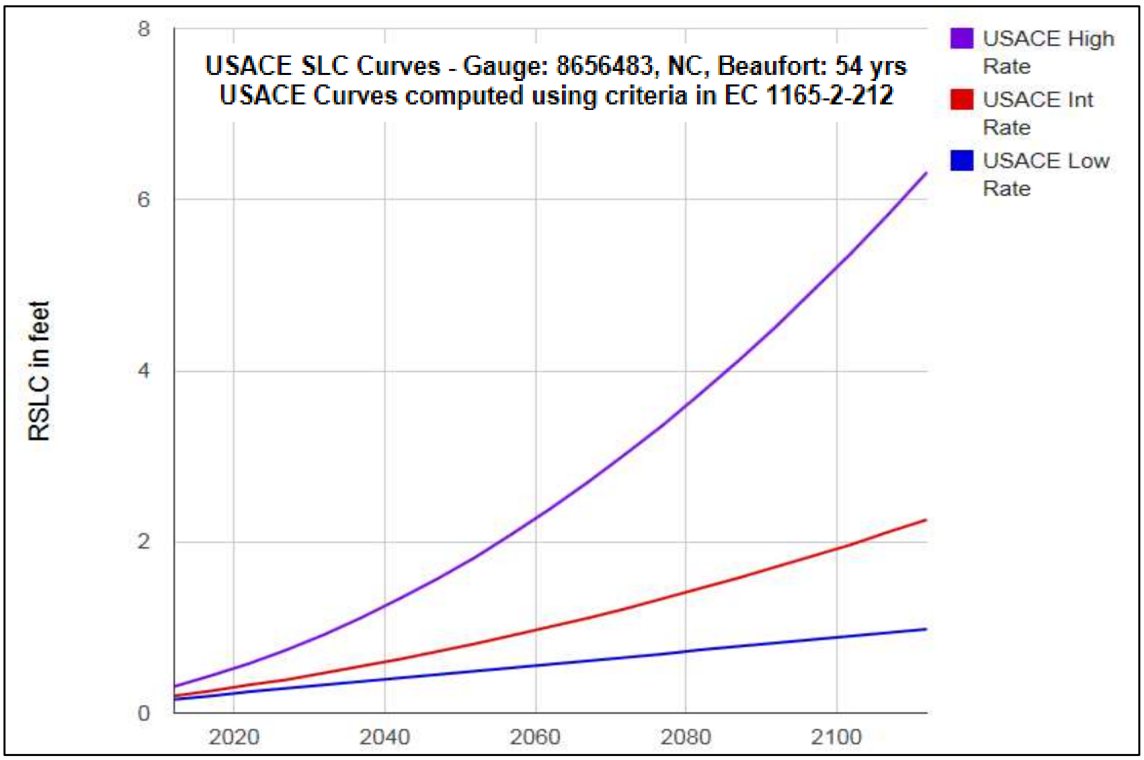
The “low” scenario (base level) relative sea level change rate is considered to be the historical rate, as noted above. The “intermediate” and “high” scenario curves reference curves and equations developed by the U.S. National Research Council’s report *Responding to Changes in Sea Level: Engineering Implications* (NRC, 1987). The “intermediate” curve is developed by applying the modified NRC Curve I with USACE equations 2 and 3, in combination with the historical local rate of vertical land movement (see Appendix B of USACE, 2011). The “high” curve is developed similarly but uses modified NRC Curve III. The USACE guidance notes that the “high” curve “exceeds the upper bounds of IPCC estimates from both 2001 and 2007 to accommodate potential rapid loss of ice from Antarctica and Greenland, but is within the range of peer-reviewed articles released since that time ….”

The USACE guidance further indicates that plan alternatives developed for one sea level change scenario should be tested against the other two scenarios.

Values of relative sea level change for the project area based on the USACE guidance are provided in Table 3-2 and are shown graphically in Figure 3-4. Consideration of the specific impacts on the performance of project alternatives is discussed in Section 7.4.4.

Table 3-2: Predicted relative sea-level change for future time-frames from 2012[1]

Project Time-Frame	Relative Sea-Level Change Scenario		
	Low (feet)	**Intermediate (feet)**	**High (feet)**
Year 2022 (10 years)	0.25	0.33	0.58
Year 2037 (25 years)	0.37	0.55	1.12
Year 2062 (50 years)	0.57	1.01	2.39
Year 2087 (75 years)	0.78	1.58	4.12
Year 2112 (100 years)	0.98	2.26	6.32



*Currently USACE guidance on Sea Level Change (EC 1165-2-212) does not address change beyond 2100. Values for curves beyond 2100 should be used with caution.

Figure 3-4: Relative sea level change at Beaufort, NC based on EC 1165-2-212

[1] Based on USACE online calculator at http://corpsclimate.us/ccaceslcurves.cfm

3.3 Beach Topography and Nearshore Bathymetry

Carteret County has a rich beach profile and bathymetry dataset. Beach profile monitoring has been performed on a consistent basis since 1999, with the Bogue Banks Beach and Nearshore Mapping Program (BBBNMP) officially starting in 2004. A more recent focus has been placed on inlet bathymetry as both Bogue and Beaufort Inlets play an important role in the condition of Carteret County beaches. Detailed multibeam surveys have been performed at both inlets in addition to some surveys at the Morehead City Harbor Ocean Dredged Material Disposal Site (ODMDS).

3.3.1 Beach Monitoring Profiles

In 1999, after 3 major hurricanes impacted Carteret County within the decade, Carteret County began to monitor the shoreline through what would eventually become the BBBNMP. From 1999-2003, various surveys were performed to assess damage from the hurricanes and help with the plans for the three-phase Bogue Banks Restoration Project. In 2004, the BBBNMP annual monitoring program was established where surveys were taken each spring (pre-storm season) and, in addition, after any major storm which impacted the area. Table 3-3 shows the available survey data for Carteret County. Figure 3-5 shows the BBBNMP survey transect locations.

Table 3-3: Carteret County Beach Profile Surveys

Date	Source	Description	Coverage
July 1991			Shackleford Banks
June 1999	CSE Baird-Stroud		Bogue Banks
June 2000	CSE		Bogue Banks
October 2000			Shackleford Banks
June 2001			Bogue Banks
May 2002	IMS		Bogue Banks
June 2002			Bogue Banks
August 2002	IMS		Indian Beach/Salter Path, Pine Knoll Shores
January 2003	IMS		Bogue Banks
April 2003	IMS		Indian Beach/Salter Path, Pine Knoll Shores
September 2003		Post-Isabel Survey	Bogue Banks
December 2003	CSE		Bogue Banks
June 2004	CSE	BBBNMP Annual Survey	Bogue Banks
October 2004	CSE	BBBNMP Annual Survey	Bear Island
May 2005	CSE	BBBNMP Annual Survey	Bogue Banks, Shackleford Banks, Bear Island
September 2005	CSE	Post-Ophelia Survey	Bogue Banks
May 2006	CSE	BBBNMP Annual Survey	Bogue Banks, Shackleford Banks, Bear Island
May 2007	CSE	BBBNMP Annual Survey	Bogue Banks, Shackleford Banks, Bear Island
July 2008	Geodynamics	BBBNMP Annual Survey	Bogue Banks, Shackleford Banks, Bear Island
June 2009	Geodynamics	BBBNMP Annual Survey	Bogue Banks, Shackleford Banks, Bear Island
June 2010	Geodynamics	BBBNMP Annual Survey	Bogue Banks, Shackleford Banks, Bear Island
June 2011	Geodynamics	BBBNMP Annual Survey	Bogue Banks, Shackleford Banks, Bear Island
September 2011	Geodynamics	Post-Irene Survey	Bogue Banks
April 2012	Geodynamics	BBBNMP Annual Survey	Bogue Banks, Shackleford Banks, Bear Island

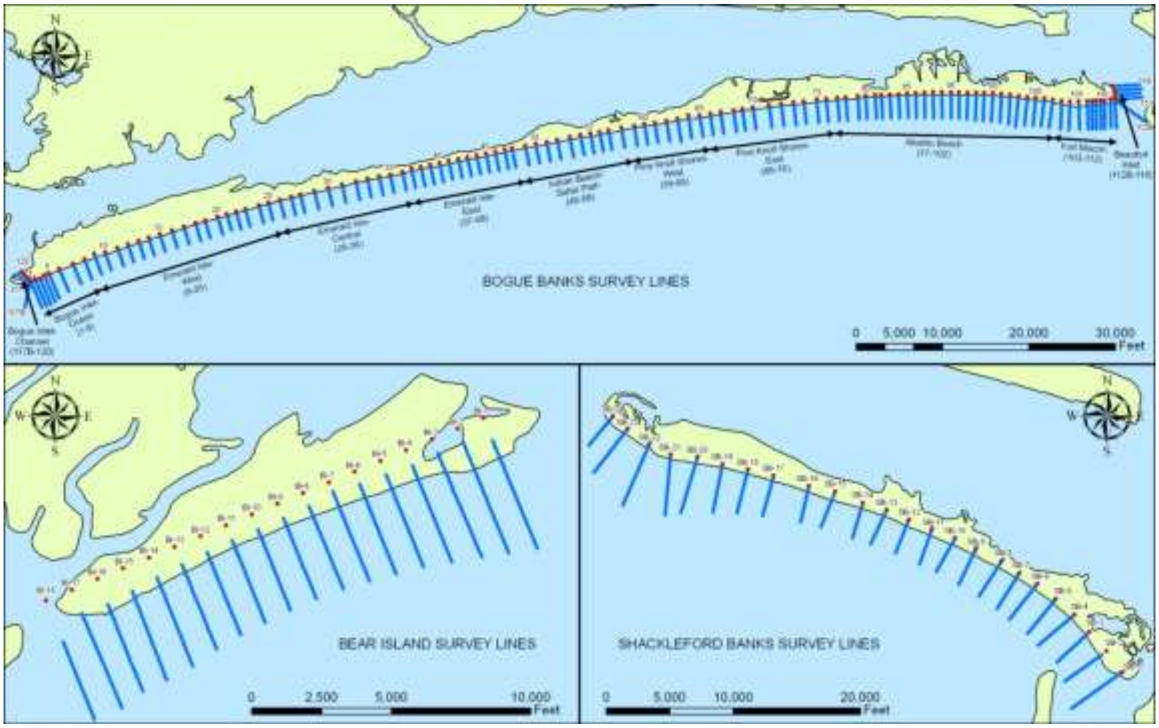


Figure 3-5: BBBNMP Survey Transects

Each year, the new survey is compared to the previous years' survey to determine changes in the beach. Shoreline change at MHW (+1.1 ft NAVD88) and volume change above +1.1 ft NAVD88, -5.0 ft NAVD88, -12.0 ft NAVD88, -20.0 ft NAVD88, and -30.0 ft NAVD88 are calculated at each transect. In addition, the total volume of each profile above -12 ft NAVD88 is compared to the set island wide trigger of 225 cy/ft and the amount of material that has been lost since the initial Bogue Banks Beach Restoration Project (Phase I, Phase II, and Phase III) is also computed to support potential post-storm FEMA funding. These losses serve as triggers for nourishment and are also considered by FEMA after declared storm events to determine federal funding the County may receive for post-storm nourishment.

3.3.2 Bathymetric Data

NOAA has developed a coarse Digital Elevation Model (DEM) which covers the Carteret County beaches by combining historical elevation data from 1869-2001. The Onslow Bay portion of the DEM contains data from 1974-2001. In addition, NOAA Chart 11543 covers Onslow Bay. Starting in 2005, multibeam data of Bogue and Beaufort Inlets was collected on numerous occasions by Geodynamics. Recently, the Morehead City Harbor ODMDS has also been surveyed. Table 3-4 shows the available bathymetry data for the area. Figure 3-6 shows an example of the 2009 multibeam data at Beaufort Inlet.

Table 3-4: Carteret County Bathymetric Data

Date	Source	Description	Resolution	Coverage
1869 to 2001	NOAA Coastal Relief Model	ArcGIS Grid	6 m x 6 m	Carteret County
1900-1998	NOAA Nav Chart 11543_1	Image (TIFF)	26 ft x 26 ft	Onslow Bay
June 2005	Geodynamics	Multibeam (ArcGIS Grid)	10 ft x 10 ft	Beaufort Inlet
June 2005	Geodynamics	Multibeam (ArcGIS Grid)	20 ft x 20 ft	Bogue Inlet
June 2007	Geodynamics	Multibeam (ArcGIS Grid)	20 ft x 20 ft	Bogue Inlet-Eastern half
January 2008	Geodynamics	Multibeam (ArcGIS Grid)	20 ft x 20 ft	Bogue Inlet-Eastern half
January 2009	Geodynamics	Multibeam (ArcGIS Grid)	5 ft x 5 ft	Beaufort Inlet
September 2009	Geodynamics	Multibeam (ArcGIS Grid)	20 ft x 20 ft	Bogue Inlet
August 2011	Geodynamics	Multibeam (ArcGIS Grid)	10 ft x 10 ft	ODMDS
April 2013	Geodynamics	Multibeam (ArcGIS Grid)	5 ft x 5 ft	ODMDS Irene Borrow Area

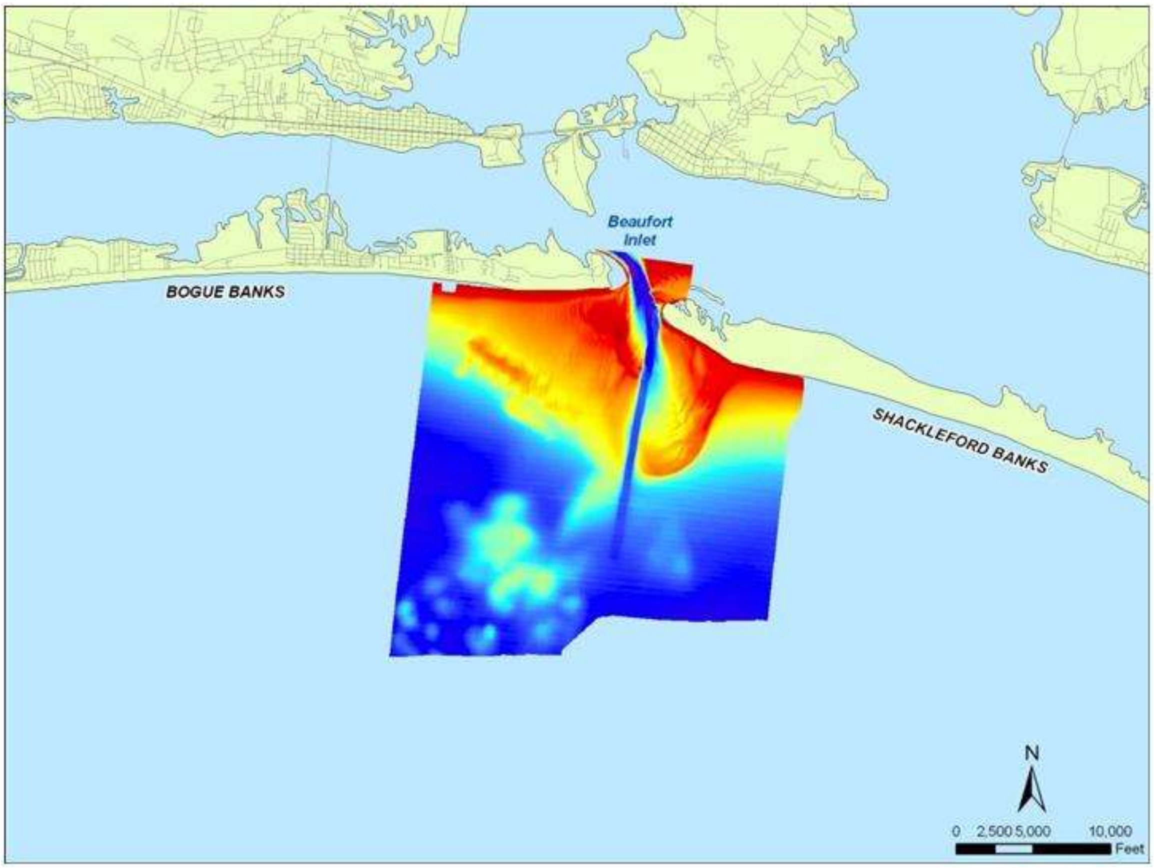


Figure 3-6: Example Multibeam Data at Beaufort Inlet

3.4 Aerial Photography

The North Carolina Division of Coastal Management (DCM) has compiled an archive of historical shoreline photography. Photography is available from various sources including DCM, USGS, NAIP, and Carteret County. Aerials of the entire Bogue Banks oceanfront shoreline were taken in 1998 and 2004. Carteret County also obtained aerial photography in 2007 and 2011. The NAIP has obtained aerial photography for a variety of dates from

2004 to 2012. In addition, inlet photography exists from 1938-2000 and has been compiled by DCM. Table 3-5 shows the available aerial photography for the area.

Table 3-5: Carteret County Aerial Photography

Inlet Photography (1938-2000)						
Date	**Source**	**Format**	**Mosaic/Tiles**	**Color**	**Resolution**	**Coverage**
1971, 1974, 1977, 1984, 1992	DCM	Mr. SID	Mosaic	B&W	1'	Onslow Beach (east), Browns Inlet, Browns Island, Bear Inlet, Bear Island, Bogue Inlet
2000	DCM	Mr. SID	Mosaic	Color	1'	Onslow Beach (east), Browns Inlet, Browns Island, Bear Inlet, Bear Island
1971, 1974, 1976, 1984, 1992	DCM	Mr. SID	Mosaic	B&W	1'	Atlantic Beach (east), Fort Macon, Beaufort Inlet, Shackleford Banks (west)
1995, 2000	DCM	Mr. SID	Mosaic	Color	1'	Atlantic Beach (east), Fort Macon, Beaufort Inlet
1938, 1949, 1956, 1958, 1960, 1971, 1976, 1987, 1992	DCM	TIFF	Mosaic	B&W	varies	Bear Island, Bogue Inlet, Emerald Isle (west)
Oceanfront Photography (1998)						
Date	**Source**	**Format**	**Mosaic/Tiles**	**Color**	**Resolution**	**Coverage**
1998	DCM	Mr. SID	Tiles	B&W	.5'	Bogue Banks
1998	DCM	Mr. SID	Tiles	B&W	.5'	Onslow Beach, Browns Island, Bear Island
1998	DCM	Mr. SID	Tiles	B&W	.5'	Shackleford Banks
Oceanfront Photography (2004)						
Date	**Source**	**Format**	**Mosaic/Tiles**	**Color**	**Resolution**	**Coverage**
2004	DCM	Mr. SID	Mosaic	Color	.5'	North Topsail (east) to Emerald Isle (west)
2004	DCM	Mr. SID	Mosaic	Color	.5'	Emerald Isle to Shackleford Banks (west)
2004	DCM	Mr. SID	Mosaic	Color	.5'	Fort Macon to Cape Lookout
Carteret County (2004)						
Date	**Source**	**Format**	**Mosaic/Tiles**	**Color**	**Resolution**	**Coverage**
2004	Carteret County	Mr. SID	Tiles	Color	.5'	Carteret County (portions of mainland), Bogue Banks
2004	Carteret County	Mr. SID	Tiles	Color	2'	Carteret County (portions of mainland), Bogue Banks
2004	Carteret County	Mr. SID	Mosaic	Color	2'	Carteret County (portions of mainland), Bogue Banks
Carteret County (2007)						
Date	**Source**	**Format**	**Mosaic/Tiles**	**Color**	**Resolution**	**Coverage**
2007	Carteret County	Mr. SID	Tiles	Color	1'	Bear Island, Bogue Inlet, Emerlad Isle (west)
2007	Carteret County	Mr. SID	Mosaic	Color	1'	Bear Island, Bogue Inlet, Emerlad Isle (west)
Carteret County (2011)						
Date	**Source**	**Format**	**Mosaic/Tiles**	**Color**	**Resolution**	**Coverage**
2011	Carteret County	Mr. SID	Mosaic	Color	1'	Carteret County Mainland, Bogue Banks
NAIP Photography (2004-2012)						
Date	**Source**	**Format**	**Mosaic/Tiles**	**Color**	**Resolution**	**Coverage**
2004, 2005, 2006, 2008, 2009, 2010, 2012	NAIP	Mr. SID	Mosaic	Color	1 m	Carteret County Mainland, Bogue Banks, Shackleford Banks

3.5 Shoreline Positions

In support of coastal planning efforts, the North Carolina Division of Coastal Management (DCM) began developing a historical shoreline database starting in the 1970s. The primary source of historical data is via interpretation of a multi-temporal collection of geo-referenced shoreline manuscripts or "T-Sheets", provided by the NOAA Coastal Services Center (CSC). DCM has also collaborated with the U.S. Geological Survey (USGS) and USACE to document the most recent shorelines based on delineation of wet-dry line as interpreted from orthophotography, as well as deriving the MHWL based on LiDAR survey data. In addition to the statewide oceanfront shoreline datasets, DCM has compiled a historical shoreline database in the vicinity of inlets, varying in length on either side of the inlet from approximately 10,000 ft to the entire stretch of shoreline leading to the next adjacent inlet. The available shoreline data and extents vary widely depending on the availability of historical photographs. Shoreline data at the inlets was developed using multiple data sources including: DOT rectified aerials, DCM orthophotos and NOAA CSC T-Sheets. In addition, MHWL data has been pulled from the various beach surveys that have been performed along Carteret County beaches since 1999. Table 3-6 shows the available shoreline data for the Study Area. Figure 3-7 illustrates an example of compiled shoreline data.

Table 3-6: Carteret County Shorelines

Inlet Shorelines			
Date	**Source**	**Description**	**Coverage**
1938, 1949, 1956, 1958, 1960, 1971, 1976, 1984, 1992, 1998, 2003	DCM	Photo-Wet/Dry	Bogue Inlet
1949	DCM	NOS T-Sheet (MHW)	Bogue Inlet
1933, 1946, 1973, 1979	NOAA/USGS	-	Beaufort Inlet
1971, 1974, 1976, 1984, 1992, 2000	DCM	NC DOT Photography	Beaufort Inlet
1946	DCM	NOS T-Sheet (MHW)	Beaufort Inlet
1997	USGS	LIDAR MHW Shoreline	Beaufort Inlet
1998	DCM	Photo-Wet/Dry	Beaufort Inlet
2004	DCM	NC DCM Photography	Beaufort Inlet
Oceanfront Shorelines			
Date	**Source**	**Description**	**Coverage**
1849-1873	USGS, Coastal Carolina	NOS T-Sheet (MHW), CERC map	Entire NC Shoreline
1925-1946	USGS, NOAA, DCM	CERC map, USACE Photos, NOS T-Sheet (MHW)	Entire NC Shoreline
1933-1952	DCM	NOS T-Sheet (MHW)	NC Shoreline (Bird Island to Kill Devil Hills)
1970-1988	USGS, NOAA, Coastal Carolina	CERC map, NOS T-Sheet (MHW)	Entire NC Shoreline
1997	USGS	LIDAR MHW Shoreline	Entire NC Shoreline
1998	DCM	Photo-Wet/Dry	Entire NC Shoreline
1999	CSE	MHW Contour	Bogue Banks
2002	IMS	MHW Contour	Bogue Banks
2003	IMS	MHW Contour	Bogue Banks
2003	DCM	NOAA Photo-Wet/Dry	NC Shoreline (Bird Island to Bear Island)
2004	DCM	NCDCM Photo-Wet/Dry	Entire NC Shoreline
2006	CSE	MHW Contour	Bogue Banks
2007	CSE	MHW Contour	Bogue Banks
2008	Geodynamics	MHW Contour	Bear Island, Bogue Banks, Shackleford Banks
2009	Geodynamics	MHW Contour	Bear Island, Bogue Banks, Shackleford Banks
2009	DCM	Photo-Wet/Dry	Entire NC Shoreline
2010	Geodynamics	MHW Contour	Bear Island, Bogue Banks, Shackleford Banks
2011	Geodynamics	MHW Contour	Bear Island, Bogue Banks, Shackleford Banks
2012	Geodynamics	MHW Contour	Bear Island, Bogue Banks, Shackleford Banks

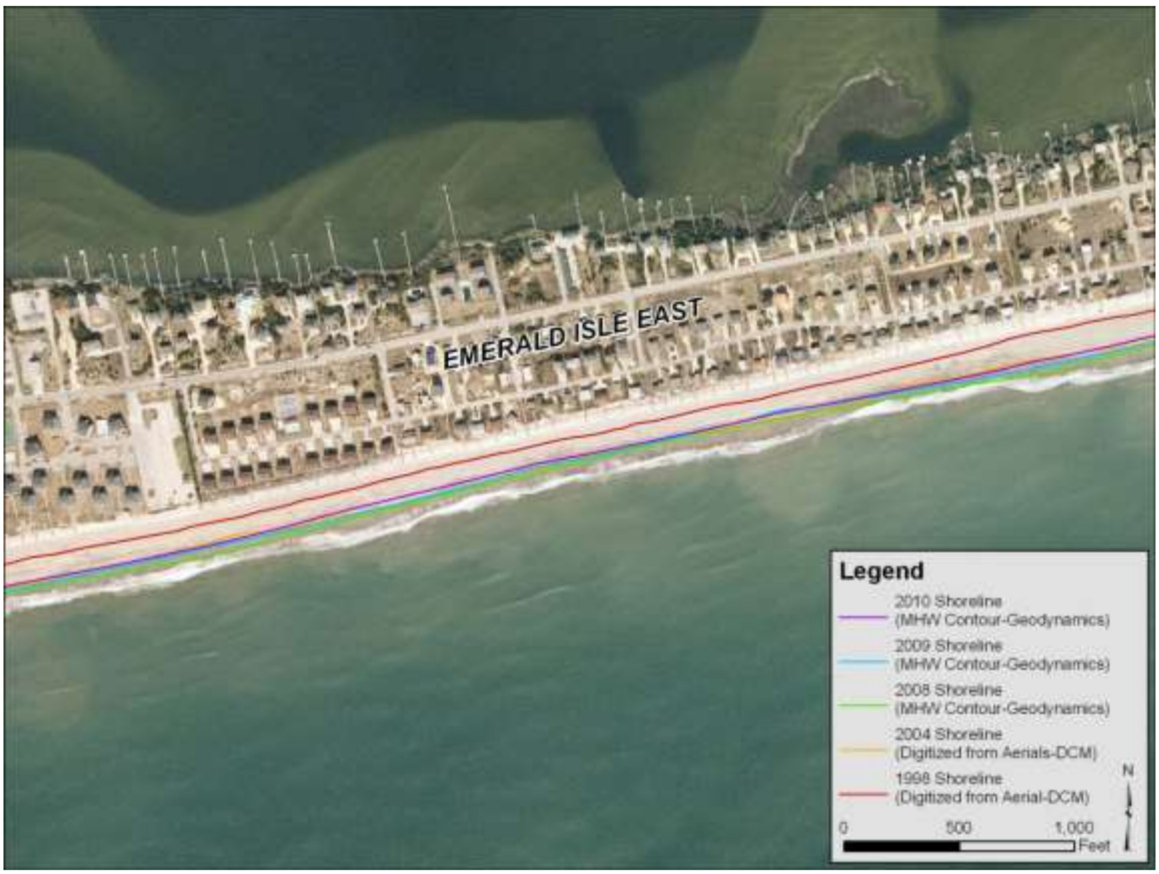


Figure 3-7: Example Shoreline Data

3.6 Sediment Resource Data

3.6.1 Native Beach Sediment Data

Before the series of nourishment projects which took place along Bogue Banks in the 2000's, native beach data was collected by the USACE as well as CSE. These data indicate a native grain size ranging from 0.2 mm to 0.3 mm. For this report, a median grain size of 0.3 mm is selected as the best representation of the native beach based upon the 64 samples analyzed by CSE in 2001. Table 3-7 summarizes the available native beach data. More detail on these studies can been seen in Section 3 of Appendix B.

Table 3-7: Available Native Beach Data

Date	Source	Mean Grain Size (mm)	Coverage
1976	USACE	0.17	Atlantic Beach (4 transects)
1999	CSE	0.3	Bogue Banks (6 transects; 20,000 ft apart)
2001	USACE	0.19	Bogue Inlet Area
2001	USACE	0.19	West Emerald Isle
2001	USACE	0.2	East Emerald Isle
2001	USACE	0.2	Indian Beach
2001	USACE	0.19	Pine Knoll Shores
2001	USACE	0.19	Atlantic Beach
2001	USACE	0.22	Fort Macon
2001	CSE	0.3	Indian Beach/Salter Path & Pine Knoll Shores (16 transects)

The native beach characteristics and parameters identified by the North Carolina Administrative Code "Technical Standards for Beach Fill Projects" (15A NCAC 07H .0312) are presented in Table 3-8.

Table 3-8: Native Beach Characteristics and Rule Parameters

Characteristic	2001 Native	NCAC Requirements	Required Borrow Site Parameters
Fines (<#230)	Reported: 0%, Assumed: <1%	<1% +5%	≤ 6%
Sand (>#230 & <#10)	Reported at 98.68%	-	-
Granular (>#10 & <#4)	Reported combined at 1.32%, Assumed 0.7% each	0.7% + 5%	≤ 6%
Gravel (>#4)		0.7% + 5%	≤ 6%
Calcium Carbonate	Reported at 15-20%	20% + 15%	≤ 35%

3.6.2 Borrow Area Sediment Data

Sediment data has also been collected to support identification of borrow areas for the various nourishment projects that have occurred along Bogue Banks. Sediment cores were obtained in the offshore borrow areas used for the Bogue Banks Restoration Project (A1, A2, B1, and B2) as well as the Morehead City ODMDS which was used for the most recent 2013 Post-Irene Renourishment Project. Both inlets (Bogue and Beaufort) and the AIWW have also been sampled and used as sediment sources in the past. Additional research into other areas offshore of Bogue Banks (Area Y and Area Z) was recently performed in 2012 in an attempt to find additional nourishment material, especially for Emerald Isle. Table 3-9 shows the available borrow area sediment data. Figure 3-8 shows the location of the potential borrow area vibracores. More detail on the analysis of these vibracores can be seen in Appendix B. A summary of the vibracores collected in 2012, in borrow areas examined for this study, is presented in the following sections.

Table 3-9: Available Borrow Area Sediment Data

Date	Source	Description	Coverage
1999	CSE	127 cores	Offshore Bogue Banks-Including Areas A1, A2, B1, & B2
2002	USACE	425 cores	Onslow Bay, Bogue Inlet, Beaufort Inlet, AIWW Tangent B
2006	CSE	14 cores	ODMDS
2007	USCG	10 cores	US Coast Guard Channel
2008	USACE	8 cores	Bogue Inlet AIWW
2012	Alpine	61 cores	Old and New ODMDS
2012	Alpine	55 cores	Borrow Area Y
2012	Alpine	5 cores	Bogue Inlet
2012	Apline	43 cores	Borrow Area Z

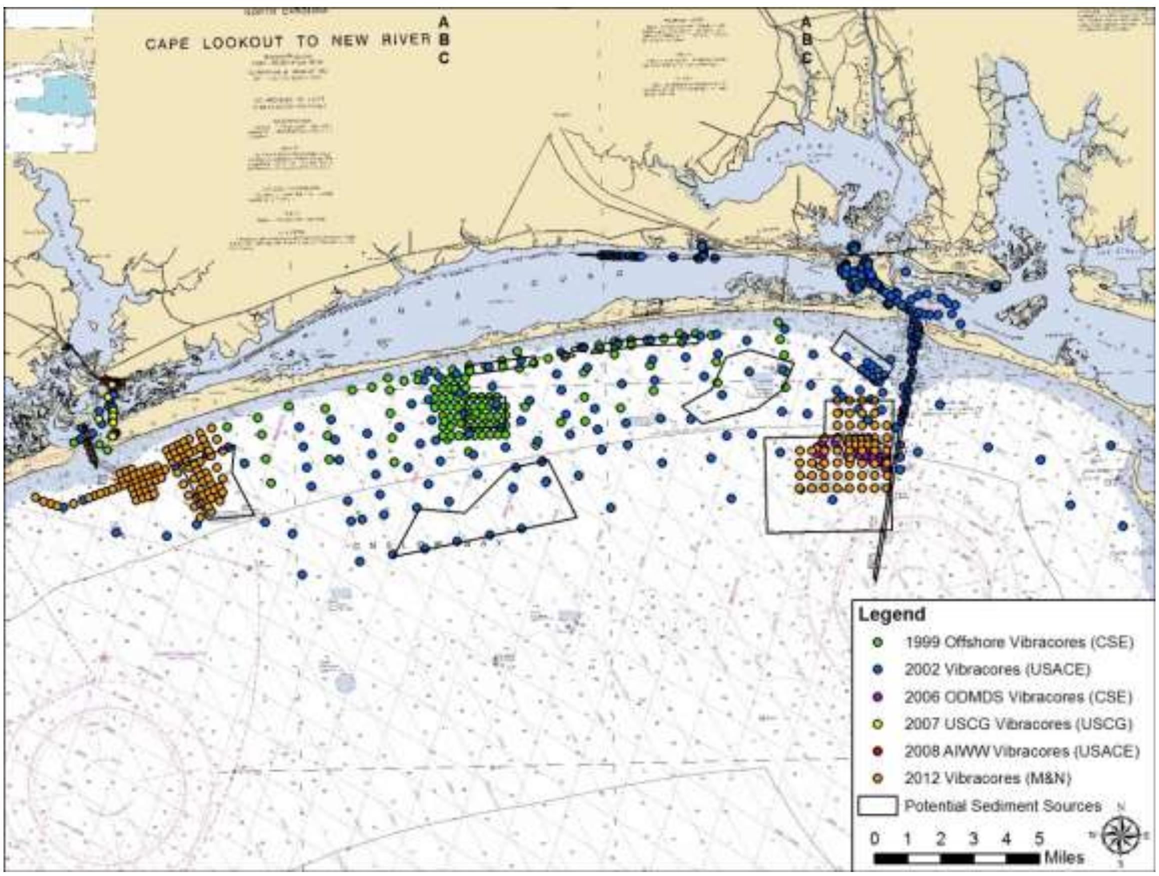


Figure 3-8: Borrow Area Vibracore Data Locations

3.6.2.1 Potential Offshore Borrow Sources for the Bogue Banks MBNP

Alpine and Coastal Tech conducted a geotechnical investigation of the main potential offshore borrow areas near Bogue Banks to identify beach-compatible sand resources for the long term beach nourishment needs of Carteret County. A detailed report can be found in Appendix B. These sites were the Old Ocean Dredge Material Disposal Site (ODMDS) located directly offshore of Beaufort Inlet, the Current ODMDS just south of the Old ODMDS, Area Y and Z directly offshore of Emerald Isle, the main ebb channel of Bogue Inlet, and the Morehead City Outer Harbor, as shown in Figure 3-9.

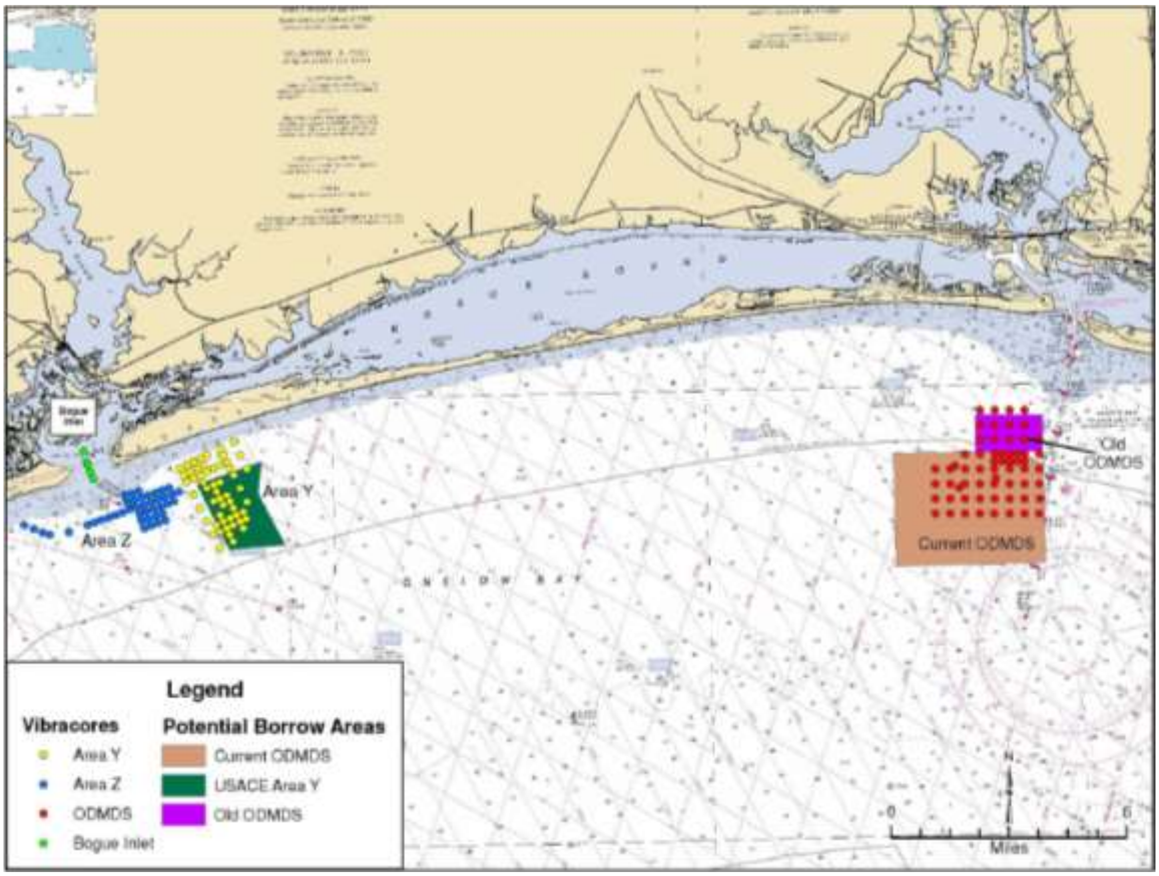


Figure 3-9: Potential Borrow Areas and 2012 Vibracore Locations (Coastal Tech, 2013)

The investigation consisted of 164 twenty-foot vibracores extracted in the Old ODMDS, Current ODMDS, Area Y, and Area Z. There were an additional 5 ten-foot vibracores extracted in Bogue Inlet by Alpine Ocean Seismic Survey.

The material in the proposed borrow areas must meet the characteristics prescribed by North Carolina Administrative Code (NCAC) "Technical Standards for Beach Fill Projects" (15A NCAC 07H .0312) resulting in the parameters listed previously in Table 3-8.

3.6.2.1.1 Old ODMDS

This site is located directly north of the Current ODMDS in State waters. The Old ODMDS was split into two sections; designated Old ODMDS 1 and Old ODMDS 2, to maximize the potential borrow area volume as shown in Figure 3-10.

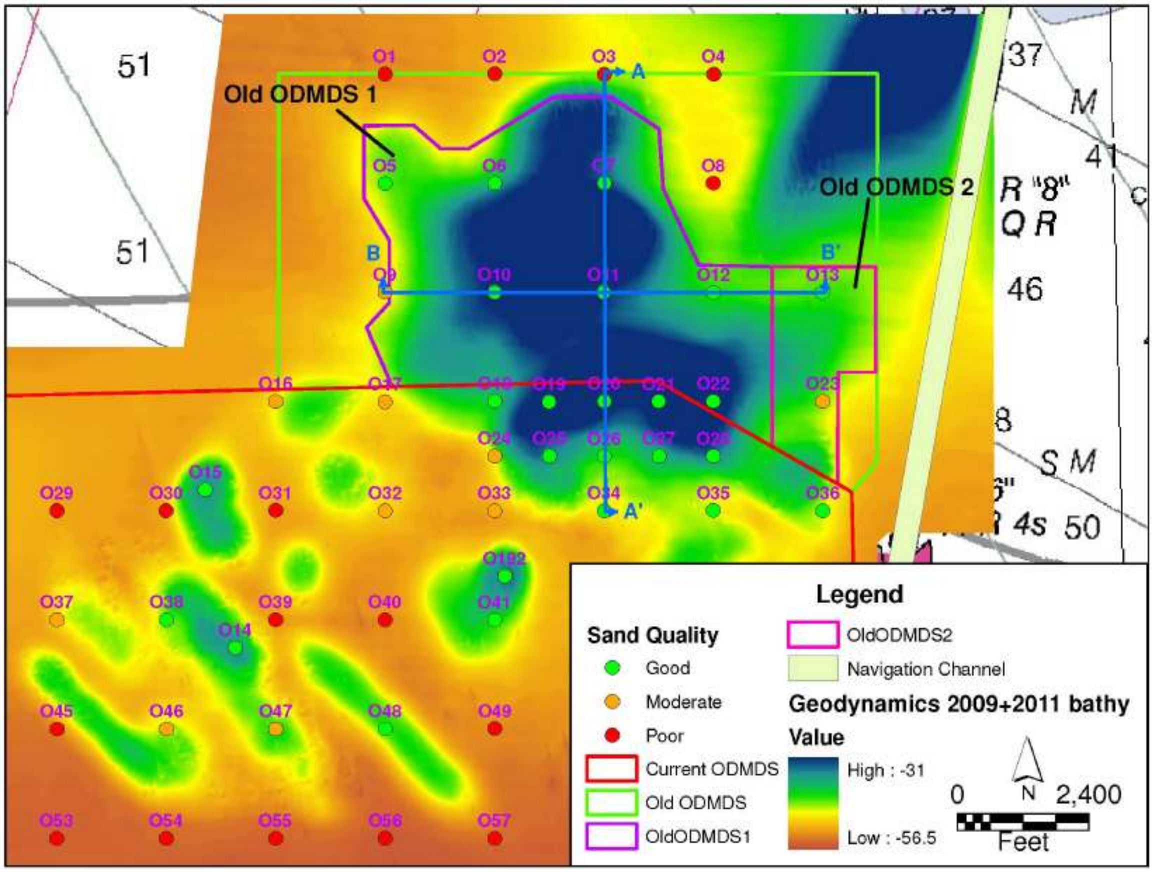


Figure 3-10: Old ODMDS Site and Vibracore Locations (Coastal Tech, 2013)

<u>Old ODMDS 1</u>

Old ODMDS 1 borrow area is location on the boarder of Current ODMDS. This area consists of fine grained, poorly sorted quartz sand with a mean grain size of 0.30 millimeters (mm) and an overfill factor of 1.30. This area is estimated to contain 13.1 Million cubic yards (Mcy) of beach compatible sand. The characteristics of this material are compliant with the parameters defined by the NCAC as shown in Table 3-10.

Table 3-10: Old ODMDS 1 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Old ODMDS 1
Fines (<#230)	≤ 6%	**0.53%**
Sand (>#230 & <#10)	-	**96.00%**
Granular (>#10 & <#4)	≤ 6%	**2.14%**
Gravel (>#4)	≤ 6%	**1.33%**
Calcium Carbonate	≤ 35%	**13.55%**

<u>Old ODMDS 2</u>

Old ODMDS 2 borrow area is similar to Old ODMDS 1 with a slightly larger mean grain size of 0.32 mm and an overfill factor of 1.25. This area is estimated to contain 1.1 Mcy of beach compatible sand that meet the NCAC criteria as listed in Table 3-11.

Table 3-11: Old ODMDS 2 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Old ODMDS 2
Fines (<#230)	≤ 6%	**0.20%**
Sand (>#230 & <#10)	-	**96.30%**
Granular (>#10 & <#4)	≤ 6%	**2.49%**
Gravel (>#4)	≤ 6%	**1.01%**
Calcium Carbonate	≤ 35%	**13.57%**

3.6.2.1.2 Current ODMDS

The Current ODMDS is located south of the Old ODMDS just outside of the 3-mile jurisdictional line in Federal waters. This area was divided into eight potential borrow areas consisting of one large mound and seven smaller disposal mounds within this location. The seven small disposal mounds were then grouped according to the level of confidence in the granularmetric data.

<u>Current ODMDS 1</u>

Current ODMDS 1 is an extension of the large mound located in Old ODMDS 1 as shown below in Figure 3-11; therefore, they have very similar sediment properties. The mean grain size is 0.30 mm and an overfill factor of 1.25 and meet all of the NCAC compatibility requirements as listed in Table 3-12. This site contains approximately 3.27 Mcy of beach compatible material. This number has been adjusted from that in Appendix B (4.23 Mcy) by subtracting out the Hurricane Irene renourishment amount which was dredged from this borrow area.

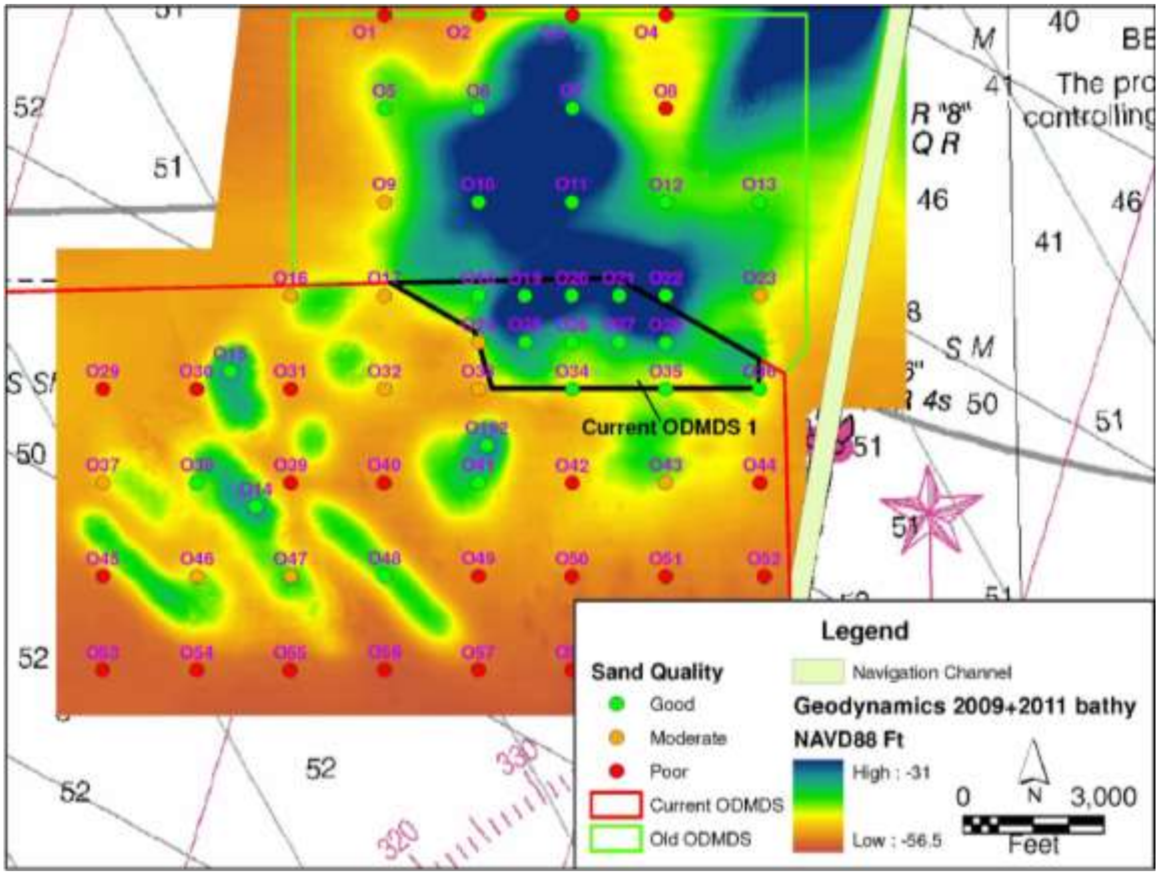


Figure 3-11: Current ODMDS 1 Site and Vibracore Locations (Coastal Tech, 2013)

Table 3-12: Current ODMDS 1 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Current ODMDS 1
Fines (<#230)	≤ 6%	**0.52%**
Sand (>#230 & <#10)	-	**96.06%**
Granular (>#10 & <#4)	≤ 6%	**2.06%**
Gravel (>#4)	≤ 6%	**1.36%**
Calcium Carbonate	≤ 35%	**13.29%**

<u>Higher Confidence Mounds</u>

The higher confidence mounds include mounds where at least one vibracore penetrates the thickest portion of the mound. This allows for more accurate representation of the stratigraphy to be defined. The higher confidence mounds include Mounds O-15, O-192, O-48, O14, and O-47, which are shown in Figure 3-12.

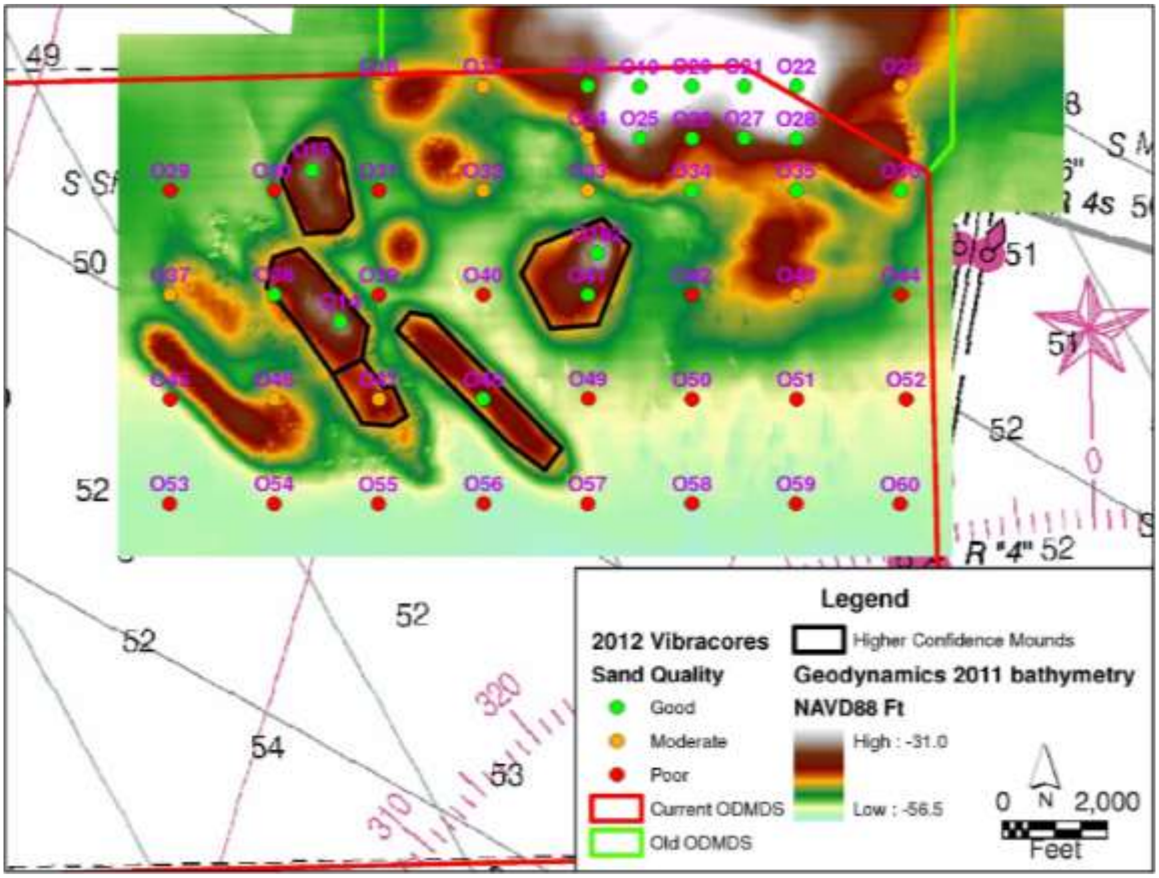


Figure 3-12: Higher Confidence Mound Sites and Vibracore Locations (Coastal Tech, 2013)

Mound O-15

Mound O-15 is located west of Current ODMDS 1 and has vibracore O-15 passing directly through the thickest section of the mound. This potential borrow area consists of fine grained, moderately sorted quartz sand and has a mean grain size of 0.24 mm, which is smaller than the native mean grain size. This results in a larger overfill factor of 1.60 and Mound O-15 being assigned a "B" ranking. All parameters defined by NCAC were met, as shown in Table 3-13; therefore, the material is considered beach compatible. The total amount of beach compatible material in this mound is approximately 356,000 cubic yards (cy).

Table 3-13: Mound O-15 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Mound O-15
Fines (<#230)	≤ 6%	**0.07%**
Sand (>#230 & <#10)	-	**99.23%**
Granular (>#10 & <#4)	≤ 6%	**0.54%**
Gravel (>#4)	≤ 6%	**0.16%**
Calcium Carbonate	≤ 35%	**10.10%**

Mound O-192

Mound O-192 is located southwest of Current ODMDS 1 and has vibracore O-192 and O-41 passing through this mound with O-192 passing through the thickest section of the mound. This potential borrow area consists of fine grained, poorly sorted quartz sand and has a mean grain size of 0.36 mm, which is coarser than the previous mound. This results in a smaller overfill factor of 1.25 and Mound O-192 being assigned an "A" ranking. All parameters defined by NCAC were met, as shown in Table 3-14; therefore, the material is considered beach compatible. The total amount of beach compatible material in this mound is approximately 785,270 cy.

Table 3-14: Mound O-192 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Mound O-192
Fines (<#230)	≤ 6%	**0.13%**
Sand (>#230 & <#10)	-	**93.07%**
Granular (>#10 & <#4)	≤ 6%	**3.43%**
Gravel (>#4)	≤ 6%	**3.37%**
Calcium Carbonate	≤ 35%	**19.59%**

Mound O-48

Mound O-48 is located southwest of Current ODMDS 1 and has vibracore O-48 passing through the middle of the mound. This potential borrow area consists of fine grained, moderately sorted quartz sand and has a mean grain size of 0.2 mm, which is significantly finer than the native sediment. This results in a larger overfill factor of 2.25 and Mound O-48 being assigned a "C" ranking. All parameters defined by NCAC were met, as shown in Table 3-15; therefore, the material is considered beach compatible. The total amount of beach compatible material in this mound is approximately 468,740 cy.

Table 3-15: Mound O-48 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Mound O-48
Fines (<#230)	≤ 6%	**5.91%**
Sand (>#230 & <#10)	-	**92.83%**
Granular (>#10 & <#4)	≤ 6%	**1.11%**
Gravel (>#4)	≤ 6%	**0.15%**
Calcium Carbonate	≤ 35%	**7.76%**

Mound O-14/O-47

Mound O-14/O-47 is located west of Mound O-48 and has vibracore O-14, O-47, and O-38 passing through the mound. This mound was split because it was assigned two different cut depths to maximize beach quality material being removed. Even though this area was split, the sediment properties were analyzed and recorded as one site. This potential borrow area consists of fine grained, poorly sorted quartz sand and has a mean grain size of 0.38 mm, which is coarser than the native sediment. This results in a smaller overfill factor of 1.20 and Mound O-14/O-47 being assigned an "A" ranking. All parameters defined by NCAC were met, as shown in Table 3-16; therefore, the material is considered beach compatible. The total amount of beach compatible material in this mound is approximately 566,028 cy.

Table 3-16: Mound O-14/O-47 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Mound O-14 / O-47
Fines (<#230)	≤ 6%	**0.23%**
Sand (>#230 & <#10)	-	**93.43%**
Granular (>#10 & <#4)	≤ 6%	**4.71%**
Gravel (>#4)	≤ 6%	**1.63%**
Calcium Carbonate	≤ 35%	**19.80%**

<u>Lower Confidence Mounds</u>

The lower confidence mounds include mounds where the vibracore is located along the edge and non that penetrate the thickest portion of the mound. This prevents an accurate representation of the stratigraphy to be defined. The lower confidence mounds include Mounds O-35 and O-46, which are shown in Figure 3-13. Coastal Tech recommends that these mounds be sampled with additional vibracores in the thickest portion of the mounds to confirm the sediment characteristic inferred from the existing cores.

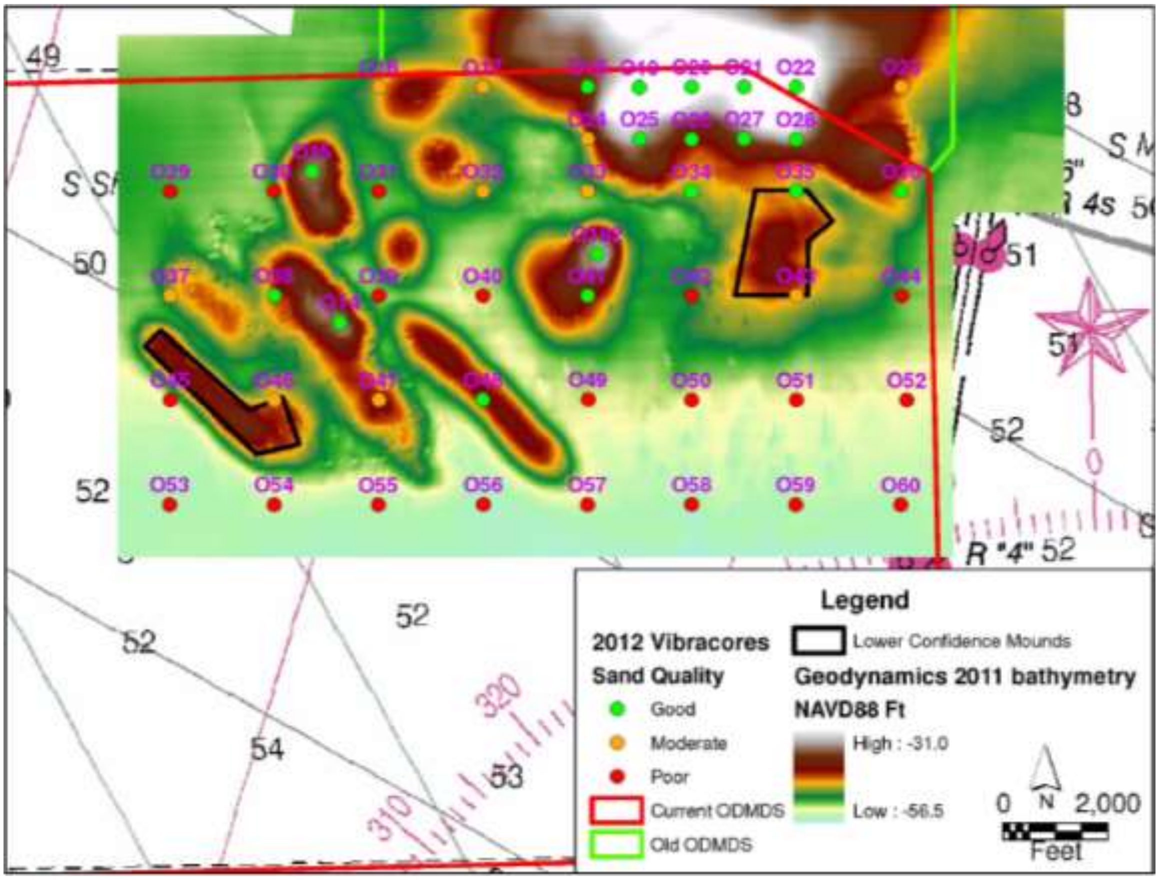


Figure 3-13: Lower Confidence Mound Sites and Vibracores (Coastal Tech, 2013)

Mound O-35

Mound O-35 is located south of Current ODMDS 1 and shares data from vibracore O-35 which was used in the analysis of Current ODMDS 1. Vibracore O-43 passes through the southern edge of this mound. These vibracores were weighted equally when the mound composite was created. This potential borrow area consists of fine grained, poorly sorted quartz sand. An overfill factor of 1.3 was calculated and Mound O-35 was assigned a "B" ranking due to the lack of sampling in the middle of the area. All parameters defined by NCAC were met, as shown in Table 3-17 below; therefore, the material is considered beach compatible. The total amount of beach compatible material in this mound is approximately 499,500 cy.

Table 3-17: Mound O-35 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Mound O-35
Fines (<#230)	≤ 6%	**0.31%**
Sand (>#230 & <#10)	-	**96.08%**
Granular (>#10 & <#4)	≤ 6%	**2.65%**
Gravel (>#4)	≤ 6%	**0.96%**
Calcium Carbonate	≤ 35%	**15.20%**

Mound O-46

Mound O-46 is located southwest of Current ODMDS 1 and only has vibracore O-46 passing through the edge of the mound. This potential borrow area consists of fine grained, poorly sorted quartz sand and has a mean grain size of 0.4 mm, which is coarser than the native sediment. An overfill factor of 1.25 was calculated and Mound O-46 was assigned a "B" ranking due to the lack of sampling in the middle of the area. All parameters defined by NCAC were met except for Granular, as shown in Table 3-18. It is believed that, upon further sampling in the center of the area, the percent granular may fall within the guidelines defined. The total amount of potential beach compatible material in this mound is approximately 493,564 cy.

Table 3-18: Mound O-46 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Mound O-35
Fines (<#230)	≤ 6%	**0.37%**
Sand (>#230 & <#10)	-	**90.60%**
Granular (>#10 & <#4)	≤ 6%	**6.27%**
Gravel (>#4)	≤ 6%	**2.76%**
Calcium Carbonate	≤ 35%	**18.17%**

Contingency Mounds

The remaining mounds in the Current ODMDS lack a vibracore within the boundary of the mound, as shown in Figure 3-14. Conceptual cut depths were assumed from the surrounding vibracores and potential volumes were calculated. These mounds do not have sediment characteristics defined. The potential volumes these mounds contain are shown in Table 3-19 with a total volume of approximately 320,000 cy.

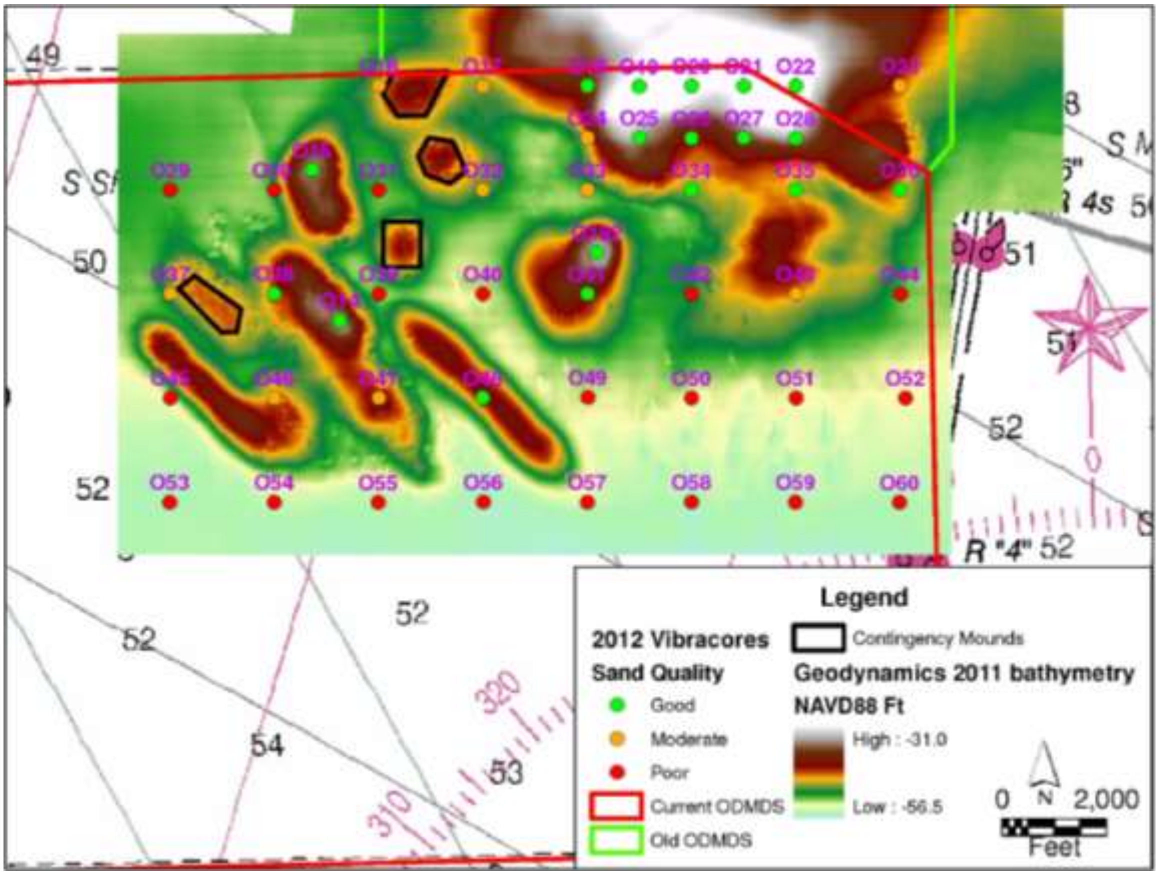


Figure 3-14: Contingency Mound Sites and Vibracores

Table 3-19: Contingency Mound Potential Volumes (Coastal Tech, 2013)

Mound	Cut Elevation NAVD88	Volume (cy)
O-16	-50 ft	95,326
O-39	-52 ft	94.352
O-37/O-38	-51 ft	71.233
O-32	-50 ft	58,543
	Total	**319,454**

3.6.2.1.3 Area Y

Area Y is located off of Emerald Isle within State waters where fifty-five vibracores were taken. Vibracores were initially taken on a 1000 foot by 1000 foot grid; however, a significant amount of fines were found in the surficial layer. The spacing was then increased to a 2000 foot grid spacing and two areas were identified as potential sites as shown in Figure 3-15.

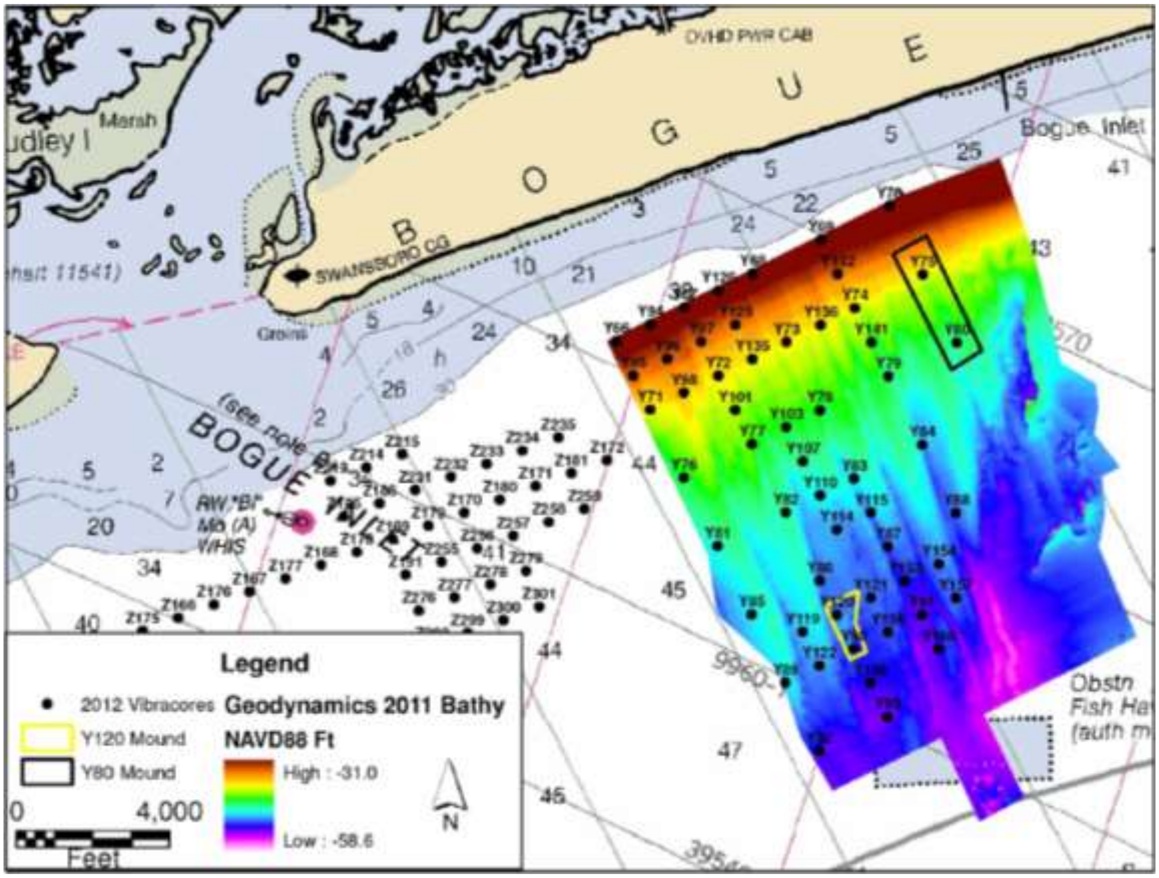


Figure 3-15: Area Y Site and Vibracores (Coastal Tech, 2013)

<u>Vibracores Y-80 / Y-75</u>

Vibracores Y-80 and Y-75 are 2000 feet apart and, due to the hardbottom buffer to the east, no vibracores were taken on that side. The vibracores taken to the west of Y-80 and Y-75 are not beach compatible. This potential borrow area consists of fine grained, moderately well sorted quartz sand and has a mean grain size of 0.23 mm, which is finer than the native sediment. All parameters defined by NCAC were met as shown below in Table 3-20. Although the parameters are met, the area should be considered a low priority with a “C” ranking due to insufficient vibracores to designate a reliable borrow area and poor quality of sediment. The potential volume is estimated at 1.08 Mcy; however, the rectangular area defined is purely conceptual and not based on the vibracores.

Table 3-20: Vibracores Y-80 & Y-75 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Vibracores Y-80 / Y-75
Fines (<#230)	≤ 6%	**2.37%**
Sand (>#230 & <#10)	-	**97.55%**
Granular (>#10 & <#4)	≤ 6%	**0.08%**
Gravel (>#4)	≤ 6%	**0.00%**
Calcium Carbonate	≤ 35%	**1.85%**

Vibracores Y-120 / Y-90

Vibracores Y-120 and Y-90 are 1000 feet apart and are located along a ridge; however, the sediment color is dark in color. This potential borrow area also exceeds the requirement set by NCAC for Gravel as shown in Table 3-21; therefore, would not be considered beach compatible. The total amount of material in this mound is approximately 379,675 cy.

Table 3-21: Vibracores Y-120 & Y-90 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Vibracores Y-120 / Y-90
Fines (<#230)	≤ 6%	**2.04%**
Sand (>#230 & <#10)	-	**86.60%**
Granular (>#10 & <#4)	≤ 6%	**3.43%**
Gravel (>#4)	≤ 6%	**7.93%**
Calcium Carbonate	≤ 35%	**1.50%**

3.6.2.1.4 Area Z

Area Z consisted of forty-three vibracores that were taken southeast of Bogue Inlet in efforts to locate the White Oak River channel, shown in Figure 3-16. Vibracore Z-174 was the only sample showed a possibility of having beach compatible material; however, it exceeded the Gravel requirement as shown in Table 3-22.

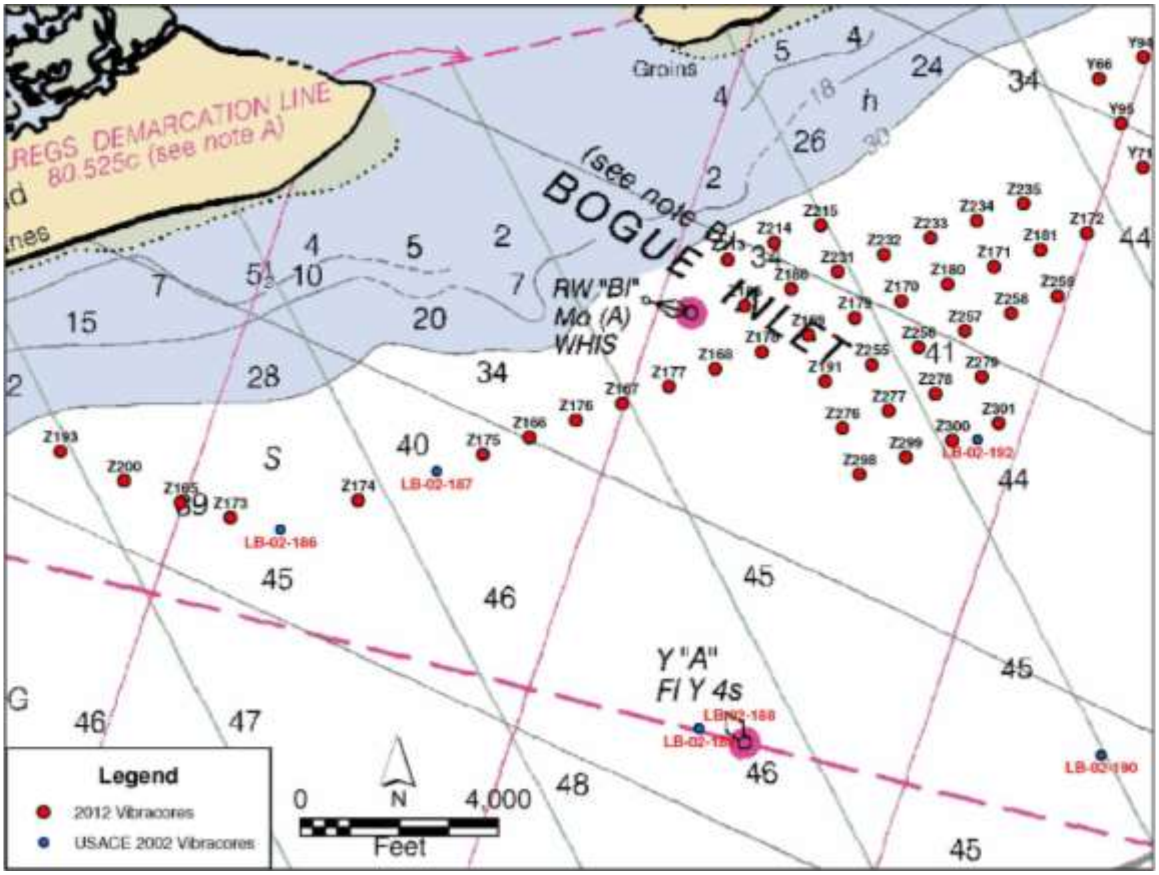


Figure 3-16: Area Z Site and Vibracores (Coastal Tech, 2013)

Table 3-22: Vibracore Z-174 Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Vibracore Z-174
Fines (<#230)	≤ 6%	**1.34%**
Sand (>#230 & <#10)	-	**84.57%**
Granular (>#10 & <#4)	≤ 6%	**2.28%**
Gravel (>#4)	≤ 6%	**11.81%**
Calcium Carbonate	≤ 35%	**11.10%**

3.6.2.1.5 Bogue Inlet Channel

Five vibracores were taken within the template of the 2005 Bogue Inlet relocation project shown in Figure 3-17. This area is fed by the surrounding beaches. The mean grain size is 0.33 mm and an overfill factor of 1.15 and meet all of the NCAC compatibility requirements as listed in Table 3-23. This site contains approximately 850,000 cy to 1 Mcy of beach compatible material.

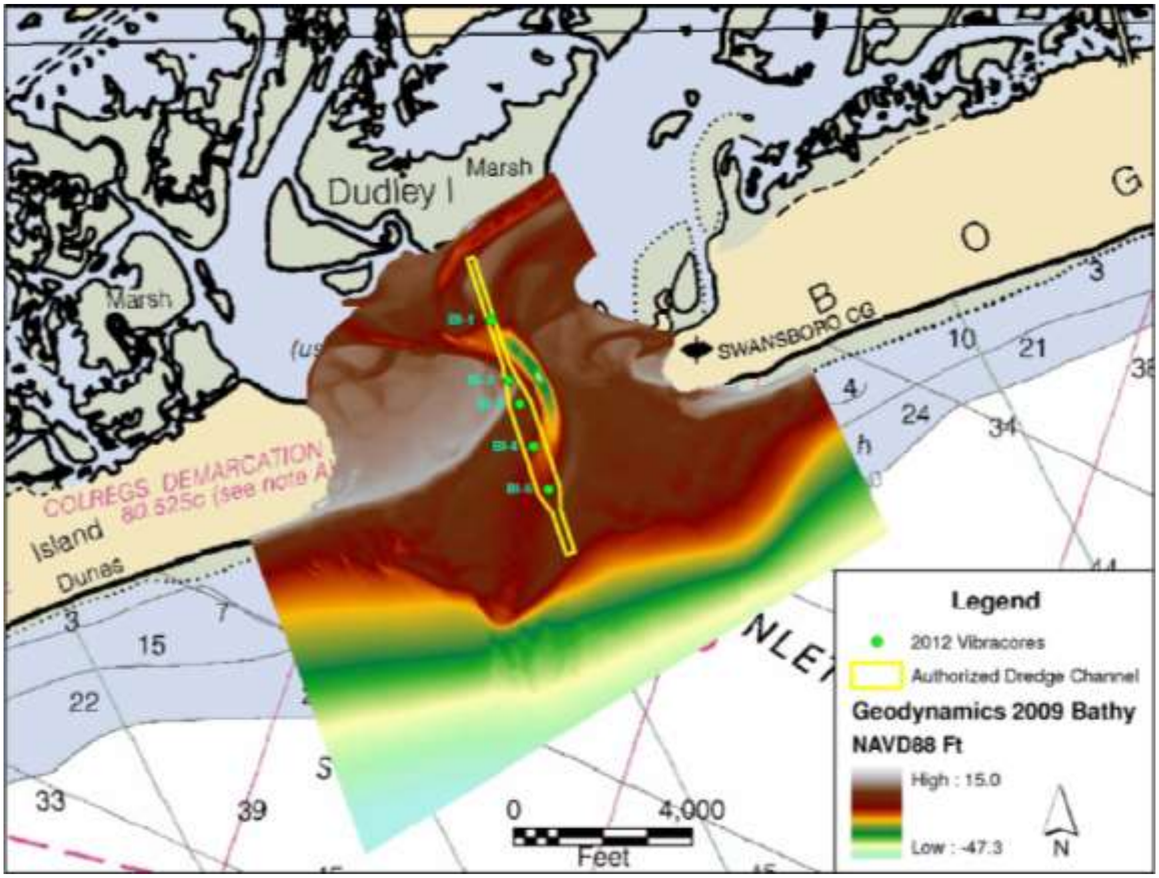


Figure 3-17: Bogue Inlet Channel Site, Vibracores, and Authorized Channel Location (Coastal Tech, 2013)

Table 3-23: Bogue Inlet Channel Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Vibracore Z-174
Fines (<#230)	≤ 6%	**0.15%**
Sand (>#230 & <#10)	-	**96.61%**
Granular (>#10 & <#4)	≤ 6%	**2.40%**
Gravel (>#4)	≤ 6%	**0.84%**
Calcium Carbonate	≤ 35%	**14.96%**

3.6.2.1.6 Morehead City Outer Harbor

The Outer Harbor consists of the Cutoff and Range A out to Station 110+00 as shown in Figure 3-18. Since this is a federal navigation project, the requirements for beach compatibility only limit the silt content to less than 10%. The characteristics of the sediment in this area meet that requirement and are listed below in Table 3-24. The USACE Morehead City Harbor draft Dredged Material Management Plan (DMMP) estimates that the Outer Harbor is shoaling at a rate of 1.2 Mcy per year (2012). Depending on the final DMMP, there could be between 228,000-635,000 cy of sand available for beach placement annually. A mid-range amount of 400,000 cy/yr is assumed to be available from this source.

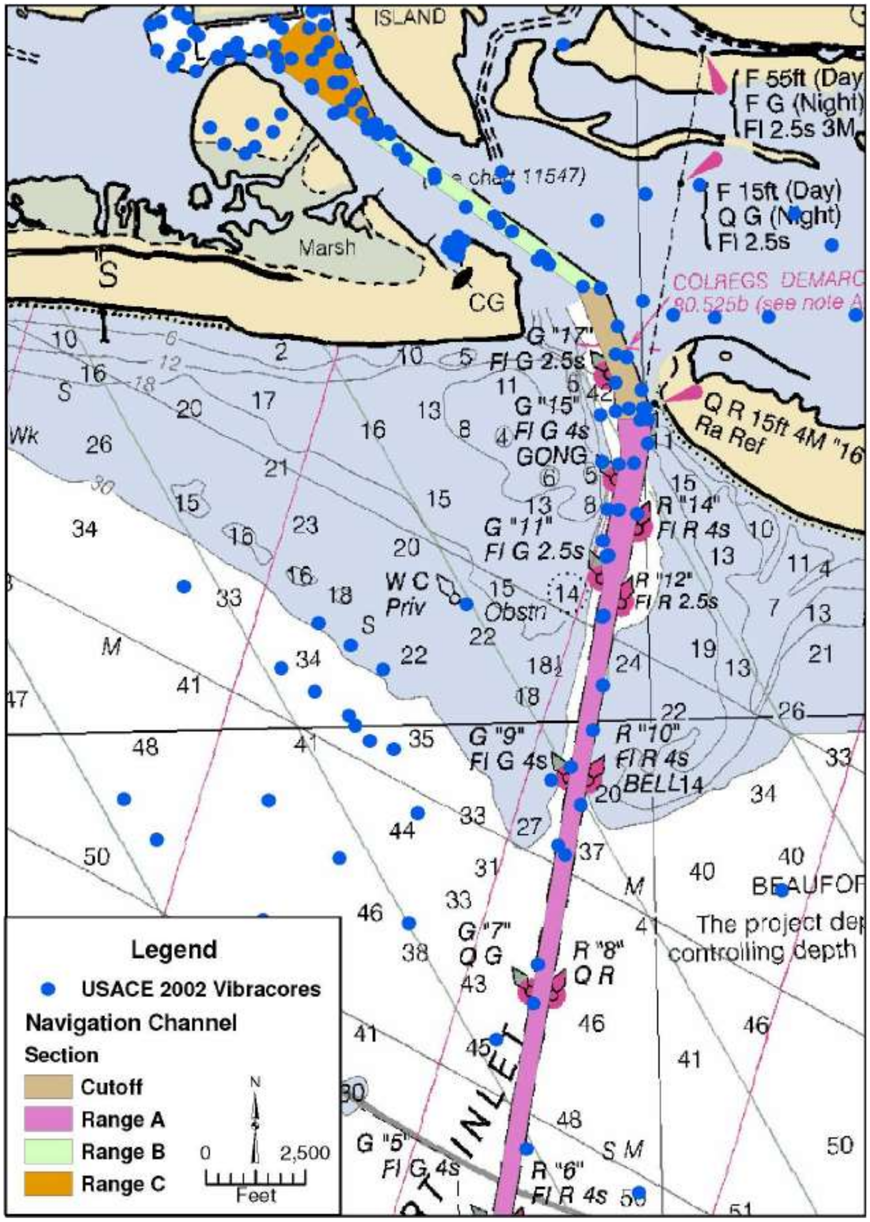


Figure 3-18: Morehead City Channel Vibracore and Reach Locations (Coastal Tech, 2013)

Table 3-24: Morehead City Outer Harbor Characteristics and NCAC Parameters (Coastal Tech, 2013)

Characteristic	Required Borrow Site Parameters	Morehead City Outer Harbor
Fines (<#230)	≤ 6%	**<1%**
Sand (>#230 & <#10)	-	**Not Reported**
Granular (>#10 & <#4)	≤ 6%	**Not Reported**
Gravel (>#4)	≤ 6%	**6.40%**
Calcium Carbonate	≤ 35%	**15.70%**

3.7 Engineering Activities Log

Carteret County has a rich history of engineering activities to abate erosion dating back to the 1830's when Fort Macon was constructed. As early as 1831 wood pilings were laid at right angles to the beach to stop erosion near the fort and in 1840 Captain Robert E. Lee was sent to study the erosion problem at Fort Macon. He recommended that stone groins be constructed. By 1845 a total of six stone groins were built around the fort which protected the shore for almost 40 years. In 1961, a stone seawall and groin system was begun. Later in 1968 the terminal groin was constructed by extending one of the existing groins. It was further extended in 1970 to its present size.

In the 1970's dredge disposal from the Morehead City Harbor channel began being deposited on eastern Bogue Banks. Since then, Bogue Banks has also undergone nourishment at the Point from Bogue Inlet dredging, various post-storm restoration projects, and a few USACE "beneficial-use" projects. Table 3-25 shows the engineering activities history for Bogue Banks.

One of the most notable engineering projects was the 2005 relocation of Bogue Inlet in which the inlet channel was relocated approximately 3,000 ft to the west and approximately 690,000 cy of dredged material was placed on western Emerald Isle in conjunction with Phase III of the Bogue Banks Restoration Project.

Table 3-25: Carteret County Engineering Activities

Fiscal Year	Project Description	Borrow Source	Placement Location	Length (ft)	Volume (cy)
1961	Fort Macon Terminal Groin Construction				
1961			Fort Macon	7,656	?
1973		State Port (Morhead City Harbor)	Atlantic Beach/Fort Macon	5,043	504,266
1978	Dredge Disposal to Eastern Bogue Banks (MCH Inner Habor Maintenance)	Morehead City Inner Harbor Maintenance Dredging	Fort Macon	11,797	1,179,600
1984	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		15,000
1986	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Morehead City Inner Harbor Maintenance Dredging and Brandt Island Pump Out	Atlantic Beach	39,129	4,168,600
1987	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		30,000
1989	USACE Navigation Dredging	Near Swansboro	Emerald Isle		45,399
1990	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		56,000
1993	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		17,000
1994	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Morehead City Inner Harbor Maintenance Dredging	Fort Macon	24,737 (total)	2,192,268
1994	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Brandt Island Pump Out	Atlantic Beach	24,737 (total)	2,472,132
1995	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		33,000
1996	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		71,000
1997	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		39,000
1999	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		48,000
2000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		16,000
2002	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Morehead City Inner Harbor Maintenance Dredging	Fort Macon		209,348
2002	Bogue Banks Restoration - Phase I -R1	Borrow Site A, B1, & B2 (Offshore of Bogue Banks)	Indian Beach (reach 1)	39,202 (total)	456,994 (total)
2002	Bogue Banks Restoration - Phase I -R2	Borrow Site A, B1, & B2 (Offshore of Bogue Banks)	Indian Beach (reach 2)	39,202 (total)	456,994 (total)
2002	Bogue Banks Restoration - Phase I -R3	Borrow Site A, B1, & B2 (Offshore of Bogue Banks)	Pine Knoll Shores (reach 3)	39,202 (total)	1,276,586
2003	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		59,000
2003	Bogue Banks Restoration - Phase II	Borrow Site A & B2 (Offshore of Bogue Banks)	Eastern Emerald Isle	31,111	1,867,726
2004	Isabel Sand Replenishment-East Reach	Morehead City Harbor ODMDS	Eastern Emerald Isle (east reach)	12,500 (total)	156,000 (total)
2004	Isabel Sand Replenishment-Mid Reach	Morehead City Harbor ODMDS	Eastern Emerald Isle (mid reach)	12,500 (total)	156,000 (total)
2004	Isabel Sand Replenishment-West Reach	Morehead City Harbor ODMDS	Eastern Emerald Isle (west reach)	12,500 (total)	156,000 (total)
2004	Section 933 - Phase I	Morehead City Outer Harbor Maintenance Dredging (Cutoff,Range A)	Indian Beach/Salter Path	15,600	699,282
2005	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Morehead City Inner Harbor Maintenance Dredging	Fort Macon	22,543 (total)	530,729
2005	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Brandt Island Pump Out	Atlantic Beach	22,543 (total)	2,390,000
2005	Bogue Banks Restoration-Phase III (& Bogue Inlet Relocation)	Bogue Inlet	Western Emerald Isle	23,760	690,868
2006	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Western Emerald Isle		77,000
2007	Ophelia Sand Replenishment-Reach 1	Bogue Banks ODMDS	Emerald Isle (reach 1)		304,037
2007	Ophelia Sand Replenishment-Reach 2	Bogue Banks ODMDS	Emerald Isle (reach 2)		344,410
2007	Ophelia Sand Replenishment-Reach 3	Bogue Banks ODMDS	Indian Beach/Salter Path (reach 3)		319,113
2007	Ophelia Sand Replenishment-Reach 4	Bogue Banks ODMDS	Pine Knoll Shores (reach 4)		73,397
2007	Ophelia Sand Replenishment-Reach 5	Bogue Banks ODMDS	Pine Knoll Shores (reach 5)		188,879
2007	Section 933-Phase II	Morehead City Outer Harbor Maintenance Dredging (Cutoff,Range A)	Pine Knoll Shores	21,120	507,939
2007	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Morehead City Inner Harbor Maintenance Dredging (Range C,Bulkhead Channel)	Fort Macon	1,992	184,828
2008	Dredge Disposal AIWW Tangent B to Pine Knoll Shores	AIWW Tangent B, Section 1	Pine Knoll Shores	646	148,393
2009	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Bogue Inlet AIWW Crossing	Emerald Point/Western Emerald Isle		64,143
2011	Dredge Disposal to Eastern Bogue Banks (MCH Outer Harbor Maintenance)	Morehead City Outer Harbor Maintenance Dredging (Cutoff, Range A & B)	Atlantic Beach/Fort Macon	16,625	1,346,700
2013	Irene Sand Replenishment-Reach 1	Morehead City Harbor ODMDS	Pine Knoll Shores	12,905	315,221
2013	Irene Sand Replenishment-Reach 2	Morehead City Harbor ODMDS	Emerald Isle East	12,504	451,600
2013	Irene Sand Replenishment-Reach 3	Morehead City Harbor ODMDS	Emerald Isle West	9,485	198,190

After the hurricanes of the 1990's, the Bogue Banks Restoration Project was developed in three phases. Phase I (2002) Nourished Indian Beach/Salter Path and Pine Knoll Shores. Phase II (2003) nourished Emerald Isle Central and Emerald Isle East. Phase III (2005), was performed in conjunction with the relocation of Bogue Inlet and nourished Emerald Isle West. After Hurricane Isabel struck in 2003, a renourishment project funded by FEMA was constructed in Emerald Isle Central and Emerald Isle East. At the same time, the USACE performed a Section 933 project to nourish Indian Beach/Salter Path using sand dredged to maintain the Morehead City Federal Navigation Project. Hurricane Ophelia impacted the area in 2005 and another FEMA funded project was put in place with reaches in Emerald Isle West, Emerald Isle East, Indian Beach/Salter Path, and Pine Knoll Shores. During this time the USACE also performed another Section 933 beneficial use project in Pine Knoll Shores. The beach remained relatively free of engineering activity (with the exception of USACE nourishment of Atlantic Beach and Fort Macon) for the next few years until Hurricane Irene impacted the area in 2011. The most recent project was performed from January-March 2013 in Emerald Isle West, Emerald Isle East, and Pine Knoll Shores and was partially funded by FEMA. Figure 3-19 shows the location and quantities of each of the nourishment activities.

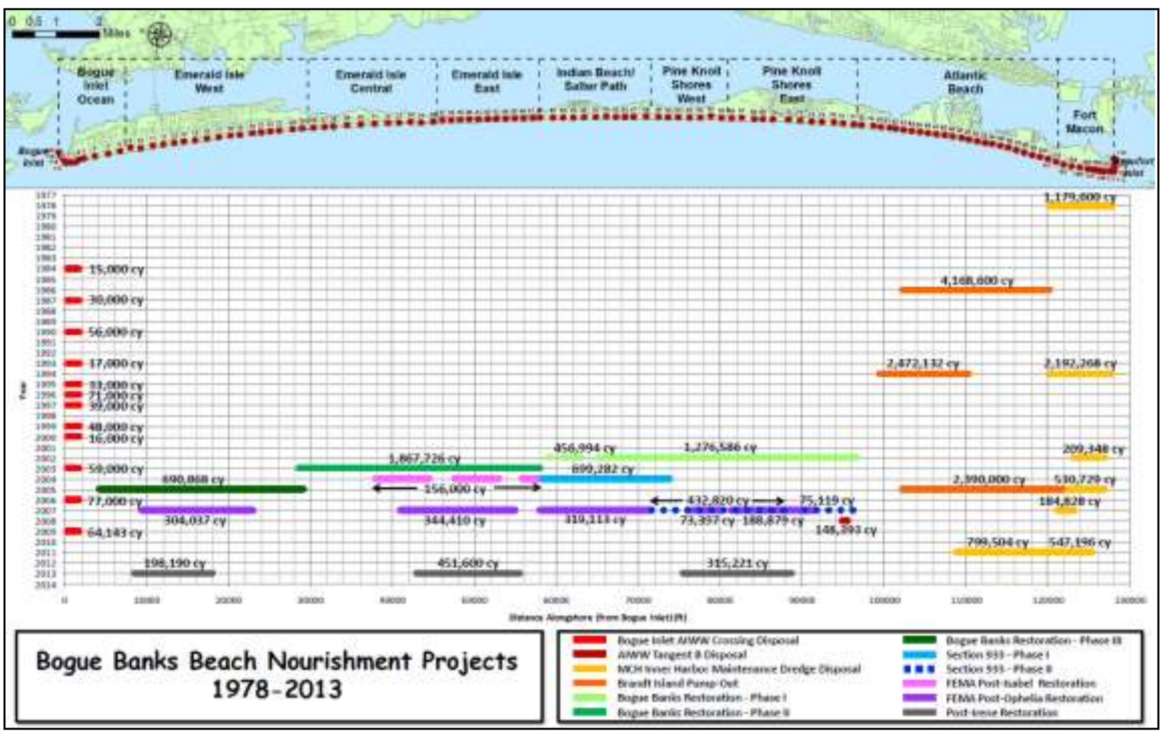


Figure 3-19: Bogue Banks Beach Nourishment History

3.8 Previous Studies by Other Consultants / Agencies

Previous studies of the area are herein referenced as taken into account during formulation of this MBNP. The following sections give a brief description of each of the previous studies.

3.8.1 Coastal Science & Engineering (CSE) Studies

3.8.1.1 Phase I and Phase II of the Bogue Banks Restoration Project

Phase I of the Bogue Banks Restoration Project encompassed placing approximately 1.73 million cy of sand on three stretches of beach in Indian Beach/Salter Path and Pine Knoll Shores from December 2002 through April 2003. Using 2001 survey data, CSE created a nourishment design template which amounted to 2.17 Mcy (approximately 57 cy/ft). CSE studied three possible offshore borrow areas, performing a sediment compatibility analysis of each relative to the native beach, ultimately utilizing areas immediately offshore of Indian Beach/Salter Path and Pine Knoll Shores (Borrow areas A, B1, and B2). They also sampled post project sediment conditions. In addition, CSE performed environmental monitoring of sea turtles and seabeach amaranth, a threatened dune plant. Unfortunately, the project was stopped prematurely due to turtle takes.

Phase II of the Bogue Banks Restoration Project encompassed placing 1.81 million cy of material on a stretch of beach along Emerald Isle Central and Emerald Isle East from January 2003 through March 2003. CSE created a nourishment design template of approximately 1.81 Mcy (approximately 58 cy/ft). The same offshore borrow sources used in Phase I were used for Phase II and CSE sampled post project sediment conditions to ensure quality of material being placed on the beach. Environmental monitoring of sea turtles and seabeach amaranth was performed along with additional biological sampling of benthic organisms within the nourished beach and offshore borrow areas.

3.8.1.2 Flow Observations: Bogue Inlet, North Carolina

CSE performed a set of flow measurements in Bogue Inlet in June 2005 after completion of the inlet relocation. The purpose was to measure the ebb and flood velocities and discharge in the new and old channels during a tidal cycle. Measurements included current and water level to estimate the discharge.

3.8.1.3 Post-Storm Reports (Isabel & Ophelia)

In September 2003, following Hurricane Isabel, CSE surveyed approximately every 5th monitoring transect from the BBBNMP. They calculated shoreline and volume change as a result of Hurricane Isabel using the April 2003 survey as pre-storm conditions.

In September 2005, following Hurricane Ophelia, CSE surveyed approximately every 5th monitoring transect from the BBBNMP. They calculated shoreline and volume change as a result of Hurricane Ophelia using the May 2005 survey as pre-storm conditions.

3.8.2 Coastal Planning & Engineering (CP&E) Studies

3.8.2.1 Bogue Inlet Channel Relocation Environmental Impact Statement

Coastal Planning & Engineering (CP&E) prepared a March 2004 report entitled *Final Environmental Impact Statement on Bogue Inlet Channel Erosion Response Project, Emerald Isle, North Carolina*. The Final EIS included a number of appendices; the one most applicable to the present engineering study is Appendix B: Engineering and Geotechnical Studies. That Appendix B in turn contains an Appendix A, a report on the historical geomorphology of Bogue Inlet prepared by William J. Cleary entitled *Bogue Inlet, NC: A GIS Based Investigation of Inlet-Induced Shoreline Changes*.

The Final EIS was prepared as part of the process of designing and permitting a solution to erosion of the western end of Emerald Isle (the Point) due to the migration of the Bogue Inlet ebb channel toward the Point in the 1990s and early 2000s. The preferred alternative solution was "the relocation of the main ebb channel to a central location that would restore the channel to a position it occupied in the mid to late 1970s." The CP&E Engineering and Geotechnical appendix documents the design considerations, channel stability calculations, and hydrodynamic modelling conducted in support of the engineering alternatives evaluation.

The Bogue Inlet geomorphology report by Cleary documents a wealth of historical aerial photography from 1938 – 2001 covering Bogue Inlet and adjacent shorelines and islands. The purpose of the report is stated to have been the investigation of "the linkage between the movement of the ebb channel and the shoreline change patterns on Bogue Banks (Emerald Isle) and Bear Island (Hammocks Beach) shorelines." Historically distinct phases of inlet migration and morphologic trends are identified and discussed. The overall changes in shoreline, island, and inlet morphology over that period are discussed. Shoreline positions from dates between 1973 and 2001 are digitized and various parameters measured. The report presents charts of changes in inlet width, channel width, and other parameters over time, and interpretations are provided.

3.8.3 USACE and Other Studies

The USACE (Section 111 Study, Interim Operations Plan, Dredge Material Management Plan (DMMP)) and Olsen Associates (2006), have completed past studies concerning the management of Beaufort Inlet as part of the Morehead City Harbor Project. These past studies have focused on the relative effects of the channel deepening on adjacent shorelines, the ebb tidal delta, and other inlet features. While some disagreements remain, agreement has been reached concerning the primary area of inlet influence from Fort Macon to the western end of Pine Knoll Shores. Ongoing efforts under the USACE Dredged Material Management Plan will clarify the likely level of beach fill placement along the eastern portions of Bogue Banks in the future.

In addition to the above, the USACE has recently released a draft feasibility report titled "Integrated Feasibility Report and Draft Environmental Impact Statement – Coastal Storm Damage Reduction – Bogue Banks, Carteret County, North Carolina" dated August 2013 for a potential 50 year Federal Shore Protection Project – subject to congressional authorization and funding. The feasibility report "identifies a National Economic Development (NED) plan, which is the plan that maximizes net benefits to the nation through reduction of future storm damages" based on application of the robust Beach-*fx* – Monte Carlo statistical model with existing conditions assumed as the June 2009 surveyed profile (USACE, 2013). The resulting initial project consists of a 2,451,254 cy initial fill placement to expand the dune and berm with renourishment on a 3-yr cycle at a volume of 1,068,746 cy per event. The annualized storm damage reduction benefits are $11,511,000 with $3,432,000 in annualized recreation benefits while annualized costs are $6,583,500 for a benefit/cost ratio of 2.3 to 1. It should be noted however, the USACE project does not include the state owned Fort Macon reach and did not include assessment of Bogue Inlet related to inlet channel and adjacent shoreline stability.

4.0 EVALUATION OF HISTORICAL BEACH PROFILE VOLUMETRIC CHANGES

4.1 Purpose and Definitions

One of the most reliable ways to analyze beach behavior and develop estimates for potential future beach nourishment needs is to examine past beach evolution with recognition of prior nourishment projects. Historical shoreline positions and beach profile morphology (including the associated volume changes) provide a basis for understanding the physics and sediment processes that caused the beach evolution. This assessment is also necessary to calibrate and validate shoreline and profile change models of the region that are used to assess alternatives.

Historical surveyed beach profiles and volume changes have been documented consistently in beach profile monitoring reports annually since 2004. In addition to these dates, additional complete surveys along Bogue Banks (alone) were completed in 1999, 2000, and 2003, as summarized in Table 3-3. These annual surveys (since 2004) have been performed along Bogue Banks, Bear Island, and Shackleford Banks as part of Carteret County's Bogue Banks Beach and Nearshore Mapping Program. This includes 122 profiles along Bogue Banks, 18 on Bear Island, and 20 profiles on Shackleford Banks. All the profiles cover both onshore (dune to wading depth) and offshore (wading depth to 30 feet) (see Figure 3-5).

The analytical/empirical and numerical modeling portions of the study considered historical and present shoreline/volumetric change rates, present sand volumes existing as of the June 2011 beach profile survey (selected since immediately before effects of Hurricane Irene), and forward-looking sand volumes required to achieve an equal level of protection (LoP) for property and infrastructure along developed reaches of the shoreline.

Past studies after the hurricanes of the 1990's have identified 225 cy/ft as (a) the average minimum healthy profile volume above -12 feet NAVD88 landward to the top of the dune and (b) a suggested minimum threshold or trigger to prompt future beach nourishment. Chapter 7.0 of the present study assesses whether this 225 cy/ft threshold value should continue to be applied across the entirety of Bogue Banks or whether varying threshold values should be specified by shoreline reach and subreach.

The following definitions are used in this report:

- Reach = a segment of shoreline wherein erosion/deposition patterns are calculated (e.g. Emerald Isle West, EI East, Pine Knoll Shores, etc.)

- Subreach = contiguous segments of shoreline within a Reach that can be represented by a single survey profile

- Existing conditions = beach profile morphology represented by the June 2011 survey, prior to Hurricane Irene.

4.2 Analytical / Empirical Assessments

4.2.1 Raw Historical Analysis

The first stage of the analytical/empirical analysis of historical data was to assess volumetric change over the period of 1999 to 2013 (13 years). Various beach profile volumes and changes were calculated over various time periods as the data allowed.

A key aspect of the historical profile evolution assessment is to determine volumetric changes in the beach profile. As limited by the data (i.e. not all surveys extend to the same offshore depth), volumetric changes were be assessed above the following elevations (NAVD88) (see Figure 4-1):

- +1.1 ft contour equivalent to MHW (represents the subaerial beach)
- -5 ft contour (dune and recreational beach)
- -12 ft contour (includes the offshore bar)
- -16 ft contour (equidistant point between -12 ft to ~depth of closure)
- -20 ft contour (near depth of closure based on previous USACE, Olsen and M&N studies related to DMMP)
- -30 ft contour (full extents of the possible active beach profile)

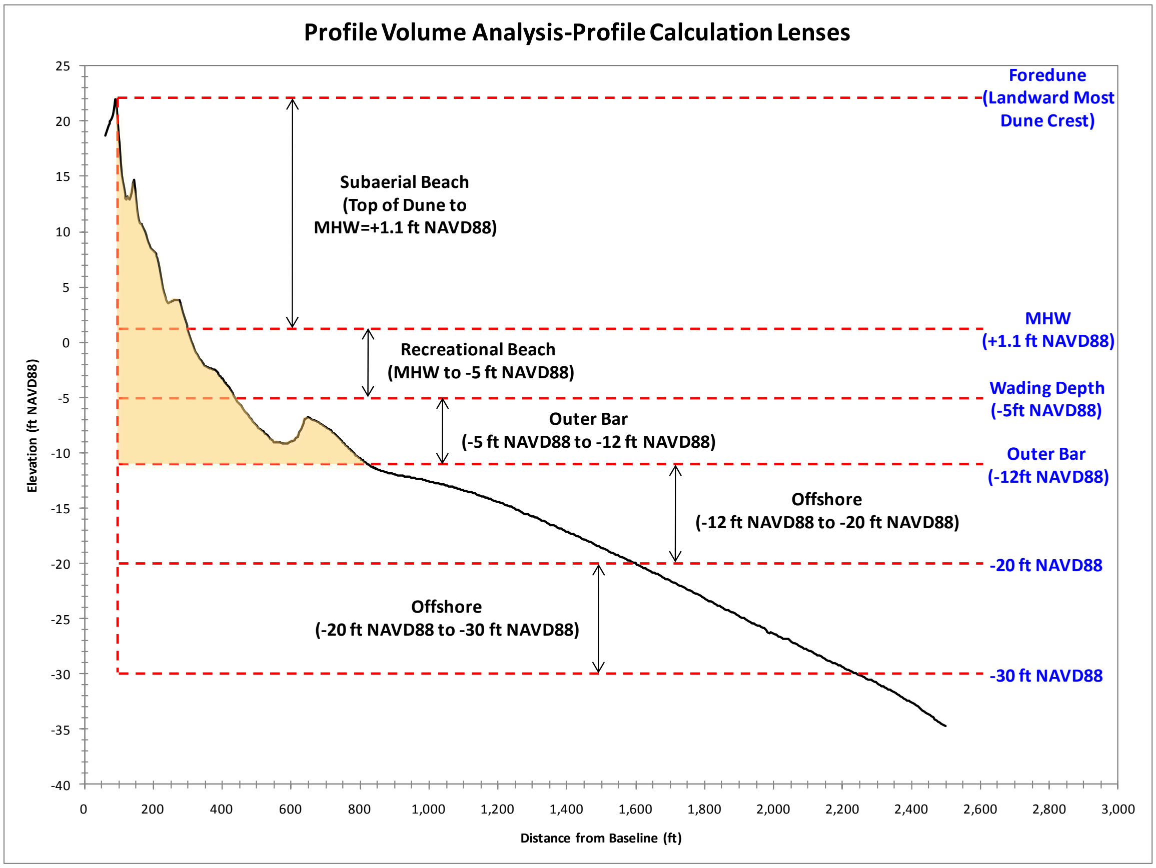


Figure 4-1: Volumetric Calculation Lenses for Historical Analysis

Past nourishment activities between surveys are also taken into account. The amounts of this nourishment were "netted out" by subtracting its volume, as determined by the historical profiles, to obtain estimates of historical background volume change rates. The profile survey locations and these past projects are illustrated in Figure 4-2.

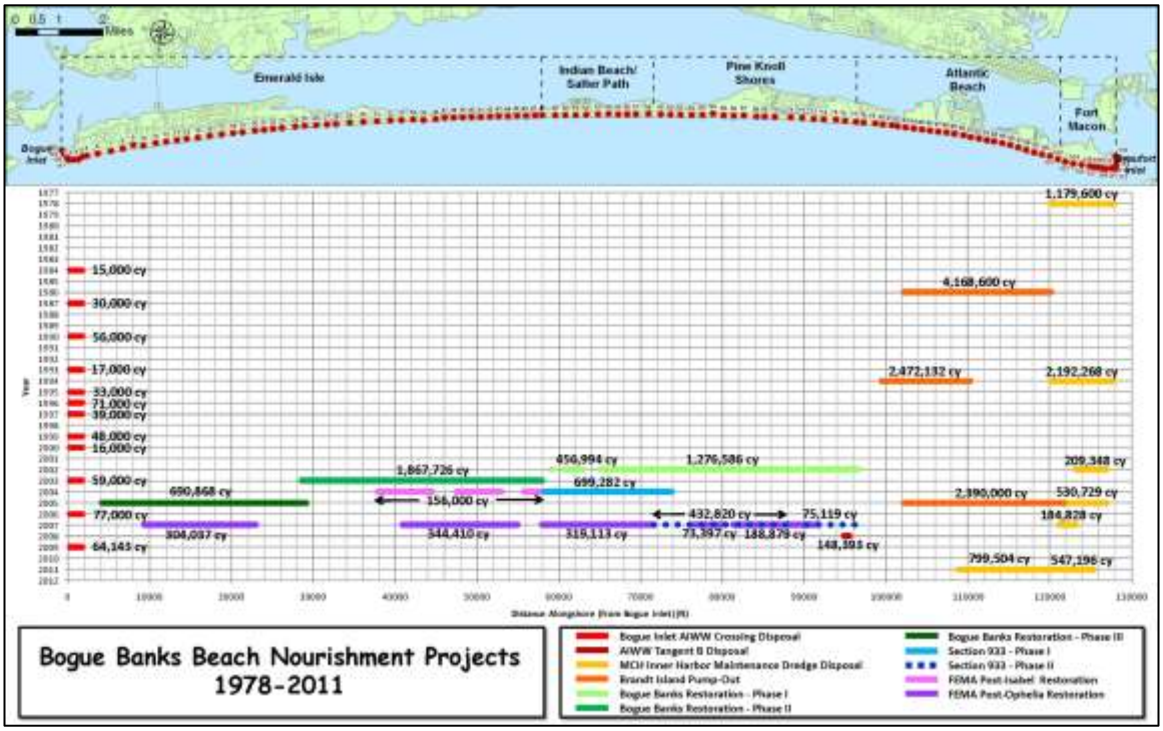


Figure 4-2: Nourishment Projects and Placement Locations Used to Subtract Volumes to Determine Background Erosion Rates

Based on a review of the profile data at representative pre- and post-project survey transects during multiple past projects, approximately 35% of nourishment volumes were placed above +1.1 ft NAVD88 while approximately 65% of nourishment volumes were placed above -5 ft NAVD88; this ratio of fill distribution is assumed applicable for each fill event. All (100%) of the nourishment volumes were placed above elevation -12 ft NAVD88 and lower elevations.

Once the background erosion rates were determined per transect and annualized per year, the unit and cumulative volume change above each elevation could be plotted for comparisons of variability of change across the island as well as to determine a preliminary estimate of annual need just to keep up with current conditions. Representative plots are shown in Figure 4-3 and Figure 4-4 for the -12 ft elevation while all elevation plots can be found in Appendix C.

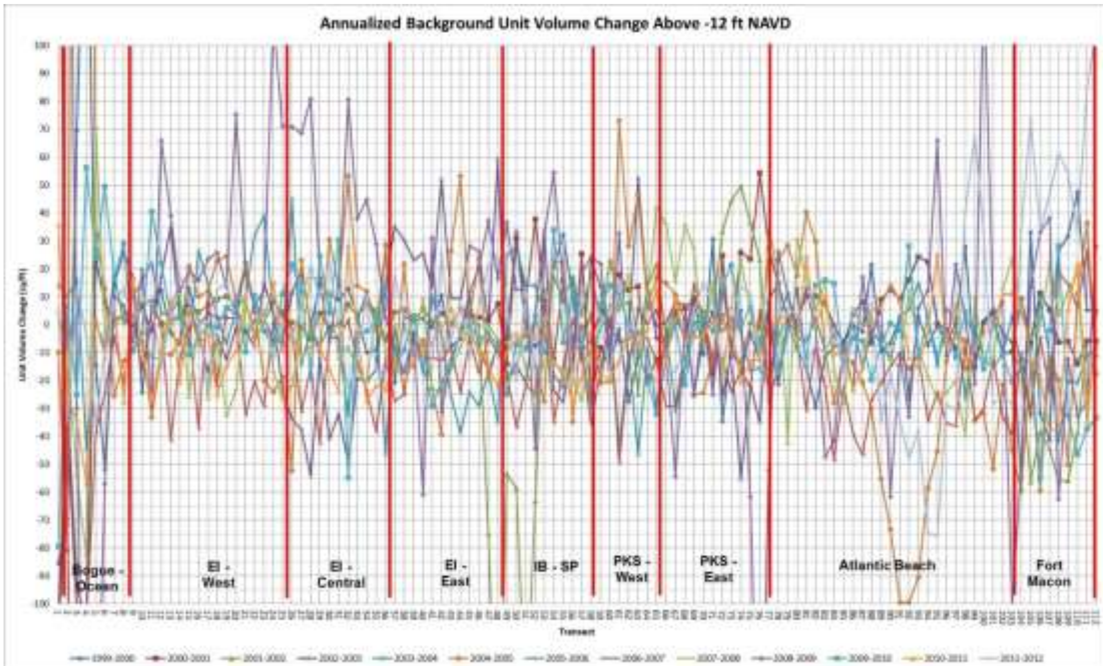


Figure 4-3: Annualized Background Unit Volume Change (Above -12.0 ft NAVD88)

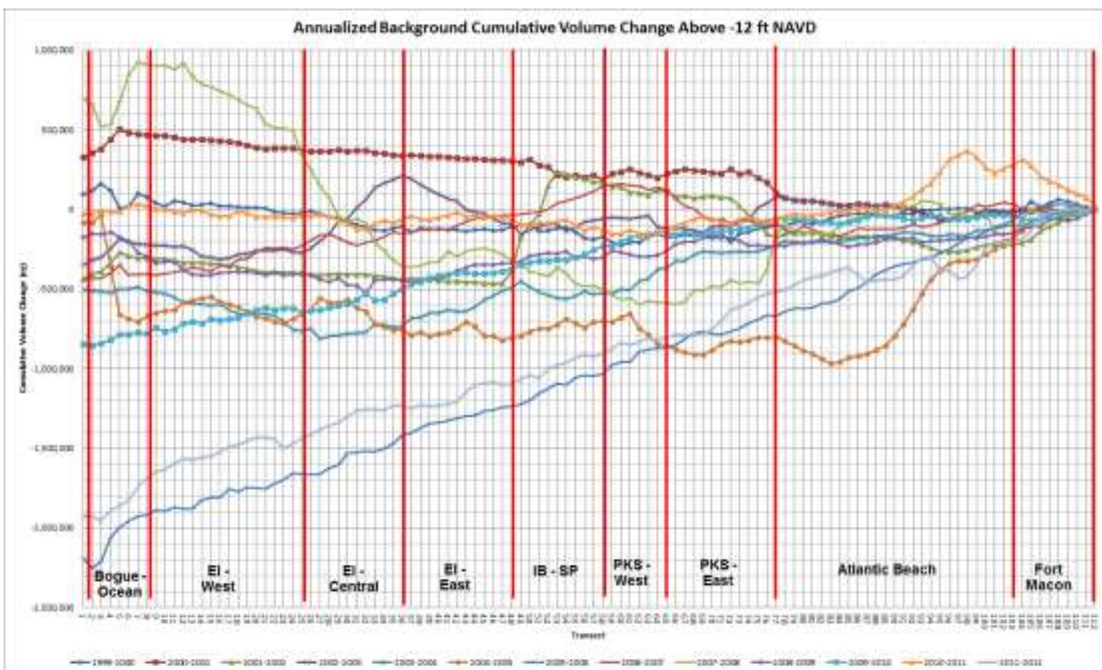


Figure 4-4: Annualized Background Cumulative Volume Change (Above -12.0 ft NAVD88)

As can be seen from the previous graphs and those shown in Appendix C, the amount of variability in the unit rate volume changes was higher near the inlets (especially for elevations -5.0 ft and -12.0 ft) as well as lower elevations.

Further investigation of the data showed that the trends for -12 ft and -16 ft were similar. The trends at +1.1 ft and -5 ft were also similar but given the rough calculations assumptions made for the portion of nourishment placed above these elevations (35% for +1.1 ft, 65% for -5.0 ft), the results for these elevations would inherently have concerns of these nourishment calculation effects on the results. As for the lower elevations of -20 ft and -30 ft, the results at these elevations show higher variability and also evidences of volume gains on occasion which is likely caused by transient onshore/offshore movements. The table below shows the overall annualized volume change per reach from 1999-2012. **Based on the results below, it would appear that the peak volume losses occur within the -12 ft and -16 ft contours and that the overall average loss per year is between 450,000 – 600,000 cy/yr over all of Bogue Banks. Removing the Fort Macon reach would change these numbers to 390,000 – 575,000 cy/yr.**

Table 4-1: Average Annual Volume Change By Reach (1999-2012)

Reach	Average Volume Change 1999-2012 (CY)				
	+1.1 ft NAVD	-5 ft NAVD	-12 ft NAVD	-16 ft NAVD	-20 ft NAVD
Bogue Inlet (1-8)	-4,082	-11,719	-39,895	-118,185	-128,922
Emerald Isle - West (9-25)	12,781	42,738	34,952	47,263	100,348
Emerald Isle - Central (26-36)	-856	4,881	-11,852	15,886	56,122
Emerald Isle - East (37-48)	-13,678	-26,068	-63,698	-100,687	-13,236
Indian Beach/Salter Path (49-58)	-40,171	-29,920	-62,358	-64,962	-28,837
Pine Knoll Shores - West (59-65)	-9,221	-10,626	-13,611	-11,991	-11,553
Pine Knoll Shores - East (66-76)	-31,758	-30,358	-70,698	-117,140	-101,693
Atlantic Beach (77-102)	-69,087	-95,389	-159,170	-225,575	-183,365
Fort Macon (103-112)	-20,108	-36,343	-63,897	-14,052	-32,811
TOTAL	**-176,182**	**-192,804**	**-450,226**	**-589,443**	**-343,946**

4.2.2 Statistical Analysis

In order to develop a more accurate basis of volume loss and ultimately sediment needs over the next 50 years for continued maintenance, an analysis of historical volume losses was performed to capture and statistically quantify the variability inherent within the existing data. After some investigation, it was determined that the Crystal Ball software (a Microsoft Excel Add-in program) would meet this need. A detailed description of the Crystal Ball software and the subsequent analyses can be found in Appendix C.

Crystal Ball allows the user to specify a distribution (normal, Gumbel, Ln Pearson III, etc.) for each assumption (in our case – unit volume change for each transect). Any equation in Excel that references an assumption, then becomes a forecast (in our case – volume change per transect/per reach/subreach of beach – depending on the length studied). Through using a Monte Carlo simulation running for hundreds of thousands of trials, the distribution of the forecasts can then be modeled and determined. Therefore, the user can end up with results such as the 50% or 75% probability that the volume change for a given transect will not exceed say 2,000 cy/yr or 3,500 cy/yr respectively. These individual results can then be added over various reaches of beach to study localized erosion/deposition patterns as well as overall volume needs on an annual and longer-term basis. Utilizing this tool gives the user increased confidence in predictions and allows for more informed decision making.

Table 4-2 summarizes the Crystal Ball analyses for the management reaches included within the MBNP. Please note that the Fort Macon reach is not included in these analyses since it is a state park and the County is not responsible for providing nourishment for this reach. Results were tabulated for 0 – 100% probability for each study reach and can be seen in Appendix C.

For comparative purposes, the Crystal Ball analysis results were tabulated and compared to the annualized sediment need determined by the USACE for its 50-yr project (Table 4-2). When one compares the results of these analyses to those of the USACE for the 50-yr Study, it became apparent that the Crystal Ball results for the 50% probability above -12ft NAVD were the closest match to the USACE proposed NED plan with which was developed with the complex Beach-fx Monte-Carlo model and was optimized to maximize net benefits for shoreline protection along Bogue Banks over 50 years. Please also note that the 50% probability results also align with the historical results shown in Table 4-1 previously for the various calculation elevations.

Nonetheless, within the Crystal Ball analyses, a number of the reaches were accretional under the 50% probability scenario and history has shown that most areas of the island have required nourishment at one time or another. Therefore, the 55% - 70% probability scenarios which reflect losses for every reach, are more representative of historical conditions. **Table 4-2 shows an overall annual loss along Bogue Banks (without Fort Macon) of roughly 450,000 cy with a 50-yr nourishment need of 22.6 Mcy just to keep up with historical erosion patterns. Again, the Crystal Ball estimate above -12ft NAVD compares reasonably well with the USACE estimate of approximately 391,026 cy/yr and a 50 year need of 19.5 Mcy.**

Table 4-2: Crystal Ball Analysis Result Table for Annual Volume Change and 50-yr Nourishment Need

Reach	Reach Length (ft)	USACE Initial Placement Density (cy/ft)	USACE Annual Renourishment (cy)	+1.1 ft Annual Loss 50% (cy)	+1.1 ft Annual Loss Density 50% (cy/ft)	-5 ft Annual Loss 50% (cy)	-5 ft Annual Loss Density 50% (cy/ft)	-12 ft Annual Loss 50% (cy)	-12 ft Annual Loss Density 50% (cy/ft)	-16 ft Annual Loss 50% (cy)	-16 ft Annual Loss Density 50% (cy/ft)	-20 ft Annual Loss 50% (cy)	-20 ft Annual Loss Density 50% (cy/ft)		-12 ft Annual Loss 50% (All Loss)(cy)	-12 ft Annual Loss Density 50% (All Loss) (cy/ft)
Bogue Inlet (1-8)	7,432	60.0	-19,228	-4,170	-0.6	-18,555	-2.5	-39,468	-5.3	-134,450	-18.1	-163,229	-22.0		-39,468	-5.3
Emerald Isle West - A (9-11)	4,056	12.2	-24,225	-176	0.0	318	0.1	-5,384	-1.3	-3,004	-0.7	1,273	0.3		-5,384	-1.3
Emerald Isle West - B (12-22)	14,283	2.0	-16,233	10,828	0.8	26,970	1.9	33,886	2.4	45,035	3.2	79,421	5.6		-4,768	-0.3
Emerald Isle West - C (23-25)	4,005	0.1	-295	2,063	0.5	7,128	1.8	6,254	1.6	7,218	1.8	19,898	5.0		-1,566	-0.4
Emerald Isle Central - A (26-32)	10,428	1.0	-5,245	-1,377	-0.1	2,913	0.3	-982	-0.1	19,080	1.8	54,148	5.2		-14,093	-1.4
Emerald Isle Central - B (33-36)	5,374	0.9	-2,133	676	0.1	-6,347	-1.2	-10,890	-2.0	-11,250	-2.1	1,711	0.3		-10,890	-2.0
Emerald Isle East - A (37-44)	8,814	16.9	-22,025	-7,074	-0.8	-24,000	-2.7	-40,472	-4.6	-73,944	-8.4	-20,702	-2.3		-40,472	-4.6
Emerald Isle East - B (45-48)	4,406	12.8	-8,410	-6,634	-1.5	-14,088	-3.2	-23,272	-5.3	-12,302	-2.8	7,201	1.6		-23,272	-5.3
Indian Beach/Salter Path - West (49-52)	5,275	19.6	-18,144	-31,167	-5.9	-34,982	-6.6	-54,380	-10.3	-35,560	-6.7	-19,498	-3.7		-54,380	-10.3
Indian Beach/Salter Path - East (53-58)	7,575	4.1	-23,753	-9,396	-1.2	-5,706	-0.8	-8,187	-1.1	-25,398	-3.4	-9,784	-1.3		-8,187	-1.1
Pine Knoll Shores - West (59-65)	9,063	3.5	-31,057	-9,343	-1.0	-14,833	-1.6	-13,726	-1.5	-12,095	-1.3	-11,184	-1.2		-13,726	-1.5
Pine Knoll Shores - East - A (66-70)	6,564	10.5	-19,056	-7,364	-1.1	-15,605	-2.4	-24,709	-3.8	-32,204	-4.9	-12,895	-2.0		-24,709	-3.8
Pine Knoll Shores East - B (71-76)	8,251	19.0	-31,562	-24,631	-3.0	-27,929	-3.4	-46,360	-5.6	-85,297	-10.3	-88,549	-10.7		-46,360	-5.6
Atlantic Beach - West (77-81)	5,388	22.9	-26,533	-2,248	-0.4	567	0.1	-125	0.0	-4,475	-0.8	-2,924	-0.5		-5,881	-1.1
Atlantic Beach - Central (82-89, 91-96)	13,771	47.5	-52,361	-45,628	-3.3	-78,963	-5.7	-96,718	-7.0	-150,104	-10.9	-128,399	-9.3		-96,718	-7.0
Atlantic Beach - Circle (90)	1,006	53.2	-4,280	-5,851	-5.8	-10,397	-10.3	-12,948	-12.9	-22,234	-22.1	-19,431	-19.3		-12,948	-12.9
Atlantic Beach - East (97-102)	6,011	80.5	-51,707	-15,394	-2.6	-25,279	-4.2	-49,398	-8.2	-48,566	-8.1	-32,756	-5.4		-49,398	-8.2
TOTAL ANNUAL VOLUME CHANGE	**121,702**	**20.1**	**-356,247**	**-156,886**	**-1.3**	**-238,788**	**-2.0**	**-386,879**	**-3.2**	**-579,550**	**-4.8**	**-345,699**	**-2.8**		**-452,220**	**-3.7**
50-yr Nourishment Need	**121,702**	**36.6**	**-17,812,350**	**-7,844,300**		**-11,939,400**		**-19,343,950**		**-28,977,500**		**-17,284,950**			**-22,611,000**	

While the historical dataset does include some storm events (Hurricanes Isabel, Ophelia, and Irene), the effects of these storms were mainly seen in the above analyses at the higher exceedance results (i.e., 65-100% probabilities). Therefore, the above analyses is assumed to be representative of normal background erosional patterns, but a separate analysis of an individual storm impacts is appropriate. This analysis would give a sense of the overall sediment need from a storm perspective as well.

To assess storm impacts, the overall dataset was restricted to the three years of 2003 to 2005 which included Hurricanes Isabel, Ophelia, and Irene. The mean and standard deviation of the volume change was calculated for each transect and placed within the Crystal Ball input. The simulations were re-run for 200,000 trials again and the results tabulated. In this case, the results were summed across the entire management reach during each trial (rather than summing the individual reaches for each trial) to determine the expected losses during a named hurricane event which would likely receive FEMA reimbursement to pay for the sand loss. It was posited that using this approach would better account for behavior during the storms where the sand is moved along reaches and the individual variability of the reaches may overstate the true volume loss. Table 4-3 shows the results for losses above -12 ft and -16 ft. **Based on the results, it is expected that the need for a given storm may range between 1.4 – 1.7 Mcy. Given that storms have occurred once every three years or so, the storm need over 50 years may range between 22.4 – 27.2 Mcy, which is comparable to 29.4 Mcy based upon the background erosion losses of 589,443 cy/yr above -16 ft NAVD since 1999 reflected in Table 5-1.**

Table 4-3: Crystal Ball Estimate of Individual Storm Volume Loss

Probability	Storm Loss Above -12 ft NAVD (cy)	Storm Loss Above -16 ft NAVD (cy)
85%	-1,644,909	-1,847,667
84%	-1,636,034	-1,839,681
80%	-1,602,871	-1,809,816
75%	-1,567,196	-1,776,197
70%	-1,534,995	-1,747,197
65%	-1,506,039	-1,719,307
60%	-1,477,667	-1,693,397
55%	-1,450,894	-1,668,206
50%	-1,424,153	-1,644,355

This relative 50/50 split of storm erosion versus background erosion was verified against the table below taken from the last monitoring report. Please note that the overall erosion calculated since 1999 is approximately 6.45 Mcy. During the three named storms, the volume loss was ~3.3 Mcy which approximates the roughly 50/50 split on storm versus background erosion determined above. Also, from Table 4-4, the overall annual loss rate (for the period of 1999-2012) has been approximately 500,000 cy/yr. Therefore, the Crystal Ball analyses for both background and storm loss combined (900,000 – 1,000,000 cy/yr total) is likely somewhat conservative, but the County would rather be sure that the Master Plan meets the expected needs for beach nourishment over the next 50 years.

Table 4-4: Average Annual Background Erosion Rate

Reach	Length (ft)	Volume Change Above -12 ft NAVD88 (cy) (1999-2012)	Nourishment Volume (cy)	Background Erosion (cy)	Average Annual Background Erosion Rates (cy/ft/yr)
Bogue Inlet-Ocean	7,432	-212,839	59,272	-272,111	-2.82
Emerald Isle West	22,344	811,451	935,633	-124,182	-0.43
Emerald Isle Central & East	29,022	1,231,310	2,368,136	-1,136,826	-3.01
Indian Beach/Salter Path	12,850	693,714	1,358,842	-665,128	-3.98
Pine Knoll Shores	23,878	1,084,840	2,311,741	-1,226,901	-3.95
Atlantic Beach	26,176	1,323,201	3,189,504	-1,866,303	-5.48
Fort Macon State Park	6,691	314,190	1,472,101	-1,157,911	-13.31
Total	**128,393**	**5,245,869**	**11,695,229**	**-6,449,360**	**-3.86**

Therefore, the overall (background and storm) sediment need over the 50 year planning horizon based on the analytical/empirical analysis is between 45.0 and 49.8 Mcy.

4.3 Numerical Modeling: SBEACH Storm Profile Response

In addition to historical volume change, determination of how the beach would respond to various return period events would also need to be quantified by modeling. Beach profiles respond most significantly to elevated water levels and waves associated with storms. Storm-induced beach profile evolution simulations were conducted for representative survey transects in each reach / subreach using the SBEACH numerical model. The model was calibrated to observed beach profile morphology from the 2005 pre- and post-Ophelia data set and verified using the 2011 pre- and post-Irene data set.

The primary purpose of the beach profile evolution numerical modeling is to assess the level of protection from storm surge and waves afforded by the beach and dune system – under existing conditions and with different project alternatives which is covered in later sections of the Engineering Report.

4.3.1 Representative Transects and Reaches

The number of transects in the regular Bogue Banks beach profile monitoring program (112) is too great to efficiently simulate existing conditions and proposed alternative projects at each and every transect. Therefore, 18 transects were selected within each reach and subreach that are representative of existing conditions beach profile morphology in each area.

Table 4-5 gives the representative transects for which levels of protection have been simulated in SBEACH, along with the length of shoreline represented. Representative transects were selected based on physical beach characteristics, historical erosion rates, and geopolitical boundaries. Detailed descriptions for each subreach, as well as the associated plots of the June 2011 profile surveys are contained in Appendix D. Figure 4-5 shows the location of the transect locations within each reach.

Table 4-5: Reach Description and Representative Profile Transects

Reach	Bogue Banks Transects	Length (feet)	Representative Transect
Bogue Inlet – Ocean (1-8)	1 through 8	7,432	6
Emerald Isle – West (9-25)	9 through 11	4,056	11
	12 through 22	14,283	17
	23 through 25	4,005	25
Emerald Isle – Central (26-36)	26 through 32	10,428	30
	33 through 36	5,374	35
Emerald Isle – East (37-48)	37 through 44	8,814	42
	45 through 48	4,406	46
Indian Beach – Salter Path (49-58)	49 through 52	5,275	50
	53 through 58	7,575	58
Pine Knoll Shores – West (59-65)	59 through 65	9,063	65
Pine Knoll Shores – East (66-76)	66 through 70	6,564	70
	71 through 76	8,251	75
Atlantic Beach (77-102)	77 through 81	5,388	79
	82 through 89 & 91 through 96	13,771	85
	90	1,006	90
	97 through 102	6,011	100
Fort Macon State Park (103-112)	103 through 112	6,691	105

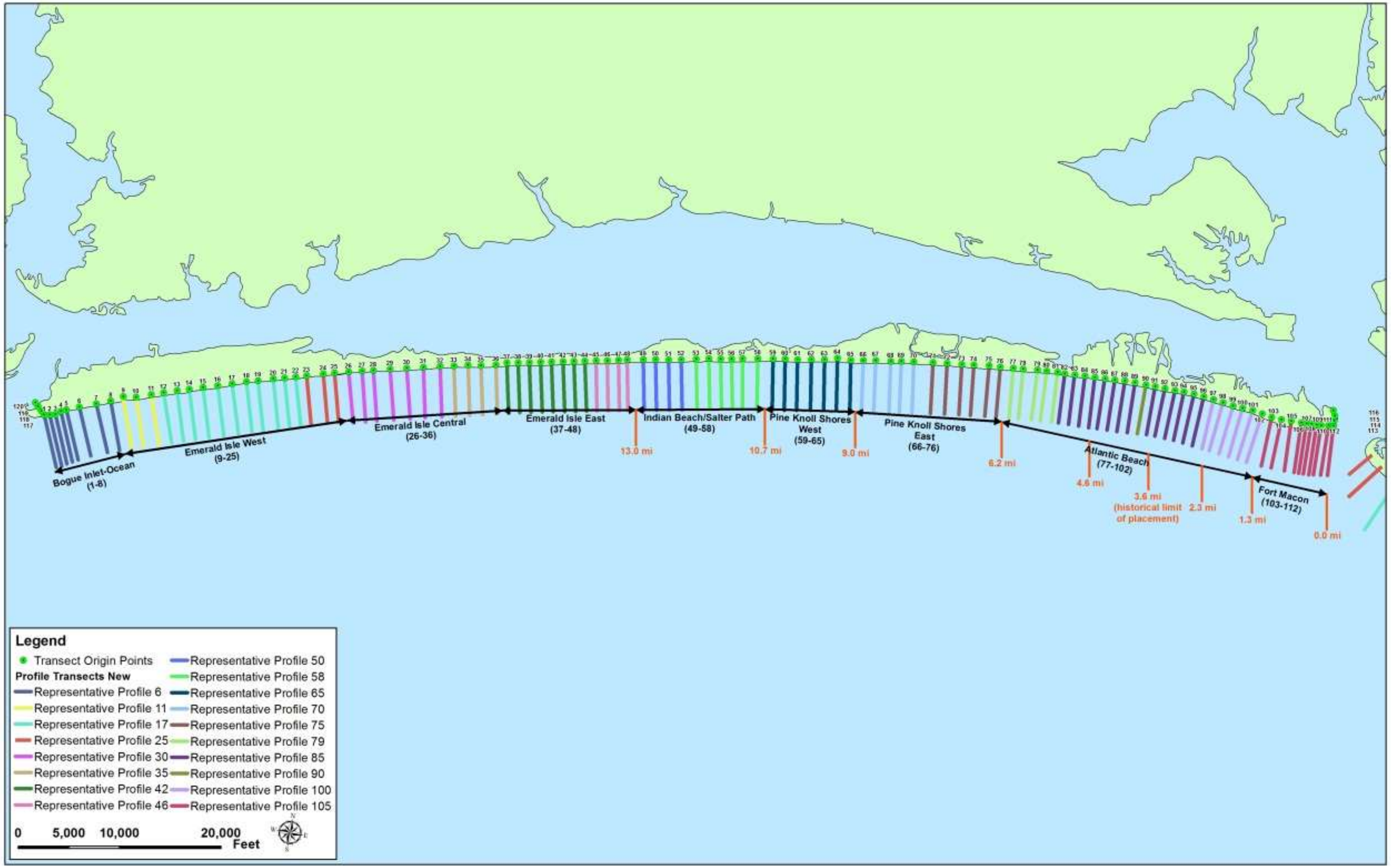


Figure 4-5: Location of Representative Transects

4.3.2 SBEACH Model Description

SBEACH is a two-dimensional (elevation [z] and cross-shore distance [x]) model developed by USACE for simulating beach and dune profile change in storm wave and water level conditions. The model is described in detail in the various USACE technical references (Larson, et al., 1989, 1990, 1998, 2004; Rosati, et al., 1993); these references and others are available from the USACE Coastal & Hydraulic Laboratory website[2].

The SBEACH model is based on cross-shore sediment transport and morphology processes, and it does not include the effects of longshore transport gradients. The model is not intended for simulating post-storm recovery of the beach profile, as would naturally occur in many coastal systems including Bogue Banks, or for long-term beach profile evolution. It is also not intended for direct support of long-term shoreline change studies, because long-term shoreline change is driven in part by longshore transport gradients. However, the use of SBEACH is appropriate to assess the ability of the beach and dune along Bogue Banks to protect landward properties and infrastructure from direct wave impact and erosion during storm waves and surges. SBEACH capabilities include the simulation of dune erosion and redistribution of sediments lower in the profile. SBEACH is also capable of simulating wave setup (water level increase at the dune due to wave action), which raises the elevation of wave attack and increases the chance of the dune being overwashed or breached in a storm event.

4.3.3 Modeled Sediment Characteristics

Surface sediment sampling and laboratory gradation testing (USACE and CSE, see Appendix B) indicated that a median grain size of D_{50} = 0.30 mm is representative of the sand comprising the beach and dune at the project site. A maximum allowable slope angle before avalanching of 36 degrees was used. The avalanching angle is a model calibration parameter. The value selected (36 degrees) is slightly higher than the recommended range in the SBEACH User Manual of 15 – 30 degrees; however, this value was set during calibration to best match the post-storm measured profiles.

4.3.4 Historical Storm Waves and Water Levels

SBEACH simulations are driven by the combined effects of storm waves acting on elevated storm water levels. At each calculation point along the profile, the model transforms the wave heights and periods given as input, with additional refraction computed if an oblique wave angle is input. Wave runup is also computed. The model computes additional elevation of input water levels due to the wave action (wave setup), and these adjusted wave and water level values are used in the profile change calculations. The wave and water level time series input to the SBEACH simulations for the calibration and verification storms are shown in Figure 4-6 and Figure 4-7.

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[2] http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Publications;118&g=92

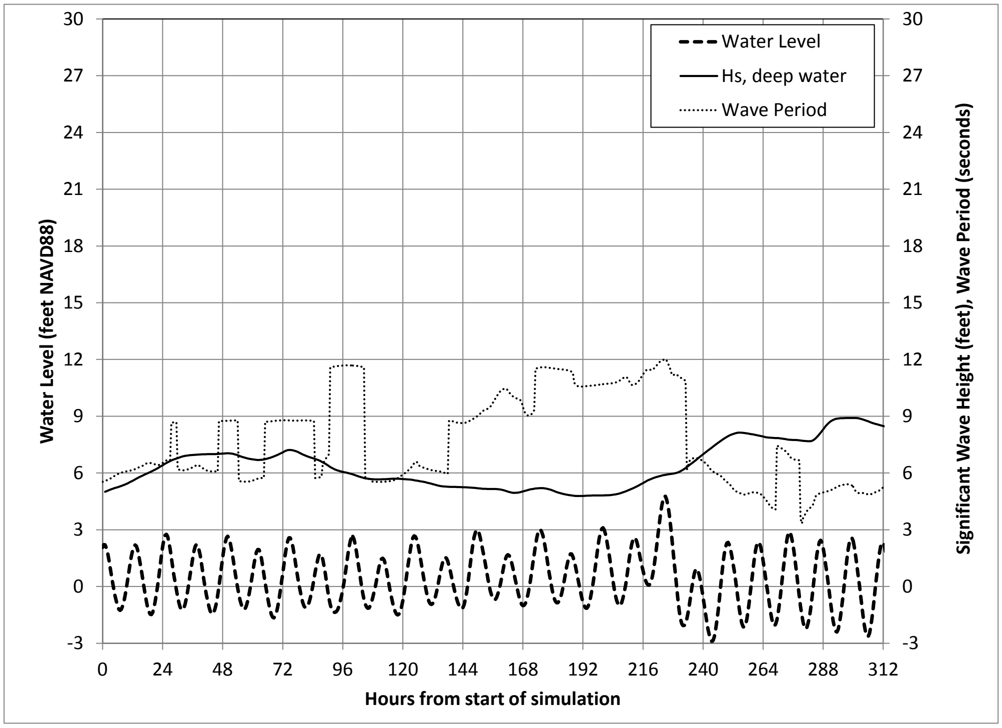

Figure 4-6: SBEACH Input Waves and Water Level, Hurricane Ophelia (2005)

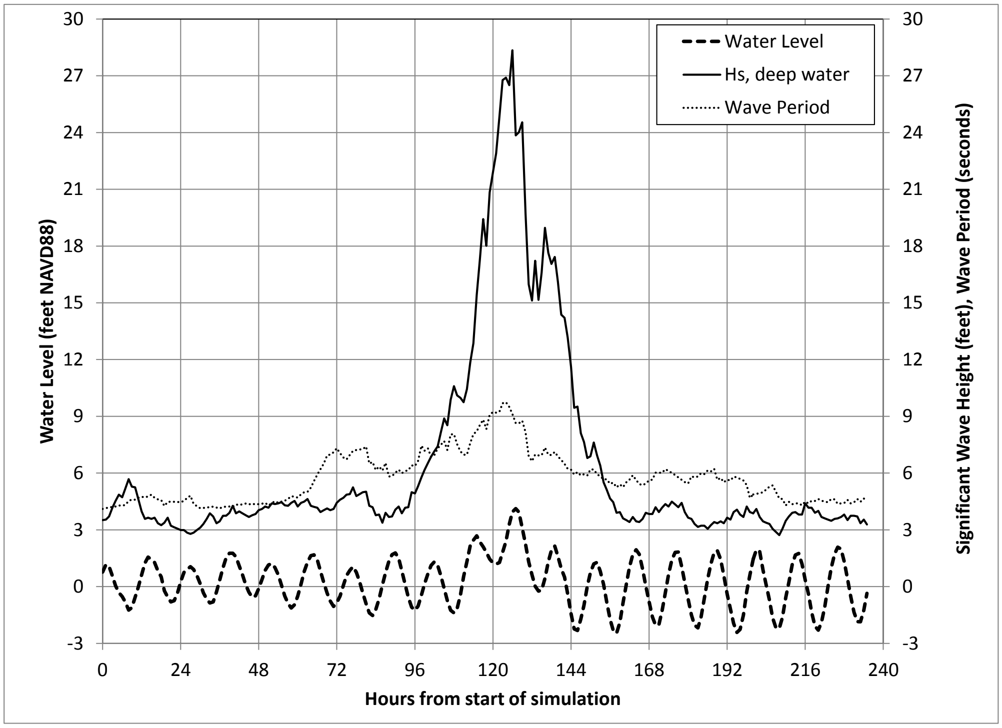

Figure 4-7: SBEACH Input Waves and Water Level, Hurricane Irene (2011)

4.3.5 Historical Storm Model Simulation Results

SBEACH parameters were calibrated to replicate, to the extent possible, the impacts of Hurricane Ophelia at 13 representative transects. The 13 transects were chosen because of pre- and post-storm data availability. The post-storm survey for Hurricane Ophelia, occurring within a week following the storm's passage, was not performed at every transect, therefore calibration was not able to be performed at all 18 representative transects. An effort was made to select at least one transect in each reach of beach for which pre- and post-storm data was available. The transects used for calibration were transect numbers 25, 30, 35, 42, 46, 50, 58, 65, 70, 75, 85, 100, and 105. The calibrated model results were then verified by simulating the impacts of Hurricane Irene. The full set of SBEACH results for both storms is provided in Appendix D.

Figure 4-8, Figure 4-9, and Figure 4-10 show typical SBEACH calibration model results for Hurricane Ophelia at Bogue Banks Transects 30, 35, and 42, respectively. These transects are representative of the SBEACH calibration set. SBEACH generally erodes the upper beach in a manner similar to the measured post-storm profiles, and it predicts the landward limit of erosion well at most transects. However, SBEACH results show the trough landward of the nearshore bar being filled in, but the measured profiles do not indicate significant filling. SBEACH also erodes the seaward face of the bar, whereas the measured profiles show the bar remaining intact and moving seaward.

In addition, most of the measured post-storm profiles show accretion, not erosion, on the beach face between the 0 ft and +3 ft NAVD88 contours, which may be associated with some immediate post-storm recovery within the zone of daily high tides and wave runup. SBEACH does not predict this pattern but shows a more "classic" equilibrium eroded profile shape from the landward limit of erosion seaward into the pre-storm trough area. It is not generally expected that SBEACH would be able to predict this accretion on the beach face, and various model settings tested during the calibration process were unsuccessful in replicating this feature.

SBEACH is used in the present study primarily to estimate the degree of beach and dune erosion (including overtopping or breaching of dunes), with associated impacts to upland structures landward of the dune, for determining the level of protection afforded by existing conditions and proposed scenarios. The SBEACH model calibration therefore focused on achieving agreement with measured profiles over the upper beach face, beach berm, and dune areas, and the calibration is generally successful in that regard.

The calibrated SBEACH model parameters were employed in simulations of Hurricane Irene (August 2011), with representative results shown in Figure 4-11, Figure 4-12, and Figure 4-13. The Hurricane Irene SBEACH simulations generally showed greater erosion of the intertidal and upper beach than the survey data indicate, and the SBEACH eroded nearshore slopes were flatter than those observed in the survey data. SBEACH was again not able to reproduce the accretion on the beach between 0 ft and +3 ft NAVD88 or the bar patterns seen in the post-storm survey data.

The agreement between SBEACH and post-storm survey data, in terms of predicting upper beach and dune erosion and landward limits of erosion, is sufficient for the purposes of estimating levels of protection for this study. The development of design storms and utilization of SBEACH to support level of protection determinations are described in Chapter 7.0.

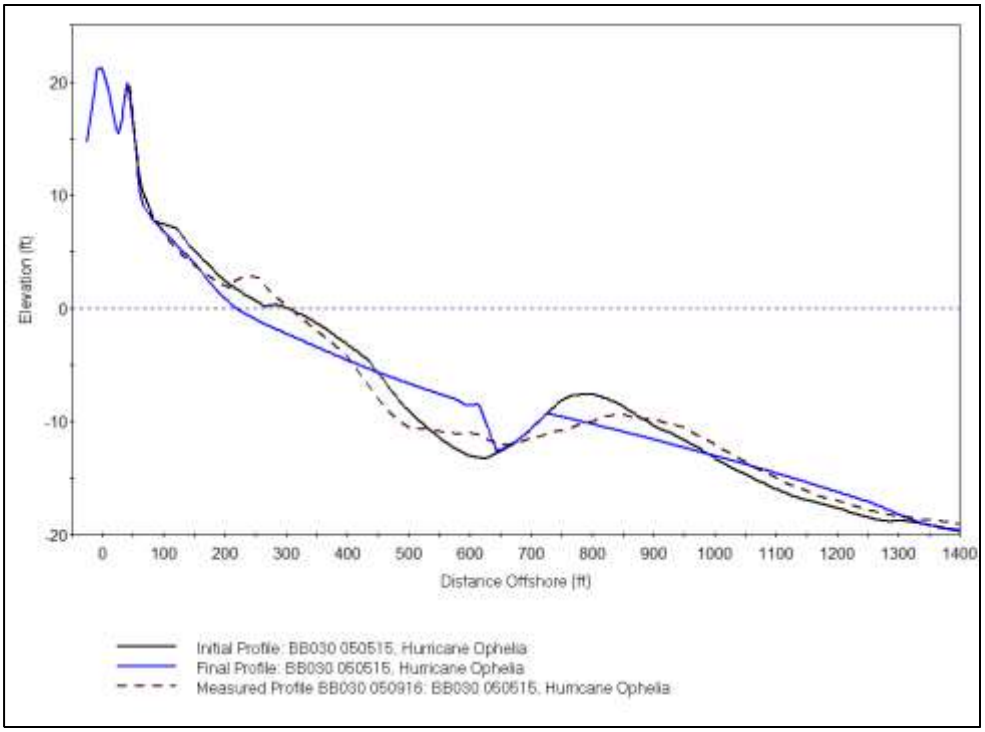

Figure 4-8: SBEACH Calibration: Hurricane Ophelia at BB030

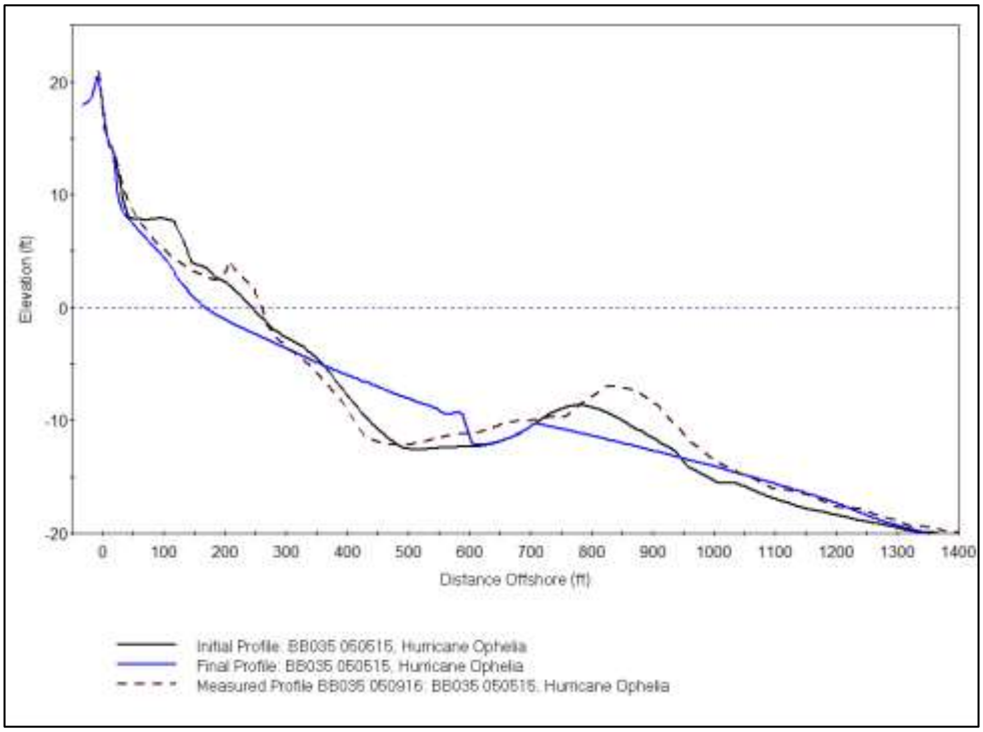

Figure 4-9: SBEACH Calibration: Hurricane Ophelia at BB035

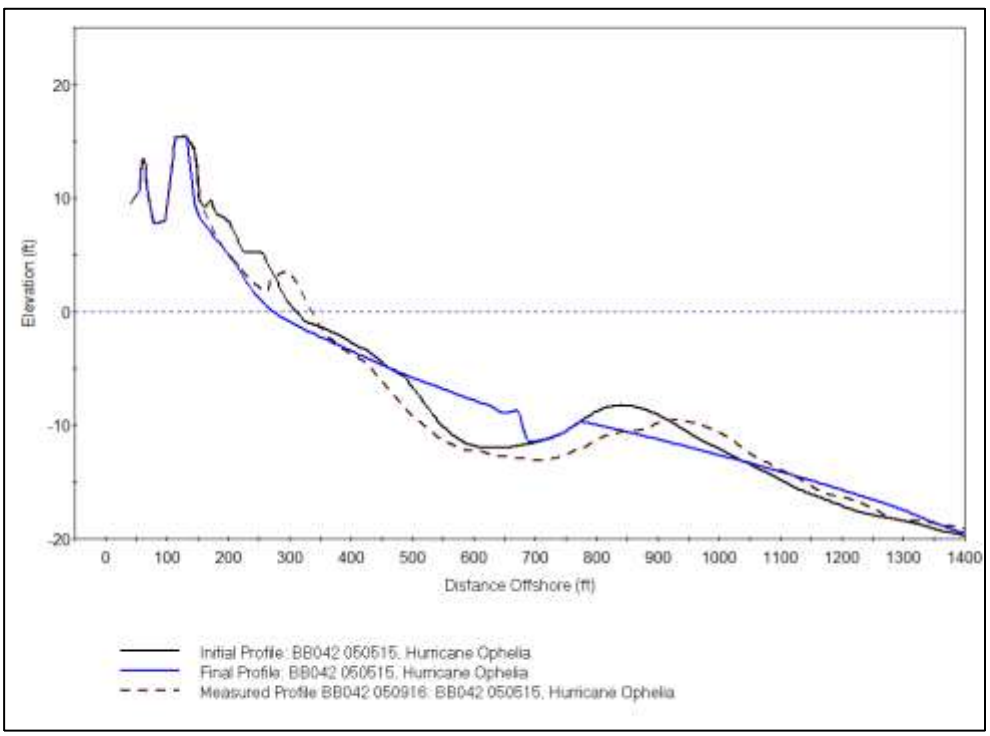

Figure 4-10: SBEACH Calibration: Hurricane Ophelia at BB042

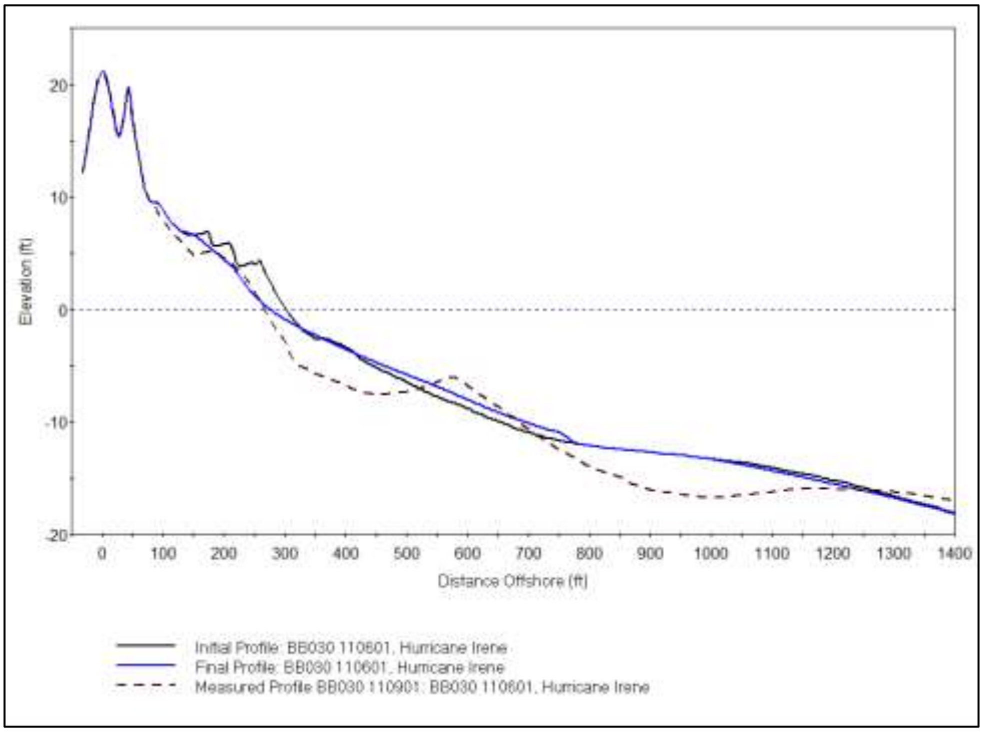

Figure 4-11: SBEACH Verification: Hurricane Irene at BB030

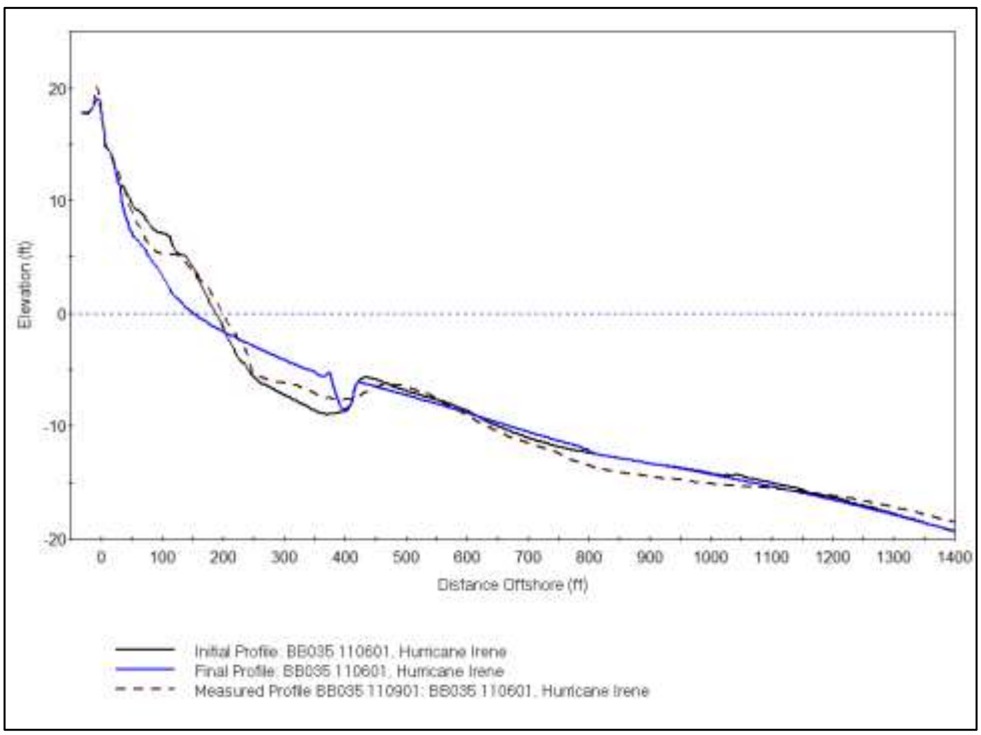

Figure 4-12: SBEACH Verification: Hurricane Irene at BB035

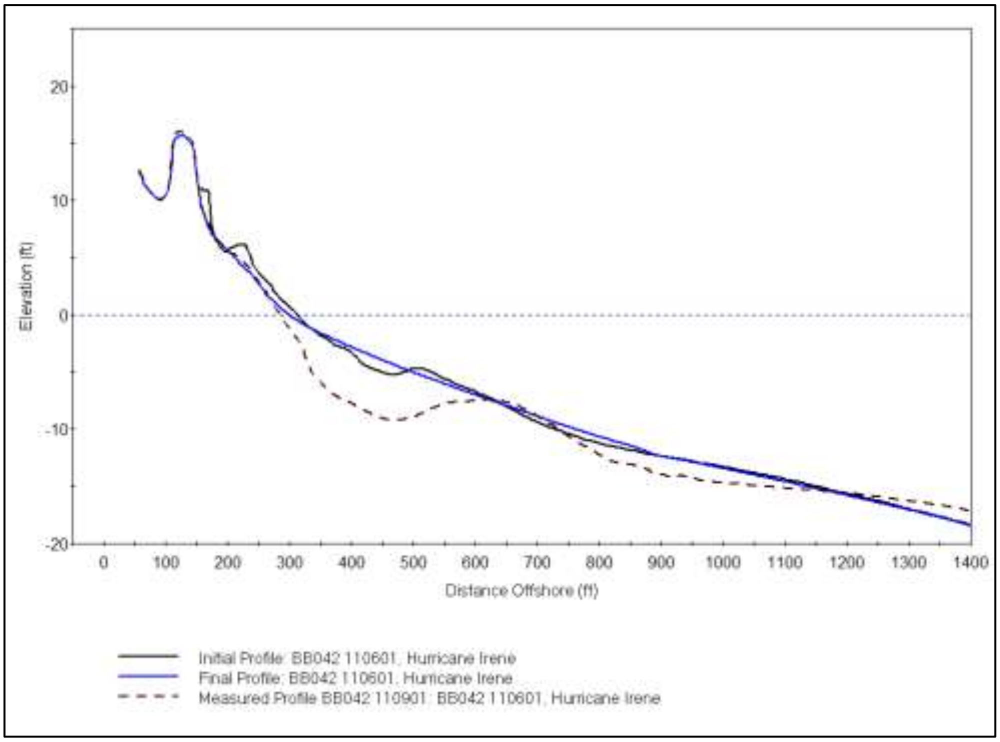

Figure 4-13: SBEACH Verification: Hurricane Irene at BB042

4.4 Beach Hotspot Evaluation

The purpose of this component of the study is to understand the causes of accelerated erosional areas – "hotspots" – observed in recent years from survey-based beach volumetric analyses. It is important to understand these hotspots and why they may be present given that these are areas that will likely require more frequent nourishments to maintain an equal level of protection as compared to more stable reaches. This analysis focuses on hotspots along Bogue Banks that are not near Beaufort Inlet or Bogue Inlet. It is known and well documented that the areas adjacent to the inlet are subject to more variable shoreline/volume losses given localized bathymetry at the inlets which concentrates wave energy to mobilize sediments and cause erosion. A primary hotspot under investigation has been historically observed approximately between survey Transects 37 and 52 in Emerald Isle-East and Indian Beach/Salter Path-West. An additional potential hotspot can also be observed in beach profile monitoring data from 2008 – 2012 in Pine Knoll Shores-East (between Transects 66 and 76).

In addition to the analytical study, detailed modeling was also compiled to investigate potential reasons for the hotspots. A numerical model, nested within the regional models described in Appendix A, was used investigate gradients in wave-driven sediment transport rates along the non-inlet shoreline reaches of Bogue Banks. The nested local model consists of dynamically coupled wave and hydrodynamic models driving a sediment transport model, on a much higher-resolution computational mesh than the regional model.

4.4.1 Analytical/Volumetric Analysis

In order to determine areas of the shoreline that should be studied in further detail with modeling, review of the analytical volumetric analysis of the monitoring data (Section 4.2.1) and the Crystal Ball analysis completed in Section 4.2.2 was completed.

Based on a review of the analytical volumetric background change results at various computational elevations, it is apparent that there are erosional hotspots with increased and more varying erosion rates (as compared to the entire island) at the Atlantic Beach, Pine Knoll Shores-East, Indian Beach/Salter Path, Emerald Isle-East and Bogue Inlet reaches.

These findings were further confirmed and with the various subreaches utilized during the Crystal Ball analyses as well as the USACE study. As can be seen from the Table 4-6, apparent hotspots are present at Bogue Inlet, both Emerald Isle-East subreaches, Indian Beach/Salter Path-West, both Pine Knoll Shores East subreaches, as well as most of Atlantic Beach. The Bogue Inlet and Atlantic Beach subreaches were not unexpected given the inlet effects within these areas. Therefore, the remainder of the hotspot areas were studied using a detailed numerical model to determine if possible causes could be determined.

Table 4-6: USACE and Crystal Ball Analyses Denoting Hotspots

Reach	Reach Length (ft)	USACE Annual Renourishment (cy)	-5 ft Annual Loss 50% (cy)	-12 ft Annual Loss 50% (cy)	-16 ft Annual Loss 50% (cy)
Bogue Inlet (1-8)	7,432	-19,228	-18,555	-39,468	-134,450
Emerald Isle West - A (9-11)	4,056	-24,225	318	-5,384	-3,004
Emerald Isle West - B (12-22)	14,283	-16,233	26,970	33,886	45,035
Emerald Isle West - C (23-25)	4,005	-295	7,128	6,254	7,218
Emerald Isle Central - A (26-32)	10,428	-5,245	2,913	-982	19,080
Emerald Isle Central - B (33-36)	5,374	-2,133	-6,347	-10,890	-11,250
Emerald Isle East - A (37-44)	8,814	-22,025	-24,000	-40,472	-73,944
Emerald Isle East - B (45-48)	4,406	-8,410	-14,088	-23,272	-12,302
Indian Beach/Salter Path - West (49-52)	5,275	-18,144	-34,982	-54,380	-35,560
Indian Beach/Salter Path - East (53-58)	7,575	-23,753	-5,706	-8,187	-25,398
Pine Knoll Shores - West (59-65)	9,063	-31,057	-14,833	-13,726	-12,095
Pine Knoll Shores - East - A (66-70)	6,564	-19,056	-15,605	-24,709	-32,204
Pine Knoll Shores East - B (71-76)	8,251	-31,562	-27,929	-46,360	-85,297
Atlantic Beach - West (77-81)	5,388	-26,533	567	-125	-4,475
Atlantic Beach - Central (82-89, 91-96)	13,771	-52,361	-78,963	-96,718	-150,104
Atlantic Beach - Circle (90)	1,006	-4,280	-10,397	-12,948	-22,234
Atlantic Beach - East (97-102)	6,011	-51,707	-25,279	-49,398	-48,566
TOTAL ANNUAL VOLUME CHANGE	**121,702**	**-356,247**	**-238,788**	**-386,879**	**-579,550**

Before the modeling commenced, a review of available multibeam surveys in the hotspot areas was also completed to determine if localized bathymetric features were present that may affect these areas. After review of available data, a detailed multibeam survey was found that included a portion of the area contained within the Emerald Isle East hotspot.

As can be seen in Figure 4-14, there appear to be some dredge cuts in deeper water offshore of Transects 37 and 38 that may allow some increased wave energy to influence this area. However, more interesting and likely more important are the features that can be seen offshore of Transects 41-43 in both deeper water and shallow areas as well which show "fingers" of deeper water that reach toward the shore (and hence would allow increased wave energy to reach the shoreline in this area). It is important to note that this area is centered at Transect 42 which is located at 12th Street within Emerald Isle. This particular location has been one of the most erodible areas of all of Bogue Banks. This data points to the relative importance of localized bathymetric/geologic features on shoreline behavior.

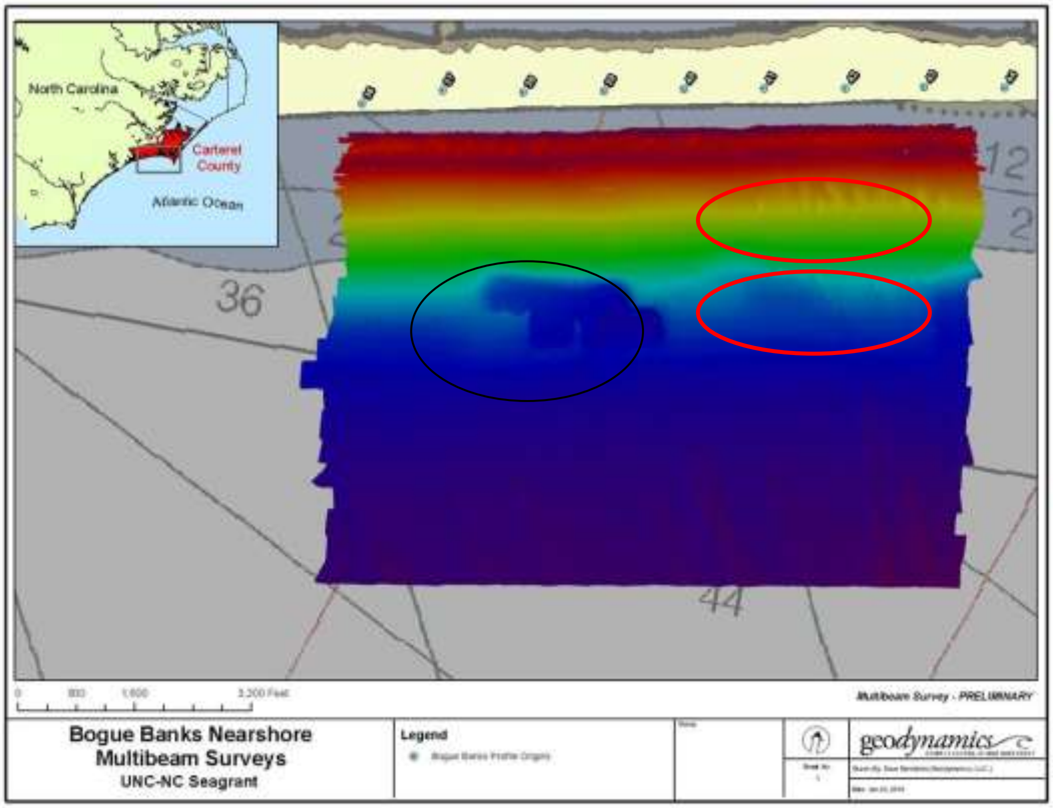

Figure 4-14: Detailed Multibeam Survey of Area Within Emerald Isle East Hotspot

This finding also then supported the use of a detailed model to investigate the hotspot areas and to try and develop an understanding of potential underlying causes.

4.4.2 Numerical Model Methodology

The local numerical model utilizes the MIKE 21 FM hydrodynamic (HD), spectral wave (SW), and sand transport (ST) software modules. The HD and SW modules work together to simulate dynamically coupled two-dimensional (2-D) depth-integrated waves and hydrodynamics, including wave-driven alongshore currents, which drive quasi-three-dimensional (Q3D) sand transport (ST) calculations.

The sediment transport model results are utilized primarily to examine gradients in the alongshore transport rates – between the hotspot(s) and adjacent beaches – that may account for the hotspot formation.

The study does not include numerical morphodynamic simulations with bed update feedback. As such, the model bathymetry is not allowed to come into equilibrium with waves during the simulation, and the results represent the sediment transport potential (not equilibrium sediment transport rates). Properly accounting for dynamic morphology updates on this long coastline, at the resolution required to resolve the hotspots, would be computationally prohibitive within the present study.

Simulations were conducted using a 1.5 month time series of tides and a wave climate representative of typical annual wave conditions in the project vicinity. This approach does not provide a statistically meaningful estimation of average annual alongshore and cross-shore transport rates comparable to those developed from beach monitoring programs and long-term littoral drift and shoreline evolution modeling (documented elsewhere in the report and in other, prior reports).

Within the limitations described above, the modeling approach accomplishes the purposes of this component of the present study, as the variations and gradients in sediment transport potential along Bogue Banks as computed and visualized from the model results advance the understanding of the historically observed erosional hot spots.

4.4.3 Numerical Model Development

4.4.3.1 Bathymetry and Computational Domain

Local model bathymetry was developed primarily from the June 2010 survey profile data, supplemented by C-MAP data as described in development of the regional model.

The local model extends from Bogue Banks survey Transect 13 in the west to Transect 84 in the east. The local model extent and bathymetry are shown in Figure 4-15, and Figure 4-16 shows the computational mesh resolution. The local model does not directly include Beaufort Inlet and Bogue Inlet. Though these inlets may have an effect on the overall sediment budgets all along Bogue Banks, they are not considered to have a significant effect on the processes causing the ***accelerated*** erosion (relative to the adjacent shoreline) in these hotspot specific areas. The hydrodynamic effects of the inlets are taken into account indirectly due to their inclusion in the regional model; effects of the inlets on sediment budget are not included.

4.4.3.2 Boundary Conditions and Sediment Transport Parameters

The Bogue Banks local model has three open boundaries – one long shore-parallel boundary and two shorter shore-normal boundaries. Water level, current velocity, and wave conditions applied at the boundaries were extracted directly from the regional model described in Appendix A.

A representative median grain size, D_{50} = 0.30mm, was used based on a review of sediment samples collected in the area by the USACE in 2002.

4.4.3.3 Simulation Period

Simulations were conducted on a single continuous time period of 11 June – 15 July 1999, using the representative annual wave climate described in Appendix A over predicted astronomical tidal water level variations (in order to simulate a representative year of waves/tides). The tidal boundary conditions applied in the regional and local model are directly related to the dates of the simulation, and they represents typical tidal water level variations in the project vicinity. The condensed representative offshore wave conditions time series was applied at the regional model boundary. The representative offshore waves are based on the June 2007 – June 2008 data at NDBC buoy #41013 (Frying Pan Shoals), filtered to extract waves with offshore significant wave heights greater than 2m and approaching from between 53°N and 217°N.

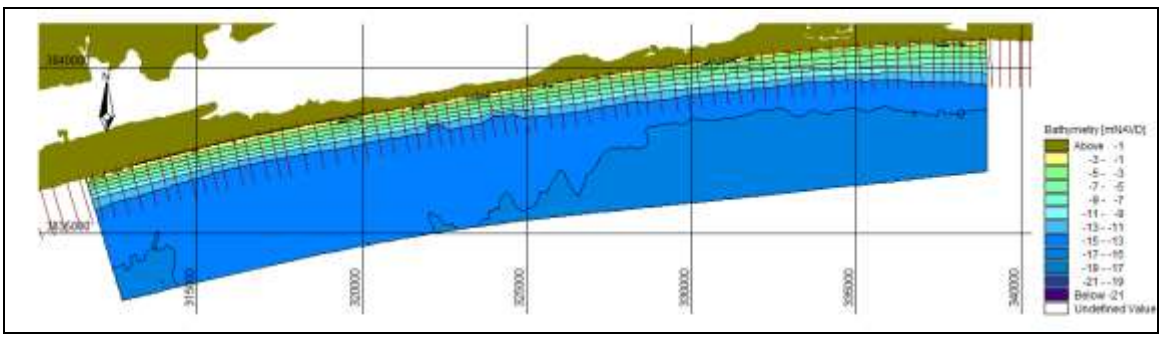

Figure 4-15: Bogue Banks Local Model Bathymetry

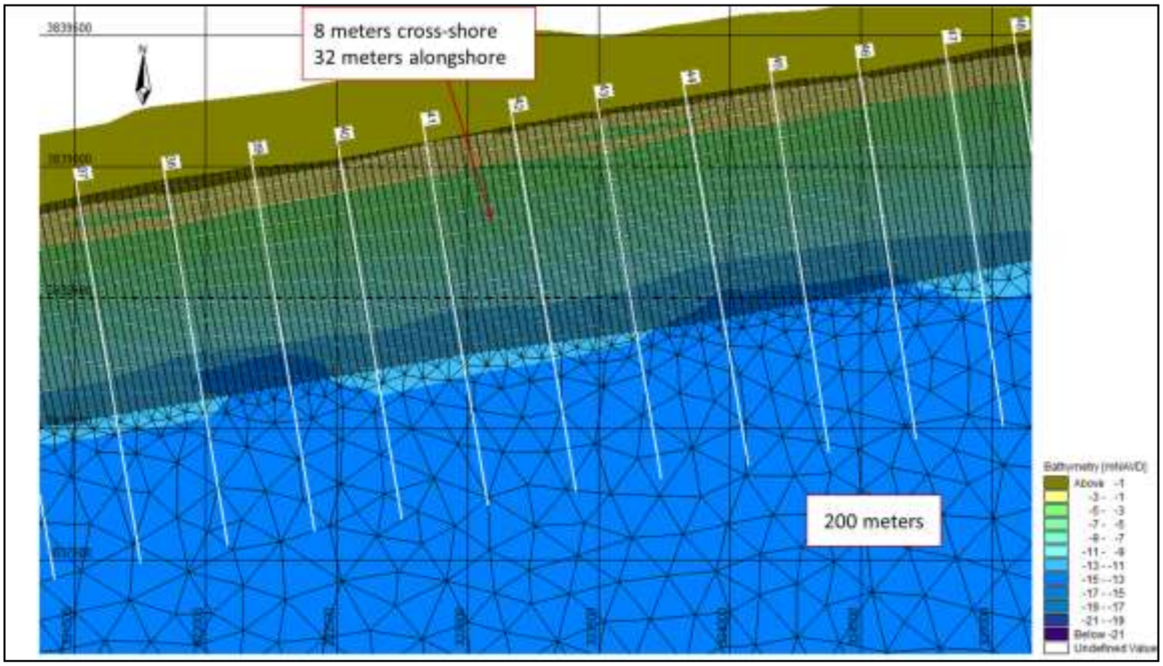

Figure 4-16: Bogue Banks Local Model Computational Mesh

4.4.4 Model Results and Discussion

In this discussion of model results, all alongshore transport rates given are positive toward the west, while cross-shore transport rates are positive in the onshore direction.

Figure 4-17 shows a representation of the average (mean) wave energy resulting from the regional wave transformation model for the 11 June – 15 July simulation, expressed as spectral significant wave height (H_{m0}) contours and wave direction vectors. Note that the [mean H_{m0}] = 1.6 and 1.7 meter contours penetrate much closer to shore in the middle and western reaches of Bogue Banks. This indicates that, on average, the eastern half of Bogue Banks and Shackleford Banks receive less wave energy than western Bogue Banks. This sheltering appears to be mainly due to the presence of Cape Lookout and its shoals, as southeasterly and easterly offshore wave energy spreads and diffracts into the lee of the Cape. Closer to shore, the orientation of nearshore bed elevation contours also plays an important role in directing wave energy.

Figure 4-18 shows a similar plot of mean wave energy along Bogue Banks from the local model results, in combination with a plot of the accumulated alongshore transport component in each grid cell of the local model during the 11 June – 15 July 1999 simulation. Survey transects are identified by number labels at five-transect intervals, for visual reference. Figure 4-19 provides a closer view of the information presented in Figure 4-18, with western reaches in the top panel and eastern reaches in the bottom panel.

The values of alongshore transport magnitude are not given in Figure 4-18 and Figure 4-19 because the units (m3/m) are difficult to interpret in two-dimensional map form. Instead, these plots indicates relative magnitudes of net westerly (positive, green to orange colors) and easterly (negative, blue colors) directed alongshore transport.

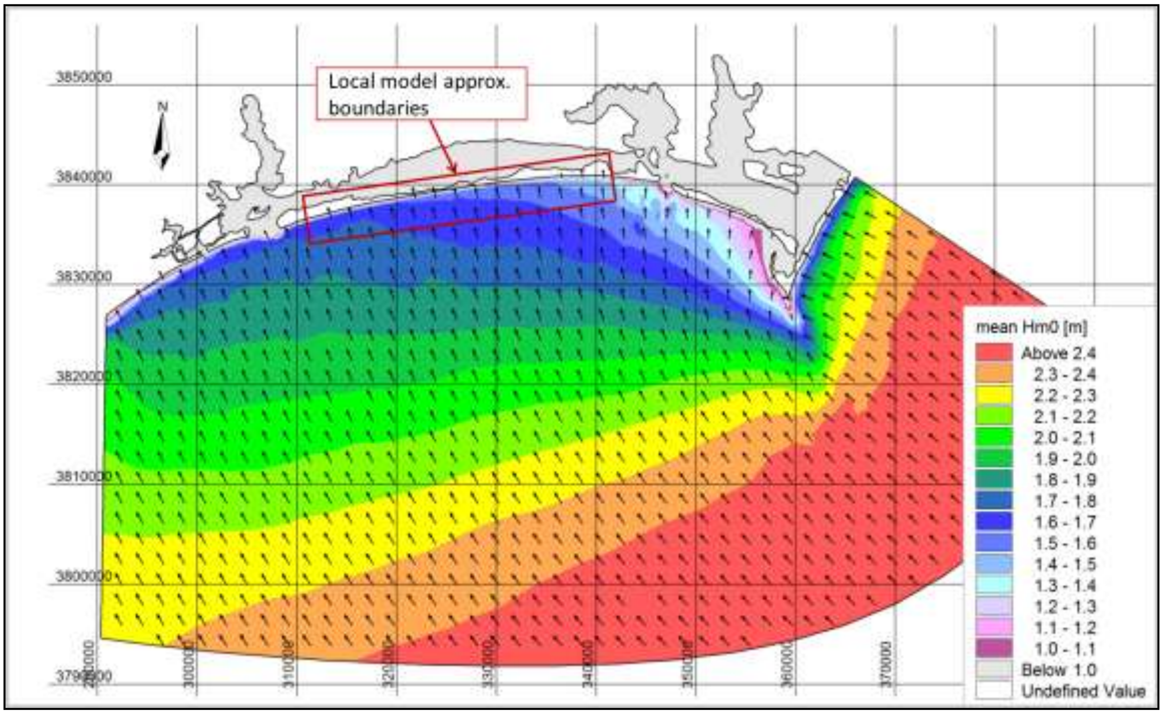

Figure 4-17: Mean of Representative Annual Significant Wave Heights and Directions

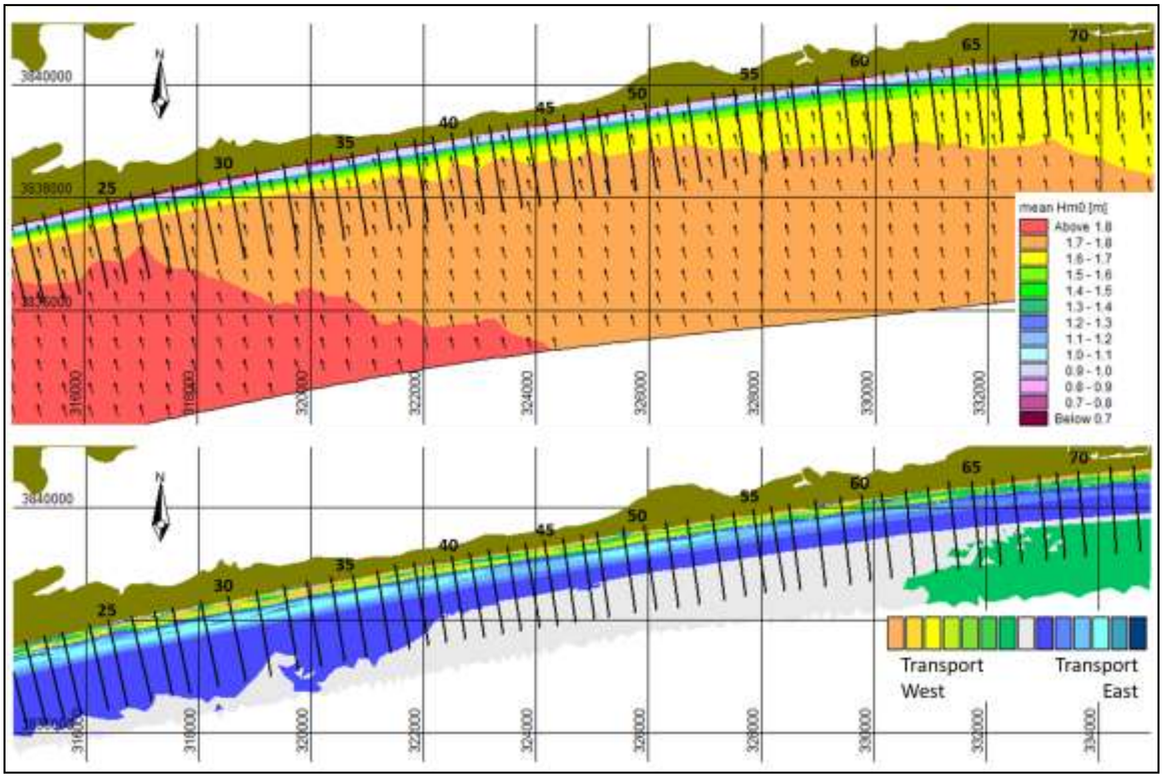

Figure 4-18: Mean Wave Heights (Top) and Accumulated Alongshore Sediment Transport Magnitudes (Bottom) From June 11 – July 15, 1999 Simulation

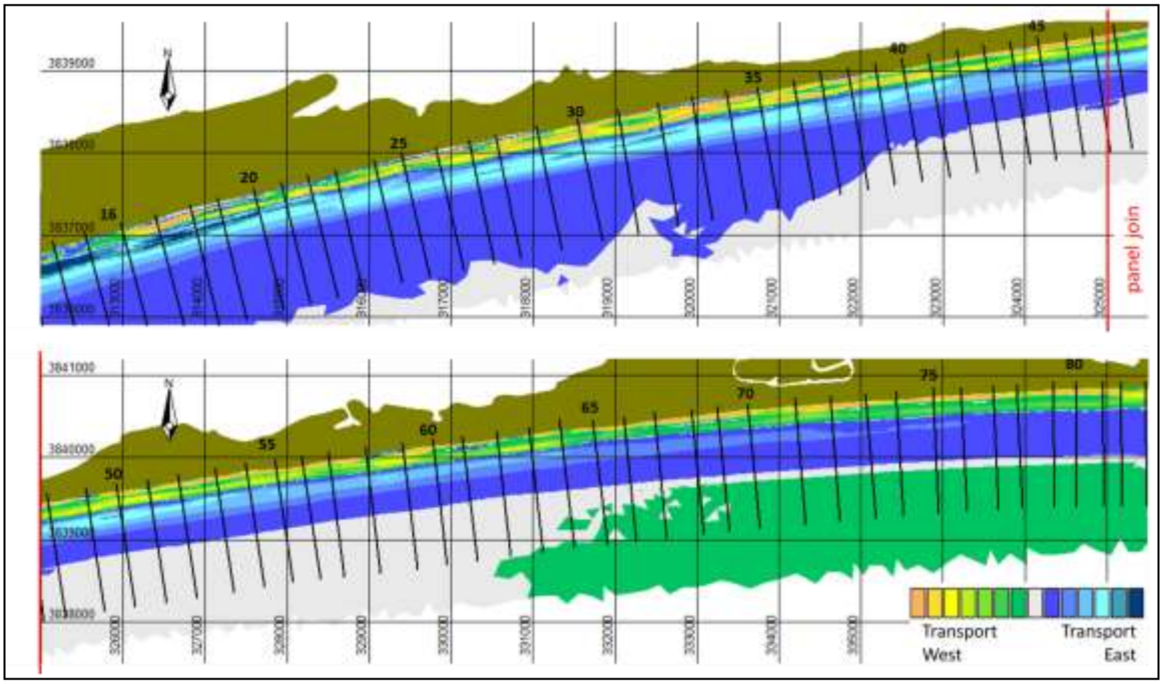

Figure 4-19: Accumulated Alongshore Sediment Transport Magnitudes For West (Top) and East (Bottom) Reaches of Bogue Banks

The local model mean H_{m0} plot echoes the trends indicted by the regional model results. The [mean H_{m0}] = 1.7 and 1.8 meter contours clearly penetrate much closer to shore in the reaches west of Transect 35, compared to that contour's proximity to shore east of Transect 50. The reach between Transect 35 and Transect 50 appears to be a transition zone, where gradients in alongshore sediment transport – and the distribution of alongshore transport across the beach profile – may be expected. The alongshore transport results in Figure 4-19 indicate a greater extent of high westerly transport (orange contours) between Transect 27 and Transect 41, compared to reaches east of Transect 41. The general lack of high westerly transport (yellow and orange contours) just east of Transect 64 indicates a further decline in westerly alongshore transport. However, there is a distinct concentrated area of orange contours nearshore between Transects 66-77 which is where a hotspot at Pine Knoll Shores-East has been observed.

The break between westerly and easterly directed alongshore transport visually observable in the figures is located approximately along the -4m NAVD88 bed contour (which is close in elevation to the -12 ft NAVD88 contour historically used by the County to track volume losses at the offshore bar).

Figure 4-20 shows a chart of net accumulated alongshore transport magnitudes resulting from the model above both the -4m NAVD88 contour (blue curve) and the -7m NAVD88 contour (red curve). The -4m contour was chosen to capture and understand the primarily west-directed alongshore transport observed to occur landward of that approximate vertical level, excluding the east-directed alongshore transport occurring seaward of the -4m to -

5m NAVD88 position. The -7m contour was chosen to approximate the reported depth of closure for Bogue Banks of 22.6 ft NAVD88 (Olsen, 2006).

Figure 4-20 reveals a dip in alongshore transport magnitude between Transect 47 and Transect 57, with the lowest point at Transect 50. Recall that a hotspot has been historically observed from profile monitoring studies in this area of Emerald Isle-East and Indian Beach/Salter Path-West. This dip, or gradient, occurs for tabulations above both -4m NAVD88 and -7m NAVD88. The tabulation above -7m NAVD88 additionally indicates very low net alongshore transport rates between Transect 48 and 54, with a reversal to net easterly transport at Transect 50. This could explain the hotspot at Indian Beach/Salter Path-West near Transects 48 to 50, in this situation where there is a rapid increase in net alongshore transport to the west out of the area without sufficient alongshore transport into the area.

Figure 4-21 shows a further computation on the alongshore transport potential. The chart trends should be "read" from right to left. First, the difference between total alongshore transport at each transect minus the transport at the preceding transect was calculated, giving the gain or loss of volume between each transect. Then, starting from the east end of the model (Transect 84, at right), a running sum was computed, and the running sum is charted on the figure. Where the curve trends downward, it indicates a net loss of sediment from the alongshore transport stream. The chart indicates dips in the curves near Transects 55 – 67 (Pine Knoll Shores-West/East) and between Transects 36 – 49 (Emerald Isle-East), areas which have been considered erosional hotspots in previous monitoring periods.

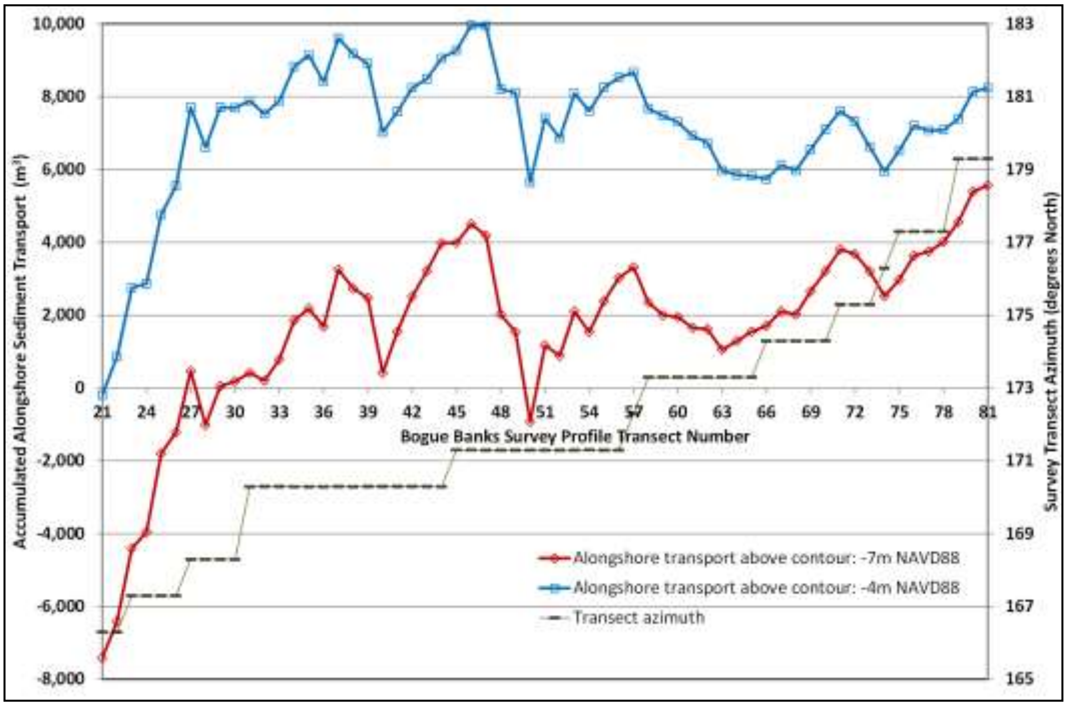

Figure 4-20: Distribution of Total Alongshore Transport Potential Under Representative Waves

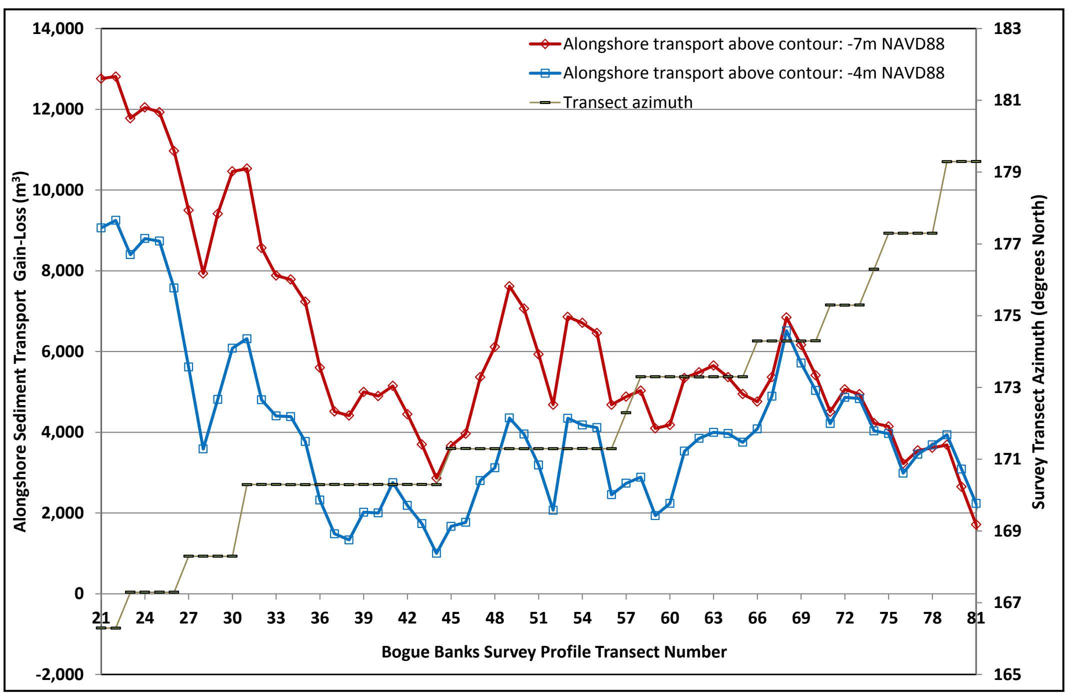

Figure 4-21: Gain/Loss in Alongshore Transport Volume at Each Transect Under Representative Waves (Computed As Running Sum from East to West)

Figure 4-22 through Figure 4-26 give an indication of the relationship between alongshore and cross-shore transport potential derived from the numerical model results at Bogue Banks survey Transects 49 through 41 in Emerald Isle-East. In each figure, the green shaded area outlines the bed profile starting from the dune at left and proceeding offshore to the -12 meter (39 feet) NAVD88 contour at right. The left y-axis gives the profile bed elevations associated with the green shading. The right y-axis indicates the accumulated (net) transport potential magnitude in cubic meters per meter of shoreline (m^3/m). The blue curve represents cross-shore transport distributed across the bed profile, where positive values are directed offshore and negative values are directed toward shore. The red curve represents alongshore transport, where positive values are directed westward and negative values are directed eastward.

Both cross-shore and alongshore transport are strongest between the shoreline and the position of the -2m NAVD88 contour. A second strong peak in alongshore transport is seen between approximately -3m and -4m NAVD88.

From Transect 49 to Transect 47 to Transect 45, the progressively increasing peaks in alongshore transport potential and total area under those red curves can be seen moving westward from the boundary of Emerald Isle-East with Indian Beach-Salter Path. Positive alongshore transport is westward, this increasing trend reflects the increasing accumulated transport rates above -4m and -7m NAVD88 seen in Figure 4-20. This gradient in alongshore transport indicates potential for greater erosion within this reach between Transect 49 to Transect 45. The pattern repeats itself between Transects 43 and 41 (Figure 4-25 and Figure 4-26).

The reach between Transect 49 and Transect 41 was chosen for display here as the most dramatic and longest contiguous trend in apparent erosion due to alongshore transport gradients observed from Figure 4-21. Other reaches exist where a similar pattern of gradients would be seen in such profile-based plots.

Figure 4-22: Distribution of Transport Across the Profile: Transect 49

Figure 4-23: Distribution of Transport Across the Profile: Transect 47

Figure 4-24: Distribution of Transport Across the Profile: Transect 45

Figure 4-25: Distribution of Transport Across the Profile: Transect 43

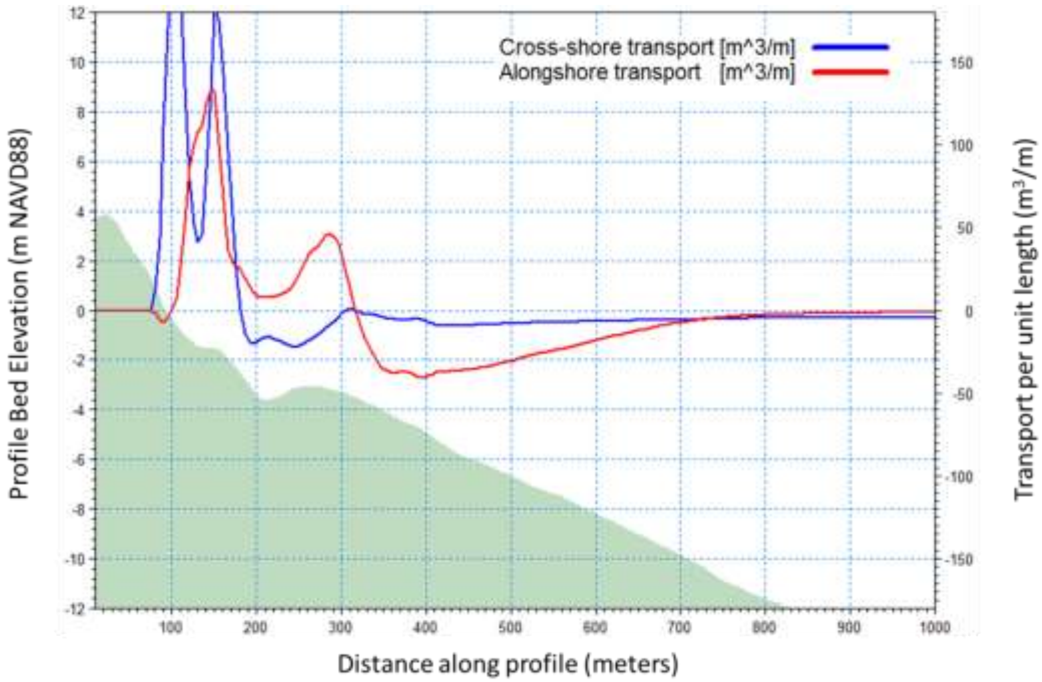

Figure 4-26: Distribution of Transport Across the Profile: Transect 41

4.4.5 Summary of Erosional Hotspots Modeling

A separate local scale model of hydrodynamic, wave, and sediment transport processes was developed for the majority of Bogue Banks, from regular monitoring survey Transect 13 in the west to Transect 84 in the east. The model was used to investigate likely causes of an erosional hotspot along a segment of Emerald Isle shoreline historically observed between Transects 30 and 50 and 66 to76.

The wave transformation model results indicate a significant gradient in mean annual wave energy along Bogue Banks, with wave energy increasing from west to east. This result alone would indicate that gradients in sediment transport-causing wave energy may be responsible for the increased erosion seen in the middle portions of Bogue Banks.

The sediment transport component of the model results further indicates gradients in net accumulated alongshore transport that would result in greater removal of sediment from these hotspot areas than is supplied by the updrift reaches.

The alongshore transport gradient indicated in the local model results is believed to be primarily due to the increased wave energy affecting the shoreline in the western reaches. This increased was energy at both hotspots is believed to be due to a combination of wave sheltering effects of Cape Lookout as well as localized bathymetric/geologic patterns.

5.0 EVALUATION OF HISTORICAL SHORELINE EVOLUTION

5.1 Purpose and Definitions

In addition to designing nourishment projects to reduce storm impacts on infrastructure, the predicted life of these nourishment projects and their effect on neighboring stretches of beach must also be determined. Using the knowledge gained from historical monitoring and the cross-shore profile evolution modeling in SBEACH about the level of protection required, the longshore behavior of these projects must then be analyzed to fully understand the effect on the system. In order to perform these analyses, an understanding of understanding of historical shoreline behavior/evolution is need.

5.2 Analytical/Empirical Analysis

DCM has developed average long-term rates of shoreline change over approximately 50 years from 1949 to 1998. DCM is currently in the process of updating their erosion rates using the 2009 shoreline, but they have not been approved yet. Figure 5-1 shows the 1998 DCM erosion rates along Bogue Banks. It should be noted that these erosion rates do not account for the multiple nourishment activities which took place on the island, especially near the inlets from 1978 to 1998. Therefore, the rates are considered very conservative, however, they do provide some insight into shoreline change patterns along the island. The strongest erosion, with the exception inlet adjacent areas, occurs from Emerald Isle East through Pine Knoll Shores. This is in agreement with the monitoring data from the past decade. The lower erosion rates and small stretches of accretion in Emerald Isle West indicate that this is a receiving beach due to the east to west transport along the island. It should be noted that the apparent accretion seen at Atlantic Beach is due to approximately 10 million cy of material being placed on the western end of Bogue Banks from the Morehead City Harbor maintenance dredging and Brandt Island Pumpouts prior to 1998. In reality, with this nourishment taken out, the monitoring data shows that this area has one of the more severe eroding shorelines with an average of approximately -5.5 ft/yr. In addition, the erosion rate at Fort Macon is actually much higher than shown in the long-term rates, when the nourishment is factored out, at approximately -13.3 ft/yr.

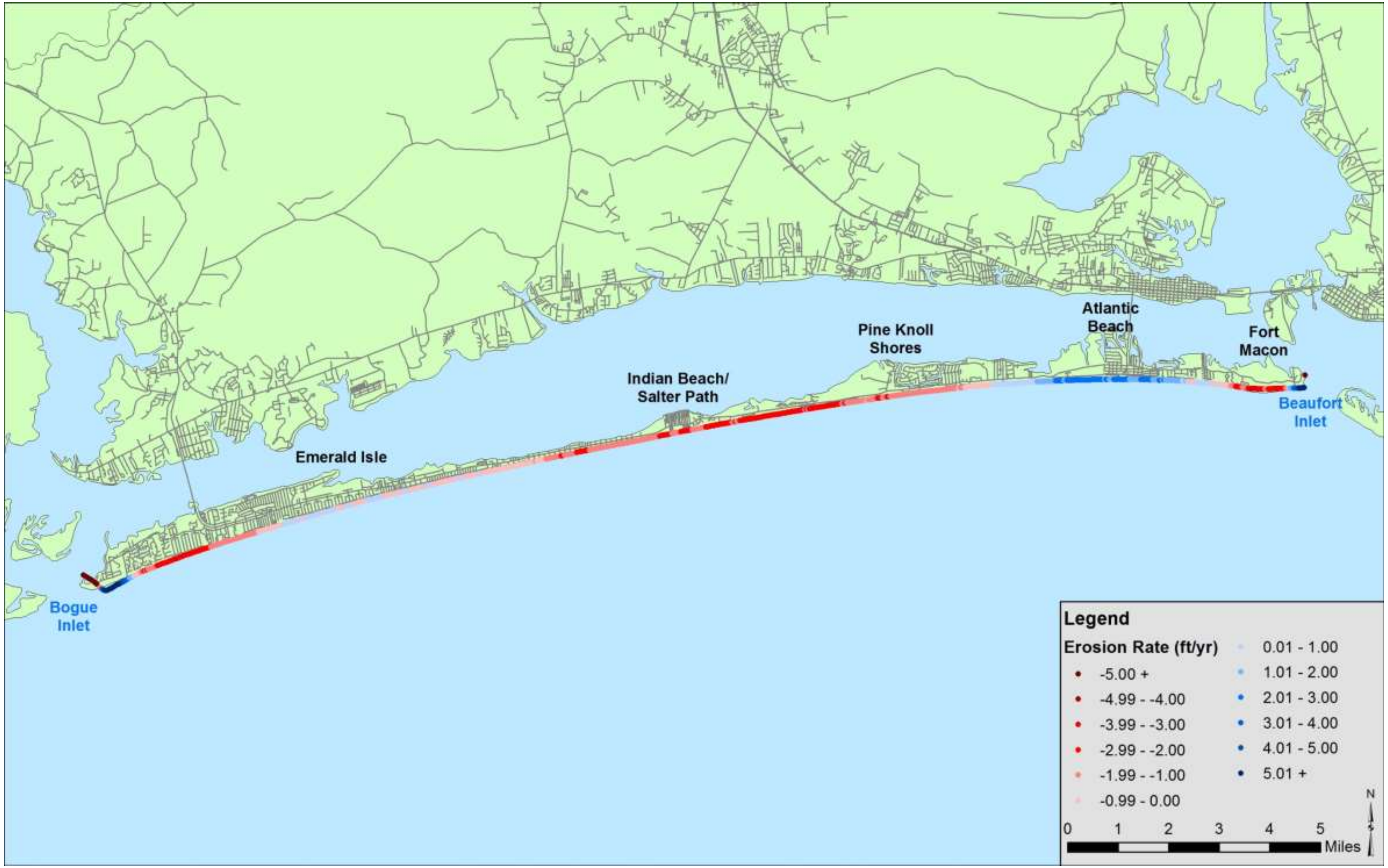

Figure 5-1: NCDCM Long-Term Erosion Rates

5.3 Numerical Modeling: GENESIS-T

GENESIS (Generalized Model for Simulating Shoreline Change) is designed to simulate long-term shoreline change based on spatial and temporal differences in longshore sediment transport induced primarily by wave action. The GENESIS modeling system allows for a number of user-specified inputs including wave inputs, initial shoreline positions, coastal structures and their characteristics, and beach fills; all of which aid in the calculation of sediment transport and shoreline change. This model was developed at the U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC), Coastal & Hydraulics Laboratory (CHL). For a more detailed description of the GENESIS model, the reader is referred to the User's Manual and Technical Reference published on the model (Hanson and Krauss, 1989, Gravens et al, 1991).

GENESIS-T is a more recent release that expands on the modeling capabilities of GENESIS, allowing for the formation of tombolos at detached breakwaters and/or T-groins. After a comparison of GENESIS and GENESIS-T, it was decided to use GENESIS-T for this study. It was determined in previous studies by M&N that GENESIS and GENESIS-T results yield almost identical predicted shorelines in the absence of tombolo formation.

GENESIS-T operates within the Coastal Engineering Design and Analysis System (CEDAS), a suite of tools developed by Veri-Tech, based on various numerical models and codes developed at CHL. GENESIS and GENESIS-T run through NEMOS, which is designed to ease in the preparation of data inputs, analysis, and manipulation for a number of related coastal models.

The GENESIS-T model has potential for many applications in the coastal environment, including evaluation of longshore sediment transport, analysis of beach fill performance, or the analysis of the impact of coastal structures on shoreline change.

The main inputs to the GENESIS-T model include:

- Shoreline Position Data – one-dimensional description of the shoreline position relative to a straight baseline position,
- Wave Data – long-term time dependent description of wave heights, periods, and directions applicable to the Study Area,
- Coastal Structures – position and characteristics of coastal structures (breakwaters, groins, jetties, or seawalls) acting along the Study Area,
- Beach Fill – starting and ending dates and location of beach fill defined by an added berm width,
- Sediment and Beach Characteristics – effective grain size, average berm height, and closure depth for the Study Area,
- Sediment Transport Parameters – used to characterize longshore sediment transport and calibrate the model, and

- Boundary Conditions – seaward boundary conditions for the input wave data and lateral boundary conditions for the shoreline (left and right).
- Regional Contour – an offshore contour to account for bathymetry which may affect wave direction/energy

5.3.1 Modeling Scope

Application of the GENESIS-T model enhances the understanding of historical longshore sediment transport and erosional patterns along the Bogue Banks Study Area and for evaluating numerous shoreline stabilization and restoration alternatives. For calibration, the GENESIS-T model is applied to evaluate the change in shoreline position for a long-term period of documented wave action from 1999 to 2008.

To establish the appropriate model parameters, the GENESIS-T model was calibrated for a June 1999 to July 2008 time period using historical MHW shoreline positions from periodic survey evaluations and coinciding wave data from the NDBC wave buoys and WIS archive (see Section 3.1) along with water level data from the NOAA tide gauge at Beaufort (see Section 3.2). GENESIS-T is primarily calibrated by adjusting the longshore sand transport coefficients (K_1 and K_2). Additionally, the model may be calibrated by adjusting the characteristic transmissivity or permeability of offshore breakwaters, groins or jetties, where applicable. In addition, boundary condition parameters (e.g. smoothing, wave input adjustments) may be altered to achieve calibration, or to test the model sensitivity. An offshore regional contour may also be incorporated to account for any bathymetric features that may impact wave direction and energy along the shoreline.

Once a calibrated model was developed, the model was run for a shorter verification time period from July 2008-April 2012. This verification time period included Hurricane Irene and an absence of multiple engineering projects, ensuring that the model performed correctly during large gaps in between nourishment intervals. Shoreline positions from the periodic survey evaluations were used in conjunction with wave data from the NDBC wave buoys and WIS archive.

5.3.2 Study Area

The GENESIS-T model coverage extended from Bogue Inlet eastward to the Fort Macon terminal groin. Figure 5-2 shows the GENESIS-T model extent and existing structure locations.

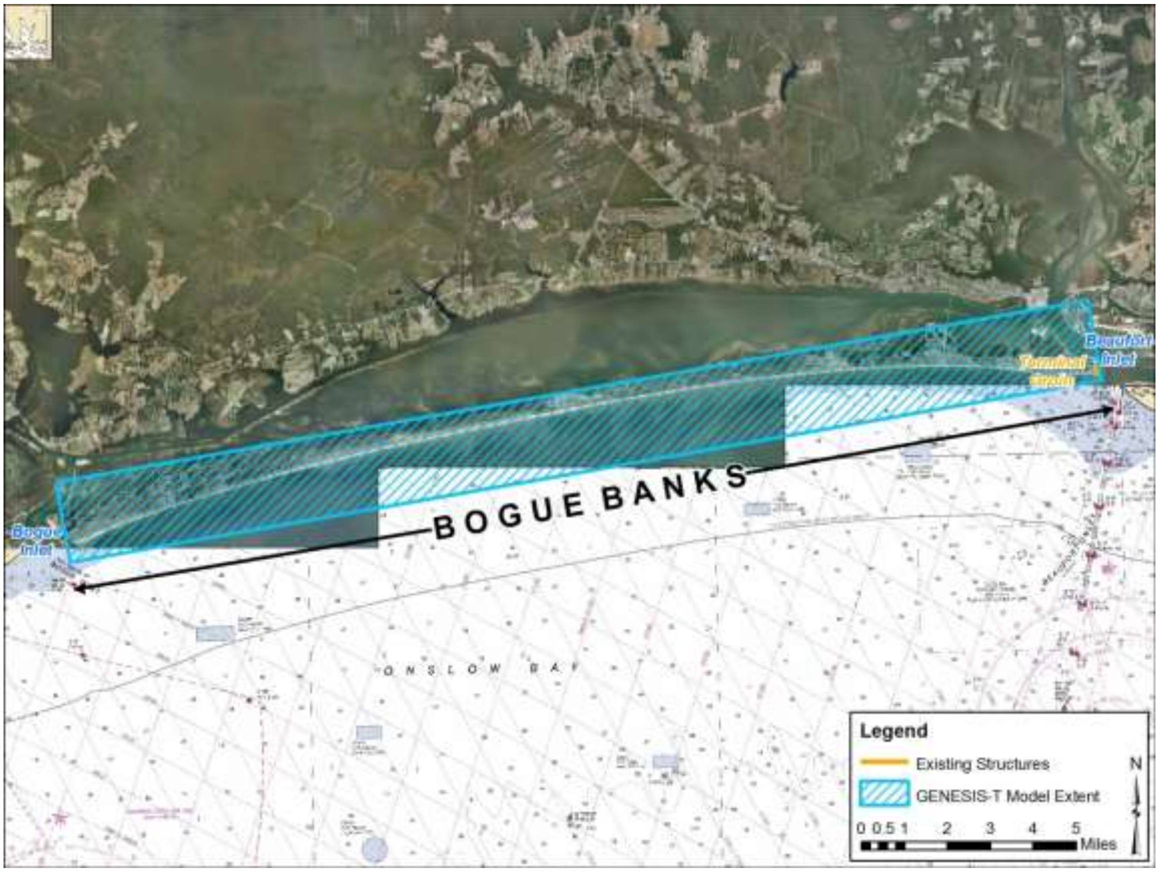

Figure 5-2: GENESIS-T Model Extent

5.3.3 Calibration Model

The GENESIS-T model was calibrated to reflect the historical trends of longshore sediment transport and the resulting shoreline change over the Study Area. The overall calibration time period was based on the availability of quality measured shoreline data and measured wave gage data. An overall calibration time period was selected where many nourishment projects took place, allowing for insurance that future nourishment project results would be predicted correctly.

For this study, the general calibration procedure involved:

- establishing known model inputs including shoreline position, waves, locations of structures, sediment and beach characteristics, and boundary conditions

- establishing initial sediment transport parameters and adjusting these parameters until the relative shoreline response (erosion/accretion) and sediment transport rates matched historical trends,

- adjusting the groin permeability of the terminal groin at Fort Macon until the shoreline response matched historical trends, and
- adjusting the regional contour to account for bathymetric influences on targeted areas of shoreline (erosion hotspots)

This calibration sequence was followed using known inputs and default initial parameters. Then, particular input parameters (sediment transport parameters, smoothing, wave input adjustments etc.) were revisited and the sensitivity of the model response to changes in these parameters was tested. In many cases, a given parameter was adjusted to yield a more accurate shoreline response. The final determined input data for the calibration model will be presented in the following sections, in the order that this information is input to the GENESIS-T model (e.g. not the true calibration sequence).

5.3.3.1 Shoreline Position Data

For shoreline input, GENESIS-T requires the shoreline be specified in a station-offset formulation whereby the station represents a position along a landward baseline and the offset is the perpendicular distance from this baseline to the shoreline. The initial shoreline used in the GENESIS-T model was the June 1999 MHW shoreline, based upon the CSE June 1999 survey. The final reference shoreline to which the model was calibrated was the July 2008 shoreline, based upon the Geodynamics July 2008 survey.

5.3.3.2 Wave Data

As mentioned previously, wave data from multiple sources (NDBC, WIS, etc.) was pieced together to develop a long term wave time series from June 1999 to July 2008. The MIKE 21 SW model discussed in Appendix A was used to transform the offshore time series of waves from the relatively deep water NDBC stations and WIS hindcast stations to a nearshore position at Bogue Banks with a depth of approximately -40 ft NAVD88 for use in the GENESIS-T model. A station file was then created in STWAVE, with 18 stations along the shoreline to which the waves were applied. This allowed for the varying of wave parameters in GENESIS-T from one end of the shoreline to the other based on local bathymetry. Figure 5-3 shows the location of the STAWAVE stations.

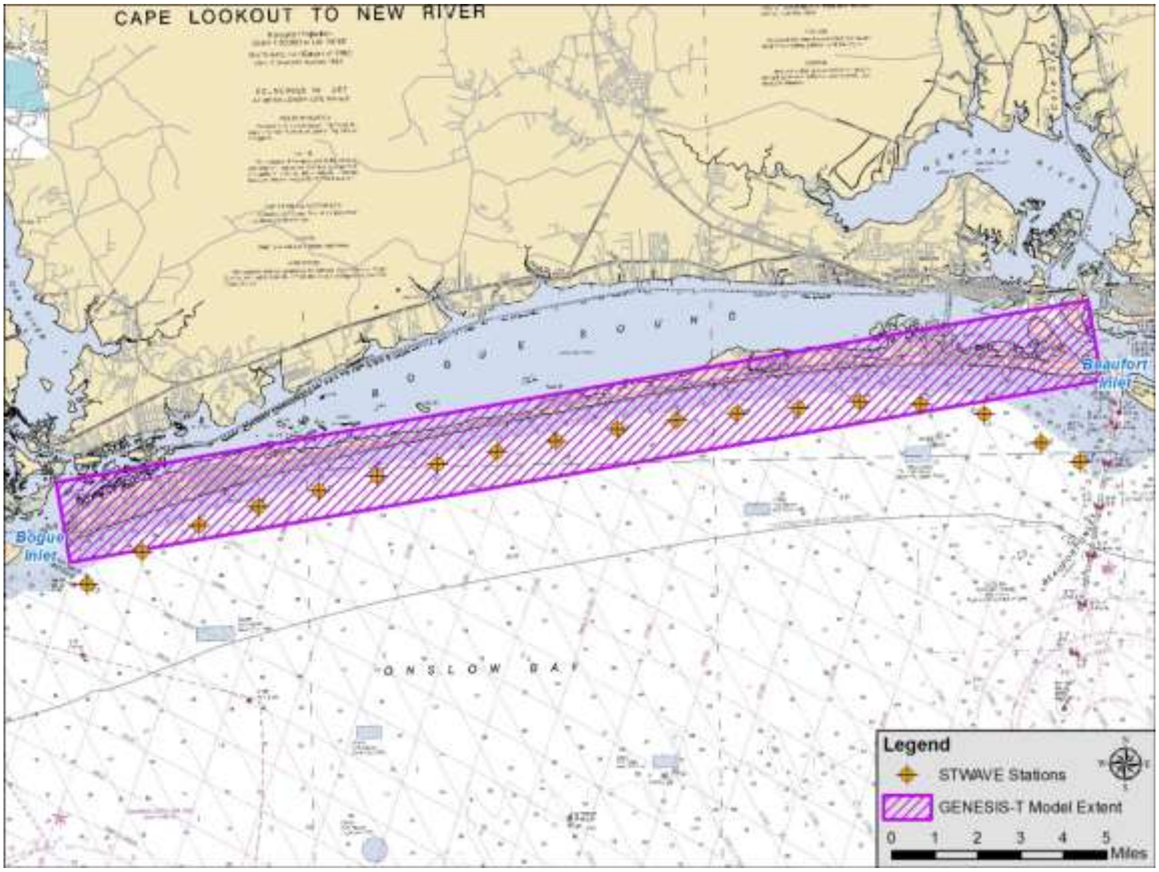

Figure 5-3: STWAVE Stations for GENESIS-T Model

5.3.3.3 Coastal Structures

GENESIS-T requires the locations and characteristics of nearshore structures as input. The coastal structures are incorporated in the GENESIS-T model by a station-offset formulation, similar to the shoreline position. Allowable structures include non-diffracting groins/jetties, diffracting groins/jetties, seawalls, and/or detached breakwaters. Each structure is modeled uniquely with respect to longshore transport and shoreline change. In general, structures exert two direct effects on the shoreline change modeling:

- Structures extending into the surf zone block a portion, or all, of the longshore transport from their updrift sides and may reduce the transport of sand towards the downdrift side. This effect may be induced by a groin or jetty.

- Structures which have seaward ends extending well beyond the surf zone, including jetties or detached breakwaters, induce wave diffraction which causes the local wave height and direction to change.

Wave transmission through and over breakwaters is controlled by the user-specified transmission coefficient (K_t). The transmission coefficient is defined as the ratio of wave heights on the shoreward side of the breakwater to the incident wave heights on the seaward side of the breakwater and may range from 0 (no transmission) to 1 (complete transmission).

Similar to detached breakwaters, a non-diffracting or diffracting groin implemented in GENESIS-T must have a defined permeability which controls the transmission of sand over and through the structure. The permeability can range from 0, implying an impermeable structure to 1, implying a completely transparent structure. The terminal groin at Fort Macon is the only existing coastal structure to be included in the model. The permeability of the existing terminal groin was set at 0.2 after trying options ranging from 0.2 to 0.7. The resulting amount of material held by the terminal groin was an adequate reflection of historical conditions.

5.3.3.4 Beach Fills

Multiple beach nourishment projects took place during the calibration period from June 1999 to July 2008. Table 5-1 shows the beach fills which took place during this time period and were included in the calibration model. The placement extents and added berm width were required as inputs and estimated from previous project drawings and reports.

Table 5-1: Beach Fill Data for GENESIS-T Calibration

Fiscal Year	Project Description	Placement Location	Volume (cy)	Added Berm Width (ft)
1999	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Western Emerald Isle	48,000	150
2000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Western Emerald Isle	16,000	50
2002	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Fort Macon	209,348	100
2002	Bogue Banks Restoration - Phase I -R1	Indian Beach (reach 1)	456,994 (total)	125
2002	Bogue Banks Restoration - Phase I -R2	Indian Beach (reach 2)	456,994 (total)	125
2002	Bogue Banks Restoration - Phase I -R3	Pine Knoll Shores (reach 3)	1,276,586	125
2003	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Western Emerald Isle	59,000	150
2003	Bogue Banks Restoration - Phase II	Eastern Emerald Isle	1,867,726	100
2004	Isabel Sand Replenishment-East Reach	Eastern Emerald Isle (east reach)	156,000 (total)	50
2004	Isabel Sand Replenishment-Mid Reach	Eastern Emerald Isle (mid reach)	156,000 (total)	50
2004	Isabel Sand Replenishment-West Reach	Eastern Emerald Isle (west reach)	156,000 (total)	50
2004	Section 933 - Phase I	Indian Beach/Salter Path	699,282	100
2005	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Fort Macon	530,729	170
2005	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Atlantic Beach	2,390,000	170
2005	Bogue Banks Restoration-Phase III (& Bogue Inlet Relocation)	Western Emerald Isle	690,868	125
2006	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Western Emerald Isle	77,000	150
2007	Ophelia Sand Replenishment-Reach 1	Emerald Isle (reach 1)	304,037	60
2007	Ophelia Sand Replenishment-Reach 2	Emerald Isle (reach 2)	344,410	60
2007	Ophelia Sand Replenishment-Reach 3	Indian Beach/Salter Path (reach 3)	319,113	60
2007	Ophelia Sand Replenishment-Reach 4	Pine Knoll Shores (reach 4)	73,397	60
2007	Ophelia Sand Replenishment-Reach 5	Pine Knoll Shores (reach 5)	188,879	60
2007	Section 933-Phase II	Pine Knoll Shores	507,939	100
2007	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)	Fort Macon	184,828	100
2008	Dredge Disposal AIWW Tangent B to Pine Knoll Shores	Pine Knoll Shores	148,393	50

5.3.3.5 Sediment and Beach Characteristics

The selected effective grain size assumed in the GENESIS-T model was 0.3 mm. This grain size was determined based on analysis of measured sediment data collected and analyzed by the USACE, CSE, and CPE as detailed in Appendix B.

The average berm height was defined as +7 ft NAVD88 and the closure depth was set to -20 ft NAVD88. These values were determined based on observations of measured survey data during the calibration and verification time period from the ongoing periodic surveys.

Figure 5-4 shows an example of 2008 and 2009 profiles, demonstrating a berm around +7 ft NAVD88 and a depth of closure around -20 ft NAVD88.

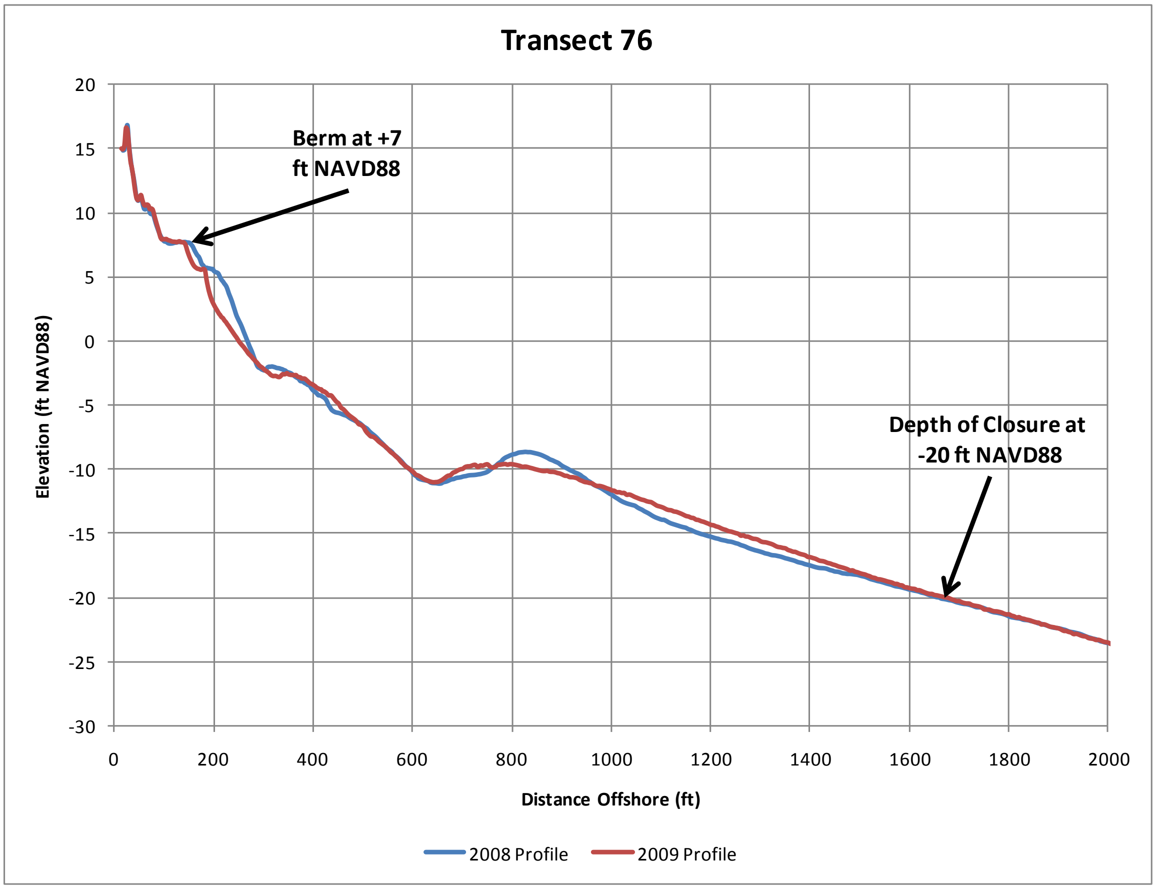

Figure 5-4: Example Profile Showing Berm and Depth of Closure Elevations

5.3.3.6 <u>Sediment Transport Parameters</u>

Longshore sediment transport is characterized by the transport parameters K_1 and K_2 in GENESIS-T. The transport rate coefficient, K_1, is used to control the time-scale and magnitude of the simulated shoreline change, while K_2 is used to control shoreline change and longshore sand transport in the vicinity of structures. Although the values of K_1 and K_2 have been empirically estimated, these coefficients are treated as calibration parameters in GENESIS-T and range in value from 0 to 1.0.

The calibration models were initially run with the default K_1 and K_2 coefficients, where $K_1 = 0.5$ and $K_2 = 0.5$. The resulting July 2008 model shoreline was compared with the measured July 2008 shoreline and the coefficients were adjusted to achieve the closest match in the model results and the measured shoreline position. In addition to shoreline position, the sediment transport rate was also compared to a previous Regional Sand Transport Study by Olsen Associates in 2006 (net transport of approximately 100,000 cy overall to the west with transport rates approximating 500,000 cy toward each inlet).

Through this procedure, it was determined that slightly increasing the K_1 value and K_2 value resulted in shoreline response which was most indicative of historical patterns. The final calibration transport coefficient values were chosen to be $K_1 = 0.6$ and $K_2 = 0.6$ after applying a range of values from 0.3 to 0.7. The larger K values allowed for the correct magnitude of sediment transport along Bogue Banks. Figure 5-5 and Figure 5-6 show the resulting transport rates from GENESIS-T and the transport rates estimated by Olsen Associates in their 2006 study, respectively. The sediment transport predicted by GENESIS-T is very similar to that estimated by Olsen Associates with a predominant net transport to the west of approximately 100,000 cy/yr and larger transport rates near each inlet (approximately 600,000 cy/yr) with (a) a divergent nodal point at the eastern end of Atlantic Beach - corresponding to area of high erosion, and (b) an increasing transport gradient near Bogue Inlet - corresponding to area of high erosion; these predicted trends are generally consistent with the historically measured data.

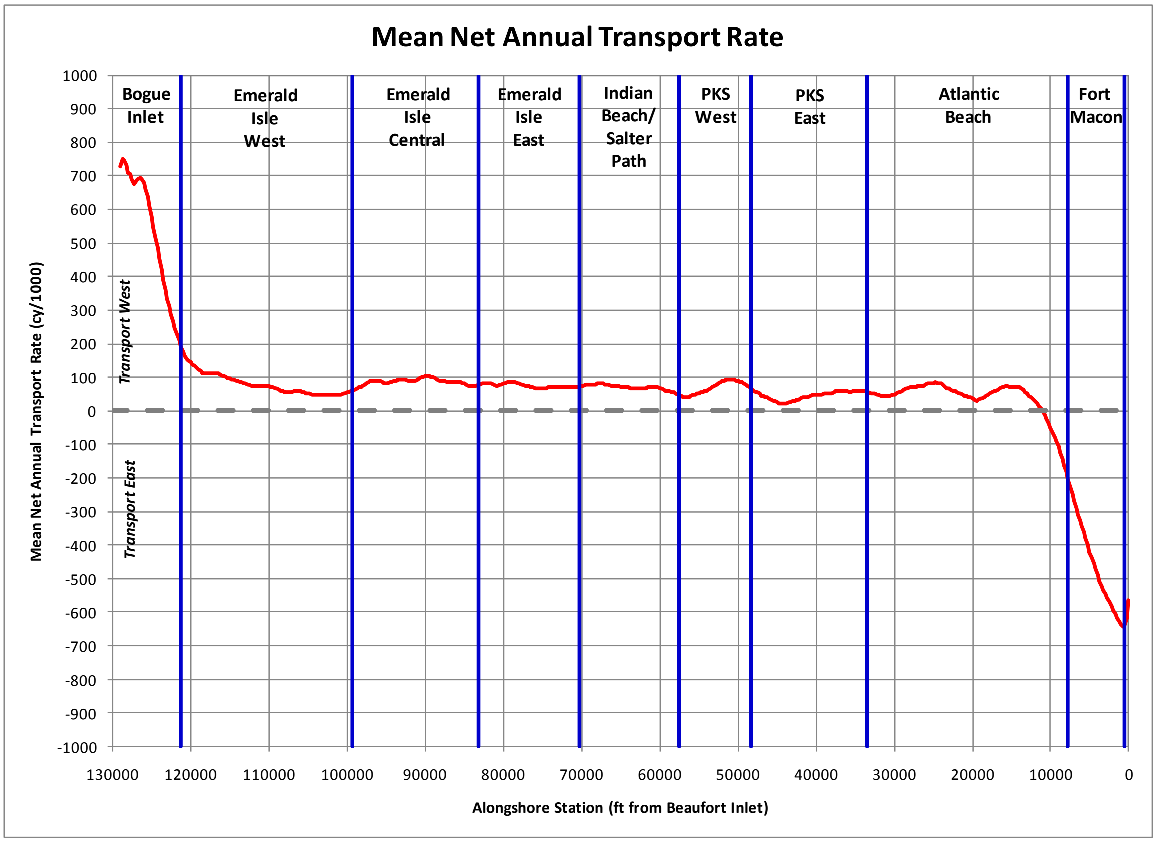

Figure 5-5: GENESIS-T Sediment Transport Rate Calibration

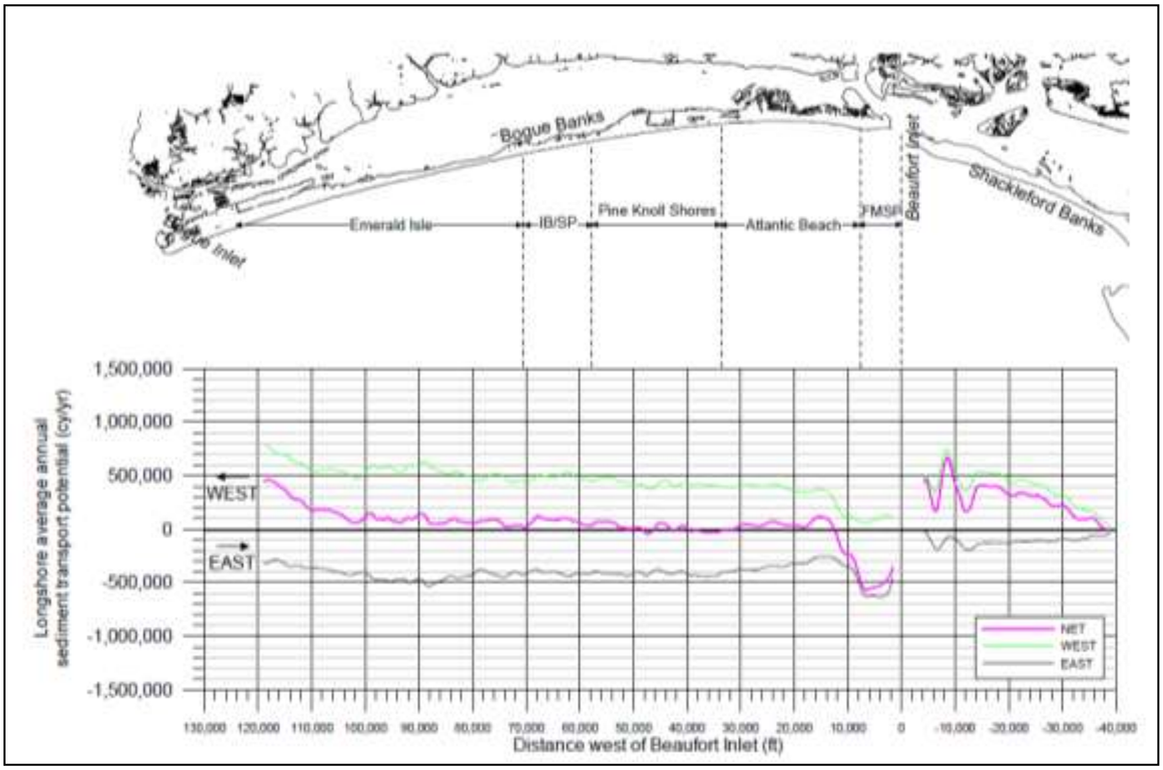

Figure 5-6: Olsen Associates Estimated Sediment Transport (2006)

5.3.3.7 Boundary Conditions

The required boundary condition inputs for GENESIS-T include the seaward wave data boundary conditions and the lateral boundary conditions at the left (west) and right (east) ends of the shoreline – as described below.

5.3.3.7.1 Seaward Boundary Conditions

Wave height, wave period, and wave direction are from the NDBC wave buoys and WIS archive, along with water level from and NOAA tide gauge at Beaufort. Within the seaward boundary conditions, the user may modify the input wave conditions (wave height and direction) to analyze the impact modeled wave conditions have on the resulting shoreline response. During calibration it was determined that the angle with which waves are applied across the boundary of the model needed to be modified slightly to better represent diffraction due to the curvature of the shoreline.

In addition, a regional contour was used to account for variations in bathymetry offshore which cause a change in wave energy and likely contribute to some of the hotspots along the island. The regional contour was also used to account for a difference in wave direction seen near the inlets as compared to the middle of the island. The smoothing factor applied with the seaward boundary conditions is an indication of how the offshore contour moves relative to the shoreline and is used to prevent unrealistic wave transformation that may occur if the shoreline changes relatively abruptly (e.g. at a groin). The smoothing value may range from 0 to 50, with a lower value indicating the offshore contour follows the shoreline position and a higher value implying that the contour is straighter than the shoreline. After numerous trials, a smoothing factor of 11 was applied in the GENESIS-T model based on the effect that this parameter was observed to have on the resulting shorelines. This low number implies that the shoreline itself is relatively smooth.

5.3.3.7.2 Lateral Boundary Conditions

The east boundary of the model was located just beyond the terminal groin structure, in order to allow for sediment transmission through the terminal groin. It was determined that due to the historical accretion of material at the terminal groin, an accretional moving boundary of 450 ft/simulation period would be appropriate. The west boundary of the model was established near the Point where a moving boundary of 90 ft/simulation period was established based on the initial and reference shoreline position data. Figure 5-7 and Figure 5-8 show the east and west boundary conditions applied in the calibration model.

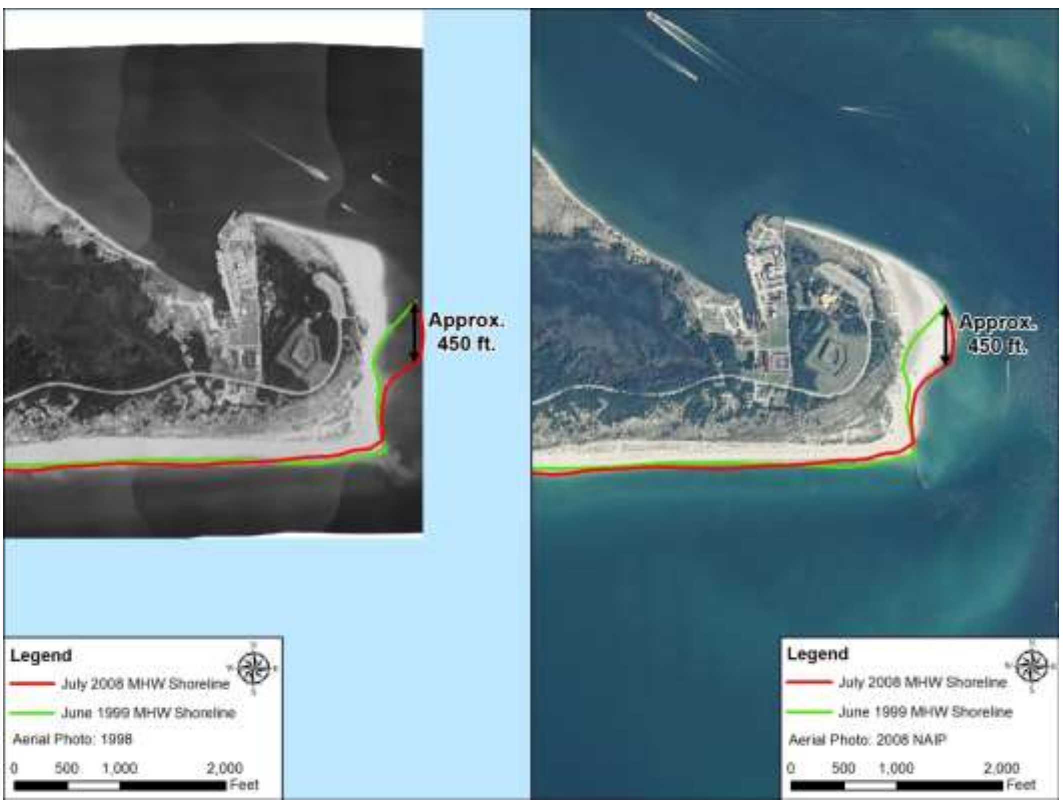

Figure 5-7: Calibration East Boundary Condition

Figure 5-8: Calibration West Boundary Condition

5.3.3.8 <u>Calibration Model Results</u>

Approximately 100 model runs were completed to achieve a reasonably calibrated model. Appendix E shows the final shoreline resulting from the GENESIS-T calibration modeling against the initial shoreline position (June 1999) and the comparable measured shoreline position (July 2008). Figure 5-9 and Figure 5-10 show example results from the GENESIS-T calibration.

Figure 5-9: Example GENESIS Calibration Results – Emerald Isle East

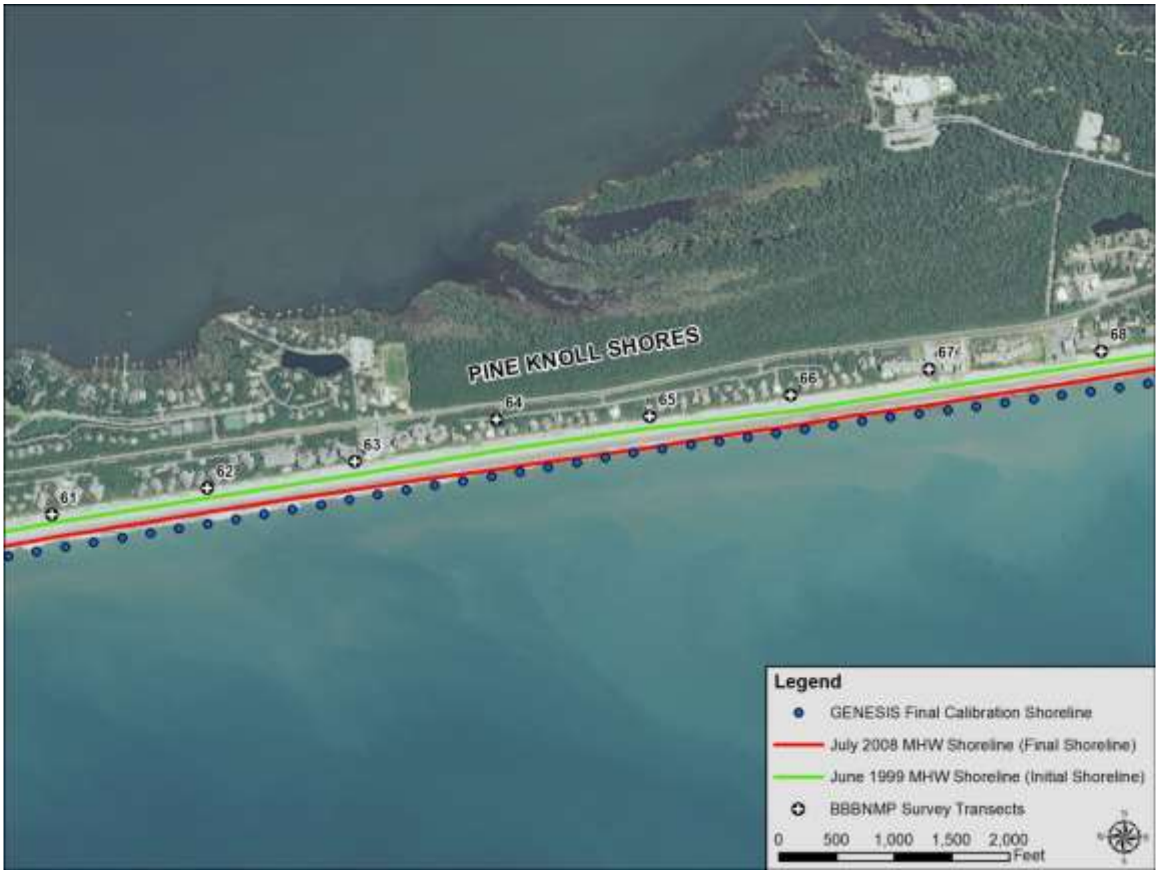

Figure 5-10: Example GENESIS Calibration Results – Pine Knoll Shores

As shown in Appendix E and reflected in Figure 5-9 and Figure 5-10 , the model output matched the measured shoreline position fairly well in some areas and not in others. The calibration shoreline was a close match in Emerald Isle, including the hotspot areas of Emerald Isle East (Transects 35-46). The model also performed very well in Atlantic Beach (Transects 78-102). The model slightly underestimates the erosion in much of Pine Knoll Shores, although it performs well at the hotspot around Transect 65. The model does not perform as well in Indian Beach/Salter Path and Beaufort Inlet, where it substantially underestimates the erosion. Given that Indian Beach/Salter Path is adjacent to the Emerald Isle East and Pine Knoll Shores hotspots, it appears that the material eroding from these may be acting as a source of material for that region in the model. Being that GENESIS is a longshore model, good performance at inlets with large ebb-tidal shoal features – such as Beaufort and Bogue inlets, where there are multiple forces at work, is usually not expected. Based on these results, all future model runs utilized the defined parameters for coastal structures (breakwater transmission and groin permeability), sediment transport (K_1 and K_2), and boundary conditions (wave angle offset and smoothing factor) which were set during the calibration modeling.

It should be noted that shoreline behavior along Bogue Banks is driven by more than just longshore transport as addressed in the GENESIS-T model; cross-shore transport also affects shoreline response, but is not addressed by GENESIS-T model. Therefore, calibration can not provide an exact match to the historical shoreline positions. An attempt was made however, to make sure that predicted shoreline changes reasonably reflected measured trends.

5.3.4 Verification Model

To validate the shoreline response in GENESIS-T based on the calibration coefficients chosen during the calibration process, a verification model was set up for a shorter time period which was absent of engineering activities from July 2008 through April 2012. Only input shorelines, beach fills, wave data, and boundary conditions were varied from the calibration model to reflect the new time period being modeled. All structures, beach characteristics, and sediment transport parameters were held consistent with those used in the calibration model.

5.3.4.1 Shoreline Position Data

The initial shoreline used in the GENESIS-T verification model was the July 2008 shoreline, created by Geodynamics from their July 2008 survey. The final reference shoreline to which the model was calibrated was the April 2012 shoreline, created by Geodynamics from their April 2012 survey.

5.3.4.2 Wave Data

As with the calibration model, wave data from multiple sources was pieced together to develop a wave time series from July 2008 to April 2012. The MIKE 21 SW model discussed in Appendix A was used to transform the offshore time series of waves from the relatively deep water NDBC stations and WIS hindcast stations to a nearshore position at Bogue Banks with a depth of approximately -40 ft NAVD88 for use in the GENESIS-T model. A station file was then created in STWAVE, with 18 stations along the shoreline to which the waves were applied. This allowed for the varying of wave parameters in GENESIS-T from one end of the shoreline to the other based on local bathymetry.

5.3.4.3 Beach Fills

There was a small nourishment project in 2009 where material from the Bogue Inlet AIWW crossing was placed on “The Point” at the western end of Emerald Isle. A small portion of this material was placed on approximately 1500 feet of oceanfront shoreline, adding around 200 ft of beach width to this area based on project graphics from the Carteret County Shore Protection Office. In addition, Fort Macon and Atlantic Beach received material from the Morehead City Harbor Maintenance Dredging in 2011. Approximately 1.35 million cy was placed on the beach, adding approximately 200 ft of berm width based on monitoring profile data. These nourishment projects were included in the beach fill input data (Table 5-2).

Table 5-2: Beach Fill Data For GENESIS-T Verification

Fiscal Year	Project Description	Placement Location	Volume (cy)	Added Berm Width (ft)
2009	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle	Emerald Point/Western Emerald Isle	64,143	200
2011	Dredge Disposal to Eastern Bogue Banks (MCH Outer Harbor Maintenance)	Atlantic Beach/Fort Macon	1,346,700	200

5.3.4.4 Boundary Conditions

As mentioned previously, the required boundary condition inputs for GENESIS-T include the seaward wave data boundary conditions and the lateral boundary conditions at the left (west) and right (east) ends of the shoreline.

5.3.4.4.1 Seaward Boundary Conditions

Seward boundary conditions for the verification model remained the same as those in the calibration model.

5.3.4.4.2 Lateral Boundary Conditions

As with the calibration, the east boundary of the model was located just beyond the terminal groin structure, in order to allow for sediment transmission through the terminal groin. It was determined that due to the historical accretion of material at the terminal groin, an accretional moving boundary of 335 ft/simulation period would be appropriate. The west boundary of the model was established near the Point where a moving boundary of 500 ft/simulation period was established based on the initial and reference shoreline position data. Figure 5-11 and Figure 5-12 show the east and west boundary conditions applied to the verification model.

Figure 5-11: Verification East Boundary Conditions

Figure 5-12: Verification West Boundary Conditions

5.3.4.5 Verification Model Results

Appendix E shows the final shoreline resulting from the GENESIS-T verification modeling against the initial shoreline position (July 2008) and the comparable final measured shoreline position (April 2012). Figure 5-13 and Figure 5-14 show example results from the GENESIS-T model verification.

Figure 5-13: Example GENESIS Verification Results – Emerald Isle East

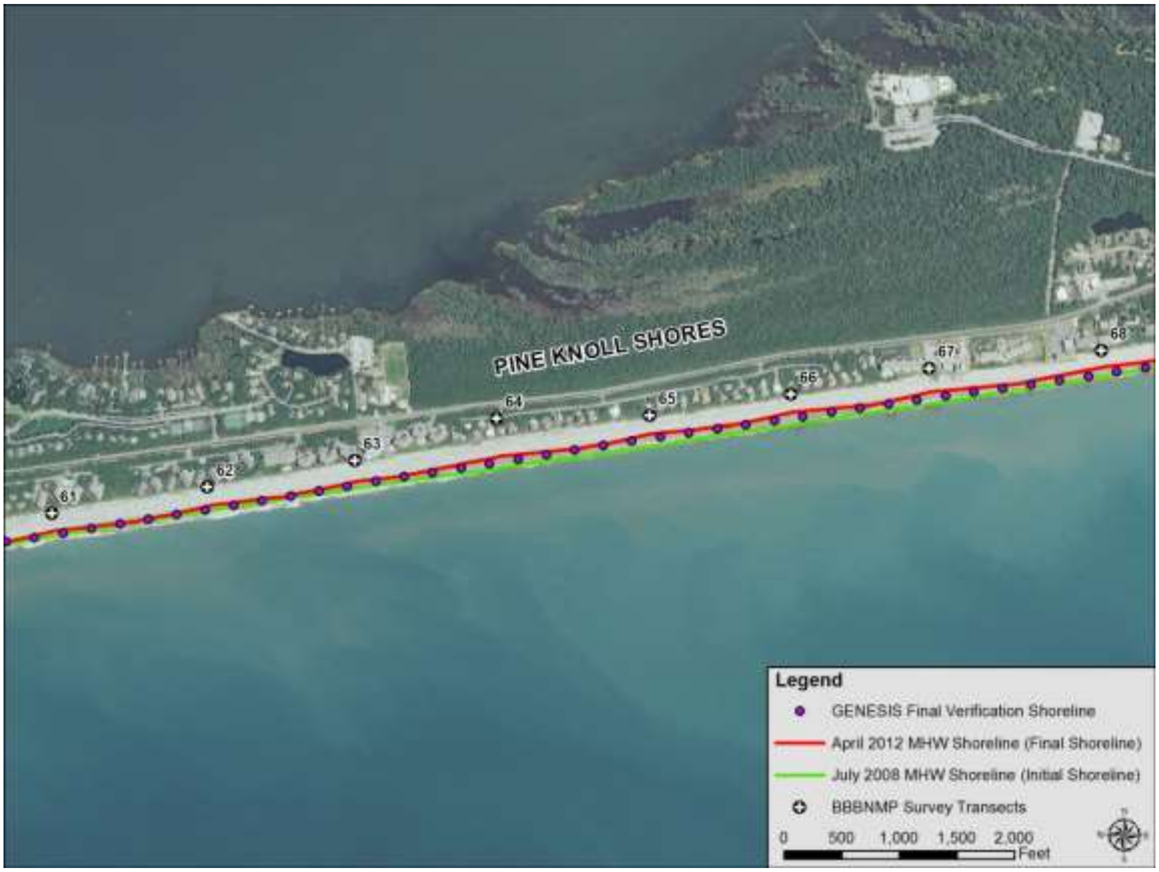

Figure 5-14: Example GENESIS Verification Results – Pine Knoll Shores

As shown in Appendix E, the model output matched the measured shoreline position fairly well in some areas and not in others. The verification model performed best in Emerald Isle West, Pine Knoll Shores, and Atlantic Beach. It slightly underestimated the erosion at Emerald Isle Central and East as well as Indian Beach/Salter Path. Based on these results, all future model runs utilized the defined parameters for coastal structures (breakwater transmission and groin permeability), sediment transport (K_1 and K_2), and boundary conditions (wave angle offset and smoothing factor) which were set during the calibration modeling.

The calibrated model was then used during the evaluation of alternatives for the Bogue Banks MBNP as can be seen in Chapter 8.0.

6.0 EVALUATION OF HISTORICAL BOGUE INLET BEHAVIOR

6.1 Introduction

In addition to studying the historical hotspots along Bogue Banks and their effect on nourishment volume needs along Bogue Banks, the behavior of Bogue Inlet is important to the study from an infrastructure protection perspective. While Beaufort Inlet is also important to Bogue Banks and has far reaching implications concerning its management, the management of Beaufort Inlet is governed by a Federal Navigation Project, and hence is not subject to County dredging, being a deep draft navigation project associated with a port.

Bogue Inlet has been the subject of local project efforts in the past. Bogue Inlet is a shallow draft inlet with federally authorized constructed-channel dimensions of 150 feet bottom width and 8 feet deep, and it has historically been dredged by sidecast dredges. In the late 1990s through early 2000s, the inlet shifted toward the Point at the eastern end of Emerald Isle, and this shift seriously threatened homes and infrastructure at that location. As can be seen in Figure 6-1, without the use of sandbags, these homes would have been lost. The inlet was successfully relocated in early 2005, and the adjacent eastern shoreline of Bogue Banks has been relatively stable since. However, the inlet throat itself has been moving eastward toward The Point since its relocation and concerns are that the adjacent inlet infrastructure may be threatened once again. Therefore, it was decided by the County that an analysis of Bogue Inlet stability and protection of infrastructure on the adjacent shoreline should be completed as part of this project.

Figure 6-1: Threatened Homes at the Point (Carteret County SPO, 2004)

A review of inlet shorelines and ebb channel centerlines was performed to evaluate the historical movement of Bogue Inlet channel and its effect on the adjacent shorelines. Furthermore, the analytical study of Bogue Inlet Channel and shoal morphology, including the White Oak and Bogue Sound Channels, was used as an initial way to form scenarios for numerical modeling to determine if there were any factors that could be discovered which caused the channel to move rapidly toward Bogue Banks.

This chapter summarizes the empirical and numerical model studies of Bogue Inlet conducted as part of this master plan. A significantly more extensive description of the analytical/empirical and numerical model studies of Bogue Inlet is provided as Appendix A to this report. The analysis and development of a preferred inlet location is discussedin Chapter 8.0.

Unless otherwise noted, all units in Chapter 6.0 are in the metric system, and all elevations are referenced to the North American Vertical Datum of 1988 (NAVD88). All horizontal coordinates are referenced to Universal Transverse Mercator (UTM) Zone 18N, WGS 1984 horizontal datum.

6.2 Bogue Inlet Study Approach

The purpose of the present study of Bogue Inlet is to understand the range of historical migration and orientation of the ebb and flood channels, and to translate that understanding into guidance for planning future maintenance of the ebb and/or incipient flood channels.

The present study primarily utilizes indicators of inlet channel and shoal morphology measurable from georeferenced historical aerial and satellite imagery and historical bathymetric surveys to develop these guidelines.

A limited program of numerical modeling supplements the empirical study by providing an understanding of sediment transport pathways and potential channel and shoal migration from various channel configurations. The Bogue Inlet local numerical model consists of dynamically coupled two-dimensional (2-D) depth-integrated waves and hydrodynamics, which drive quasi-three-dimensional (Q3D) sand transport and bed morphodynamic calculations.

6.3 Inlet Channel Migration Empirical Analysis Results

Based on historical aerial photography (Cleary, 2005), NOS T-Sheet digitization, and LiDAR topography the shoreline position on either side of Bogue Inlet was digitized for various dates from 1871 to 2012 to determine the envelope of shoreline change which has occurred in the past. Table 6-1 shows the shoreline dates and sources from which they were developed that were compiled for the Bogue Inlet empirical analysis. Figure 6-2 displays the resulting shorelines overlain on 2012 NAIP aerial photography. In addition, the main ebb channel centerlines were also digitized from the historical aerial photography, and these are presented in Figure 6-3, overlain on 2012 NAIP aerial photography.

Table 6-1: Historical Bogue Inlet Shorelines

Year	Shoreline Source	Year	Shoreline Source
1871	NOS T-Sheet MHW Contour	1992	Digitized Wet/Dry Line
1933	NOS T-Sheet MHW Contour	1997	Digitized Wet/Dry Line
1938	Digitized Wet/Dry Line	1998	Digitized Wet/Dry Line
1949	Digitized Wet/Dry Line	2003	Digitized Wet/Dry Line
1956	Digitized Wet/Dry Line	2004	Digitized Wet/Dry Line
1958	Digitized Wet/Dry Line	2006	Digitized Wet/Dry Line
1960	Digitized Wet/Dry Line	2007	Digitized Wet/Dry Line
1971	Digitized Wet/Dry Line	2008	Digitized Wet/Dry Line
1973	NOS T-Sheet MHW Contour	2009	Digitized Wet/Dry Line
1976	Digitized Wet/Dry Line	2010	Digitized Wet/Dry Line
1987	Digitized Wet/Dry Line	2011	Digitized Wet/Dry Line
		2012	Digitized Wet/Dry Line

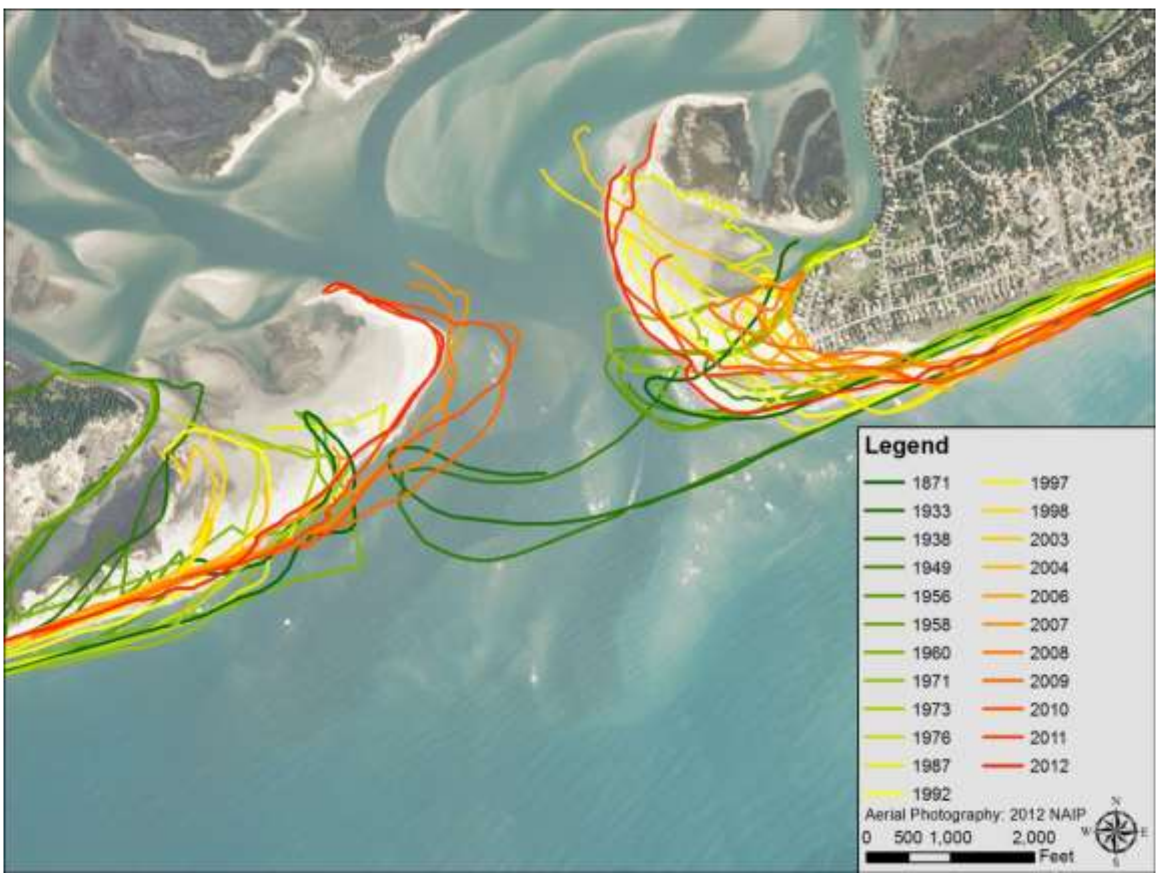

Figure 6-2: Historical Bogue Inlet Shorelines

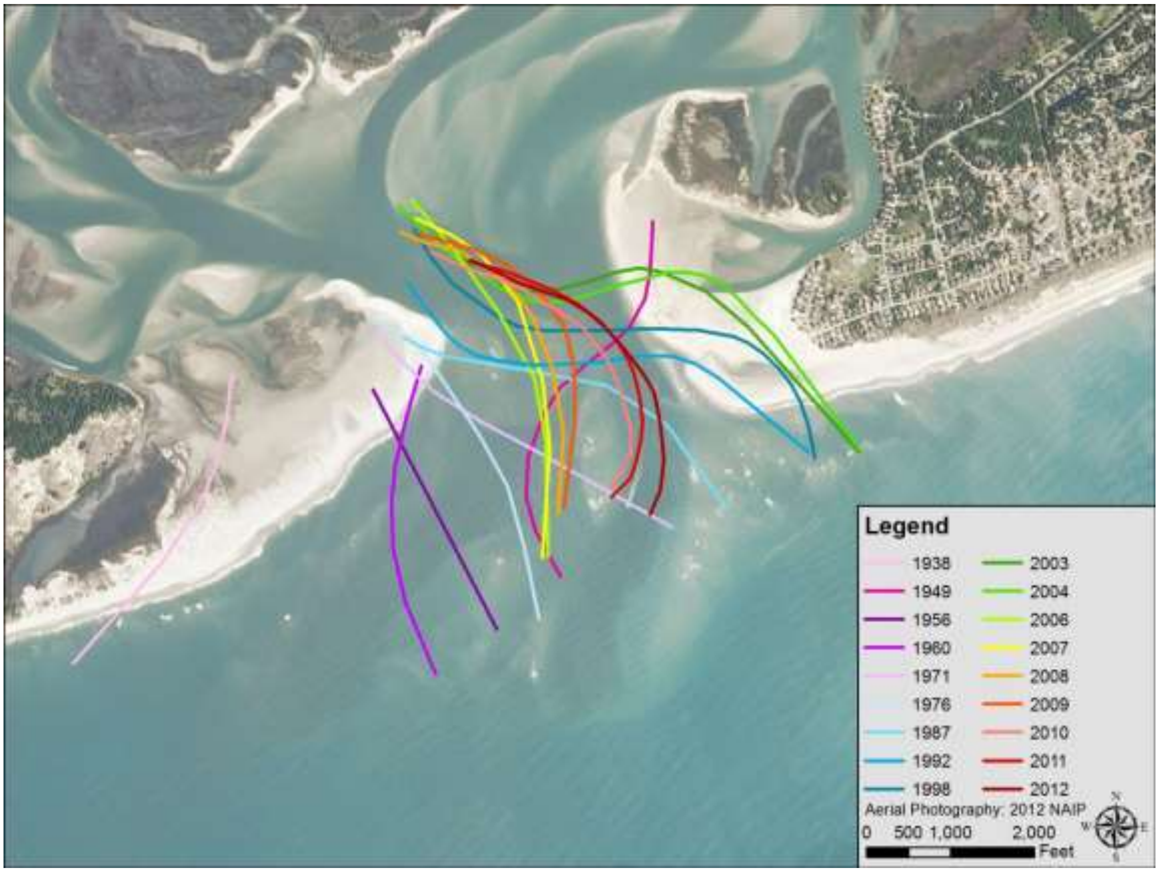

Figure 6-3: Historical Bogue Inlet Ebb Channel Centerlines

From the shorelines and inlet ebb channel digitized locations, several patterns became evident. It appears that before 1987, the ebb channel was located westward toward Bear Island. Sometime between 1987 and 1992, the ebb channel began traveling consistently eastward. It appears that once the channel migrated eastward beyond a certain point, migration accelerated and caused rapid erosion of the beachfront. The shoreline stability near the Point was thus compromised, and erosion of the beach fronting the Point began to occur between 1992 and 1998, continuing through 2004. The channel was mechanically relocated to the center of the inlet in 2005.

To investigate the processes that may contribute to a "tipping point" in channel position or orientation, a numerical modeling component has been included in this phase of study to supplement (e.g. to test, support, expand upon) knowledge gained and recommendations from the empirical analysis of the historical data. Idealized and simplified (schematized) representations of different types of inlet channel configurations simulated in the numerical model were based on observations described below.

Several inlet geometry components were traced from the historical aerial imagery. Figure 6-4 shows the delineation of empirical study components superimposed upon a 1938 aerial photo of Bogue Inlet. Definitions of each parameter in the figure are given in Appendix A. Throughout this chapter, the terms clockwise (CW) and counterclockwise (CCW) are used to describe rotation of the channel azimuths (skew lines) with respect to a line normal (perpendicular) to a Reference Line, shown in the figure below.

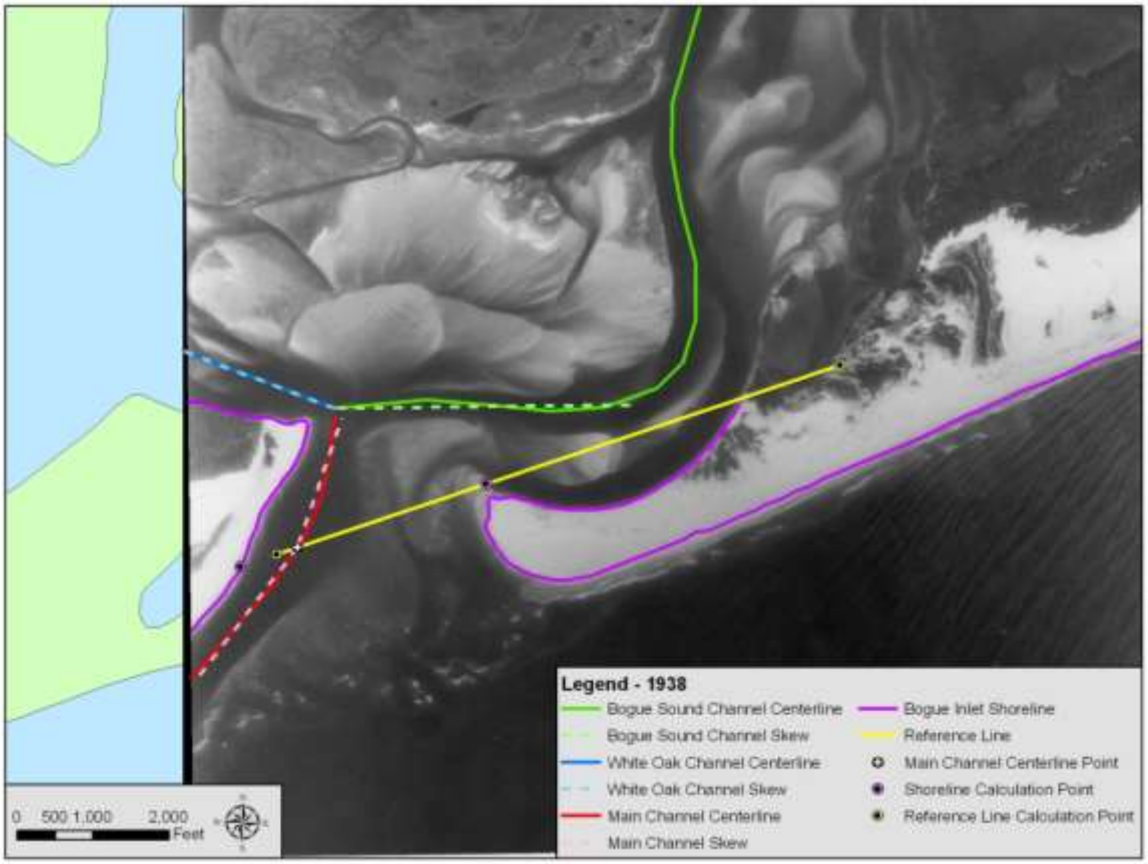

Figure 6-4: Bogue Inlet Analytical Morphology Parameters

In the earliest period of historical photographs (1938 – 1960, Figure 6-5), the main ebb channel moved from a position hard against the Bear Island shoreline (1938) with an extreme CW skew (relative to the reference line) to a position in 1956 generally in the center of the inlet with a normal to slightly CCW skew. The main channel did not migrate intact during this time; rather, the aerials indicate multiple flow channels within the inlet at various times, and it may be that the 1938 ebb channel simply closed as a channel or channels opened at different positions.

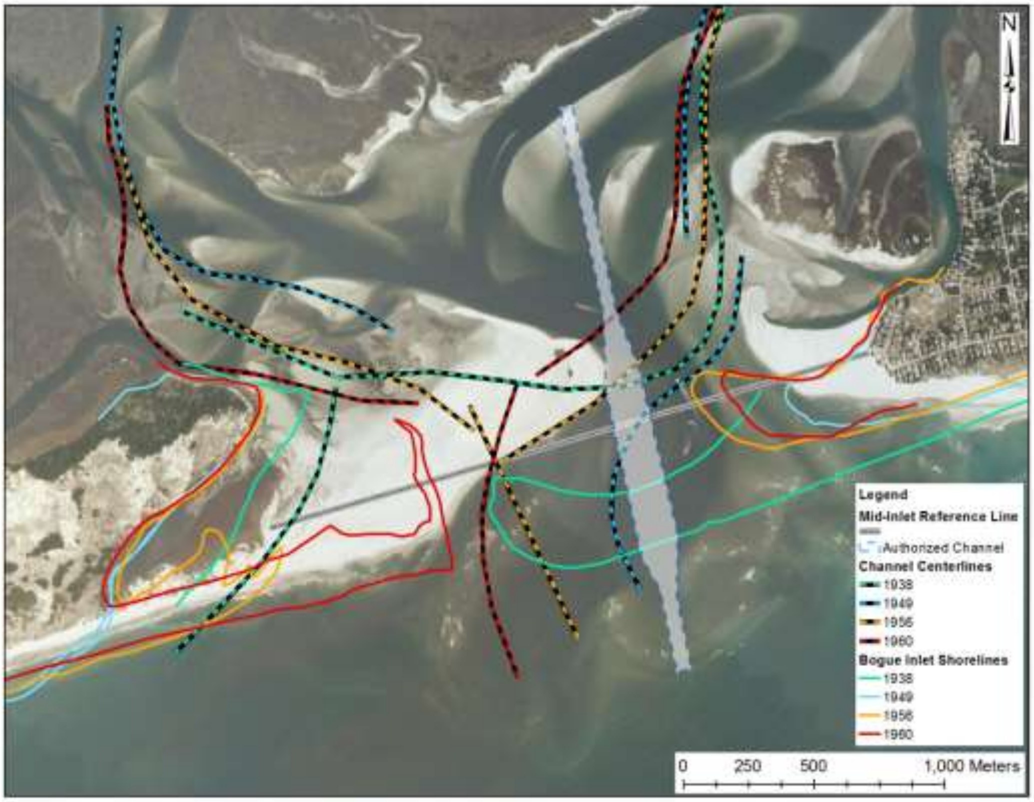

Figure 6-5: Historical Aerial Channels and Shorelines: 1938 to 1960

The main ebb channel position did not change significantly between 1956 and 1960, though the skew angle rotated significantly, to a position well CW of the reference line normal. A long spit had formed off of Bear Island – the outline of which may be seen as shoals in 1956.

It appears that the main channel migrated approximately 1,000 feet eastward between 1960 and 1976, with extreme swings in the skew angle relative to the reference line normal (Figure 6-6) and reoriented to a severe CCW skew angle. Between 1976 and 1987, the main ebb channel migrated 1,500 feet eastward, and the skew orientation was again significantly CCW from the reference line normal.

First indicated in the 1987 photo, a large spit formed on the west end of Bogue Banks, oriented far more shore-normal than shore-parallel. This spit feature continued to exist through to the present-day, at times with channels carved through it near the Coast Guard station.

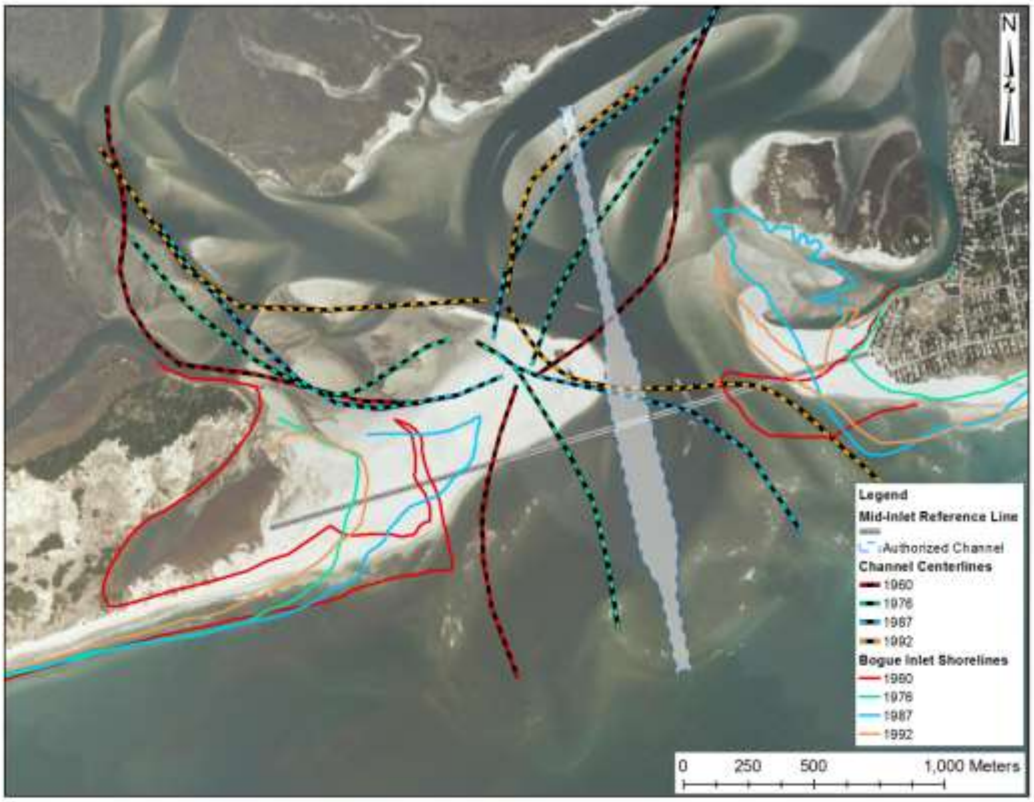

Figure 6-6: Historical Aerial Channels and Shorelines: 1960 to 1992

The main channel moved over 2,000 feet towards Bogue Banks between 1976 and 1987, and then moved another 1,300 feet eastward between 1987 and 1992 (Figure 6-7). The 1992 channel position further east than all of the previous photos dates except the 1949 channel. The channel migrated further eastward from 1992 to 2004, though at relatively slow rate of change. The main channel skew remained extremely CCW to the reference line normal from 1987 to 2004.

The period between 1987 and 2004 was the most "stable" period with respect to main channel skew angle in the limited history of the inlet observable from these combined 17 aerial photo snapshots. The ebb channel position moved only 500 feet from 1998 to 2004, though man-made efforts to protect the developed portions of Emerald Isle (and possibly the geology underlying this historically more stable portion of Emerald Isle) may have been responsible for preventing further eastward movement.

Figure 6-7: Historical Aerial Channels and Shorelines: 1992 to 2004

The main ebb channel of Bogue Inlet was relocated in 2005 as part of a local Town of Emerald Isle/Carteret County project, with planning and engineering studies documented in the report by CP&E (2004). No aerial photos were available in the data set from immediately pre- or post-construction of the relocation project. In the 2006 photo (Figure 6-8), the relocated main ebb channel is seen approximately 3,000 feet west of its 2004 position. The pre-construction ebb channel can also still be seen against the western end of Emerald Isle; that remnant channel was left by the relocation project to fill in naturally over time.

The alignment of the Authorized Channel constructed in 2005 aligned more directly with the Bogue Sound channel (also the Atlantic Intracoastal Waterway connection) than with the White Oak River channel. The skew of both the landward and seaward segment of the Authorized Channel were nearly normal (slightly CW) to the reference line. Over the next several years, from 2006 to 2011, the main ebb channel's connection with the White Oak River channel appears to have deepened, and the skew of the main ebb channel's landward segment progressively rotated more CCW to align more smoothly with the White Oak River channel. The White Oak channel skew rotated more CW, further connected with the main ebb channel. At the same time, the seaward segment of the main ebb channel rotated more CW – a configuration reflected by the numerical model simulations described in Section 6.4 of this report – and the "curved" ebb channel began to migrate eastward again toward Bogue Banks. The connection point between the White Oak, Bogue Sound, and main inlet ebb channels has not migrated eastward to the extent that the main channel mid-point has migrated, and the landward segment of the main channel has elongated since 2006.

Figure 6-8: Historical Aerial Channels and Shorelines: 2005 to 2011

As of mid-2013, the main ebb channel had migrated approximately 1,360 feet from the position of the Authorized Channel centerline in 8 years, and it was still approximately 1,500 feet from its historically furthest eastward 2004 position. If this trend continues, it might be expected that the 2004 position would be reached in another 6 to 8 years, or 14 years from relocation to the Authorized Channel.

Table 6-2 shows a summary of the channel alignments captured by historical imagery.

Table 6-2: Bogue Inlet Analytical Study Calculations from Historical Imagery

Year	[1]Width feet	[2]Dist. to Bear Island feet	[2]Dist. to Bogue Banks feet	[3]Ocean Seg-ment Angle ºN	[3]Sound Seg-ment Angle ºN
1938	3,413	788	2,625	217	18
1949	9,640	6,919	2,721	187	28
1956	6,195	3,552	2,642	153	333
1960	3,870	792	3,078	178	15
1971	3,767	1,741	2,026	120	308
1976	6,511	2,735	3,776	156	326
1987	4,587	2,900	1,688	125	282
1992	5,547	5,205	342	128	305
1998	7,028	6,623	404	136	289
2003	7,349	6,871	479	138	294
2004	6,592	6,264	328	142	291
2006	5,724	2,553	3,171	175	332
2007	4,364	1,875	2,489	179	333
2008	4,113	1,497	2,617	176	328
2009	3,317	1,086	2,231	185	324
2010	3,878	2,794	1,084	173	313
2011	4,058	3,371	687	180	310

[1]Width measured between apparent Bear Island and Bogue Banks inlet shoulder shorelines.

[2]Distance from channel centerline to either Bear Island or Bogue Banks apparent shorelines.

[3]Azimuth in degrees relative to true North. Perpendicular to Reference Line has an azimuth of 161 ºN.

While the ***position*** of the main ebb channel (and significant flood channel) is an important influence on contemporary erosion (i.e. at any given time) of Bogue Banks or Bear Island, the ***alignment*** of the main ebb channel also appears to be an important factor in estimating the future morphologic behavior of the inlet for management decisions. A primary goal of this study is to develop guidance for anticipating future inlet behavior in advance, so that appropriate mitigation measures can be employed proactively.

The historical channel alignments can be grouped into a few types as indicated in Figure 6-9, where:

- Type 1 (orange) – ebb channel is aligned significantly CW of the Authorized Channel landward of the reference line.

- Type 2 (red) – ebb channel aligned significantly CCW of the Authorized Channel landward of the reference line, and moderately CCW of the Authorized Channel seaward of the reference line. The inlet channel was in a Type 2 configuration, positioned very close to the Bogue Banks shoreline, just prior to relocation in 2005. Type 2 alignments are seen alternating with Type 1 alignments in the 1930s – 1960s. In the 17 year period prior to relocation, the inlet appears to have continued in a Type 2 alignment. It is worth noting that Type 2 alignments have been exhibited over a wide range ebb channel inlet lateral positions since the 1960s.

- Type 3 (green) – ebb channel aligned moderately CCW of the Authorized Channel landward of the reference line, and moderately CW of the Authorized Channel seaward of the reference line. Type 3 configurations are observed only post-relocation, as the straight-aligned Authorized Channel begins to migrate. The angle between the landward and seaward portions of the ebb channel has been steadily increasing, as the landward portion rotates more CCW and the seaward portion rotates more CW.

- Type 4 (blue) – ebb channel aligned generally "straight" approximately in line with the Authorized Channel.

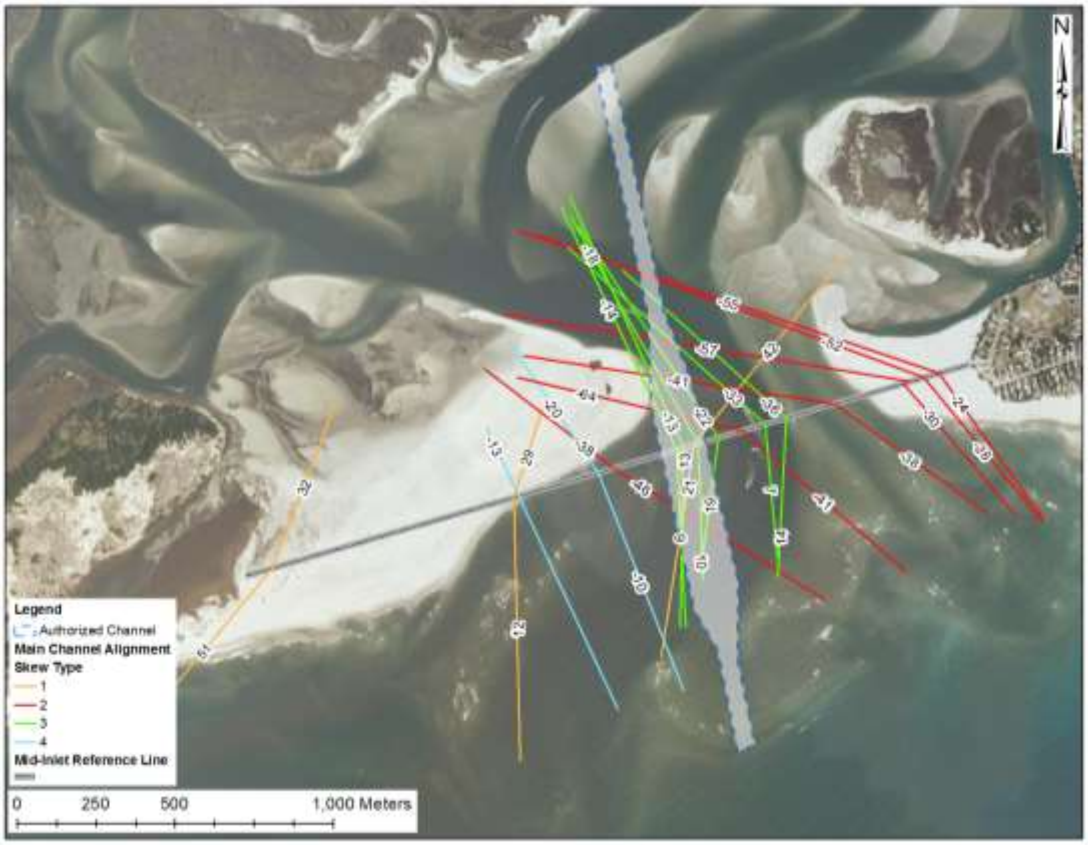

Figure 6-9: Historical Main Ebb Channel Alignments by Type

Through all of these years, it is possible that the orientation (skew) of the main ebb channel is heavily influenced by the relative fraction and intensity of ebb discharges coming from the White Oak River vs. those from the Bogue Sound side of Dudley Island. This may be a key factor in understanding the morphology of Bogue Inlet's channel and shoal system, but it is very difficult to discern from historical data, as no records have yet been found of measured flows in either of the branches.

One of the questions that the numerical model portion of this study attempts to answer is whether there is a "tipping point" in one or more channel geometry parameters, or in a combination of parameters such as landward skew + seaward skew, beyond which the eastward (or westward) migration of main ebb channel is likely to be reinforced and accelerated, or else be unlikely to naturally recover to a more mid-inlet position.

The numerical morphodynamic modeling component of this study investigates this hypothesis by running model simulations primarily on schematized Type 2 and Type 3 inlet channel configurations. Inlet channel alignment cases simulated in the numerical model study are summarized below; the cases and model results are discussed in greater detail in Appendix A.

6.4 Bogue Inlet Local Numerical Model

6.4.1 Purpose and Approach

The purpose of the numerical model portion of the Bogue Inlet study is to extend the empirical analysis of historical data. The local model provides additional information on sediment transport pathways within the inlet and its shoals. The morphological model results facilitate and investigation of whether "tipping points" may exist – i.e. inlet ebb channel positions or orientations which would indicate acceleration of channel migration toward the barrier islands.

The local numerical model consists of dynamically coupled two-dimensional (2-D) simulations of waves, flow, sand transport, and associated bed change (morphodynamics) and hydrodynamics, which drive quasi-three-dimensional (Q3D) sand transport calculations.

The position and orientation of the main and back channels at the end of each model case run were compared with the starting condition of those features, and the overall trends in bed change were evaluated. Determinations were made as to whether each case, considered alone, showed a tendency toward accelerated movement toward Bogue Banks or Bear Island.

6.4.2 Bogue Inlet Local Model Area

Figure 6-10 shows the extents of the local Bogue Inlet computational area. The extents of the domain were selected in order to allow relatively smooth transitions from regional model hydrodynamics (particularly in the sound and channels around Dudley Island) and to place the seaward boundaries far enough away from the areas of greatest interest to avoid artificial boundary forcing impacts. The model resolution within the inlet was selected to ensure that several computational points would exist across all significant channel features. Further details on the development of the Bogue Inlet local model are provided in Appendix A.

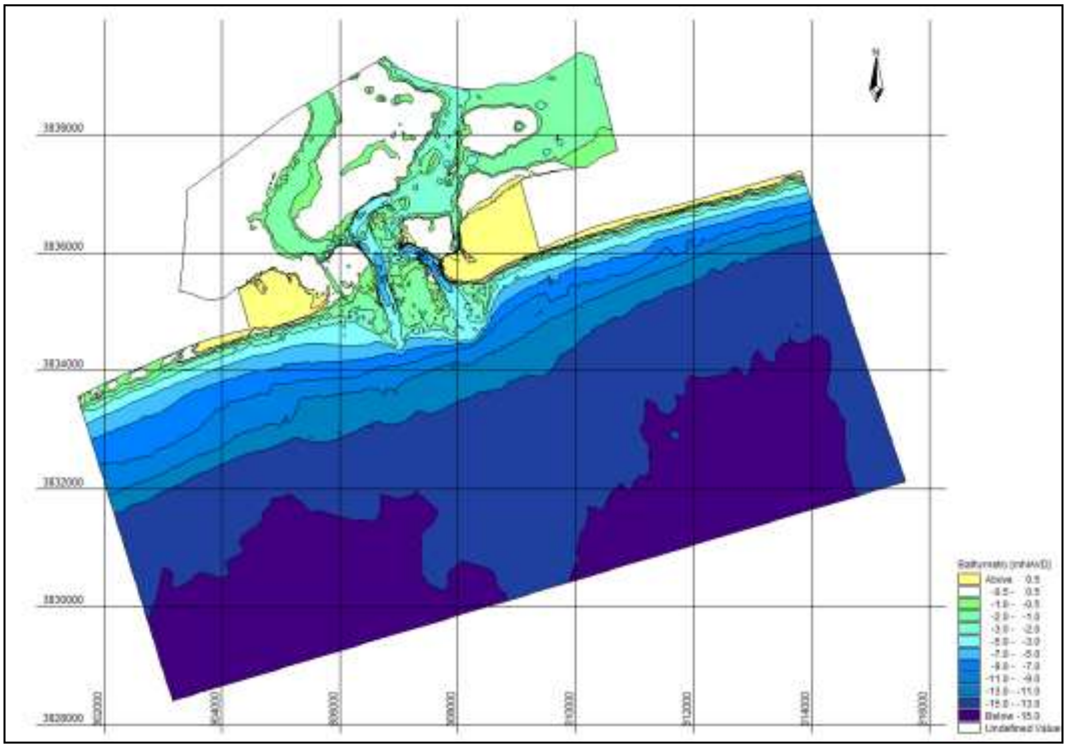

Figure 6-10: Bogue Inlet Local Model Domain and Bathymetry

6.4.3 Model Cases: Schematized Inlet Scenarios

Due to the time-consuming nature of this high-resolution local model, it was necessary to limit the number of physical inlet channel configurations simulated. Five separate physical configurations (cases) were initially developed, and one more was added after evaluation of the initial five. All six cases are identified and the channel configuration briefly described in Table 6-3. The cases were designed to bracket the range of most relevant channel configurations observed in the GIS-based empirical analysis of historical Bogue Inlet morphology (representing Type 1, Type 2, and Type 3 categories of ebb channel alignment).

Table 6-3: Bogue Inlet Schematized Channel Configurations Cases

Case (Type)	Description of Schematized Channel Configuration
1 (Type 4)	Authorized ebb channel (baseline), azimuth 168°N
2 (Type 2)	Ebb channel 25 degrees CCW from Authorized
3 (Type 3)	Landward ebb channel 20 degrees CCW from Authorized; Seaward ebb channel 15 degrees CW from Authorized
4 (Type 3)	Landward ebb channel 35 degrees CCW from Authorized; Seaward ebb channel 10 degrees CW from Authorized
5 (Type 2)	Landward ebb channel 55 degrees CCW from Authorized; Seaward ebb channel 30 degrees CCW from Authorized
8 (Type1)	Ebb channel 15 degrees CW from Authorized

Model Case 3 and Case 2 showed results that were similar to but generally less significant and less useful than Case 4 and Case 5 (respectively). Therefore, while Case 2 and Case 3 are documented in Appendix A, they are not discussed further in this report. Figure 6-11 through Figure 6-14 show the starting bathymetry maps input to the model simulations for Cases 1, 4, 5, and 8 (highlighted in Table 6-3). Elevations above 0m NAVD88 and below -9.5m NAVD88 exist in each of the model bathymetries, but those contours have been made invisible in the figures so that the aerial image can be seen. The results of these four cases are presented and discussed in this chapter. Additional model case inputs, graphical results, and text descriptions of all cases are presented in greater detail in Appendix A.

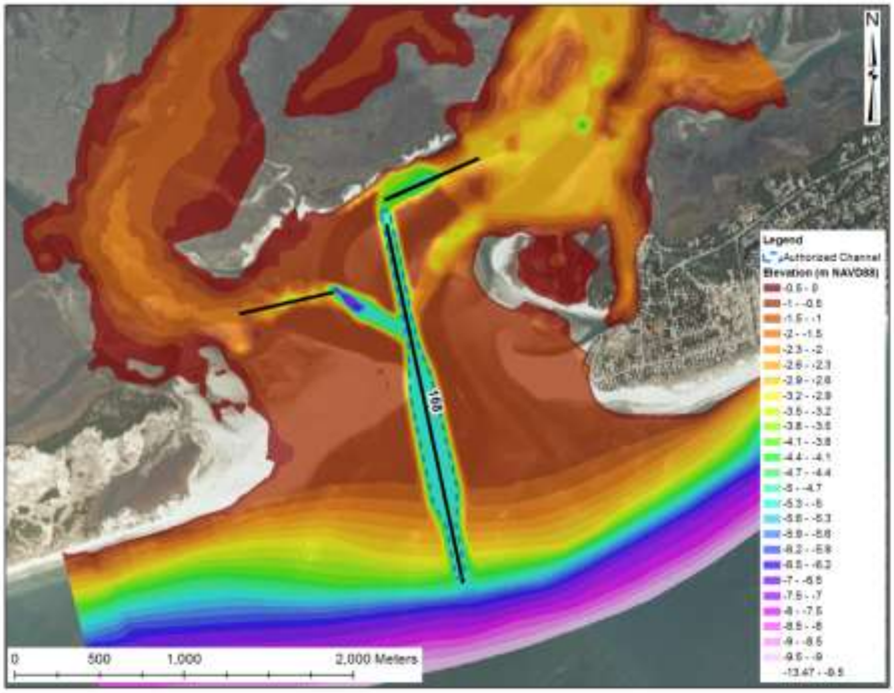

Figure 6-11: Bogue Inlet Local Case 1 Starting Bathymetry

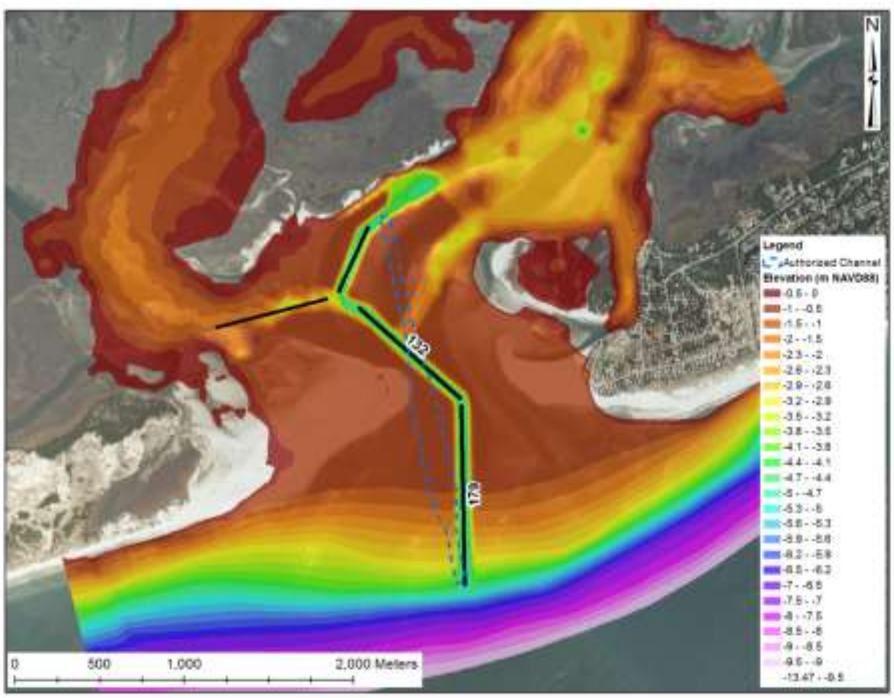

Figure 6-12: Bogue Inlet Local Case 4 Starting Bathymetry

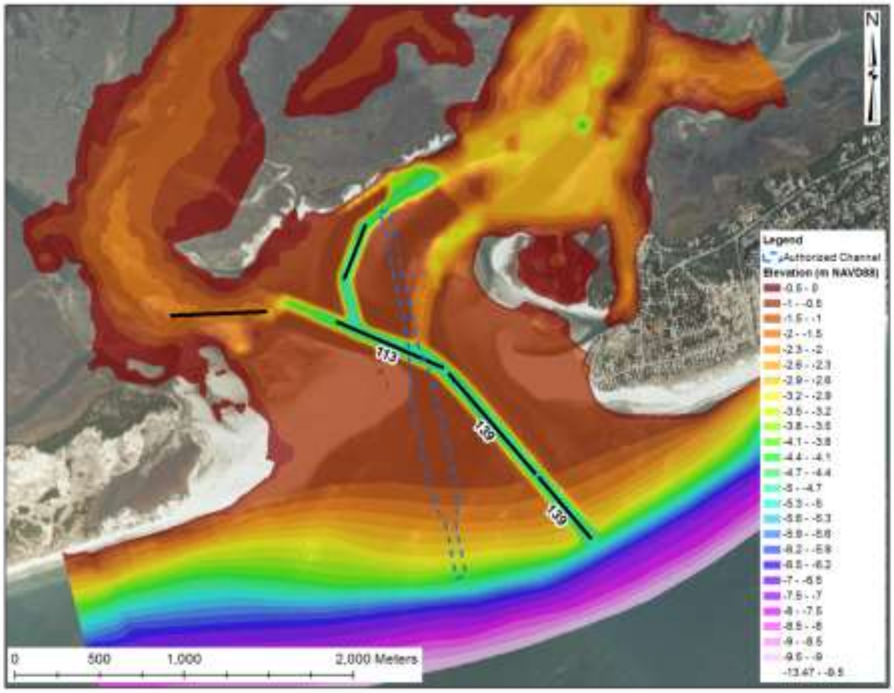

Figure 6-13: Bogue Inlet Local Case 5 Starting Bathymetry

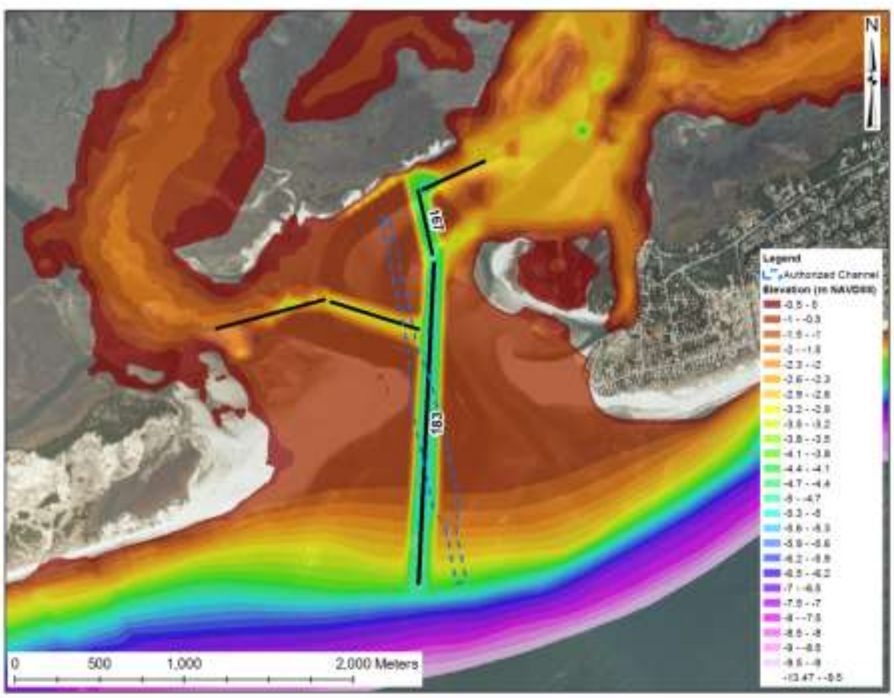

Figure 6-14: Bogue Inlet Local Case 8 Starting Bathymetry

6.4.4 Model Results for Case 1

Figure 6-11 represents the Authorized Ebb Channel relocation described in CP&E (2004) and constructed in 2005. The Case 1 ebb channel has an azimuth of approximately 168^{o}N and an authorized centerline depth of -5m NAVD88. Case 1 is simulated primarily as a baseline condition for evaluating the inlet morphodynamic behavior observed in the other cases.

Case 1 represents Type 4, using the Authorized Channel relocation design as a template. The inlet bathymetry at the end of the simulations is shown in Figure 6-15. The ebb channel landward of the reference line rotated slightly CCW, and it rotated CW seaward of the reference line. The overall effect was to take the seaward channel centerline closer to Bear Island by approximately 500 feet.

The schematized model configurations are limited in the real-world time period they cover, due to computational run time. However, only for Case 1, a longer-term continuous simulation was conducted using astronomical tides and synchronous measured offshore waves for the time period August 2005 – August 2006. The model starting bathymetry was based directly on the 2005 post-relocation multi-beam survey. The model bed change was sped up by a factor of two to extend the effective simulation time to approximately two years, to allow comparison of the model results with a 2007 aerial photo of the inlet.

Figure 6-16 shows the ending bathymetry from this longer simulation. The model bathymetry contours indicate that the channel centerline migrated slightly to the west, and stayed within the bounds of the channel observable from the aerial image. The seaward portion of the channel widened and rotated CW, and the contours align very well with the channel exit seen on the aerial. The remnant channel along the shoreline of Bogue Banks (left in place during the 2005 relocation) shoaled significantly; this feature is also seen in the aerial.

This long-term continuous simulation, with accelerated morphology updating, indicated reasonable matching with observed shoals and channels. Though it is not practical to run more of the various model Cases for year-long or multi-year continuous simulation periods, the general success of this long-term simulation adds confidence to the use of the schematized model results for the present study's purposes.

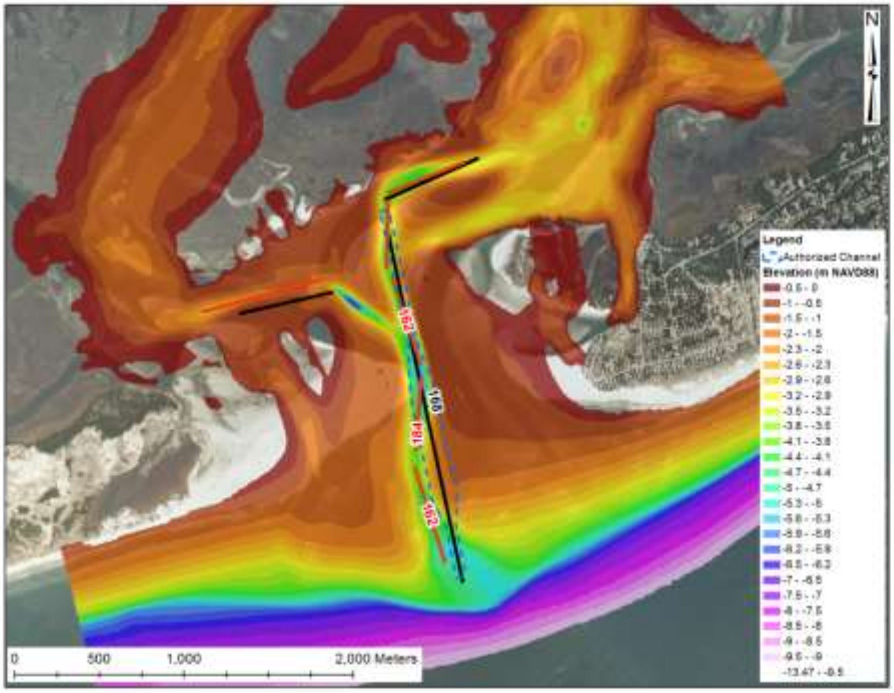

Figure 6-15: Case 1 Resulting Morphology

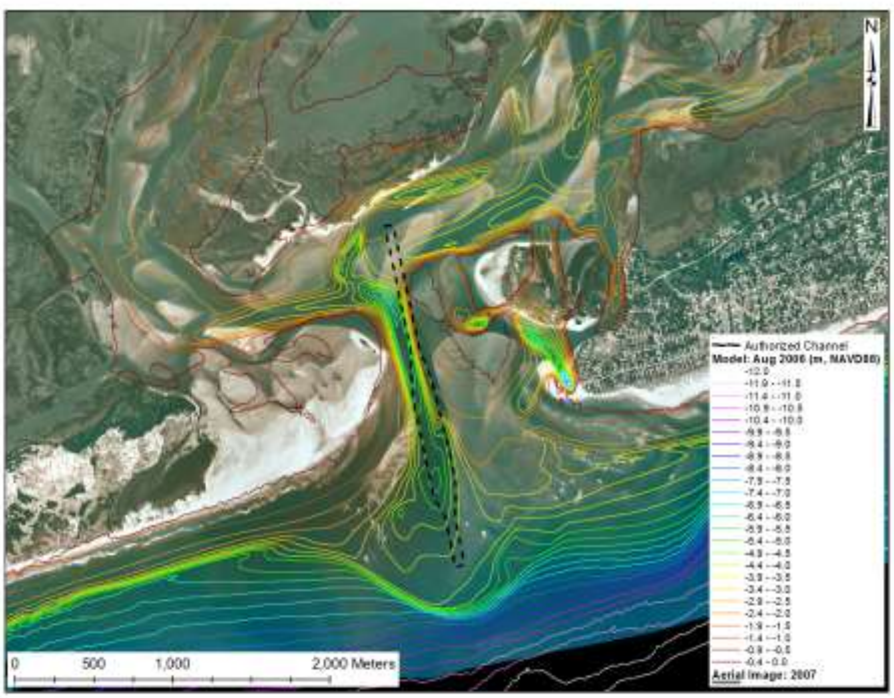

Figure 6-16: 2005-2006 Model Simulation Morphology Over 2007 Aerial Image

6.4.5 Model Results for Case 4

Case 4 represents a Type 3 configuration with a greater angle between the landward and seaward channel reaches. Figure 6-17 illustrates the changes in channel and shoal configuration for Case 4 at the end of the model simulations. The main channel migrated westward toward Bear Island and the width of the channel increased. The main channel straightened, the White Oak channel shoaled and rotated toward Dudley Island, as did the Bogue Sound channel. An incipient flood channel near Bear Island increased in width and length. The main ebb channel depths continued to increase (becoming closer to the Authorized Channel depth of -5 m NAVD88), and the channel centerline moved slightly westward of the Authorized Channel envelope.

The Case 4 results do not show a meaningful transition back toward a straighter channel (similar to Case 1), nor is any significant eastward migration indicated. The movement of the seaward channel exit significantly toward Bear Island remains in both the Case 4 model results and in the historical imagery from 2007 – 2010, with some acceleration of this movement seen in the 2010 imagery.

The Case 4 channel configuration generally reflects the main ebb channel shape (doglegged) and position relative to the Authorized Channel observed in 2009 – 2010. The model results indicate that such a channel would begin to straighten and migrate westward, not further eastward as has been observed in 2012 and 2013. This discrepancy between the model results and the recent observed channel morphology changes indicates that there has been some process at work in the past few years (at least) that is not reflected in the model processes; this issue and simulations targeted at resolving it are discussed further in Appendix A.

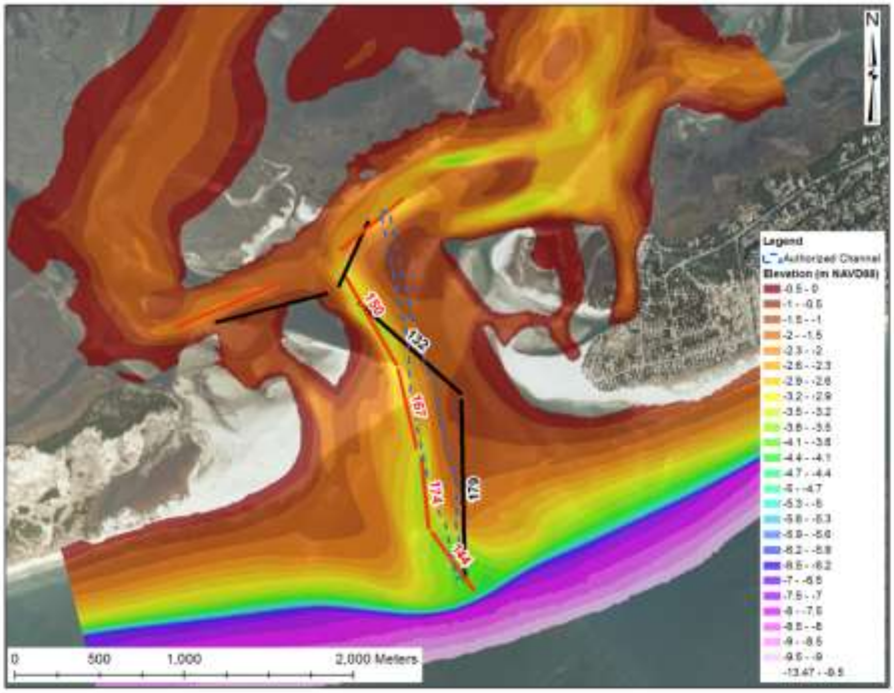

Figure 6-17: Case 4 Resulting Morphology

6.4.6 Model Results for Case 5

Case 5 represents a Type 2 configuration with an angle between the landward and seaward channel reaches (a more realistic case than the Case 2 straight-line channel). Figure 6-18 illustrates the changes in channel and shoal configuration at the end of the Case 5 simulations. The landward portions of the main ebb channel shoaled. The average position of the channel did not move consistently eastward or westward – instead the various legs of the channel rotated CW and CCW through the simulations, placing the legs at various distances from Bogue Banks. As a broad but shallow incipient channel appears to form in the center of the inlet, the original main ebb channel shoals in its seaward reach. The developing second channel is positioned several hundred feet westward of the centerline of the Authorized Channel.

The Case 5 channel configuration was expected to be the one most likely to show accelerated migration toward Bogue Banks. The channel did not migrate eastward, but rather showed a tendency to shoal as another channel formed in the center of the inlet.

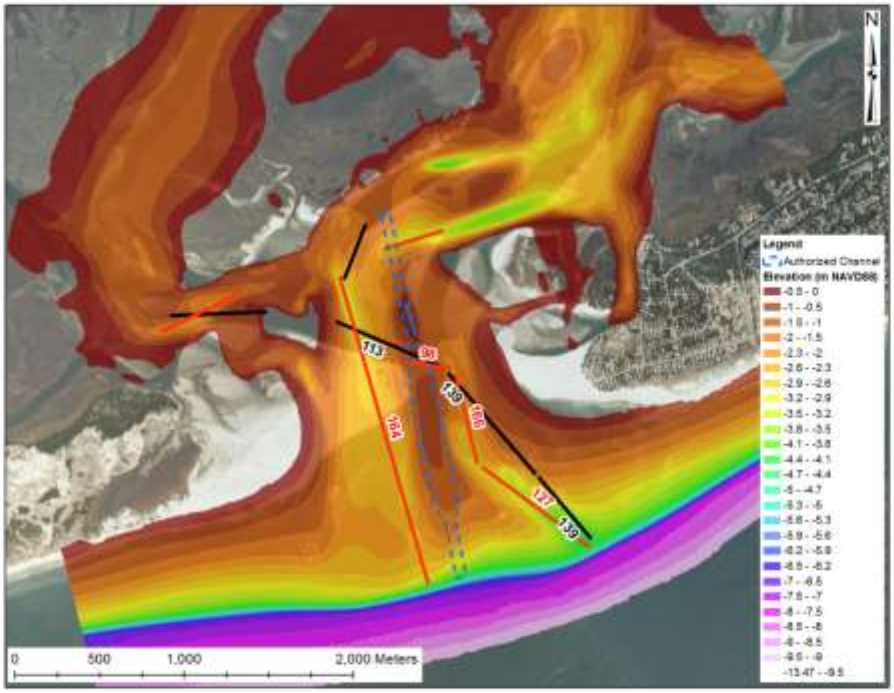

Figure 6-18: Case 5 Resulting Morphology

6.4.7 Model Results for Case 8

Case 8 represents a Type 1 configuration with a non-doglegged main channel rotated CW from the reference line normal. In this configuration, it is likely that flows from the Bogue Sound back channel may dominate migration of the landward to middle portions of the channel.

The initial migration of the ebb channel in Case 8 was very similar to the trends seen for Case 4 and Case 1. As shown in Figure 6-19, the seaward channel reach both rotated CW and widened significantly, while the landward channel reach did not change in position or rotation. The channel depths in the middle reach grew shallower.

In Case 8, the channel reach migrated toward Bear Island and rotated CW. No portion of the channel migrated toward Bogue Banks. This may be due to the more efficient hydraulic connection with the Bogue Sound channel brought about by the CW skew of the main channel. A channel in this configuration appears to be slightly more stable in position than the Case 1 configuration representing the Authorized Channel (see Figure 6-20).

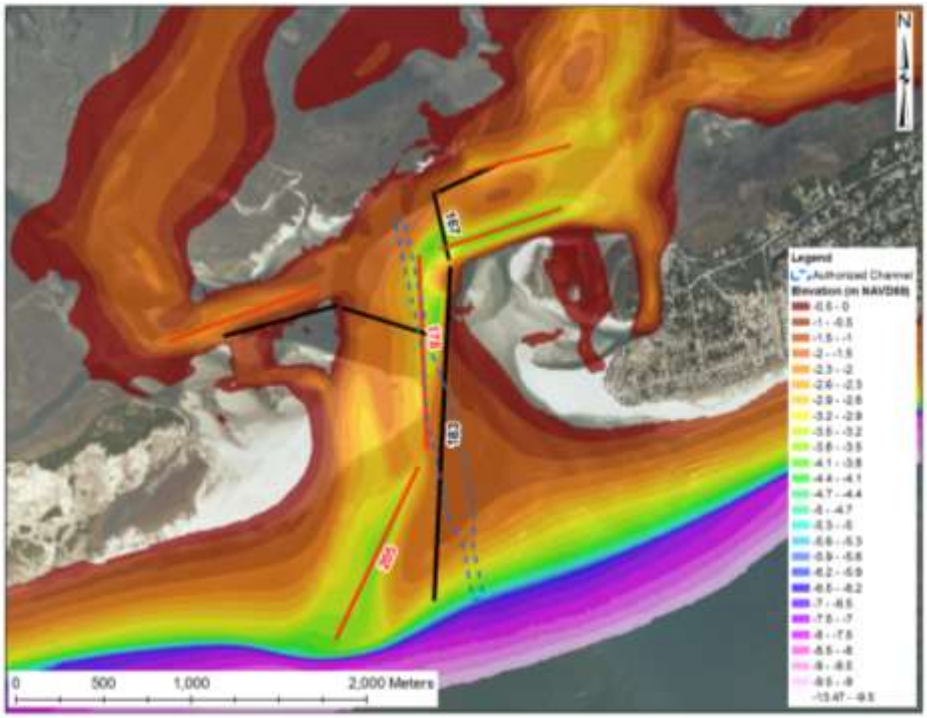

Figure 6-19: Case 8 Resulting Morphology

Figure 6-20: Example 2005 Authorized Channel Rotated 15 Degrees

6.5 Summary and Conclusions

An empirical study of Bogue Inlet channel morphology was conducted using historical aerial imagery from 1938 – 2011. The study was conducted by defining and then measuring a small set of geometric parameters such as the position and alignment of the main ebb channel and the two landward channels connecting Bogue Inlet with Bogue Sound and the White Oak River. The analytical study component indicated extreme variability in the ebb channel position and alignment from 1938 to approximately 1987, while from 1987 – 2004 the channel moved consistently eastward and maintained a counterclockwise (CCW) alignment relative to a hypothetical "straight line" through the middle of the inlet. Since the ebb channel was relocated in 2005 to an approximate straight alignment at a mid-inlet lateral position, the ebb channel has again migrated eastward, though at a lesser rate than seen in the 1987 – 1992 migration. The post-relocation channel also has not yet realigned to a consistent CCW orientation, but currently has a CCW alignment landward and CW alignment seaward of the defined Reference Line. The analytical study component appears to indicate that the ebb channel will eventually migrate further east and that the ebb channel may need to be relocated again at some future date.

The numerical model simulations generally indicated that – from most of the starting inlet geometries – the main channel would tend to migrate back toward the center of the inlet and prefer a generally shore-normal alignment similar to the previously-constructed Authorized Channel. The Case 5 simulations indicated that, while the originally-specified main ebb channel did not itself migrate significantly toward the inlet center, it would shoal and begin to lose hydraulic connection with the White Oak and Bogue Sound channels, and a second channel would form near the Authorized Channel position. The Case 8 simulations showed that a slight improvement that may provide longer timeframes for stability appears to be to rotate the channel by 15 degrees clockwise as shown in Figure 6-20.

The schematized Case model simulations provided results that are in some ways counter to what has been observed with respect to inlet migration post-2005 relocation. Particularly, the Case 4 starting condition generally reflects the main ebb channel shape and position relative to the Authorized Channel observed in 2009 – 2010, but the model results behaved differently than expected from recent observed channel positions. This trend in the model and tests conducted on the model in an attempt to investigate it are discussed in Appendix A.

7.0 BEACH NOURISHMENT LEVEL OF PROTECTION ANALYSIS AND NOURISHMENT TRIGGER ASSESSMENT

7.1 Introduction

In addition to the study of existing Bogue Inlet behavior to determine an optimal solution for protection of infrastructure adjacent to the inlet, the overall beach nourishment need and appropriate triggers for renourishment actions to provide adequate protection for infrastructure along Bogue Banks was also needed.

While the Crystal Ball analysis outlined in Section 4.2 provided a good estimate of the long term needs to maintain the beaches in their current state (approximately 452,220 cy/yr and 22.6 Mcy over the 50 year project) and this estimate matched well with the USACE estimate of approximately 356,347 cy/yr and 17.8 Mcy over 50 years, the overall level of protection across the island has not been quantified by anyone to date.

In fact, a key element of the project purpose is to provide an equivalent level of protection (LoP) to upland structures across all of Bogue Banks – **not equal sand, but equal protection**. This LoP determination would also be critical in developing new nourishment triggers for the island as part of developing an engineered beach; the current nourishment trigger is currently set at 225 cy/ft across the whole island for the volume from the landward top of dune out to -12 ft NAVD88 (see Figure 7-1).

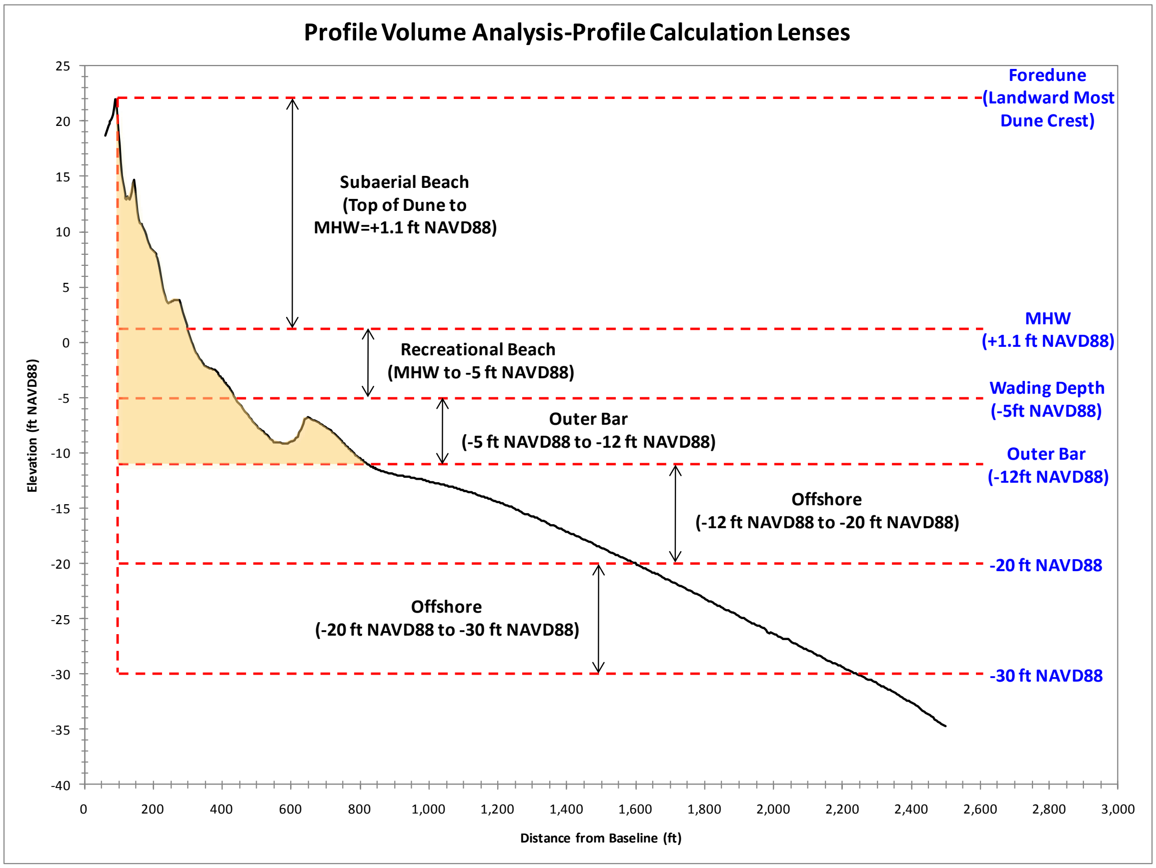

Figure 7-1: Current FEMA Trigger Volume – 225 cy/ft (Shaded Area)

7.2 Approach

Target beach and dune profile templates, referred to as Design Scenarios, were developed for the 18 representative transects. The Design Scenarios were developed iteratively using SBEACH simulations to evaluate the LoP provided at each transect. For each transect, the existing condition profiles from the SBEACH models initially described in Section 4.3 were modified to reflect changes to the berm width and/or dune height and width, and six separate design storms were simulated.

The level of protection afforded is determined as the profile's ability to resist breaching and severe overtopping during extreme storm events of a certain annual probability of exceedance (stated as return period, the inverse of this probability) so as to avoid damage to upland structures.

For the existing conditions simulations, SBEACH was run with initial profiles from the June 2011 survey data[3]. The post-storm beach and dune profiles resulting from the SBEACH simulations were inspected and coastal engineering judgment applied to conclude the level of protection afforded by the existing profiles. The level of protection (LoP) offered by the existing beach and dune system was evaluated by assessing the landward limit of dune erosion and potential for dune flooding / overtopping – indicated by the SBEACH simulations of the synthetic design storms – relative to the position of the most seaward line of development (most seaward or "first row" of upland structures) at each of the 18 representative transects along Bogue Banks (Table 4-5).

Level of protection is indicated as a set of qualitative categories indicating the degree to which the first row of structures would be impacted by a specific design storm. The LoP categories used in this study and their definitions are:

- Undermined – Profile eroded to the position of (or landward of) the first row of structures, thus undermining their foundations. This is considered a severe impact for the present level of protection analysis.

- Threatened – Profile eroded to very near the seaward limits of the first row of structures, such that the stability of the foundations may be threatened. This is considered a severe impact for the present level of protection analysis.

- Major Overtopping – Eroded profile, water level, and maximum wave crest elevation, combined with position and elevation of first row of structures, indicate that the lower levels of structures are likely to be flooded or impacted by moving water. This is considered a severe impact for the present level of protection analysis.

- Minor Overtopping – Eroded profile, water level, and maximum wave crest elevation indicate that the dune would be overtopped, but overtopping at first row of structures appears to be minimal. This category of impact is not considered, in the present study, as a severe impact for the level of protection analysis.

- No Impact – Neither the eroded profile, water level, nor the maximum wave crest elevation indicate that sediment movement or moving water will occur at the first row of structures.

The "first row of structures" positions utilized in the LoP evaluations were digitized from 2011 aerial photography. Structures positions used in the LoP analysis were an average of the positions adjacent to each representative transect, based on a line connecting the seaward edges of the structures along the island's length.

[3] This date was chosen as the most recent beach profile set prior to the erosion damage inflicted by Hurricane Irene (August 2011). It is noted that the 2013 USACE Feasibility Study used the June 2009 profiles as the "existing conditions" initial profiles due to when this portion of the USACE study was completed.

As described in Appendix A, the SBEACH design storms were developed synthetically based on analysis of historical hurricanes and tropical storms, combined with statistical estimates of extreme water levels (based on tide gauge data) and offshore extreme wave conditions (based on Atlantic WIS hindcast data) at various return periods. A typical pattern or "shape" of storm surge and waves was created based on Hurricane Fran's pattern and an empirical relationship between peak storm wave intensity and duration of the rising and falling legs. **Hurricane Fran was estimated to have been between a 10-year and 25-year return period wave event at this location.**

Storm rising and falling leg (wave height) durations and peak wave periods occurring during storms were found to be loosely correlated with storm peak significant wave height. A relationship between peak wave period (T_p) and significant wave height (H_s) was determined and applied to generate wave periods for each design storm.

Finally, the time series of nearshore waves input to SBEACH were extracted from a MIKE 21 SW wave model (Appendix A) that was used to transform the offshore design storm waves to nearshore locations of depth approximately -40 feet NAVD88. Peak values of waves and water levels input to SBEACH are given in Table 7-1.

Table 7-1: Wave Height, Wave Period, and Total Water Level Input to SBEACH at Peak of Design Storm Simulations

Return Period	Synthetic Storm Number	Offshore H_{m0} feet (depth=95 ft)	Nearshore H_{m0} feet (depth=40 ft)	Nearshore T_P seconds (depth=40 ft)	Water Level feet NAVD88
100-year	1	51.0	21.0	12.8	9.5
50-year	2	44.6	19.5	12.0	8.0
25-year	3	38.6	18.5	11.4	5.6
10-year	4	31.2	17.8	10.9	5.4
5-year	5	26.2	16.6	10.4	4.8
2-year	6	20.5	14.2	9.8	4.4

The post-storm beach and dune profiles resulting from the SBEACH simulations were inspected and coastal engineering judgment applied to develop conclusions regarding the LoP afforded by the Design Scenario profiles. The SBEACH initial profiles were modified with respect to dune height, dune width, and/or beach berm width until the profile performed acceptably in the storm return period being targeted by each Design Scenario.

7.3 Level of Protection with Existing Conditions (June 2011) Profiles

The LoP offered by the existing beach and dune system was evaluated by assessing the results of the existing conditions SBEACH simulations for the design storms. The June 2011 profiles were selected as representative of the existing conditions since the 202 profiles were impacted by Hurricane Irene. Table 7-2 summarizes the level of protection resulting at each of the 18 representative transects for the 25-year, 50-year, and 100-year return period (4%, 2%, and 1% annual chance, respectively) synthetic design storms.

Table 7-2: Level of Protection for Existing Conditions SBEACH Profiles

Reach	Bogue Banks Transect	Initial Volume (cy/ft)	25-year RP Level of Protection	50-year RP Level of Protection	100-year RP Level of Protection
Bogue Inlet – Ocean (1-8)	6	254.1	No Impact	No Impact	Minor Overtopping
Emerald Isle – West (9-25)	11	265.3	No Impact	Undermined	Undermined
	17	300.6	No Impact	Undermined	Undermined
	25	292.3	No Impact	Undermined	Undermined
Emerald Isle – Central (26-36)	30	266.3	No Impact	No Impact	No Impact
	35	230.8	No Impact	Undermined	Undermined
Emerald Isle – East (37-47)	42	230.5	No Impact	Undermined	Undermined
	46	254.6	No Impact	Undermined	Undermined
Indian Beach – Salter Path (48-58)	50	290.2	No Impact	No Impact	No Impact
	58	266.6	No Impact	No Impact	No Impact
Pine Knoll Shores – West (59-65)	65	235.3	No Impact	Minor Overtopping	Undermined
Pine Knoll Shores – East (66-77)	70	271.1	No Impact	Minor Overtopping	Major Overtopping
	75	276.2	No Impact	Minor Overtopping	Major Overtopping
Atlantic Beach (78-102)	79	269.3	No Impact	Minor Overtopping	Undermined
	85	300.9	No Impact	Threatened	Undermined
	90	363.8	No Impact	Undermined	Undermined
	100	494.9	No Impact	No Impact	No Impact
Fort Macon State Park (103-110)	105	364.7	n/a	n/a	n/a

The SBEACH simulations indicated that for the June 2011 existing conditions the beach and dune system provided a level of protection equivalent to No Impact at the first row of structures for all 18 of the representative transects in the 25-year return period design storm.

At the 50-year return period design storm level, severe impacts to the first row of structures were indicated at approximately half of the representative transects. Finally, severe impacts were indicated at all but four of the representative transects at the 100-year return period design storm level.

Figure 7-2 through Figure 7-7 show sample existing beach profiles, the seaward limits of the first row of structures, and SBEACH results for Bogue Banks Transects 11 and 70 for the three design storm levels in Table 7-2. Appendix D contains plots of the SBEACH results at all 18 transects.

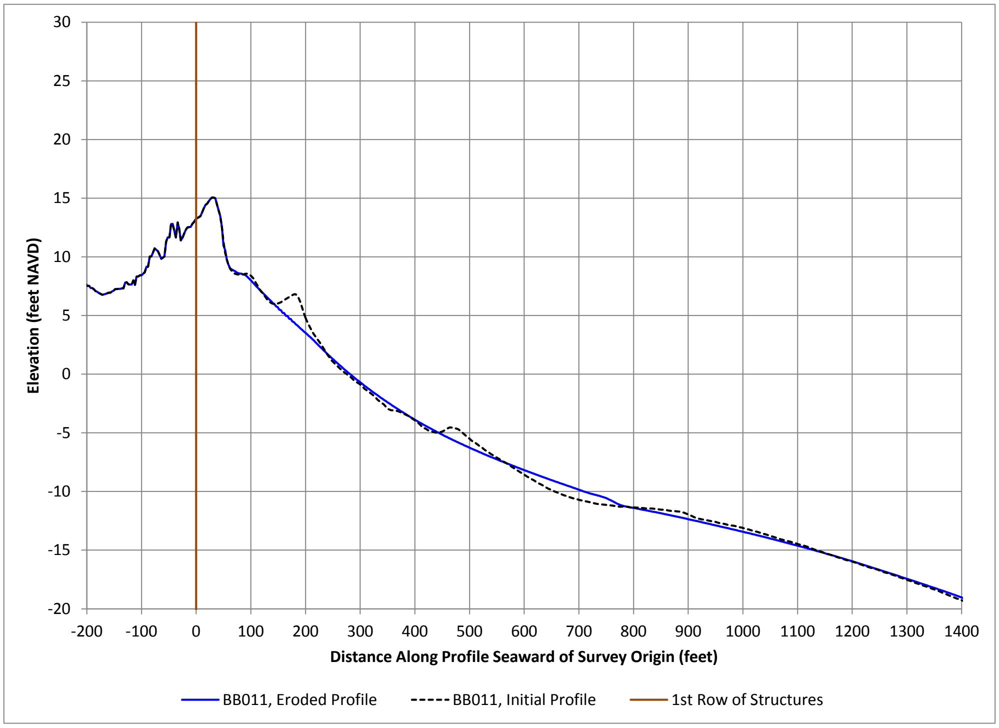

Figure 7-2: SBEACH Results, Existing Conditions, 25-year RP, Transect 11

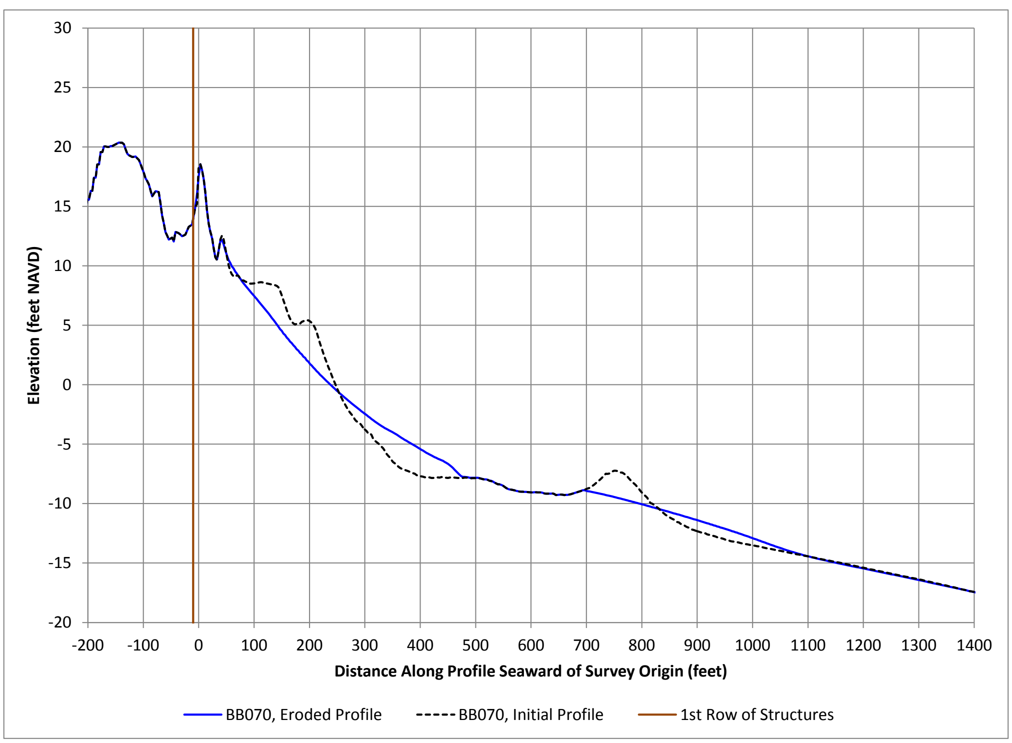

Figure 7-3: SBEACH Results, Existing Conditions, 25-year RP, Transect 70

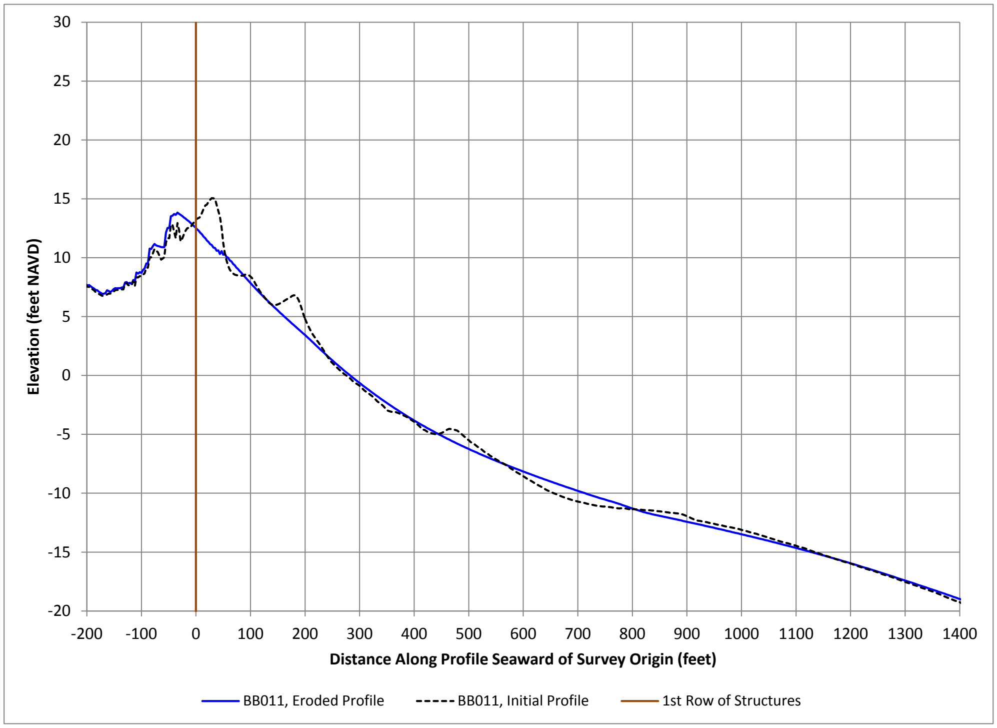

Figure 7-4: SBEACH Results, Existing Conditions, 50-year RP, Transect 11

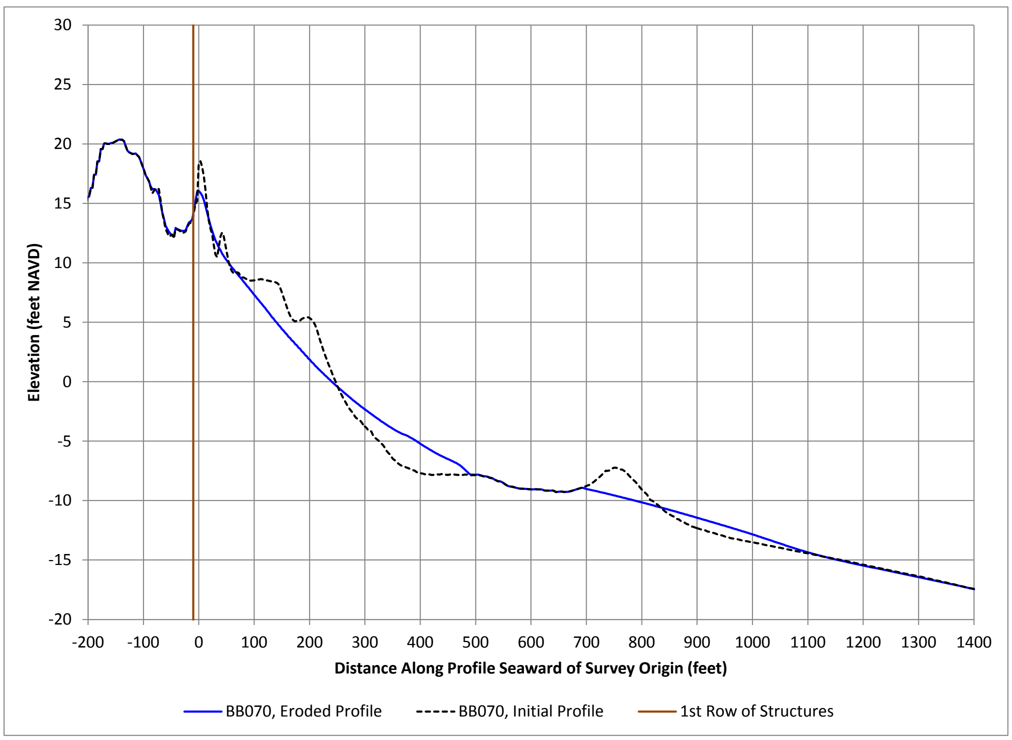

Figure 7-5: SBEACH Results, Existing Conditions, 50-year RP, Transect 70

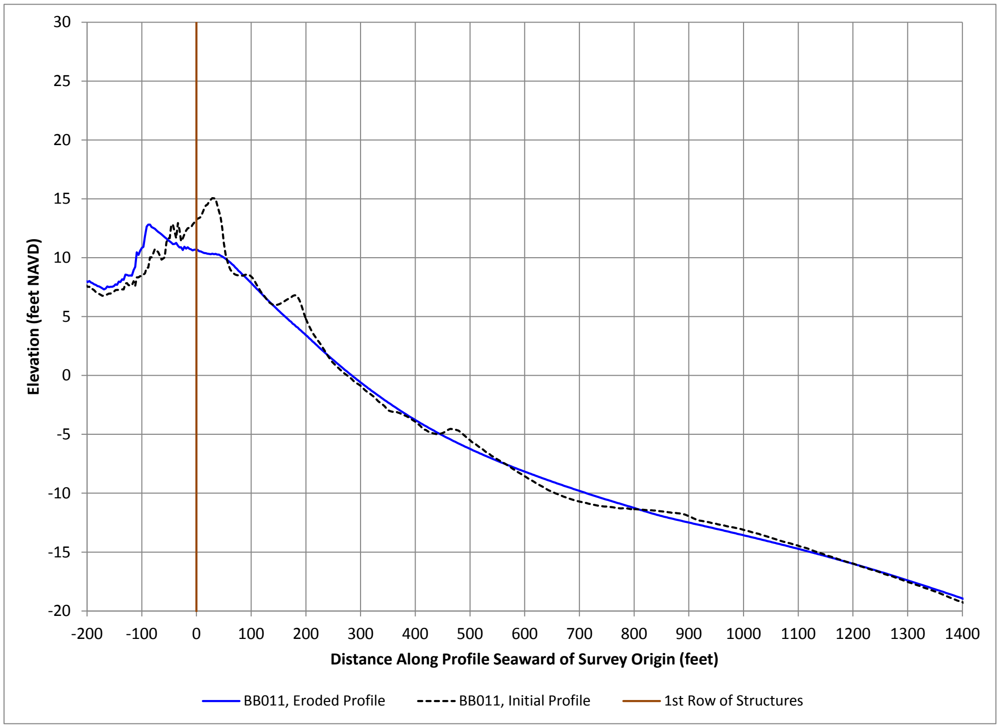

Figure 7-6: SBEACH Results, Existing Conditions, 100-year RP, Transect 11

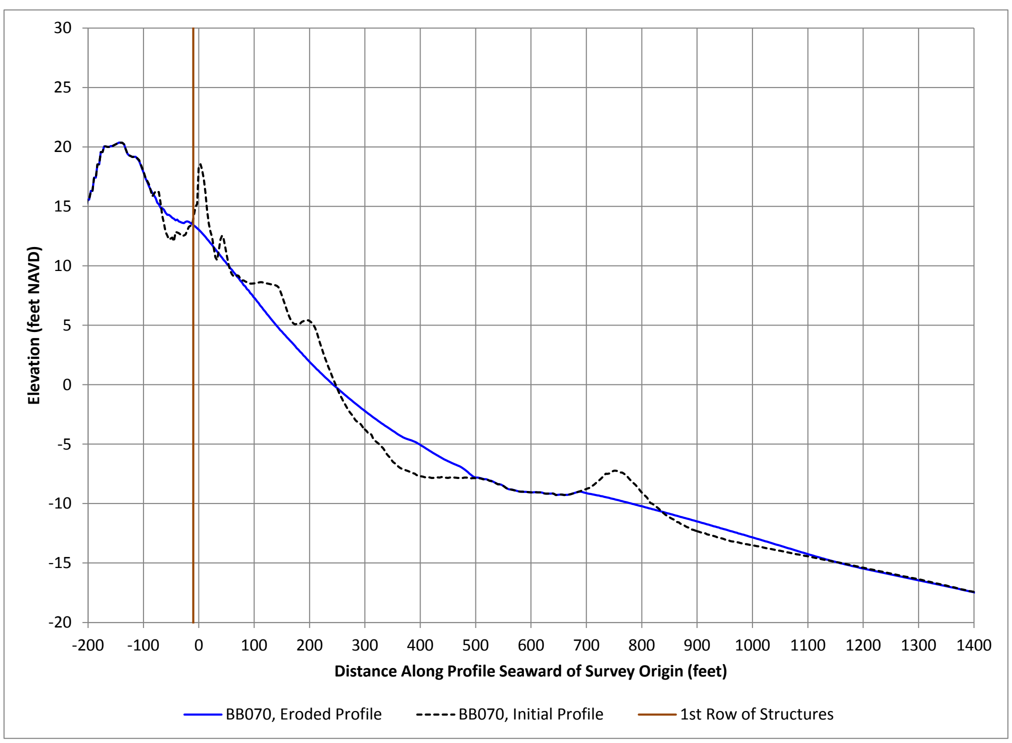

Figure 7-7: SBEACH Results, Existing Conditions, 100-year RP, Transect 70

Bogue Banks Transects 6, 30, 50, 58, and 100 did not show any severe impacts from storm-induced erosion in the SBEACH simulations. (Transect 6 did show minor overtopping at the 100-year return period level). The reasons for this level of protection fall into two categories. At some transects, the primary dune crest was significantly higher than the maximum wave crest elevation and/or greater than average volume existed seaward of the primary dune crest. Transect 58 is shown as an example of this case in Figure 7-8.

At other transects, the primary dune was not especially high or wide, but the first row of structures was situated with adjacent grades significantly higher than the design storm water levels and/or relatively far landward of the primary dune crest. In these cases, the location of the first row of structures made them less vulnerable to storms than other locations. Transect 6 is shown as an example of this case in Figure 7-9.

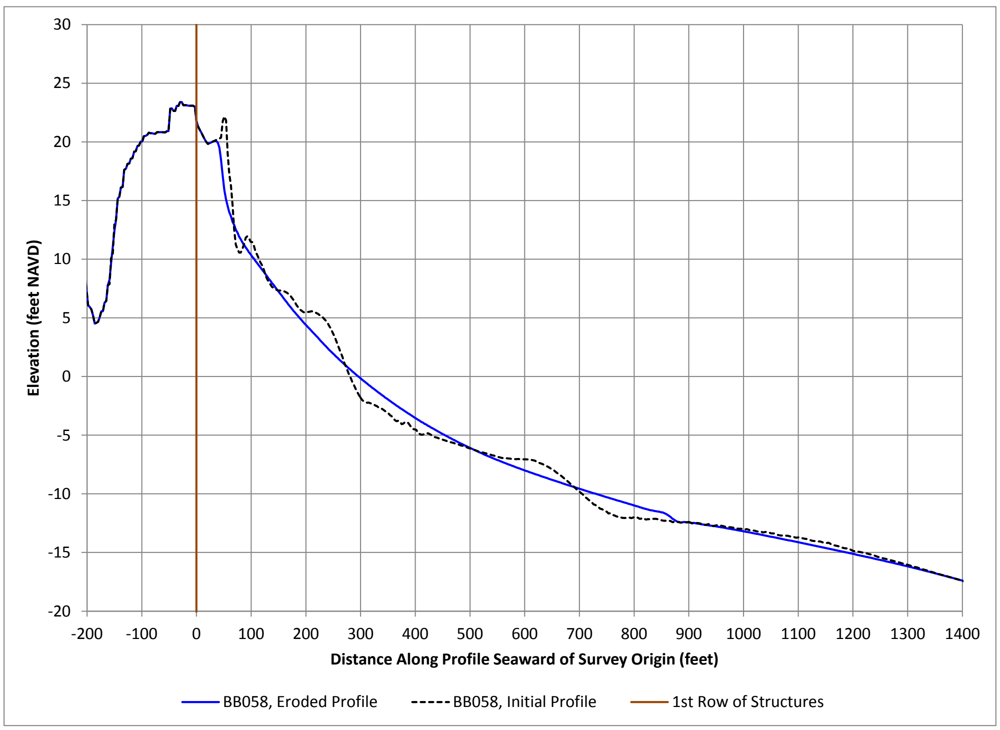

Figure 7-8: SBEACH Results, 100-year RP, Transect 58

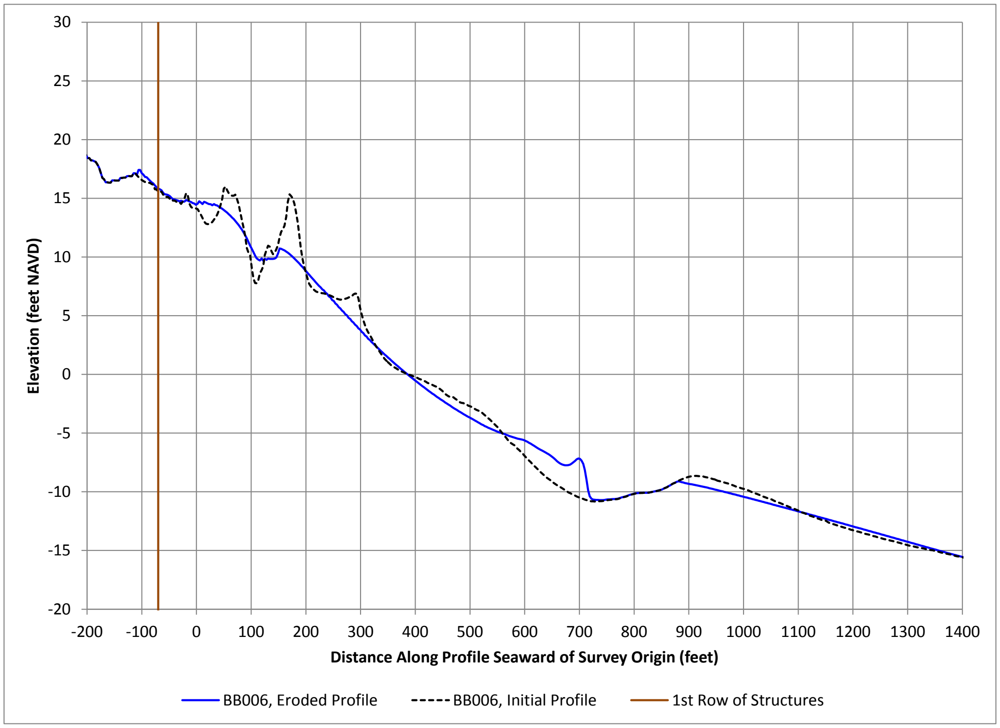

Figure 7-9: SBEACH Results, 100-year RP, Transect 6

Profile volumes seaward of the dune crest and above -12 ft NAVD88 (as is currently done for the existing island wide 225 cy/ft trigger) computed on June 2011 existing condition SBEACH initial profiles (i.e. pre-storm profiles) are shown in Figure 7-10. The bars for all 18 transects are green to indicate that none of the transects indicated severe impacts from the 25-year return period design storm. The dashed black horizontal line at 225 cy/ft indicates the County's current guidance threshold for requiring beach renourishment activity. In June 2011, all of the representative transects had initial volumes greater than 225 cy/ft, though a few were very close to this value.

Figure 7-11 and Figure 7-12 show the same type of information but with the bars color-coded to indicate performance in the 50-year and 100-year return period design storms, respectively. The red bars indicate severe impacts, while the blue bars indicate minor overtopping.

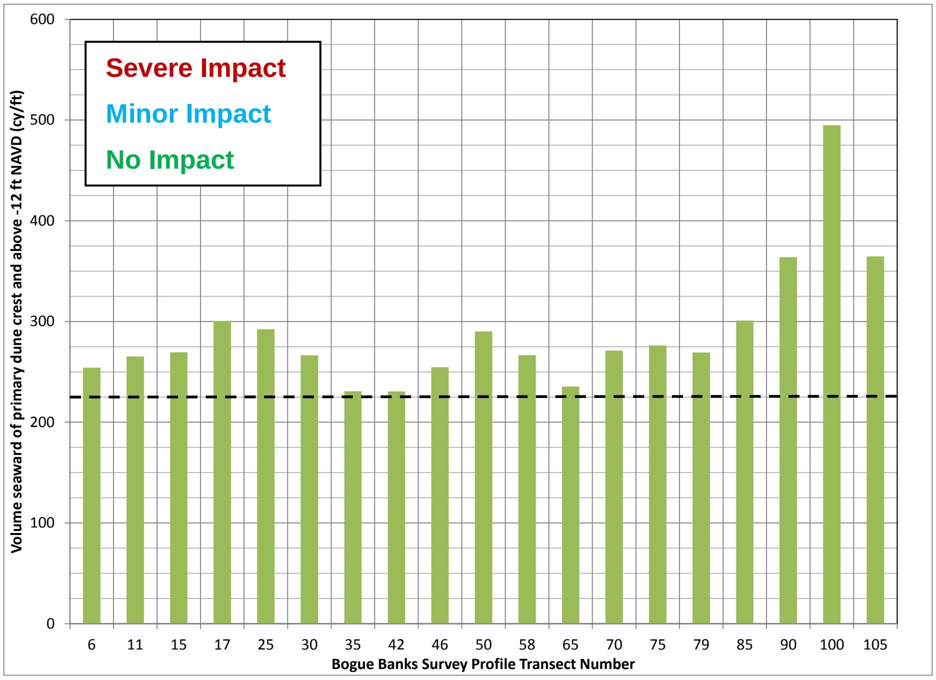

Figure 7-10: Existing Condition SBEACH Pre-Storm Profile Volumes Coded for 25-year Return Period Performance

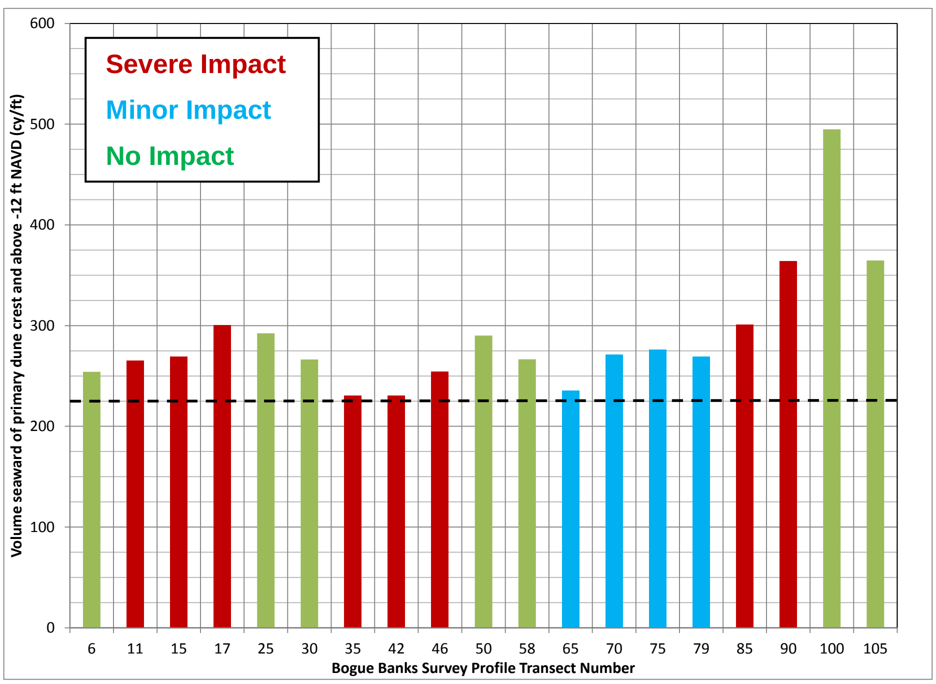

Figure 7-11: Existing Condition SBEACH Pre-Storm Profile Volumes Coded for 50-year Return Period Performance

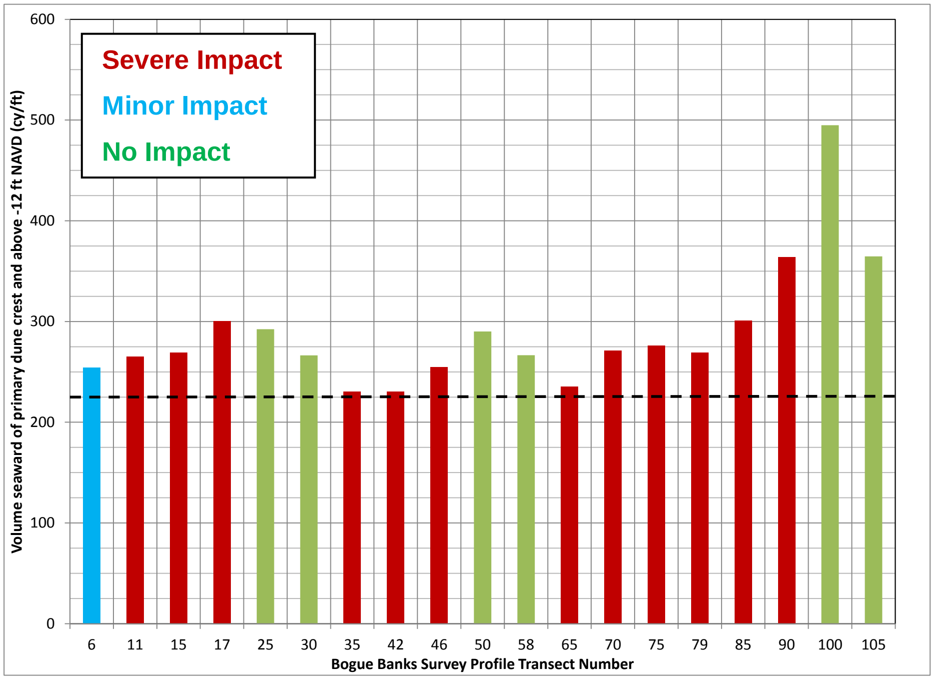

Figure 7-12: Existing Condition SBEACH Pre-Storm Profile Volumes Coded for 100-year Return Period Performance

In summary, the June 2011 existing conditions of the beach and dune system are considered to provide a sufficient level of protection along all of the Bogue Banks reaches for up to a 25-year return period design storm event. While available volume is an important factor, the height and width of the berm and dune are at least equally important. For extreme events required configurations for achieving specific levels of protection have been explored and are documented in Section 7.4 of this report.

7.4 Beach Nourishment Design Scenarios and Level of Protection Determinations

7.4.1 Scenarios

Beach nourishment design scenarios were developed provide and maintain equivalent levels of protection – from open-coast storm surge and wave impacts – to all developed reaches of Bogue Banks. Alternatives were developed to first construct, if necessary, initial dune and beach berm enhancements to provide the target Level of Protection (LoP) for each scenario with the expectation that the Crystal Ball analysis outlines in Section 4.2 would provide the estimated volume, then to maintain the minimum target level of protection via phased, recurring beach renourishments over 50 years into the future.

Three Design Scenarios for the beach and dune profile were developed, using the 18 representative transects identified in Section 4.3.1 to evaluate the LoP provided over each subreach of Bogue Banks. An acceptable LoP is characterized by no severe impacts, according to categories defined in Section 7.3, in the targeted design storm return period. The evaluation of Design Scenarios focused on LoP for design storm return periods of 25, 50, and 100 years. No return periods less than 25 years were evaluated, because all the representative transects showed acceptable LoP (no severe impacts) in the 25-year return period design storm. Therefore, no initial berm or dune expansion would be necessary to create a Design Scenario with acceptable LoP in the 25-year return period storm, and it is reasonable to consider maintaining that LoP as the lower limit for forward-looking beach management planning.

Conversely, initial iterations on Design Scenario development indicated that a Design Scenario capable of achieving a LoP of no severe impacts in the 100-year return period storm would require highly unrealistic volumes (over 5 million cubic yards) and expense to construct and maintain.

Therefore, the generation of Design Scenario profiles centered around achieving acceptable LoP in the 50-year return period storm (Scenarios #1 and #2) and the 25-year return period storm (Scenario #3).

Design Scenario #1 was the addition, to the June 2011 existing conditions profiles, of a variable amount of dune width at an elevation between +16 to +18 ft NAVD88 and the establishment of a berm width of 60 feet at an elevation between +6 to +8 ft NAVD88. The construction of additional dune and berm volume to create Design Scenario #1 would require between 2.0 and 2.5 million cubic yards of beach quality sediment. The construction would be required in reaches as identified in Table 7-3, with the approximate required volumes per linear foot of shoreline. Charts for each transect in the table showing SBEACH initial and final (eroded) profiles plus June 2011 surveyed profiles and position of first row of structures are shown for Design Scenario #1 in Appendix D.

Table 7-3: Additional Dune and Berm Volume to Construct Design Scenario #1

Reach	Bogue Banks Transects	Length (feet)	Rep. Transect	Volume Required to Construct Design Scenario #1 (cubic yards / linear foot)
Bogue Inlet – Ocean	1 through 8	7,432	6	none
Emerald Isle – West	9 through 11	4,056	11	16.4
	12 through 22	14,283	17	18.6
	23 through 25	4,005	25	31.1
Emerald Isle – Central	26 through 32	10,428	30	none
	33 through 36	5,374	35	46.5
Emerald Isle – East	37 through 44	8,814	42	37.1
	45 through 48	4,406	46	44.4
Indian Beach – Salter Path	49 through 52	5,275	50	none
	53 through 58	7,575	58	none
Pine Knoll Shores – West	59 through 65	9,063	65	none
Pine Knoll Shores – East	66 through 70	6,564	70	none
	71 through 76	8,251	75	none
Atlantic Beach	77 through 81	5,388	79	none
	82 through 89 & 91 through 96	13,771	85	67.4
	90	1,006	90	44.6
	97 through 102	6,011	100	none
Fort Macon State Park	103 through 112	6,691	105	none

Design Scenario #2 was developed based on the first design scenario profiles, and differs only at transects where additional dune and berm construction was ***not*** required to achieve Design Scenario #1. At profiles that were well beyond achieving acceptable LoP in the 50-year return period storm, volume was removed from the SBEACH input profiles until the SBEACH results indicated that all 18 of the representative profiles would just achieve acceptable 50-year return period LoP. Therefore, in the second design scenario, some of the existing conditions profiles were modified by adding dune and berm volumes, while several others were modified by removing dune and berm volume. The construction of additional dune and berm volume to create Design Scenario #2 is identical to Design Scenario #1 at between 2.0 and 2.5 million cubic yards. The purpose of this scenario was to determine at which volume each representative transect would just have enough volume to protect against the 50 yr event.

Development of Design Scenario #3 followed a similar procedure as the second scenario. All of the existing conditions profiles showed acceptable LoP in the 25-year return period design storm. Starting from those existing conditions profiles, volume was removed from each input profile until the SBEACH results indicated that all 18 of the representative profiles would just achieve acceptable 25-year return period LoP. No beach or dune construction is necessary to establish Design Scenario #3, because it is based on removing beach and dune volume relative to the June 2011 existing conditions profiles.

Results and interpretation of SBEACH simulations for each of the three design scenarios area discussed below.

7.4.2 Modeling of Alternatives in SBEACH

SBEACH simulations were used iteratively to develop the beach profile geometry (dune height and width, and berm elevation and width) required to achieve the LoP targeted for each of the three profile design scenario sets. Each profile in the existing conditions SBEACH design storm models (Section 4.3) was modified initially to reflect an estimate of the profile geometry required to achieve an acceptable LoP. SBEACH was then run for the six design storms at each profile, and the resulting profile erosion was evaluated. This was necessarily an iterative process continuing until an acceptable LoP was achieved for each profile. Once a profile was completed and an acceptable LoP was achieved, work moved on to the next profile.

7.4.2.1 Design Scenario #1

Recall that the SBEACH simulations indicated that the existing conditions beach and dune system provided a level of protection equivalent to No Impact at the first row of structures for all 18 of the representative transects in the 25-year return period design storm. Design Scenario #1 adds dune height and width, and provides a minimum of 60 feet of beach berm at an elevation between +6 and +8 ft NAVD88, at profiles that showed severe impacts in the 50-year return period storm for existing conditions SBEACH runs.

The LoPs resulting at each of the 18 representative transects for the 25-year, 50-year, and 100-year return period (4%, 2%, and 1% annual chance, respectively) synthetic design storms for Design Scenario #1 are presented in Table 7-4. This design scenario results in achievement of acceptable LoP in the 50-year design storm at all of the representative transects, except for BB090. This transect represents only 1,006 linear feet at The Circle in Atlantic Beach, and at this very flat area with no frontal dunes. None of the realistic design scenarios considered will improve the LoP beyond Threatened in events greater than the 25-year return period storm for this transect.

As noted in Section 7.3, several of the Bogue Banks transects (6, 30, 50, 58, and 100) did not show any severe impacts from storm-induced erosion in the existing conditions SBEACH simulations for any of the design storms simulated. No changes were made to the profiles at these transects to create Design Scenario #1, and the SBEACH results showed identical LoP as in existing conditions.

Table 7-4: Level of Protection for Design Scenario #1 SBEACH Profiles

Reach	Bogue Banks Transect	Initial Volume (cy/ft)	25-year RP Level of Protection	50-year RP Level of Protection	100-year RP Level of Protection
Bogue Inlet – Ocean	6	254	No Impact	No Impact	Minor Overtopping
Emerald Isle – West	11	282	No Impact	No Impact	Threatened
	17	319	No Impact	No Impact	Undermined
	25	323	No Impact	Minor Overtopping	Threatened
Emerald Isle – Central	30	266	No Impact	No Impact	No Impact
	35	277	No Impact	No Impact	Undermined
Emerald Isle – East	42	268	No Impact	No Impact	Major Overtopping
	46	299	No Impact	No Impact	Undermined
Indian Beach – Salter Path	50	290	No Impact	No Impact	No Impact
	58	267	No Impact	No Impact	No Impact
Pine Knoll Shores – West	65	235	No Impact	Minor Overtopping	Undermined
Pine Knoll Shores – East	70	271	No Impact	Minor Overtopping	Major Overtopping
	75	276	No Impact	Minor Overtopping	Major Overtopping
Atlantic Beach	79	269	No Impact	Minor Overtopping	Undermined
	85	375	No Impact	No Impact	Major Overtopping
	90	408	No Impact	Threatened	Threatened
	100	495	No Impact	No Impact	No Impact
Fort Macon State Park	105	365	n/a	n/a	n/a

7.4.2.2 Design Scenario #2

Design Scenario #2 was developed from Design Scenario #1, by retreating the starting beach and dune at transects 6, 30, 50, 58, and 100 to ***just*** achieve acceptable LoP in the 50-year return period design storm. Table 7-5 summarizes the LoP resulting at each of the 18 representative transects. The reduction from existing conditions volumes at certain profiles resulted in a lower LoP in the 100-year return period design storm at two transects, namely BB030 and BB058. These two profiles that showed No Impact in the existing conditions and Design Scenario #1 simulations are Undermined in the Design Scenario #2 simulations.

Table 7-5: Level of Protection for Design Scenario #2 SBEACH Profiles

Reach	Bogue Banks Transect	Initial Volume (cy/ft)	25-year RP Level of Protection	50-year RP Level of Protection	100-year RP Level of Protection
Bogue Inlet – Ocean	6	238	No Impact	No Impact	Minor Overtopping
Emerald Isle – West	11	282	No Impact	No Impact	Threatened
	17	319	No Impact	No Impact	Undermined
	25	323	No Impact	Minor Overtopping	Threatened
Emerald Isle – Central	30	237	No Impact	No Impact	Undermined
	35	277	No Impact	No Impact	Undermined
Emerald Isle – East	42	268	No Impact	No Impact	Major Overtopping
	46	299	No Impact	No Impact	Undermined
Indian Beach – Salter Path	50	243	No Impact	No Impact	No Impact
	58	241	No Impact	No Impact	Undermined
Pine Knoll Shores – West	65	235	No Impact	Minor Overtopping	Undermined
Pine Knoll Shores – East	70	271	No Impact	Minor Overtopping	Major Overtopping
	75	287	No Impact	Minor Overtopping	Major Overtopping
Atlantic Beach	79	269	No Impact	Minor Overtopping	Undermined
	85	375	No Impact	No Impact	Major Overtopping
	90	408	No Impact	Threatened	Threatened
	100	318	No Impact	No Impact	No Impact
Fort Macon State Park	105	365	n/a	n/a	n/a

With Design Scenario #2, No Impact conditions are maintained at all transects for the 25-year return period design storm. At the 50-year return period design storm level, only Minor Overtopping was indicated at four transects, and the profile at transect 90 (The Circle in Atlantic Beach) was Threatened as in Design Scenario #1. Severe impacts were indicated at all but three of the representative transects at the 100-year return period design storm level.

Figure 7-13 through Figure 7-18 show sample existing condition beach profiles and SBEACH results for Bogue Banks transects 11 and 70 for three design storms. Appendix D contains plots of the SBEACH results at all 18 transects.

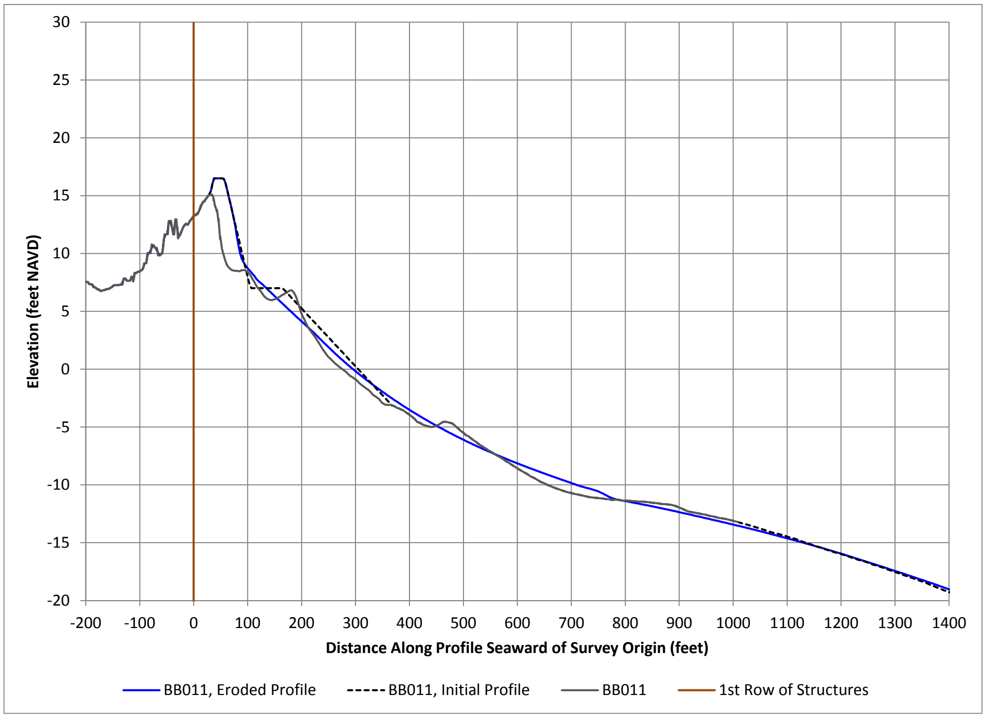

Figure 7-13: SBEACH Results, Design Scenario #2, 25-year RP, Transect 11

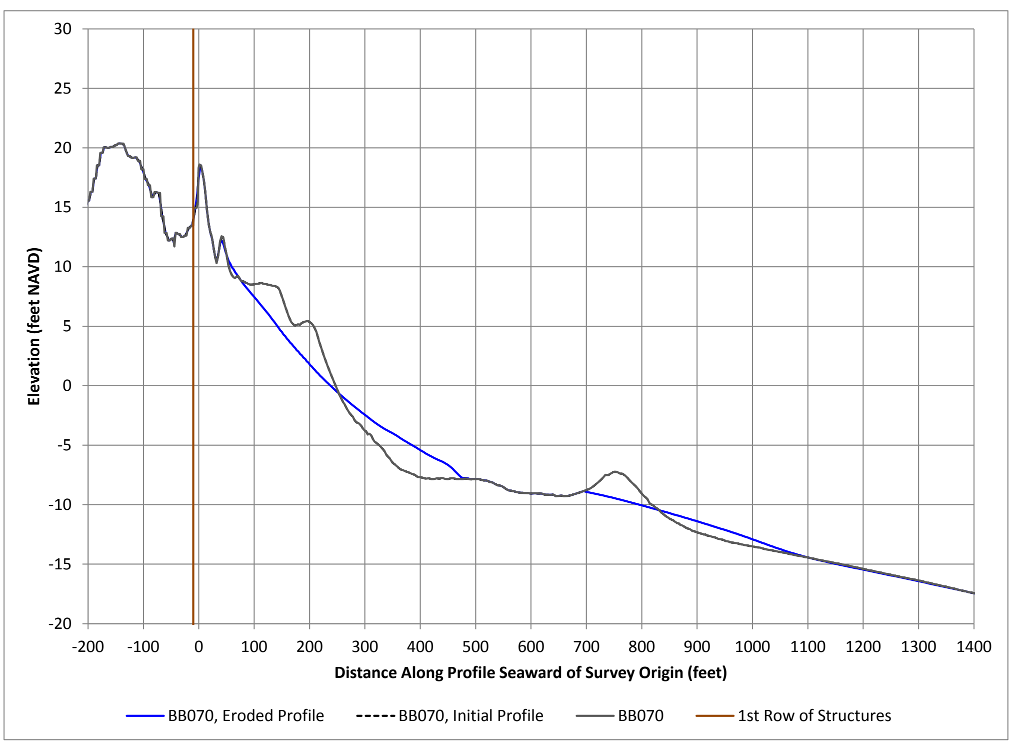

Figure 7-14: SBEACH Results, Design Scenario #2, 25-year RP, Transect 70

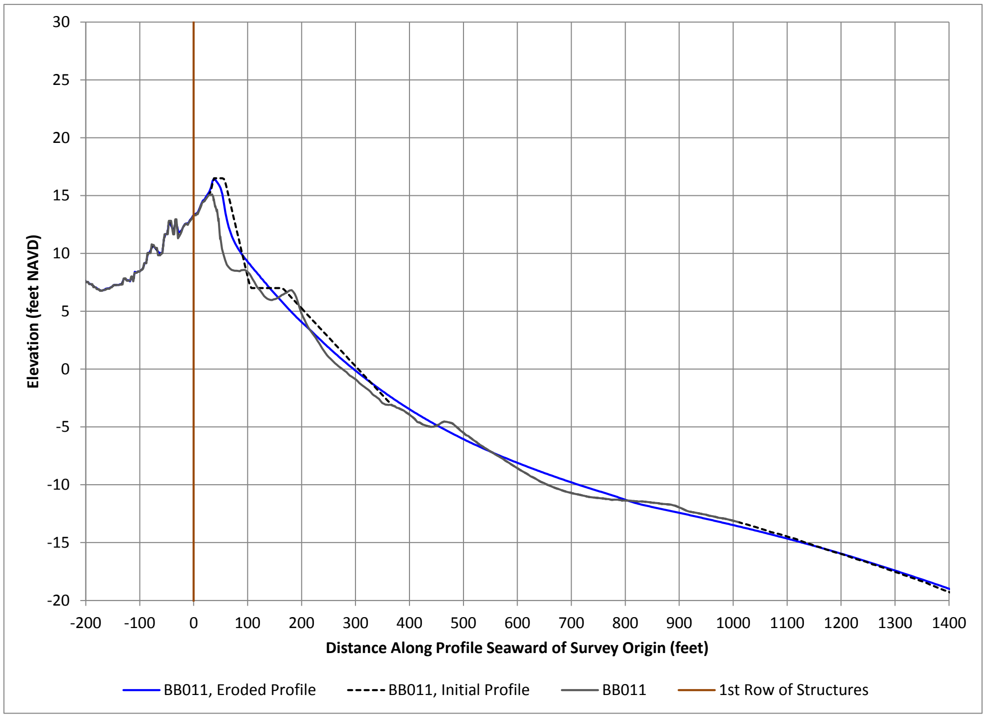

Figure 7-15: SBEACH Results, Design Scenario #2, 50-year RP, Transect 11

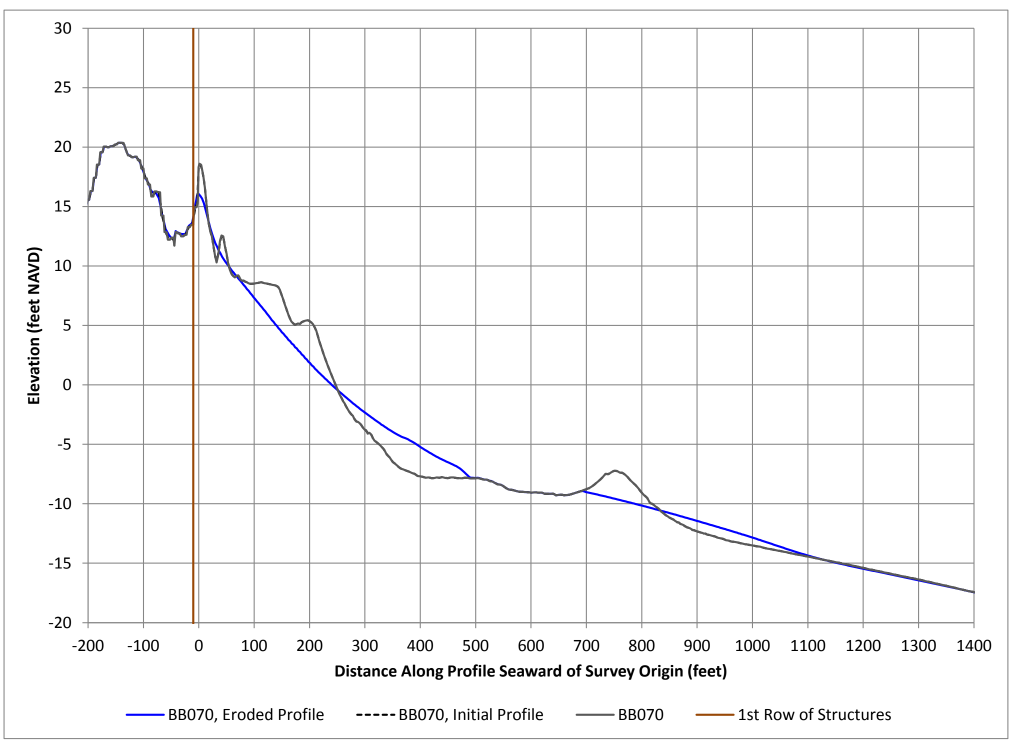

Figure 7-16: SBEACH Results, Design Scenario #2, 50-year RP, Transect 70

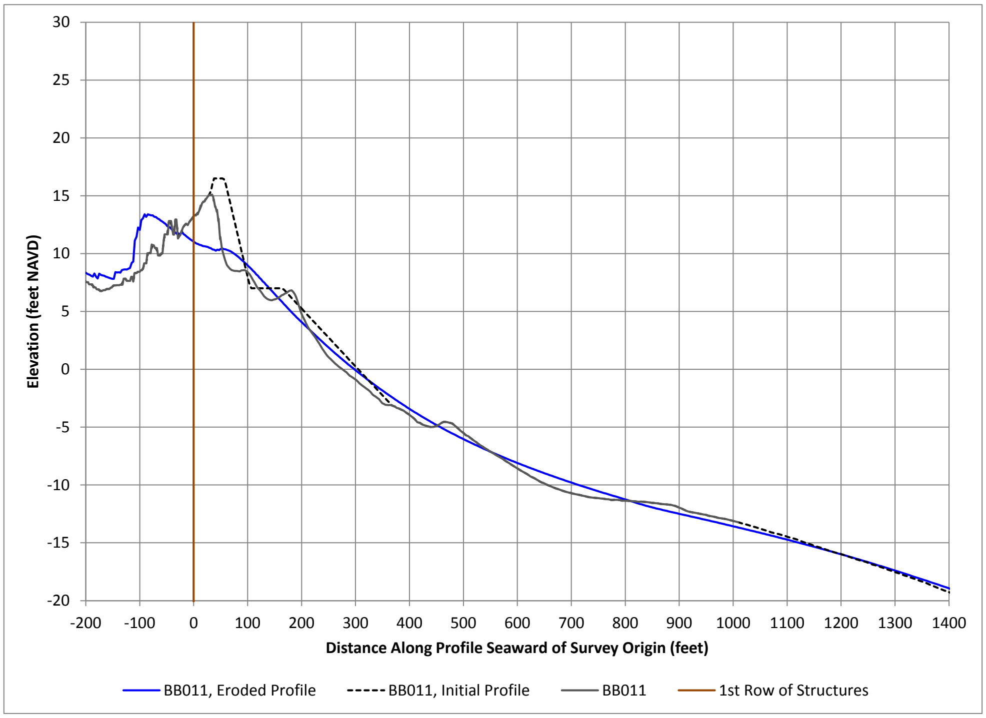

Figure 7-17: SBEACH Results, Design Scenario #2, 100-year RP, Transect 11

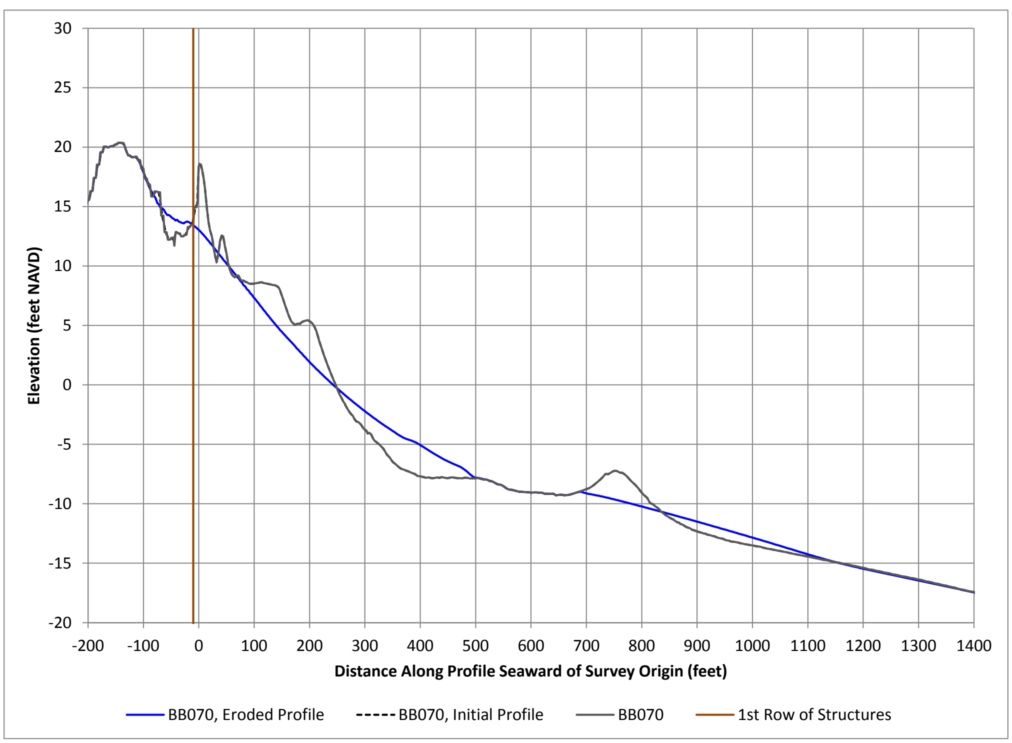

Figure 7-18: SBEACH Results, Design Scenario #2, 100-year RP, Transect 70

Recall that Bogue Banks Transects 6, 30, 50, 58, and 100 did not show any severe impacts from storm-induced erosion in the SBEACH simulations, for any of the design storms. In the Design Scenario #2 simulations, these profiles were artificially eroded by manually editing the starting profiles iteratively to the point where the LoP was just acceptable in the 50-year return period storm. Examples of these artificially retreated starting profiles at shown for Transect 58 and Transect 6 in Figure 7-19 and Figure 7-20. The lines labeled BB058 and BB006 represent the original existing conditions (June 2011) profiles at each transect.

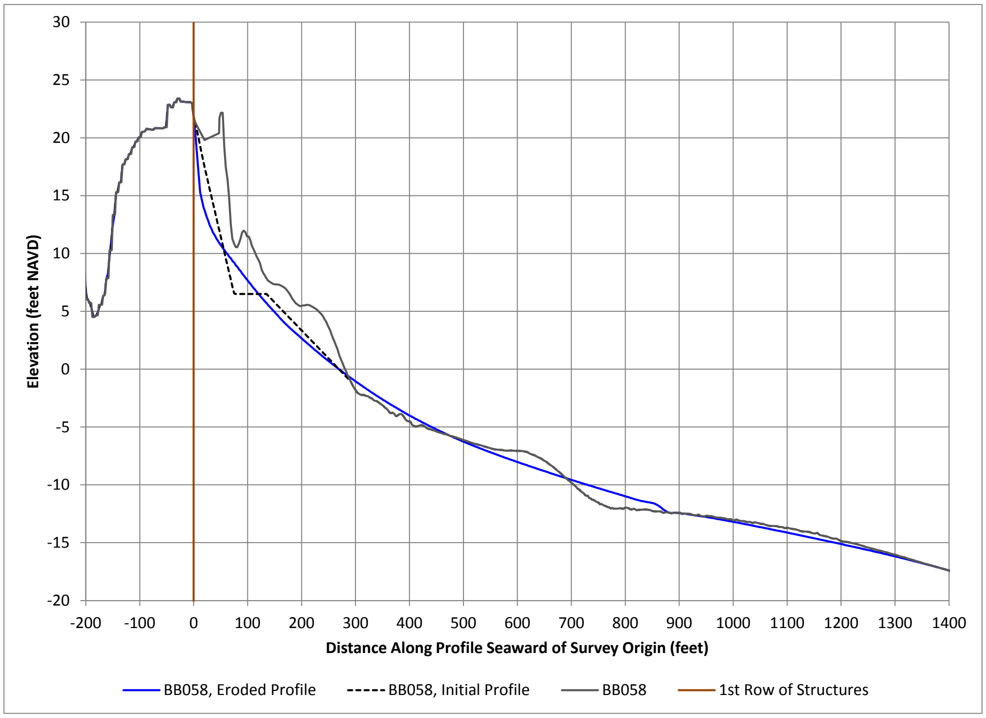

Figure 7-19: SBEACH Results, Design Scenario #2, 100-year RP, Transect 58

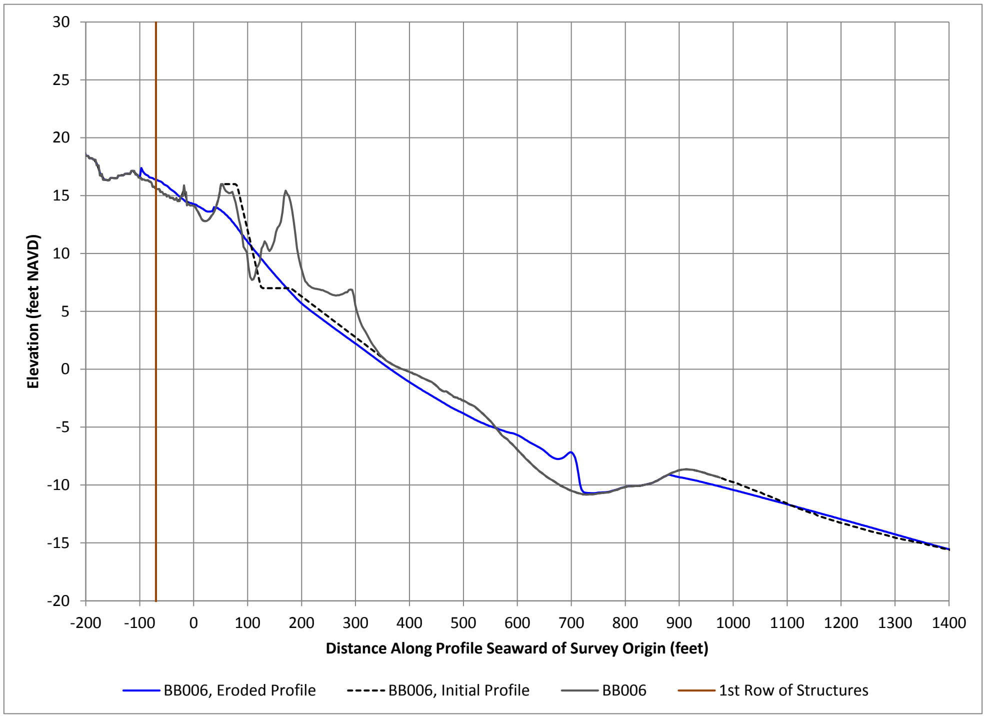

Figure 7-20: SBEACH Results, Design Scenario #2, 100-year RP, Transect 6

7.4.2.3 Design Scenario #3

Design Scenario #3 was developed from the existing conditions profiles, by retreating the starting beach and dune profiles to ***just*** achieve acceptable LoP in the 25-year return period design storm. Table 7-6 summarizes the LoP resulting at each of the 18 representative transects.

The reduction from existing conditions volumes resulted in severe impacts at all developed transects, except number 50, in the 50- and 100-year design storms. It was not feasible to manually retreat the starting profile at Transect 50 to a point where impacts occurred to the first row of structures. The existing grade at the first row of structures is approximately +29 ft NAVD88, and even with a starting profile retreated to within 10 feet of this position, the SBEACH simulations did not indicate that erosion would threaten or otherwise impact the structures.

Table 7-6: Level of Protection for Design Scenario #3 SBEACH Profiles

Reach	Bogue Banks Transect	Initial Volume (cy/ft)	25-year RP Level of Protection	50-year RP Level of Protection	100-year RP Level of Protection
Bogue Inlet – Ocean	6	103	No Impact	Undermined	Undermined
Emerald Isle – West	11	230	No Impact	Undermined	Undermined
	17	272	No Impact	Undermined	Undermined
	25	242	No Impact	Undermined	Undermined
Emerald Isle – Central	30	213	No Impact	Undermined	Undermined
	35	207	No Impact	Undermined	Undermined
Emerald Isle – East	42	214	No Impact	Undermined	Undermined
	46	235	No Impact	Undermined	Undermined
Indian Beach – Salter Path	50	216	No Impact	No Impact	No Impact
	58	229	No Impact	Threatened	Undermined
Pine Knoll Shores – West	65	196	No Impact	Undermined	Undermined
Pine Knoll Shores – East	70	218	No Impact	Undermined	Undermined
	75	222	No Impact	Major Overtopping	Major Overtopping
Atlantic Beach	79	225	No Impact	Undermined	Undermined
	85	248	No Impact	Undermined	Undermined
	90	364	No Impact	Undermined	Undermined
	100	276	No Impact	Threatened	Undermined
Fort Macon State Park	105	365	n/a	n/a	n/a

Figure 7-21 through Figure 7-26 show sample existing condition beach profiles and SBEACH results for Bogue Banks Transects 11 and 70 for three design storms. Appendix D contains plots of the SBEACH results at all 18 transects.

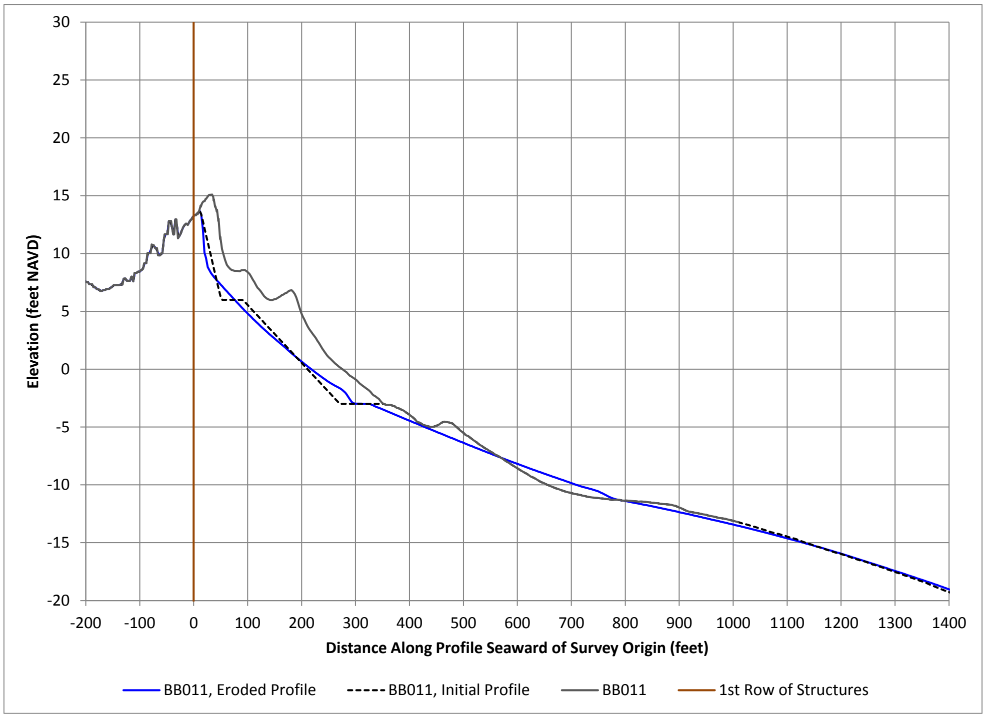

Figure 7-21: SBEACH Results, Design Scenario #3, 25-year RP, Transect 11

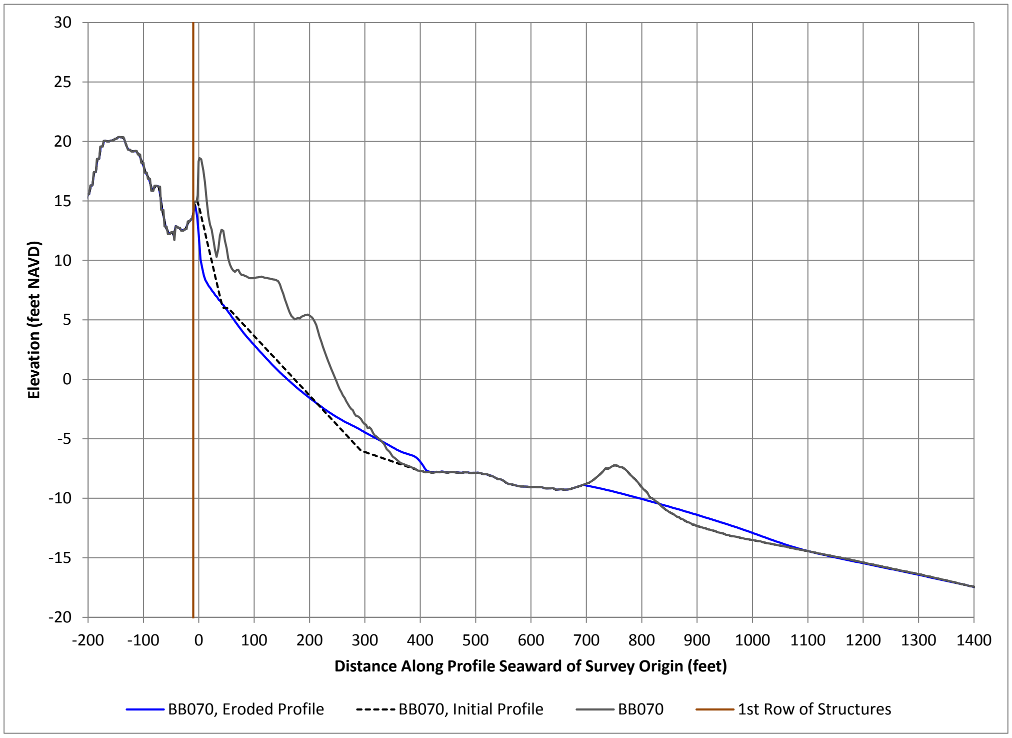

Figure 7-22: SBEACH Results, Design Scenario #3, 25-year RP, Transect 70

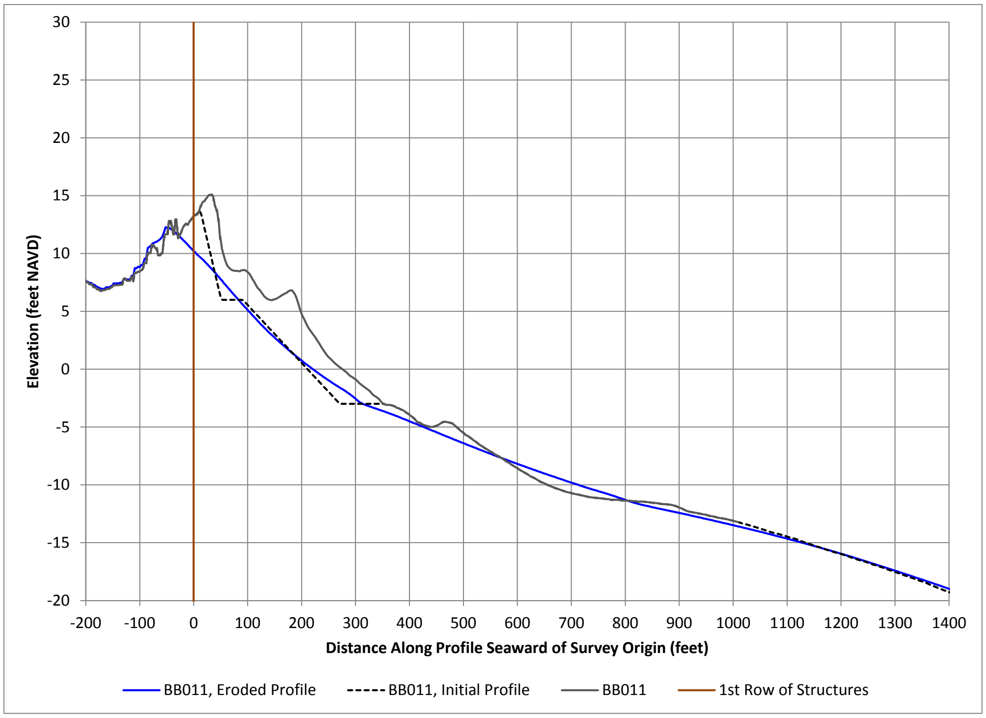

Figure 7-23: SBEACH Results, Design Scenario #3, 50-year RP, Transect 11

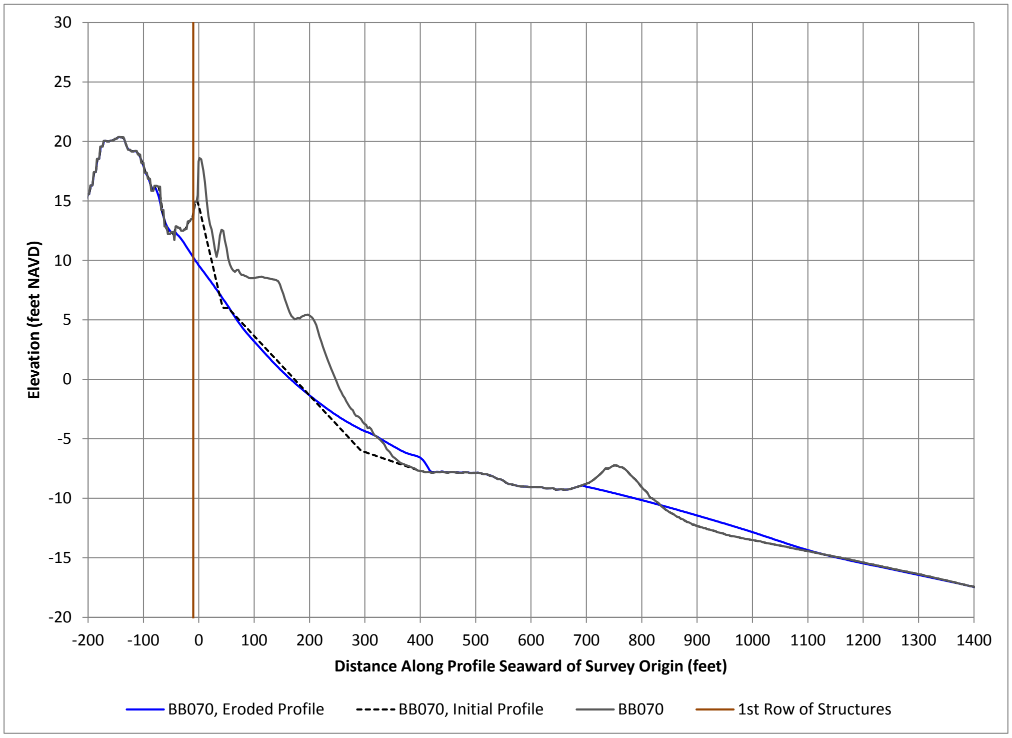

Figure 7-24: SBEACH Results, Design Scenario #3, 50-year RP, Transect 70

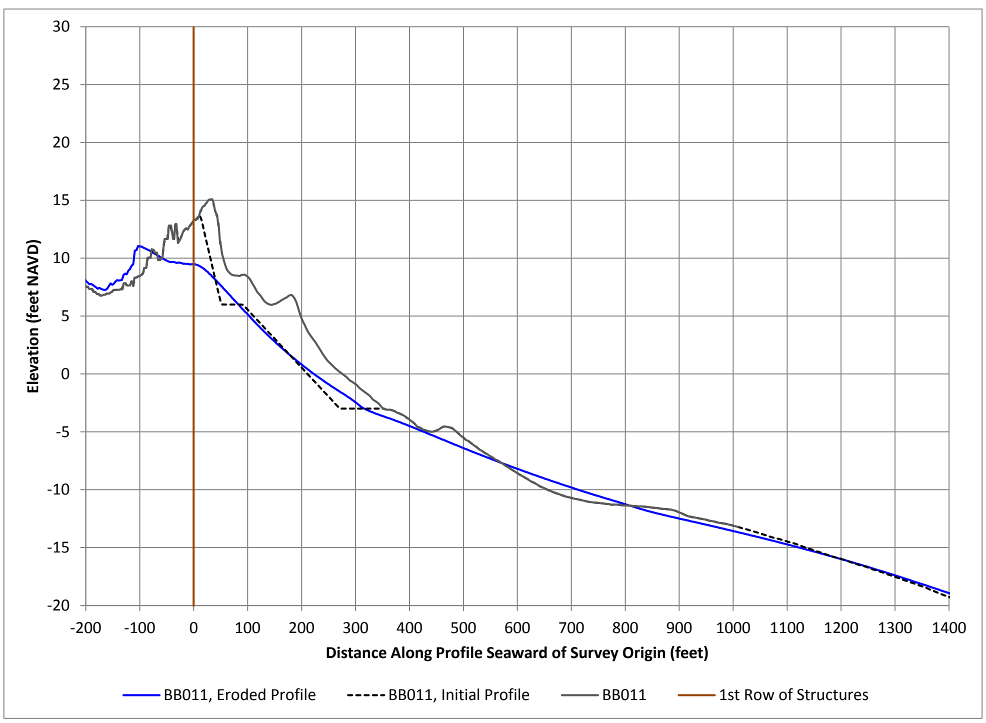

Figure 7-25: SBEACH Results, Design Scenario #3, 100-year RP, Transect 11

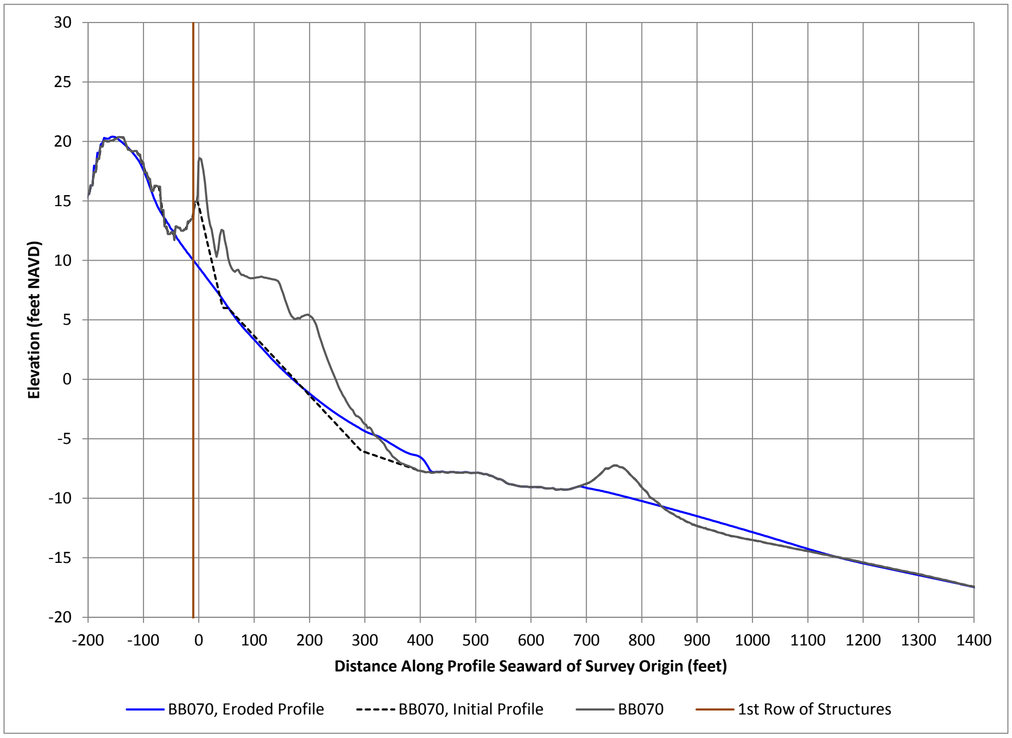

Figure 7-26: SBEACH Results, Design Scenario #3, 100-year RP, Transect 70

7.4.3 Level of Protection Summary and Selection

As outlined in the previous sections, the current beach profiles are adequate to provide protection for a 25-yr event, while some targeted dune building in various reaches would be required to provide protection for a 50-yr event. As stated previously, a project of approximately 2.2 Mcy would be needed to provide this 50-yr event level of protection. It is interesting to note that the initial project developed by the USACE for its NED plan is just over 2.4 Mcy, but the distribution of the initial project material is across the entire island while the estimate from our analysis shows that the needs are concentrated in areas with very low-lying dunes (Emerald Isle-West, portion of Central and East as well as Atlantic Beach) – see Table 7-7.

Table 7-7: Comparison of USACE Initial Project with 50-yr LoP Initial Project

Reach	Reach Length (ft)	USACE Initial Placement (cy)	USACE Initial Placement Density (cy/ft)	50 -yr Initial Placement (cy)	50-yr Initial Placement Density (cy/ft)
Bogue Inlet (1-8)	7,432	445,907	60.0	0	0.0
Emerald Isle West - A (9-11)	4,056	49,604	12.2	66,518	16.4
Emerald Isle West - B (12-22)	14,283	28,527	2.0	265,664	18.6
Emerald Isle West - C (23-25)	4,005	421	0.1	124,556	31.1
Emerald Isle Central - A (26-32)	10,428	10,466	1.0	0	0.0
Emerald Isle Central - B (33-36)	5,374	4,571	0.9	249,891	46.5
Emerald Isle East - A (37-44)	8,814	149,031	16.9	326,999	37.1
Emerald Isle East - B (45-48)	4,406	56,295	12.8	195,626	44.4
Indian Beach/Salter Path - West (49-52)	5,275	103,409	19.6	0	0.0
Indian Beach/Salter Path - East (53-58)	7,575	31,275	4.1	0	0.0
Pine Knoll Shores - West (59-65)	9,063	31,715	3.5	0	0.0
Pine Knoll Shores - East - A (66-70)	6,564	69,193	10.5	0	0.0
Pine Knoll Shores East - B (71-76)	8,251	156,733	19.0	0	0.0
Atlantic Beach - West (77-81)	5,388	123,192	22.9	0	0.0
Atlantic Beach - Central (82-89, 91-96)	13,771	653,582	47.5	928,165	67.4
Atlantic Beach - Circle (90)	1,006	53,553	53.2	44,868	44.6
Atlantic Beach - East (97-102)	6,011	483,783	80.5	0	0.0
TOTAL ANNUAL VOLUME CHANGE	**121,702**	**2,451,256**	**20.1**	**2,202,288**	

While this initial project does seem feasible it is important to note that the project would likely cost between **$22 - $27.5M** based on recent dredging/placement costs. Since this project cost would likely be borne mainly by the County and Towns, the amount of time that it would take **to raise this level of funds at current funding streams would be 5 – 7 years**. **Since current funding streams are needed to meet the overall maintenance requirements to be described in Chapter 8.0, providing a LoP for a 50-yr event across the entire island was determined to not be feasible, and therefore a 25-yr event LoP was selected**. The County and Towns could always work toward a 50-yr level of protection if an unusual number of quiet years were to be experienced, but it was decided that it would be most prudent to select the 25-yr event LoP. Figure 7-27 also show the difference in the volume trigger above the -12 ft elevation (volume from top of landward dune out to -12 ft NAVD) that would be needed for a 50-yr event versus the 25-yr event and the volume available in the 2011 survey (before Hurricane Irene). **It should be noted that all of these calculations were also completed for the +1.1, -5, -12, -16 and -20 ft elevations. However, when considering the fact that nourishment projects usually place material out to the -12 ft elevation and the fact that the USACE preferred alternative annual beach need matched our estimates for the -12 ft elevation, it was decided that the -12 ft elevation should be used to determine the appropriate triggers for the LoP and future nourishment activities. Another reason to use the -12 ft NAVD elevation is the 13-yr history of data and comfort in using this elevation by the County and Towns as well as FEMA.**

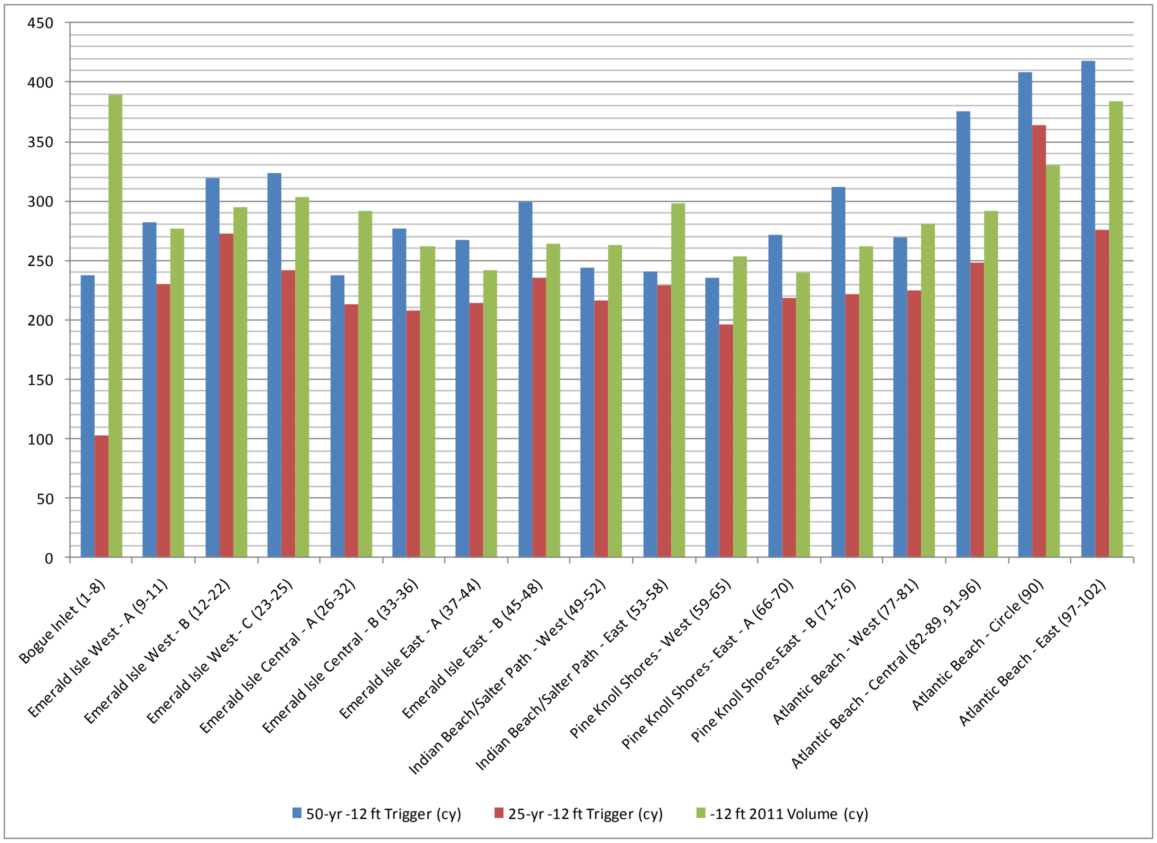

Figure 7-27: 50-yr Event Trigger vs. 25-yr Event Trigger vs. 2011 Volume (-12 ft NAVD88)

Figure 7-28 through Figure 7-34 also show how the 50-yr event trigger will be difficult to maintain over time given historical volumes over the monitoring dataset. While in some areas, the 50-yr LoP could be reached, it would be nearly impossible over the entire island given current funding streams. For the following figures, please note that the bars show the volume present above -12 ft NAVD88 for each of the years data that is available. The top dashed line represents the 50-yr event volume trigger while the bottom dashed line represents the 25-yr event volume trigger.

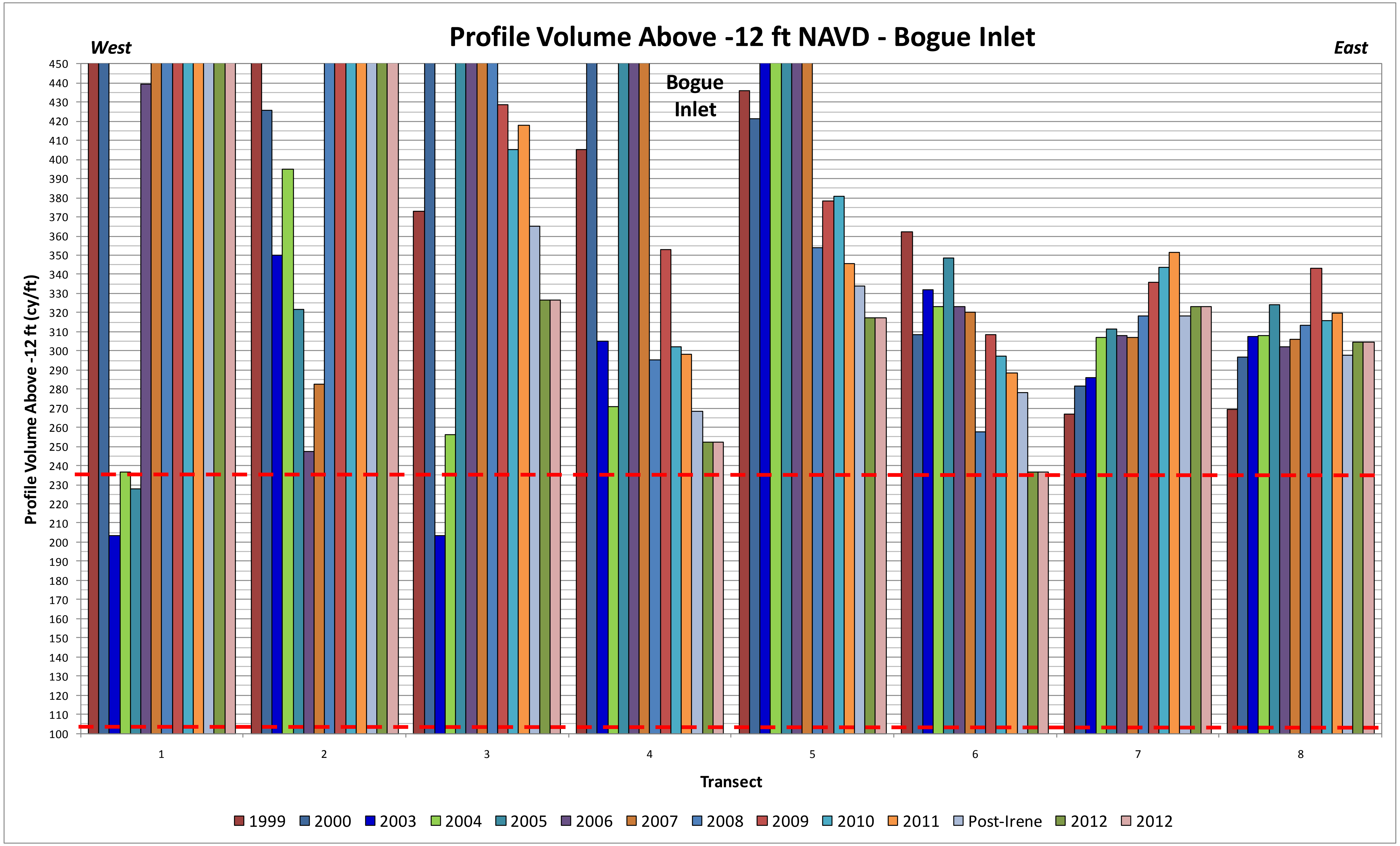

Figure 7-28: Profile Volume Above -12 ft NAVD88 – Bogue Inlet

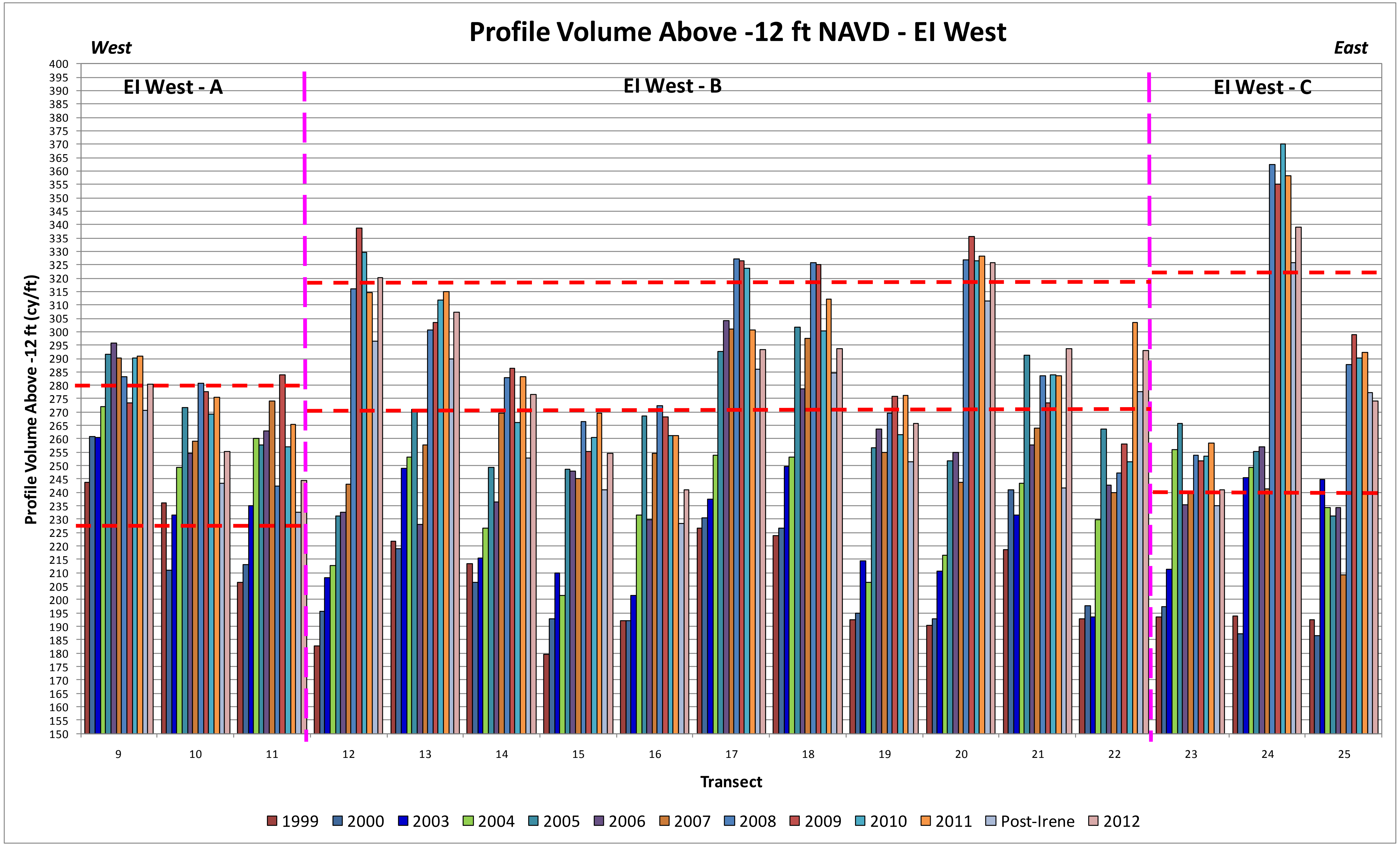

Figure 7-29: Profile Volume Above -12 ft NAVD88 – Emerald Isle West

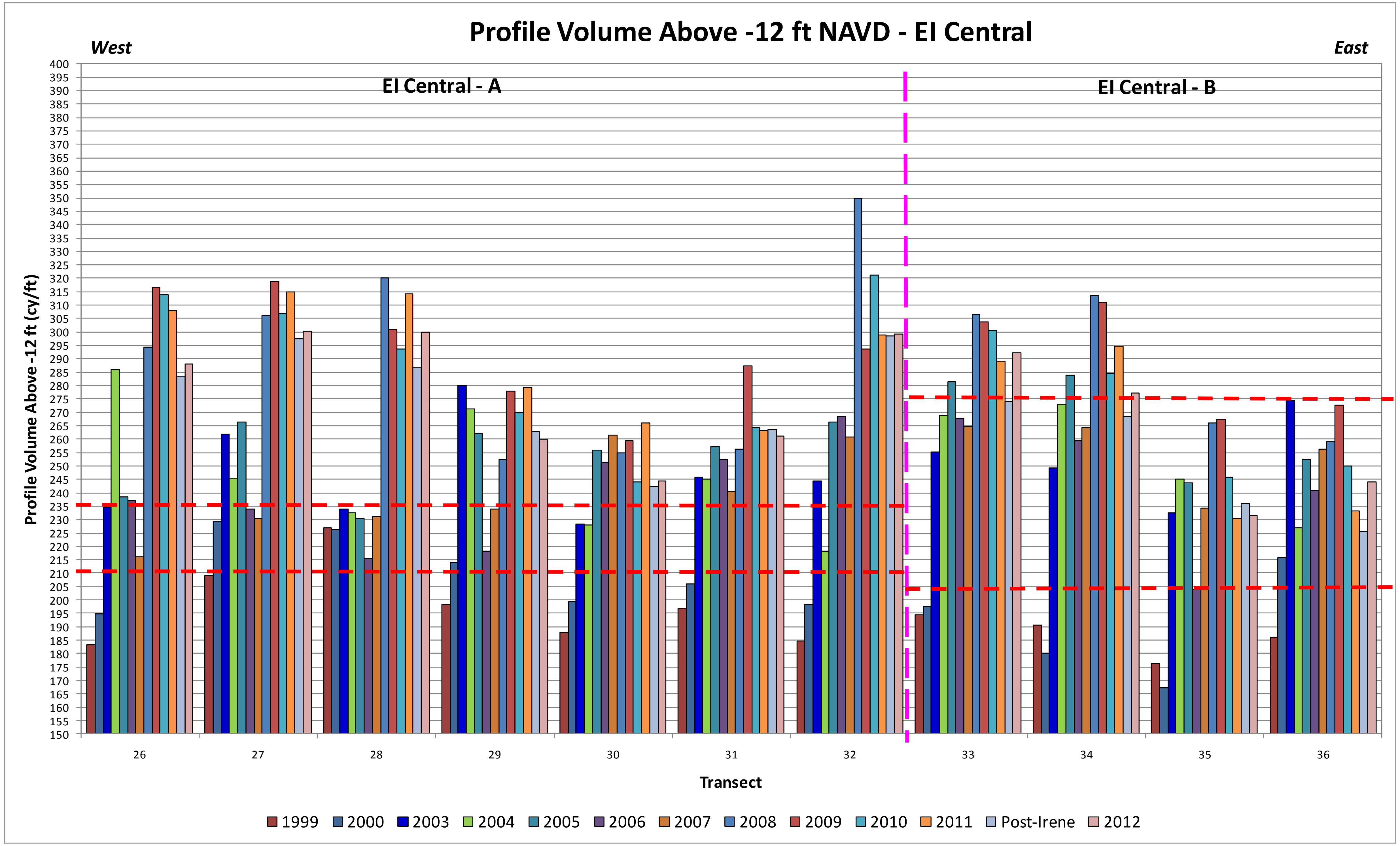

Figure 7-30: Profile Volume Above -12 ft NAVD88 – Emerald Isle Central

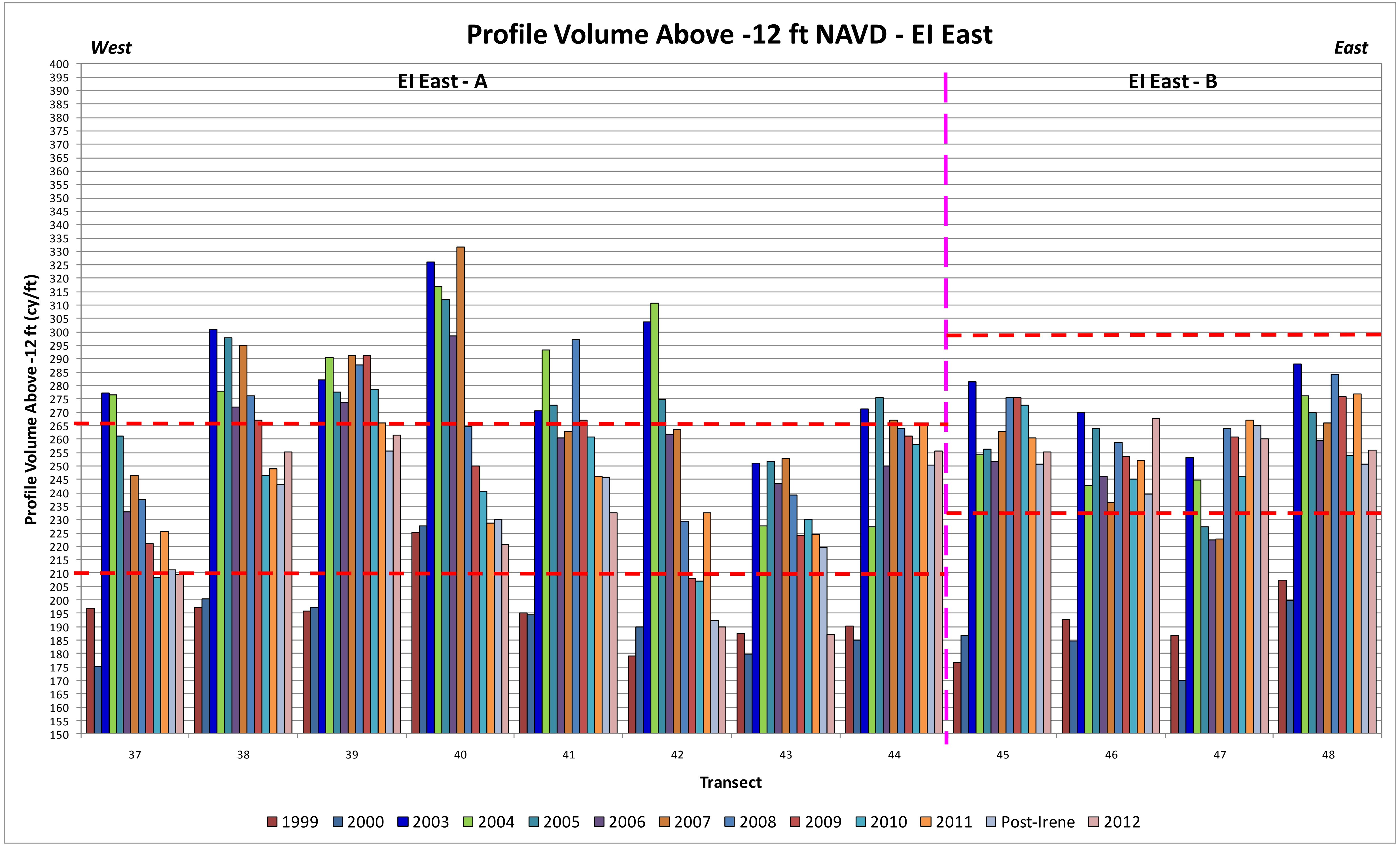

Figure 7-31: Profile Volume Above -12 ft NAVD88 – Emerald Isle East

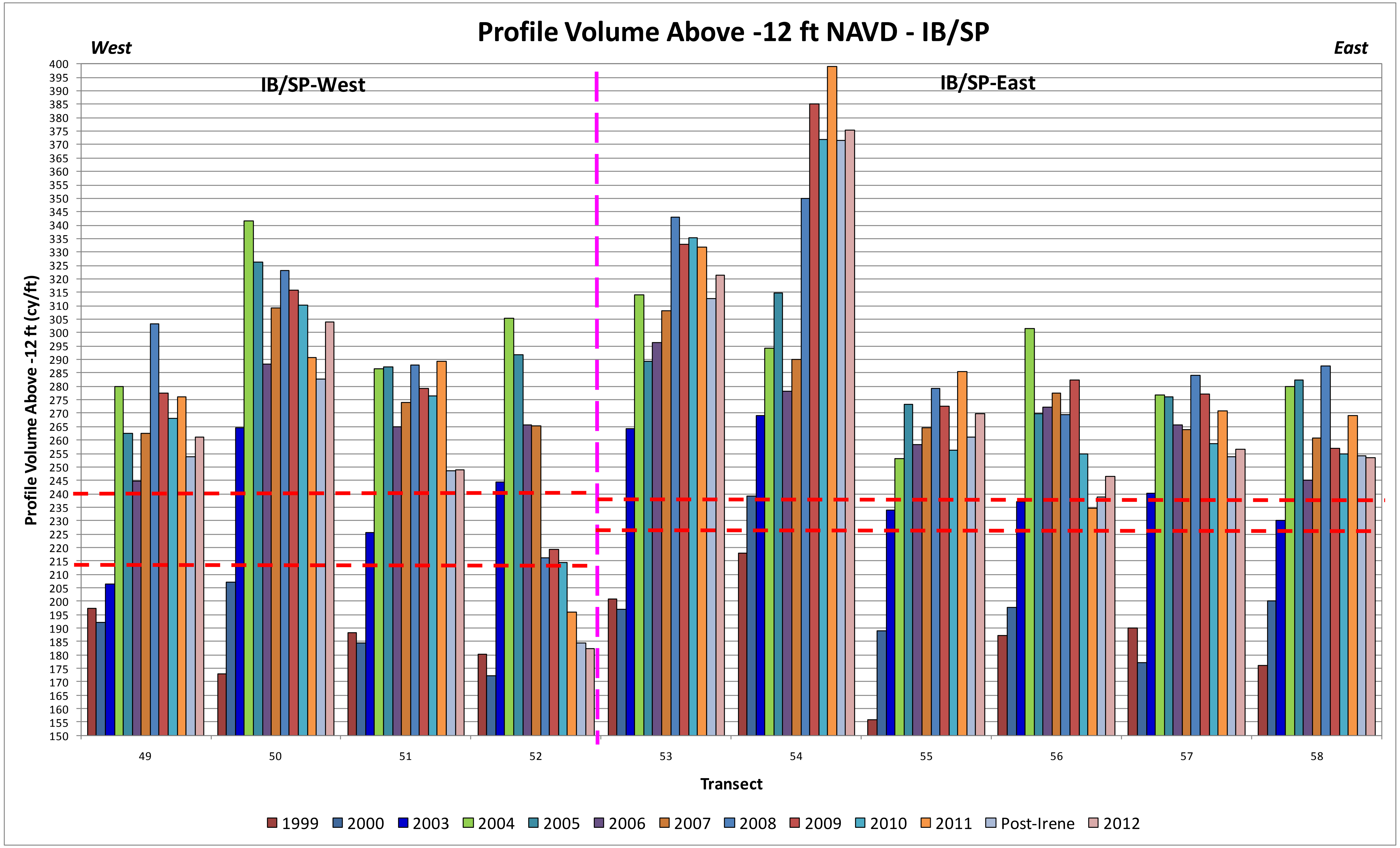

Figure 7-32: Profile Volume Above -12 ft NAVD88 – Indian Beach/Salter Path

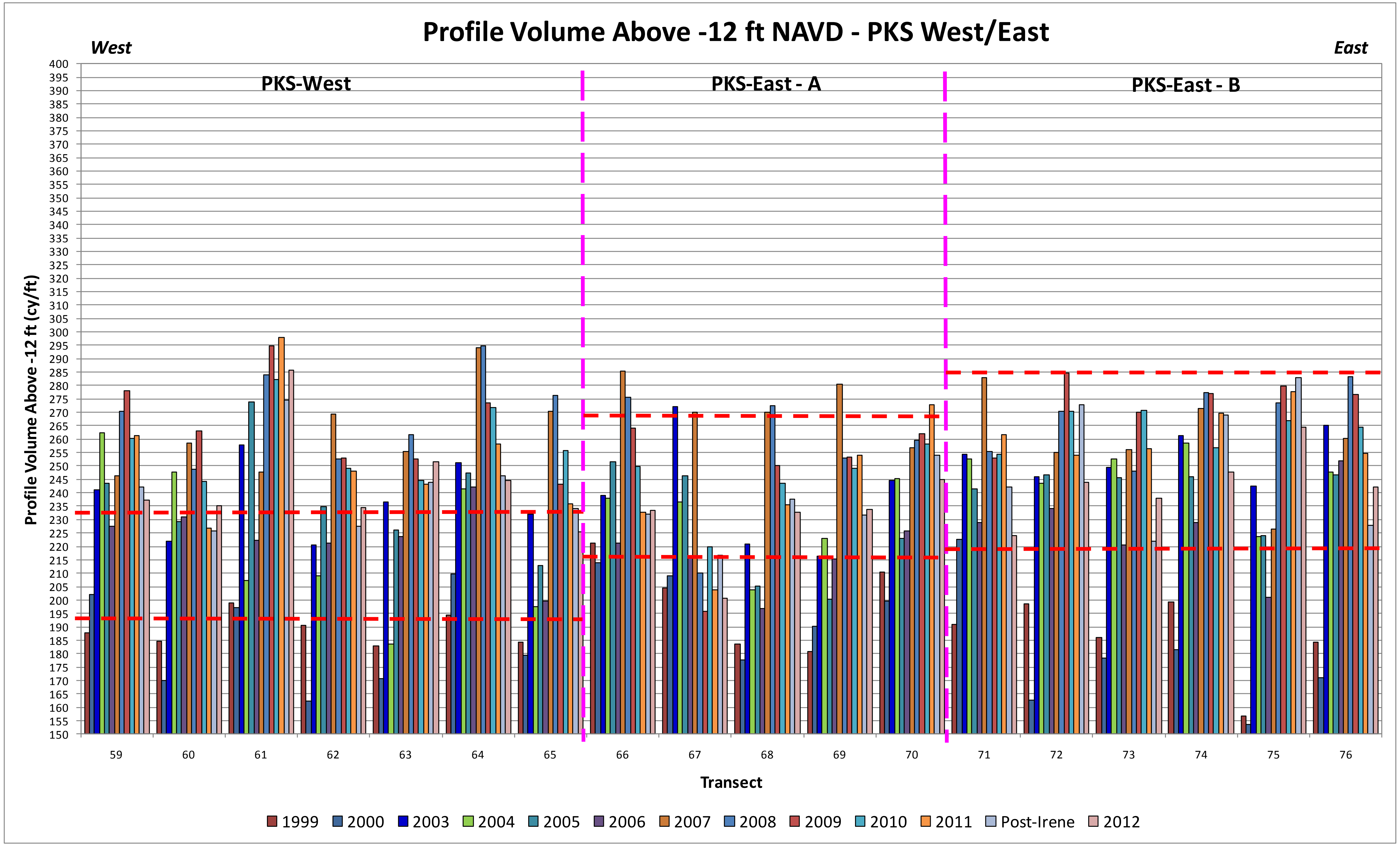

Figure 7-33: Profile Volume Above -12 ft NAVD88 – Pine Knoll Shores West & East

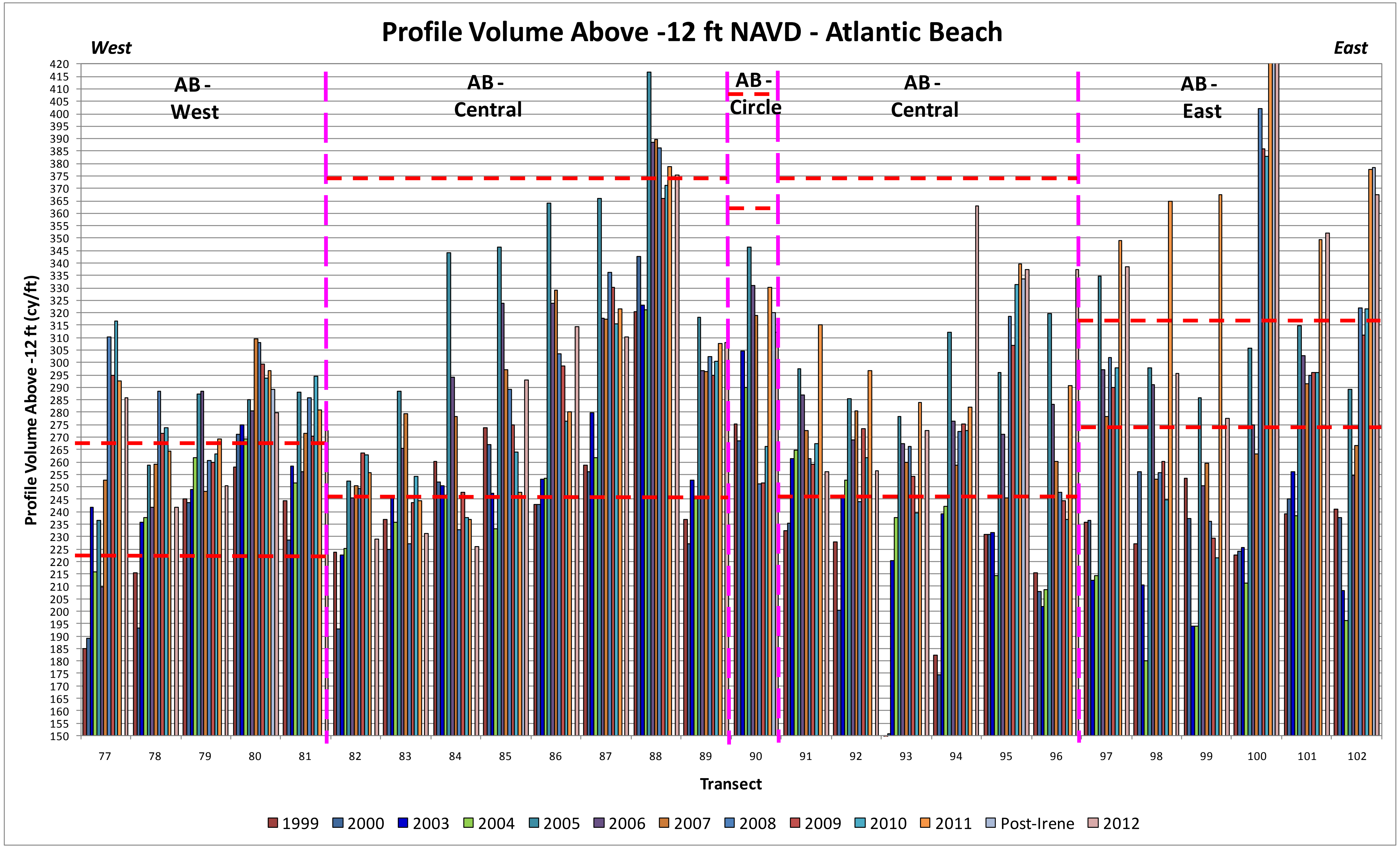

Figure 7-34: Profile Volume Above -12 ft NAVD88 – Atlantic Beach

Given all the above results, it can be seen why the 50-yr event LoP may be attainable but would likely not be sustainable. Therefore, the 25-yr event was selected as the final LoP for the master plan as a sustainable project to achieve.

7.4.4 Consideration of Sea Level Rise

As discussed in Section 3.2.5, standard USACE guidance and calculation tools indicate relative sea level change (SLC, rise) values in the project vicinity of 0.57 feet (low), 1.01 feet (intermediate), and 2.39 feet (high) at a point in time approximately 50 years into the future. Under Design Scenarios #1, #2, and #3, the dune height, and to a lesser extent the berm height, has been optimized to just provide acceptable LoP in a specific design storm return period event. One implication of sea level rise is that the dune crest, berm elevations, and profile slopes would need to rise by approximately the same amount as relative sea level in order to maintain an equivalent LoP. An evaluation of the amount of sand volume that would be required to raise the dune and berm elevations under the Design Scenarios is shown in Table 7-8, with different amounts estimated for each of the three USACE recommended sea level rise scenarios.

The volumes were estimated very approximately through a simple calculation of the cross-sectional area that would be added by raising the elevations by the given SLC value over a typical dune crest width, berm width, and connecting slopes on the 18 representative transects. The volume needed to adapt is very similar for Design Options #1, #2, and #3.

Table 7-8: Additional Volumes Needed to Adapt Design Scenarios to Relative Sea Level Change Scenarios

Design Scenario	Low SLC: +0.57 feet	Intermediate SLC: +1.01 feet	High SLC: +2.39 feet
Design Scenarios #1, #2, and #3	1,030,000 cubic yards	1,825,000 cubic yards	4,300,000 cubic yards

Any changes to the target beach profiles to achieve the project's objective would not be made all at once, but gradually over the project lifetime. It is recommended that the approximate volumes in Table 7-8 be considered in planning efforts and long-term budgeting estimates. In practice, it is envisioned that individual maintenance renourishments, dune enhancement projects, and post-storm recovery nourishments would consider adding dune and/or berm elevation incrementally as time progresses. In this way, the required elevation changes would be achieved progressively over the plan's lifetime. **However, based on USACE guidance provided at the PRT meetings, the intermediate value should be used for planning purposes. Therefore, the additional need to account for potential sea level change would be 1,825,000 cy, equating to 46.8 to 51.6 Mcy.**

7.5 Nourishment Trigger Determination

With the 25-yr event now selected as the finalized level of protection, the development of nourishment triggers could commence. Again, it is important to note that the potential of triggers at all of the computation elevations was considered, but ultimately the elevation of -12 ft NAVD was selected due to reasons stated earlier. Table 7-9 shows the various trigger volumes above -12 ft NAVD for both the 25-yr and 50-yr events as well as the amount in place as of 2011 (pre Hurricane Irene). Interestingly, the island wide average 25-yr trigger was computed to be 230 cy/ft, which is nearly identical to the previously used 225 cy/ft over the last 13 years. However, as noted in the table, there were concerns with the calculation as completed for the Bogue Inlet reach which is significantly affected by the shape of the profile at the inlet. For this reason, the 50-yr trigger volume was selected as the final value for the Bogue Inlet subreach (also note that using the 238 cy/ft result is very similar to the 230 cy/ft 25-yr event result for the Emerald Isle West – A subreach).

Table 7-9: Calculated Volume Triggers Above -12 ft NAVD88 for Various RP Events

Reach	Reach Length (ft)	50-yr, -12 ft Trigger (cy)	25-yr, -12 ft Trigger (cy)	-12 ft 2011 Volume (cy)
Bogue Inlet (1-8)	7,432	238	103	389
Emerald Isle West - A (9-11)	4,056	282	230	277
Emerald Isle West - B (12-22)	14,283	319	272	295
Emerald Isle West - C (23-25)	4,005	323	242	303
Emerald Isle Central - A (26-32)	10,428	237	213	292
Emerald Isle Central - B (33-36)	5,374	277	207	262
Emerald Isle East - A (37-44)	8,814	268	214	242
Emerald Isle East - B (45-48)	4,406	299	235	264
Indian Beach/Salter Path - West (49-52)	5,275	243	216	263
Indian Beach/Salter Path - East (53-58)	7,575	241	229	298
Pine Knoll Shores - West (59-65)	9,063	235	196	253
Pine Knoll Shores - East - A (66-70)	6,564	271	218	240
Pine Knoll Shores East - B (71-76)	8,251	287	222	262
Atlantic Beach - West (77-81)	5,388	269	225	281
Atlantic Beach - Central (82-89, 91-96)	13,771	375	248	291
Atlantic Beach - Circle (90)	1,006	408	364	330
Atlantic Beach - East (97-102)	6,011	318	276	384
TOTAL	**121,702**			
AVERAGE		**288**	**230**	**290**

Once the Bogue Inlet result was replaced, the resulting overall average rose to 238 cy/ft (see Table 7-10). This result makes sense in the fact that the 225 cy/ft original trigger was based on profile volumes in Atlantic Beach (which had weathered the hurricanes well) AFTER the hurricanes. It would only make sense that the PRE-storm volume would be higher and given that the past hurricanes over the last decade have had roughly 1.2 -1.5 Mcy of erosion this would mean that the pre-storm volume island-wide was approximately 10-13 cy/ft higher than the 225 cy/ft after the event. Therefore, the overall average of 238 cy/ft for the entire island was determined to be very reasonable.

Nonetheless, while determination of the individual subreach triggers was needed, it would not be practicable to have individual nourishment actions be dictated by a single subreach while adjacent subreaches would not require sand placement. Therefore, the individual subreaches were re-examined to determine which subreaches should be grouped together for nourishment reach determination. As can be seen from Table 7-10. the Bogue Inlet subreach is similar to the Emerald Isle West – A subreach and so on. The table shows the proposed management reaches and the weighted trigger volume above -12 ft NAVD based on the subreach lengths. The resulting management reaches are on average 2-3 miles long with the exception of the Pine Knoll Shores and Atlantic Beach management reaches which are somewhat longer and cover the entire Town in each case. For the proposed management reaches, the weighted trigger is 233 cy/ft with triggers varying from 211 cy/ft for Emerald Isle Central to 266 cy/ft for portions of Emerald Isle West.

Table 7-10: Revised Calculated Trigger Volumes Above -12 ft NAVD88 for Various RP Events

Reach	Reach Length (ft)	50-yr, -12 ft Trigger (cy)	25-yr, -12 ft Trigger (cy)	Adjusted 25-yr, -12 ft Trigger (cy)	Preliminary -12 ft Trigger (cy)	-12 ft 2011 Volume (cy)
Bogue Inlet (1-8)	7,432	238	103	238	235	389
Emerald Isle West - A (9-11)	4,056	282	230	230		277
Emerald Isle West - B (12-22)	14,283	319	272	272	266	295
Emerald Isle West - C (23-25)	4,005	323	242	242		303
Emerald Isle Central - A (26-32)	10,428	237	213	213	211	292
Emerald Isle Central - B (33-36)	5,374	277	207	207		262
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Emerald Isle East - B (45-48)	4,406	299	235	235		264
Indian Beach/Salter Path - West (49-52)	5,275	243	216	216	224	263
Indian Beach/Salter Path - East (53-58)	7,575	241	229	229		298
Pine Knoll Shores - West (59-65)	9,063	235	196	196	211	253
Pine Knoll Shores - East - A (66-70)	6,564	271	218	218		240
Pine Knoll Shores East - B (71-76)	8,251	287	222	222		262
Atlantic Beach - West (77-81)	5,388	269	225	225	254	281
Atlantic Beach - Central (82-89, 91-96)	13,771	375	248	248		291
Atlantic Beach - Circle (90)	1,006	408	364	364		330
Atlantic Beach - East (97-102)	6,011	318	276	276		384
TOTAL	**121,702**					
AVERAGE		**288**	**230**	**238**	**233**	**290**
					Weighted	

8.0 ENGINEERING ALTERNATIVES CONSIDERED

8.1 Prescreening of Alternatives

As part of the engineering analyses, a prescreening of alterntives was completed. North Carolina's policies allow for multiple strategies to be used along North Carolina's beaches and inlets. With the exception of temporary sandbags and a limited number of "grandfathered" pre-existing permanent hardened structures, North Carolina's coastal management policies allow only "soft" solutions (e.g., beach nourishment, inlet dredging/bypassing/management, setbacks, and structure relocation) with the exception of a current pilot study which is allowing up to four (4) terminal groin structures. The historical policy against permanent erosion control structures is intended to avoid downdrift impacts, such as increased erosion, that can be associated with these structures. **For the above reasons, alternatives including structures such as offshore/nearshore breakwaters or groins were removed from consideration.**

Sand Transfer Plant

Some innovative solutions were also considered such as sand transfer plants. A sand transfer plant consists of a pipeline with pumps to transfer sand from an updrift beach to a downdrift beach (see Figure 8-1 below). However, this alternative was removed from consideration as well due to the following issues that would make installation at Beaufort Inlet infeasible.

1. Nearly all of the sand transfer plants currently in existence are adjacent to shallower inlets with longshore transport rates lower than the shoaling rates in the Morehead City Harbor Channel. One of the most substantial systems is in Australia next to a 20' deep channel. This plant has a long trestle pier and significant infrastructure to house the number of jet pumps required to provide transport for roughly 500,000 m3 / yr.

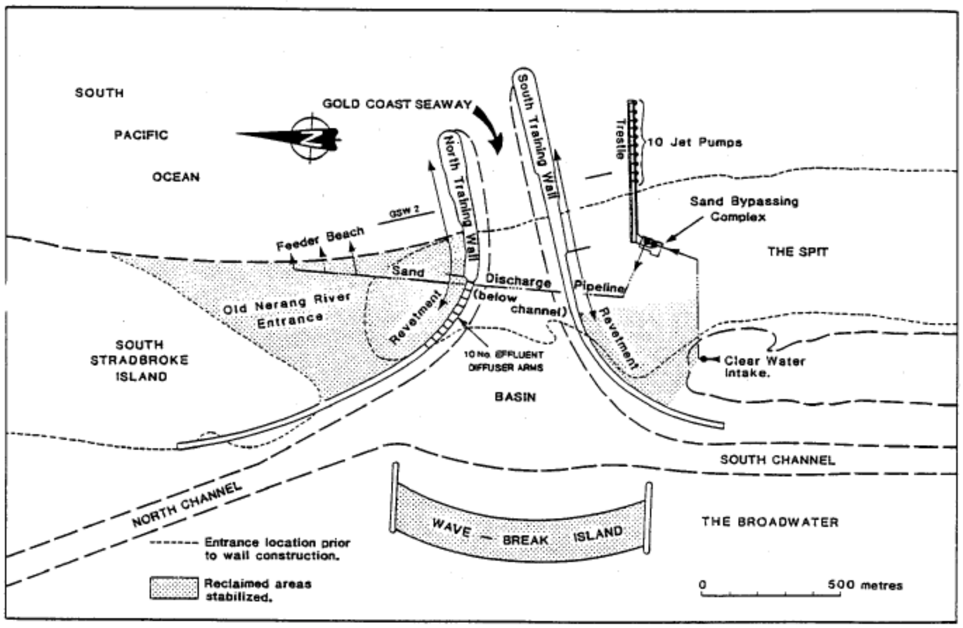
2. A fixed plant that is smaller would not be feasible given that the system would need to transport material up to 3-4 miles to be sure that the material would benefit the downdrift beaches and not end up right back in the inlet. (This is caused by the depth of the current inlet which makes its area of influence quite large)

3. Given that all this infrastructure would have to be installed on the National Park Service (NPS) side, it was deemed infeasible since Carteret County does not own the land and the NPS has turned down our suggestions for even a small terminal groin. A structure across the inlet for the discharge pipeline would also be needed (a bridge that would not impede port traffic) or the pipeline would have to be bored down 60-70' to go under the channel. Boring the pipeline so deep and creating this low spot would be cause for concern of clogging and maintenance.

4. The ownership issues and how this all interacts with the USACE and maintenance of the channel also precluded any thoughts of the construction of a sediment trap

on the NPS side as well. A fixed sediment trap to dredge from and some type of structure to capture sediment within the trap would be needed and as stated previously, the NPS has rejected our suggestions for even a small terminal groin to be considered to limit island erosion and shoaling within the channel.

Nerang River Entrance Sand Bypassing System, System layout (Witt and Hill, 1987).



Schematic of Nerang River Entrance Sand Bypassing System (Witt and Hill, 1987).

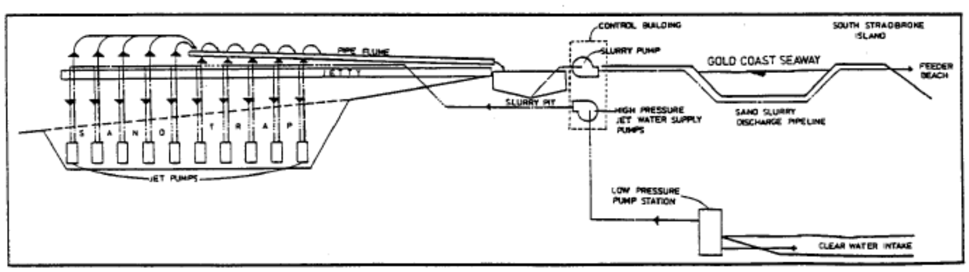


Figure 8-1: Example Sand Bypassing System

Nearshore Berm

Nearshore berms can potentially function as a source of sand for eroding beaches and provide a limited measure of storm protection to oceanfront property through wave energy attenuation. Berm construction usually entails the placement of material in shallow water just off the beach to create a nearshore sand feature that functions in the same manner as a natural sandbar. The construction of such a berm along Bogue Banks could be completed using compatible sand from an inlet or offshore borrow source such as the MCH ODMDS.

Dredging technology allows for berm construction in water depths as shallow as 15 feet, and the dissipation of waves as they pass over the berm during normal water levels may provide some mitigation of background shoreline erosion. However, during storm events when water levels are elevated; storm waves would pass over the berm, erode the beach, and present a threat to upland property. In addition, although some sand may be transferred from the berm to the beach, the volumetric extent of transfer would be insufficient to maintain a functional recreational beach. The USACE's "Integrated Dredged Material Management Plan and EIS" for MCH identifies "nearshore placement areas" (potentially equivalent to a "nearshore berm") as a potential disposal areas associated with future USACE MCH maintenance dredging, and these types of features have been used in the past. However, past studies and surveys of these berms have shown that these current features are located too far offshore to have any measurable effect on the beaches and littoral system. Therefore, nearshore berms are not proposed as part of the Applicant's requested authorization under the proposed MBNP as such berms do not reliably or sufficiently, in and of themselves, preserve the beach-dune system and thus do not meet the Project purpose and need.

Submerged Breakwaters

Submerged breakwaters are offshore detached shore-parallel structures that are intended to reduce shoreline erosion through the attenuation of wave energy. A variety of designs have been employed along the Atlantic Coast; including prefabricated concrete reefs, sills, reef balls, and sand-filled geotextile tubes. In 1995, an experimental 1,260-meter (m) submerged breakwater consisting of inter-locking concrete units was installed for shore protection in Palm Beach, Florida. However, the structure was removed after monitoring revealed erosion rates 2.3 times higher than those before the project (Browder et al. 1996). A recent evaluation of submerged breakwaters along the US Atlantic Coast by the USACE Coastal and Hydraulics Laboratory found that most breakwaters have not performed well in open coast settings unless they were mounted on hardbottom (Morang et al. 2014). Furthermore, NC coastal management regulations currently prohibit the use of offshore submerged breakwaters. With the noted insufficiencies for submerged breakwater structures in environmental settings which is similar to Bogue Banks, and the prohibition of such hardened structures by the State of North Carolina, this alternative was deemed not reasonable and eliminated from further evaluation.

Restrictions on New Development (Beach Rezoning or Construction Moratorium)

Restricting or limiting future construction along eroding beaches through rezoning or a construction moratorium can effectively limit the exposure of new structures to potential storm damage if implemented under suitable or applicable conditions. For Bogue Banks, much of the developable upland areas on Bogue Banks are approaching full build-out and not conducive to such rezoning measures, particularly along the oceanfront and second-row lots. Rezoning would not provide any substantial reduction in the storm damage risk to existing structures and upland property on the island and implementing these type measures would not help in long-term protection needs of the island's existing infrastructure and homes. Any restriction on new development would fail to protect the shoreline and would be economically infeasible; therefore rendering the alternative unreasonable.

Beach and inlet management strategies allowed in North Carolina are often interrelated. For example, material dredged to maintain an inlet for navigation might be placed on the beach. Some overall general strategies and considerations are given in the following table (Table 8-1). The table below was used as a starting point in discussions with the USACE Project Review Team (PRT) process. The final alternatives selected for analysis are outlined in the following section.

Table 8-1: Potential Beach and Inlet Management Strategies

BEACH	INLET
▪ Nourishment (size, frequency, location, method, …) ▪ Coastal Zone Management Practices (setbacks, structure relocation, public access, …) ▪ Storm Recovery (dune reconstruction, planting, beach dozing, breach fill, …)	▪ Dredging (size, frequency, location, method, …) ▪ Sand Bypassing (size, frequency, location, method, …) ▪ Inlet Management/Relocation

8.2 Development of Alternatives

Development of the engineering alternatives to be considered was completed as part of the USACE Project Review Team (PRT) process. Over multiple meetings, the PRT selected the following alternatives for consideration.

- No Action (Status Quo)

- Reloaction/Abandonment

- USACE SAW 50-yr Federal Storm Damage Reduction Project

- Beach Renourishment Only
    - Upland Sources Only
    - AIWW Sources Only
    - Offshore Sources Only
    - Upland/AIWW/Offshore Sources Combination

- Beach Renourishment and Inlet Management
    - Non-Structural Inlet Management
    - Structural Inlet Management
    - Hybrid Approach (Structural & Non-Structural Inlet Management)

8.3 No Action (Status Quo)

8.3.1 Alternative Description

The "No Action" alternative would actually still encompass continued placement of material by the USACE from the Morehead City Harbor Channel project on Fort Macon and Atlantic Beach; in addition, USACE placement of material at the Point from the Bogue Inlet AIWW crossing disposal would persist. Additional limited erosional hotspot response nourishment projects implemented by the individual municipalities using offshore borrow areas and limited relocations of the Bogue Inlet ebb channel would also be expected.

While the USACE maintains Bogue Inlet with its sidecast dredges, they prefer to utilize industry pipeline dredges on a 2-3 year basis to dredge the AIWW inlet crossing and place the material on the beach. The dredged shoal material is pumped to the westernmost oceanfront shoreline of Emerald Isle, known as The Point. The average dredged volume placed along the beach per event is approximately 44,000 cubic yards yards – equivalent to 20,200 cy/yr. Table 8-2 shows a summary of the AIWW dredge disposal to western Emerald Isle.

Table 8-2: Bogue Inlet AIWW Dredge Disposal to Western Emerald Isle

Year	Dredge Volume (cy)
1984	15,000
1987	30,000
1990	56,000
1993	17,000
1995	33,000
1996	71,000
1997	39,000
1999	48,000
2000	16,000
2003	59,000
2006	77,000
2009	64,000

Historically, placement of material on Fort Macon and Atlantic Beach has been performed by the USACE as part of the Morehead City Harbor Federal Navigation Project. Beach quality material from the navigation channel as well as previously stock piled material from Brandt Island have been placed on Fort Macon and Atlantic Beach as far west as the Circle. Table 8-3 shows the historical placement history, which corresponds to approximately 1,630,500 cubic yards per average dredge event – equivalent to 47,955 cy/yr.

Table 8-3: Morehead City Harbor Federal Navigation Project

Year	Pumped from Brandt Island (cy)	Piped From Navigation Channel (cy)
1978	-	1,179,600
1986	4,168,600	-
1994	2,472,132	2,192,268
2002	-	209,348
2005	2,390,000	530,729
2007	-	184,828
2011	-	1,346,700

Beginning in 2011, the USACE implemented a three year Interim Operations Plan (IOP) to adequately maintain the Federal Navigation Project through 2013, which placed material on Bogue Banks in Year 1 (2011). Material from the navigation channel was not placed on Bogue Banks during the remaining two years (2012 & 2013). The USACE is also in the later stages of developing a Dredged Material Management Plan (DMMP) addressing longer term dredging and disposal issues at the harbor that encapsulates a twenty year time horizon. The DMMP will be instituted for the following two decades (2013 - 2034) and will include an agreement with the County on future cost sharing nourishment plans to place material further on Bogue Banks instead of the nearshore disposal area. Material could potentially be placed westward of the Circle, all the way to the eastern edge of Pine Knoll Shores. However, there is a serious possibility that material may also be placed on Shackleford Banks. At best, it is expected that an average of 400,000 cy/yr (split over multiple projects every 3 years) would be placed from Fort Macon to the Circle and westward to Pine Knoll Shores.

Although there is no historical precedent for continuing hotspot nourishment projects under Alternative 1, there are known erosional hotspots along Emerald Isle and Pine Knoll Shores where it is clear that structures will be imminently threatened in the near future. It is assumed that an imminent threat to structures along these reaches would elicit a response by the individual municipalities in the form of localized hotspot response nourishment projects. Analysis of island-wide monitoring profile data was used to identify the known hotspot areas by calculating background erosion rates and subtracting out nourishment effects for the individual profiles. An annual loss rate of 90,542 cy was calculated for the hotspot reaches using procedures outlined in Section 4.2.2 of this report. Based on the annual loss rates and considering the mobilization/demobilization costs of nourishment, it is anticipated that the hotspot reaches (together) would be nourished with ~1.0 MCY of sand every 11 years. The actual frequency and volumetric extent of these projects would vary according to background erosion rates and the extent of shore protection degradation along specific reaches, as well as the frequency and extent of storm damage and the availability of local shore protection funding. The implementation costs associated with these beach nourishment events would be fully funded by the local municipalities, potentially with assistance from the County. Although the majority of Atlantic Beach represents a major erosional hotspot, it is assumed that continuing USACE placements of navigation dredged material from the MCH channels would be sufficient to mitigate background erosion.

In addition to the hotspot renourishment events, Alternative 1 includes the relocation of the Bogue Inlet ebb tide channel to a more central location on an as-needed basis only. During the 1980s and 1990s, rapid eastward migration of the channel resulted in severe erosion of the west end Emerald Isle shoreline. The erosional threat to homes and infrastructure on the west end led to armoring of the inlet shoreline with sandbags, and the eventual relocation of the ebb channel to a mid-inlet position in 2005. The 2005 ebb channel realignment and nourishment project, which constituted Phase III of the non-federal Bogue Banks Restoration Project, moved the channel approximately 3,500 feet west towards Bear Island to alleviate the imminent erosional threat to the western tip of Emerald Isle. Approximately 690,868 cy of dredged material from the new inlet channel was placed on the west end of Emerald Isle. The cost of the 2005 ebb channel relocation and nourishment project was approximately $10.9 M. Although an additional realignment event is not currently needed or planned, it is expected that the Town of Emerald Isle and/or the County would pursue such a project if erosional conditions similar to those preceding the 2005 project were to reoccur. It is anticipated that ebb channel realignments would follow the design and methods employed during the 2005 project. Accordingly, realignments would entail the construction of a channel ~6,000-feet-long with variable bottom widths ranging from 150 to 500 feet. Relatively shallow inlet depths would require the use of a cutterhead dredge to excavate the new mid-inlet channel. Channel excavation is anticipated to yield just over 1.0 MCY of beach compatible dredged material. It is anticipated that ~0.2 MCY of the dredged material from the new channel would be used to construct a closure dike across the old channel, with the remaining ~0.85 MCY of material being pumped directly onto the Western Beach of Emerald Isle. Excavation would proceed inland from the seaward terminus of the new channel, with dredged material initially being pumped onto the Emerald Isle beaches. As work nears the inshore terminus of the new channel, disposal would be redirected to the designated dike construction area in the old channel.

Throughout most of the period since the 2005 relocation, the ebb channel has migrated east at a rate of ~170 ft/yr; however, in recent years the rate has slowed to ~80-120 ft/yr. In total, the channel has migrated ~1,650 feet westward over the 10-year period since the 2005 relocation project. The ebb channel is currently located 1,850 ft west of the nearest structure on Emerald Isle. At the current rate, the ebb channel could approximate the position of the 2005 pre-project channel in approximately 8 to 13 years, in which case it is anticipated that plans for a realignment project would be initiated to protect the Emerald Isle shoreline. Although the number of realignment events that might be undertaken is not known, it is assumed that realignments would occur as a reactionary response to severe erosional conditions that present an imminent threat to homes and infrastructure. For impact analysis purposes, it is assumed that at least two channel realignment events would occur over the next 50 years. The implementation cost of realignments would likely be incurred by the Town of Emerald Isle and the County.

The "No Action" alternative would not provide enough material to Indian Beach/Salter Path and Emerald Isle which have significant long term needs. The small amount of AIWW dredge material from Bogue Inlet is also not adequate to meet the long-term needs of the area adjacent to Bogue Inlet. Therefore, the "No Action" alternative is not feasible and will not meet the project purpose to abate erosion along all 25 miles of Bogue Banks.

8.3.2 Existing Conditions Numerical Model (GENESIS-T)

Using the previously calibrated GENESIS-T model, an existing conditions GENESIS-T model was run to determine the changes in the study area which would take place with no mitigation of the existing erosion problem (especially with Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores). This model also served as the basis for decision making and comparison of proposed erosion control alternatives. The existing conditions model run involved a 12 year simulation representing the predicted future response of the shoreline under long-term typical wave action, using the wave data of data developed for the calibration model from the NDBC wave buoys, WIS archive, and NOAA tide gauge. The initial shoreline in the existing conditions model was the measured April 2012 shoreline. The lateral boundary conditions were changed to represent an average shoreline change over the entire calibration and verification modeling period from June 1999 to April 2012. All other parameters in the GENESIS-T model were the same as defined for the calibration model including the structural characteristics, sediment and beach characteristics, sediment transport coefficients, and seaward boundary conditions.

Appendix E shows the structural configuration implemented in this model run and the predicted shoreline position after a 12 year time period (April 2024). The resulting shoreline is compared against the initial shoreline position. As shown, the model predicts significant erosion in Emerald Isle East and Pine Knoll Shores while Bogue Inlet and Atlantic Beach remain very healthy. Based on Bogue Banks history, this seems to be very reasonable with the exception of Emerald Isle West which has been a historically slightly stable reach. Indian Beach/Salter Path has also always been a slightly more stable area overall with the remaining regions seeing the most erosion. Figure 8-2 and Figure 8-3 show example results from the GENESIS-T existing conditions model.

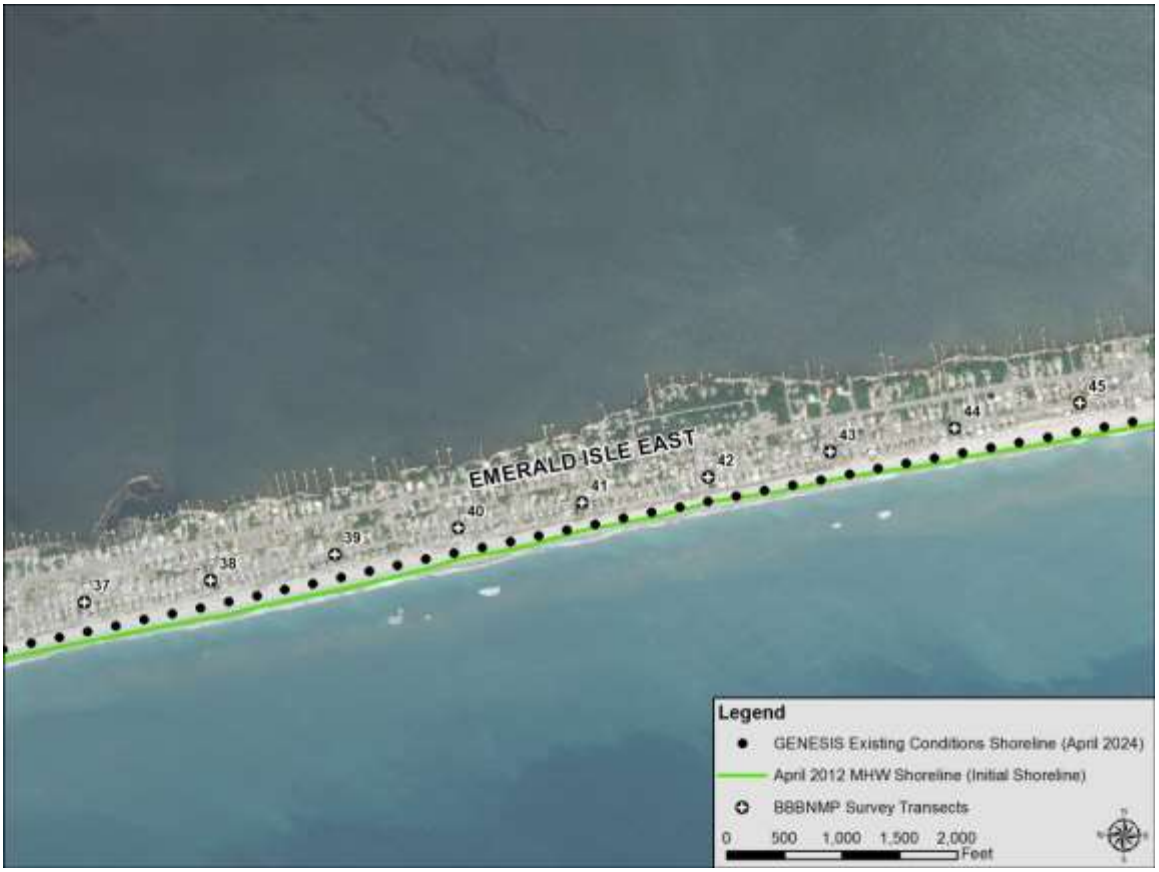


Figure 8-2: Example GENESIS Existing Conditions Results – Emerald Isle East

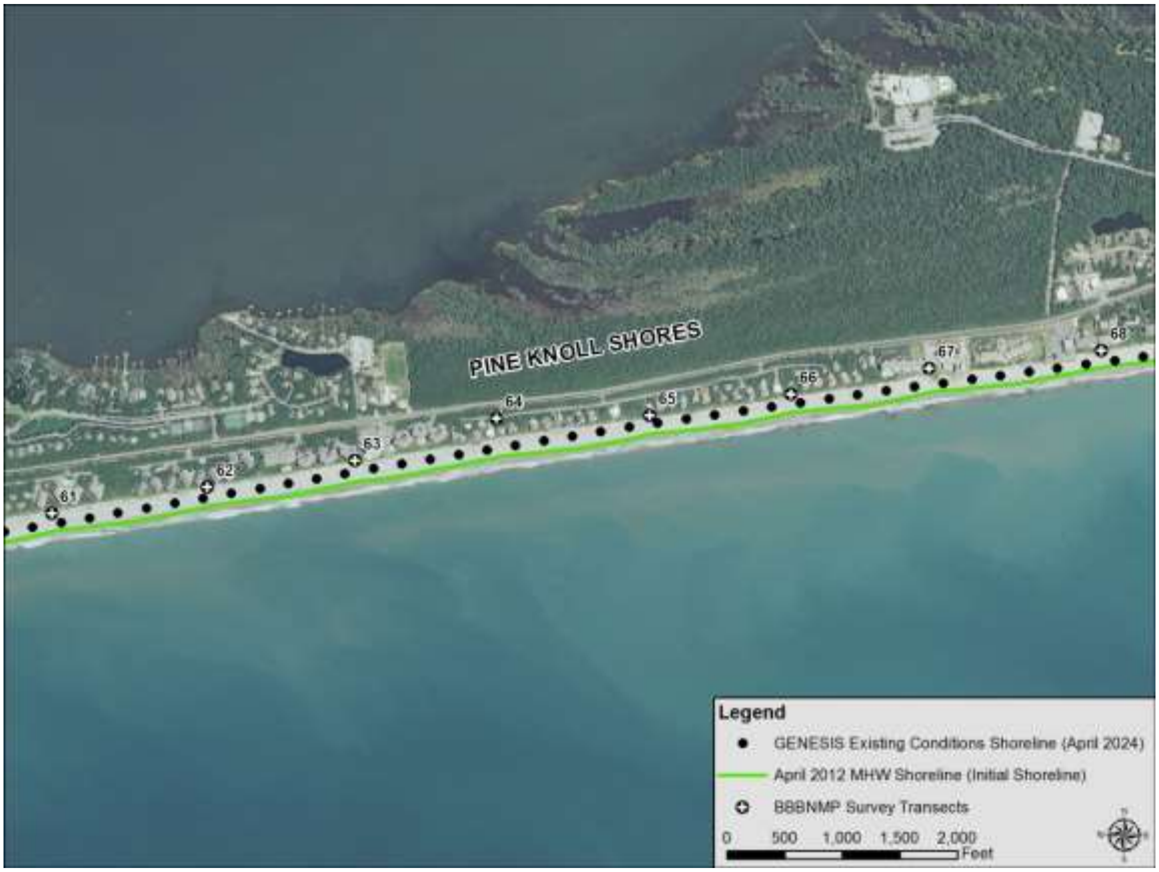


Figure 8-3: Example GENESIS Existing Conditions Results – Pine Knoll Shores

Based on the GENESIS-T model results, the absence of any action would put much of the infrastructure along Bogue Banks in danger and greatly reduce the amount of beach available for recreation. Therefore, the status quo option is, again, not feasible and will not meet the project purpose and need for all 25 miles of Bogue Banks. Therefore, it was dropped from any further analysis.

8.4 Relocation / Abandonment

The relocation/abandonment alternative would consider relocating damaged/threatened structures to other portions of the island. Unfortunately, this is not a feasible option due to costs and the limited number of vacant parcels remaining on the island. Table 8-4 shows the breakdown of parcels on Bogue Banks. Figure 8-4 shows an example of full and vacant oceanfront parcels along Bogue Banks.

Table 8-4: Parcel Usage on Bogue Banks

	Total Number	Total Use Value	Total Acres
Bogue Banks Parcels - Whole Island	16,050	$6,541,648,966	10,857
Bogue Banks Parcels - Non Oceanfront	14,718	$4,226,387,589	9,899
Bogue Banks Parcels - Oceanfront	1,332	$2,315,261,377	958
Bogue Banks Vacant Parcels - Whole Island	1,612	$393,411,152	802
Bogue Banks Vacant Parcels - Non Oceanfront	1,498	$311,330,634	732
Bogue Banks Vacant Parcels - Oceanfront	114	$82,080,518	70

Figure 8-4: Example Full (Developed) and Vacant Oceanfront Parcels

Based on the County data, while only 8.3% of the parcels on Bogue Banks are oceanfront, they constitute 35.4% of the tax value. While some of that value might be translated to the 2nd row lots, the overall effect on the County and Town tax bases might be truly devastating, not to mention the effects on tourism with a narrow beach and structures waiting to be relocated. Assuming a combined tax rate of $0.45/$100 (County and Town), the loss in annual tax revenue for these structures would be over $10 million. This does not include the costs to the homeowner to relocate.

In addition, the availability of lots is also an issue. Of the 1332 oceanfront parcels, only 114 of those are vacant; therefore, relocation would be necessary for the structures on just over 1200 parcels. Although there are approximately 1500 vacant parcels on the remainder of the island (not including vacant oceanfront parcels), the size of the vacant parcels would not be large enough to accommodate all the current oceanfront structures. Many of the oceanfront parcels include hotels, large condo buildings, townhouses, and other multiple-dwelling units. Vacant lots large enough to accommodate these are not available on the remainder of the island for relocation. The oceanfront parcels containing structures, which could possibly need relocation in the future, currently take up approximately 888 acres of land. The remaining vacant non-oceanfront parcels on the island only encompass 732 acres. Therefore, the oceanfront parcels which could need relocation in the future take up approximately 156 acres more of land than the remaining non-oceanfront vacant parcels on the island. Relocation of many of the stand alone houses to other parts of the island could be possible. However, relocation of the hotels, condos, townhouses, and multiple-dwelling units would not be possible. Even if it were possible, the cost of relocation/rebuilding would also be staggering. Even assuming a lot and building price of $500,000, the cost to relocate all oceanfront lots with structures (1,218 lots) would be over $600 million. Given that the average oceanfront lot value is $1.7 million, a more reliable cost would be $1 million/lot, equaling almost $1.3 billion. **Given the level of cost, the relocation/abandonment alternative is deemed to not be economically feasible and does not meet the project purpose and need. This alternative was therefore dropped from further consideration.**

8.5 Federal Storm Damage Reduction Project

The USACE Coastal Storm Damage Reduction Study has developed a National Economic Development (NED) plan based on a cost/benefit analysis of beach nourishment and the associated economic value of the protection (i.e. reduction of storm damages) and recreation provided. The plan was developed using the economic model Beach-*fx* which takes into account the value of damaged infrastructure vs. the cost of nourishment. While the project is still in the planning phase, a tentative NED plan has been identified. Table 8-5 shows the project at it varies across the island. Figure 8-5 shows the idealized profile shape required for use in the Beach-*fx* platform.

Table 8-5: USACE NED Plan

USACE Economic Reach	BBBNMP Transect	Landward Dune Slope (X:1)	Max Dune Elevation (ft)	Dune Width (ft)	Seaward Dune Slope (X:1)	Berm Height (ft)	Berm Width (ft)	Foreshore Slope (X:1)
4-10	4-7	4	16	95	-4	5.5	50	-15
11-15	8-11	4	15	45	-4	7	50	-15
16-21	12-17	4	20	10	-4	7	50	-15
22-92	18-81	4	x	x	-4	7	50	-15
93-110	82-97	4	18	18	-4	5.5	50	-15
111-117	98-102	4	x	x	-4	5.5	50	-15

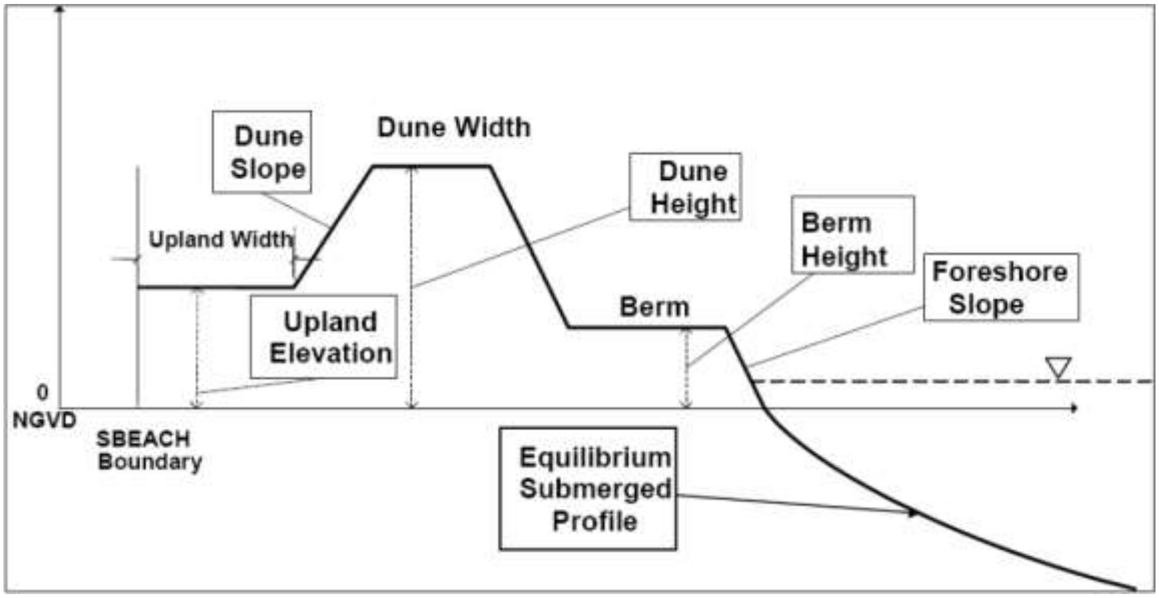


Figure 8-5: Beach-*fx* Idealized Profile Shape

Initial construction would require approximately 2.45 Mcy of material based upon initial conditions set by the June 2009 profiles (due to study timeline). The renourishment cycle would be every three years following initial construction and require approximately 1.07 Mcy of sand. Over the course of 50 years, this would call for approximately 19.55 Mcy of material. The project provides an estimated average annual $11,511,000 in coastal storm damage reduction benefits and $3,432,000 in recreational benefits at an average annual cost of $6,583,500 per year. This is a benefit/cost ratio of 2.3 to 1. **While the project has moved forward with completion of the feasibility study, it is questionable whether the project will ever be funded or implemented. Therefore, this project cannot be counted on to meet the project purpose and need and was dropped from further consideration.** However, if the project ever were to be funded, the County would adjust this plan to supplement the USACE project where needed.

8.6 Beach Nourishment Only

8.6.1 Upland Sources Only

The Division of Energy, Mineral and Land Resources of the North Carolina Department of Environment and Natural Resources (NCDENR) has a database of permitted active and inactive upland mines. From this database, a list of active sand and gravel mines within 30 miles of Bogue Banks (estimated to be feasible from a trucking cost persepective), which included mines in the surrounding counties of Craven, Jones, and Onslow, was generated. Mine owners were contacted to see if the sand in their mine met the requirements set for beach compatibility as well as the approximate volume of that sand. A majority of mine owners did not know the grain size distribution if the sand in their mine; however, most were confident that the mine did not meet the requirements. These sites were removed from the list. Other owners described the color of the sand in the mine that would not be considered compatible, which were then also removed. None of the remaining owners knew the full sediment distribution of the sand in their mines. Based on their judgment, they believe that their sand could be considered beach compatible. These mines are listed below in Table 8-6 and locations are presented in Figure 8-6. If the need arises, further testing should be completed to verify the compatibility based on the current state rules for beach compatibility.

Table 8-6: Upland Source Summary Table

Mine Owner	Location Name	County	Bonded Area (acres)	Volume Available (cy)	Latitude	Longitude
Julian M Brown Jr	Julian M Brown Jr Sand Mine	Carteret	34	1,000,000 permitted	34.820	-76.720
Sunland Builders	S&P Sand and Gravel Mine	Carteret	23	80,700	34.712	-77.006
Carters Machine and Planer Fabrication	Carter Mine	Carteret	3	Unknown	34.754	-76.733
Rouse's Septic Tank Services	Rouse Borrow Pond	Carteret	5	Unknown	34.727	-76.890
Cieszko Construction Company	Whitehall Borrow Pit	Craven	25	100,000	34.874	-76.854
W R Willis Trucking & Construction	W R Willis Mine	Onslow	39	200,000	34.794	-77.347

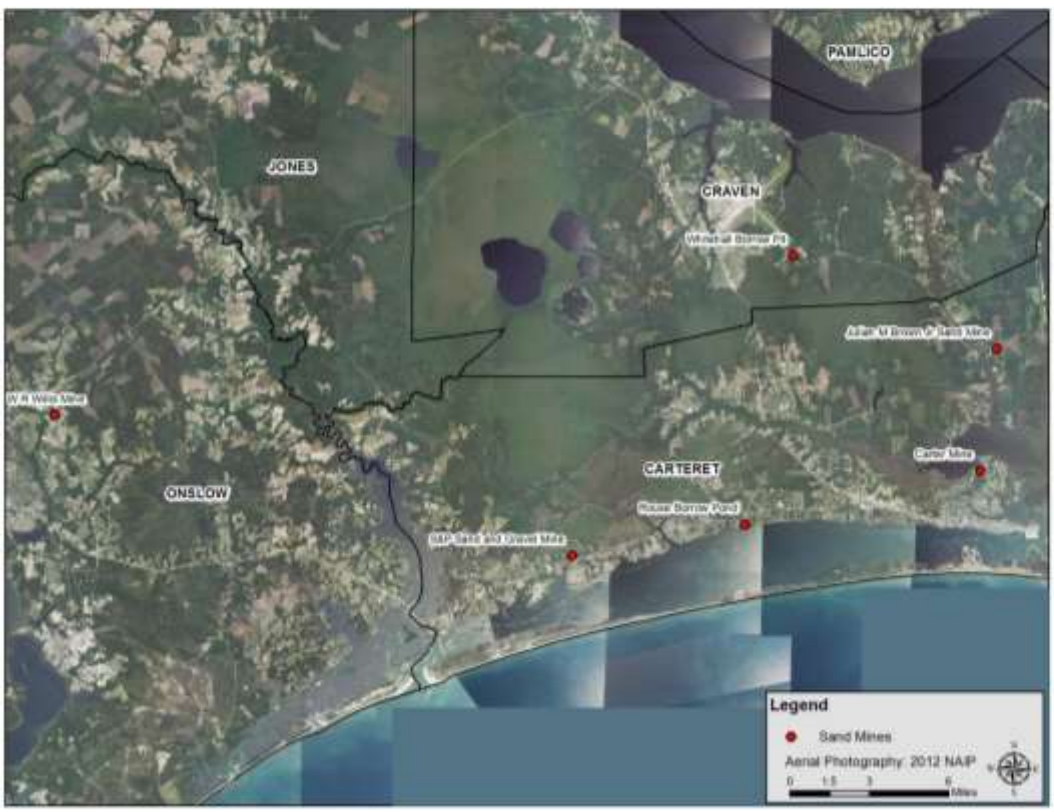


Figure 8-6: Sand Mine Locations

The sand mine owned by Mr. Brown is permitted to 1,000,000 cy; however, he does not know the current availability or sand size distribution. From a visual inspection, Mr. Brown thought the sand in his mine would be well matched for beach sand.

A representative for Sunland Builders provided a USGS soil survey of the S&P Sand and Gravel Mine. There are approximately 5 acres with 10 feet depth of sand remaining that might be considered beach compatible. Additional steps would most likely need to be taken to reduce the percent fines to ensure beach compatibility.

The owners of both Carter Mine and Rouse Borrow Pit described the sand in their mine as possible beach compatible sand; however, did not have any details about the distribution or the amount of sand. These mines are very small and most likely would not be able to contribute a significant amount to a beach nourishment project.

The owner of the Whitehall Borrow Pit also described the sand in his mine as looking like beach sand and knew that there was 9% passing the #200 sieve. Being that the limits for fines for native sand (NC Admin Code) references the #230 sieve; this could be a match with further analysis. The owner also noted that the mine was close to depletion, with only 100,000 cy of sand remaining.

Mr. Willis described the sand in his mine as looking like beach sand; however, a sediment analysis has not been performed. The remaining volume for this mine is around 200,000 cy.

The combined volume of the sand mines totals 1,380,700 cy - assuming that the entirety of Mr. Brown's mine could be utilized. This is the amount of sand that is currently available from the surrounding mines and will vary in the future. **Given the limited amount of sand in these mines compared to the need, these upland mines should be considered for the overall project but solely for possible use for small "hotspot" projects in the future, if needed, because they do not meet the 50-yr need.** If utilized, additional studies would be required at that time.

8.6.2 AIWW Sources Only

Dredge disposal areas are located all along the Atlantic Intracoastal Waterway (AIWW) in North Carolina (see Figure 8-7). The USACE performs maintenance dredging for navigation along the AIWW and disposes the sand in these areas.

A visual inspection of aerial photography for each disposal area was performed and areas that were in close proximity to a vibracore location were examined first. If the sand described by the vibracore and associated geotechnical report met the beach compatibility standards, it was determined to be a viable site. It is important to note that a majority of these areas have not had a sediment analysis performed; therefore, it cannot be confirmed that the sand meets the compatibility criteria. Also, a majority of the sites are either partially vegetated or fully vegetated. Disposal Area 60 was the only site where a vibracore was taken; therefore, an representation of the sand in this area was obtained.

The other areas did not have a vibracore nearby, so a sand thickness was assumed for each area of 5 feet, based on finding at Disposal Area 60. Volumes were then calculated based on this assumption and the area found from ArcGIS. Assuming that 90% of the available sand will be placed, the total volume available from the dredge disposal areas is 1,288,800. Table 8-7 summarizes the AIWW disposal Area information.

Table 8-7: AIWW Disposal Area Summary

Disposal Area	Owner	Vibracore	Area (ft^2)	Thickness (ft)	Volume (cy)
DA 22	Weyerhaeuser Company	NA	1,000,000	5	185,000
DA 26	The Baugus Family LLC	NA	1,541,000	5	285,000
DA 60	Jones, John R	LB-02-178	896,000	8.7	289,000
DA 61	Weeks, Haywood Jr.	NA	729,196	5	135,000
DA 62	Weeks, Haywood Jr.	NA	164,285	5	30,000
DA 64	Weeks, Haywood Jr.	NA	782,939	5	145,000
DA 65	Coderre, Shane Ronald	NA	582,865	5	108,000
DA 82	State of NC	NA	171,000	5	32,000
DA 88	State of NC	NA	552,000	5	102,000
DA 94	No Data	NA	652,000	5	121,000
				Total =	1,432,000
				Total (90%) =	**1,288,800**

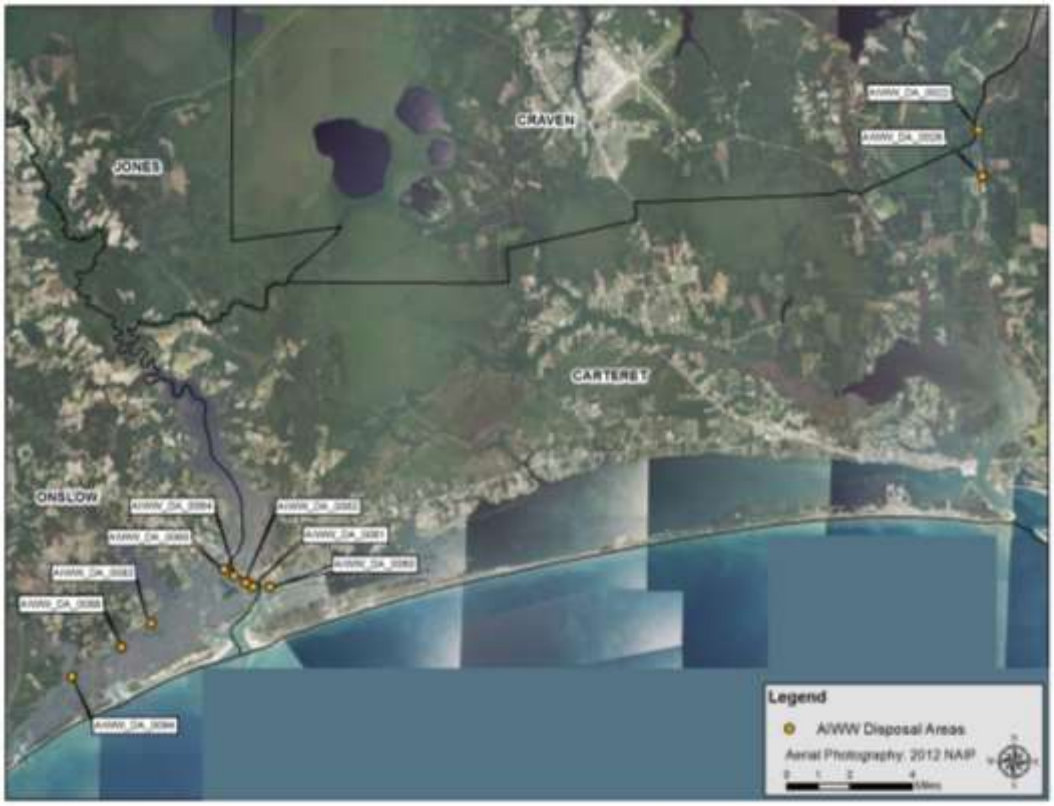


Figure 8-7: AIWW Disposal Area Locations

Disposal areas 88 and 94 most likely will not be utilized due to the large travel distance via water of 8 and 10 miles respectively. Also, disposal areas 82, 88, and 94 are the only areas not privately owned. All other sites will require owner authorization for the use of sand on their property. Disposal areas 22 and 26 are also a long distance via water to Bogue Banks; however, there is road access to these locations and the sand can be transported via truck to Bogue Banks. **Again, given the limited amount of sand at these sites, they were dropped for further consideration for this project because they do not meet the 50-yr need. However, these sites could possibly be utilized for small "hotspot" projects in the future, if needed.** If utilized, additional studies would be required at that time.

8.6.3 Offshore Sources Only

The potential offshore borrow areas previously presented in Section 3.6.2 are summarized and ranked in Table 8-8. An estimated 18,865,314 cy of beach compatible material given an "A" ranking are recommended for use as a sand source for nourishment of Carteret County beaches. There was an estimated 1,348,975 cy of beach compatible material given a "B" ranking and if further testing validates the sediment present, an "A" ranking could be given. Finally approximately 2,248,268 cy of material received a "C" ranking, and should not be used as a sand source for Carteret County except as a last resort.

Table 8-8: Characteristics, Ranking, and Volume of Non-Renewable Potential Borrow Areas (Coastal Tech, 2013)

Area	Section	Navigation	Volume (cy)	Mean Grain Size (mm)	Fines (%)	CaCO3 (%)	Overfill Factor	Rank
Native Beach	CSE 2001 Composite	-	-	0.3	< 1	≤ 20	-	-
Old ODMDS	Old ODMDS 1	No	13,138,307	0.3	0.53	13.6	1.25	A
	Old ODMDS 2	No	1,098,108	0.32	0.2	13.6	1.25	A
Current ODMDS	Current ODMDS 1	No	3,268,601	0.3	0.52	13.3	1.25	A
	O-192 Mound	No	785,270	0.36	0.13	19.6	1.25	A
	O-14/O47 Mound	No	566,028	0.38	0.23	19.8	1.2	A
	O-15 Mound	No	355,920	0.24	0.07	10.1	1.6	B
	O-35 Mound	No	499,491	0.3	0.31	15.2	1.3	B
	O-46 Mound	No	493,564	0.4	0.37	18.2	1.25	B
	O-48 Mound	No	468,740	0.2	5.91	7.8	2.25	C
	Remaining Mounds	No	320,000	-	-	-	-	C
Area Y	Y-80 Mound	No	1,079,853	0.23	2.37	1.5	2.5	C
	Y-120 Mound	No	379,675	0.4	2.04	1.5	1.3	C

Overall, the offshore sources can be expected to provide approximately 22,453,557 cy of material. The 50 year estimate for the amount of material needed for Bogue Banks, to account for background erosion and storms, ranges from approximately 45 Mcy to 49.8 Mcy (46.8 to 51.6 Mcy with moderate sea level rise). **Therefore, while the offshore sources provide a significant amount of sand, it is not enough to cover the 50 year need alone.**

8.6.4 Combination of Upland, AIWW, and Offshore Sources

The total volume available when the upland sources, AIWW disposal areas, and the offshore sources are combined is presented in Table 8-9. The total non-renewable volume available from these sources is 25,123,057 cy. The overall sediment need for Bogue Banks over the 50 year planning horizon based on the analytical/empirical analysis is between 45.0 and 49.8 Mcy (46.8 to 51.6 Mcy with moderate sea level rise). **Therefore, the volume of the combined upland, AIWW, and offshore sources will also not be enough to meet the 50 year need alone.**

Table 8-9: Summary of Non-Renewable Potential Borrow Areas

Area	Total Volume (cy)
Sand Mines	1,380,700
AIWW Disposal Areas	1,288,800
Offshore Sources	22,453,557
TOTAL	**25,123,057**

8.7 Beach Nourishment with Inlet Management

Given that the inlets (Beaufort and Bogue) have been utilized in the past as sand sources for placement of sand on the beach, these inlets were examined based on past and current studies to determine the sediment volume that possibly could be utilized for this project.

8.7.1 Non-Structural Inlet Management

The first aspect on inlet management to be studied was to determine if non-structural inlet management would be feasible. Given that North Carolina has historically had strong laws concerning hard structures along the coastal shorelines and has preferred to encourage the uses of soft approaches such as dredging and inlet management (Masonboro, Shallotte, etc.) for inlet stability, it was decided to look at this approach first.

8.7.1.1 Beaufort Inlet

For Beaufort Inlet, the management of this inlet is relatively fixed and set by the USACE as part of the Morehead City Harbor project. As shown in Figure 8-8, the portions of the channel which have beach compatible material includes a portion of Reach C, Ranch B, the Cutoff and Range A out to Station 110+00 (see Section 3.6.2.1.6 for discussion of beach compatibility). The USACE estimates that the shoaling volume within this portion of the channel is 1,206,500 cy/yr. (USACE, 2012 DMMP).

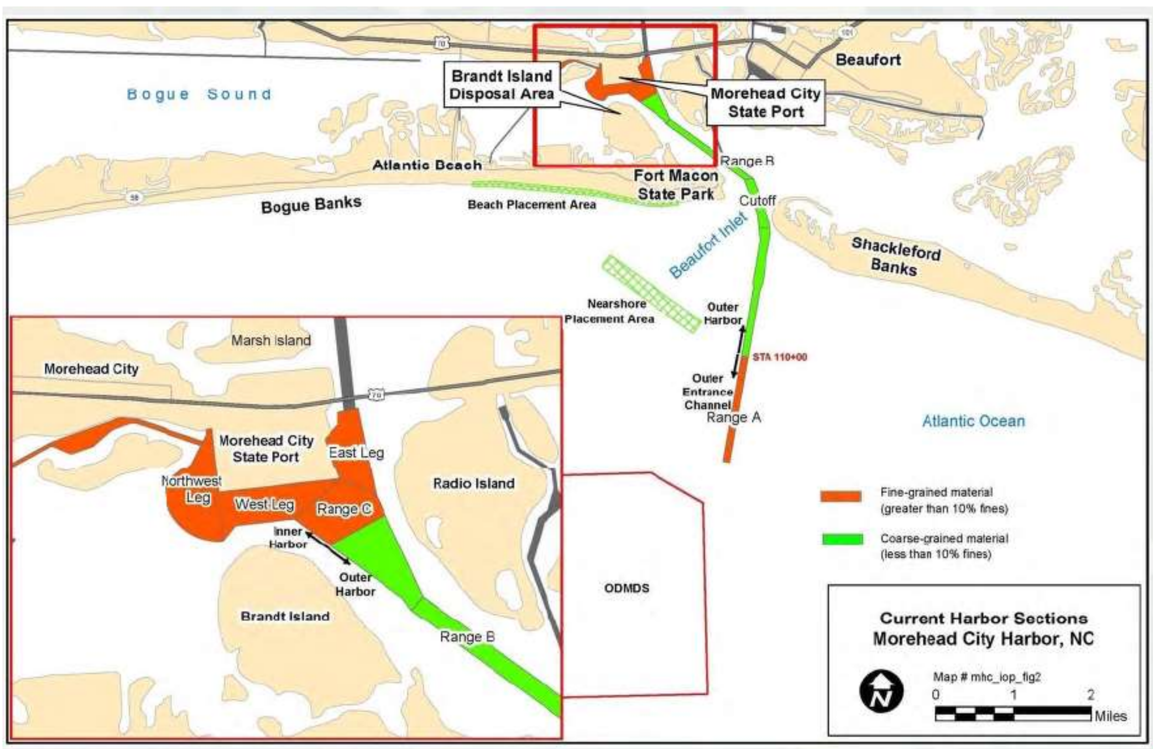
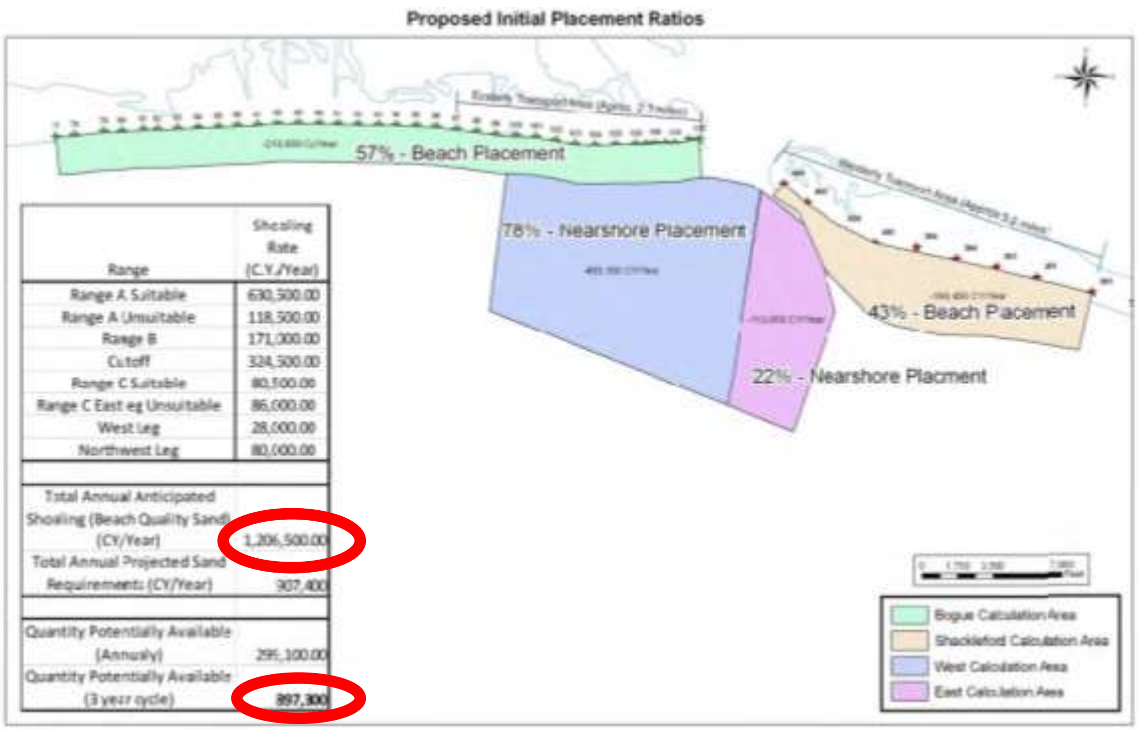


Figure 8-8: Beach Compatible Portions of Beaufort Inlet (USACE)

The USACE DMMP is currently being updated and will likely not be finalized for a few years. At this point, there are considerations being made for a three-year rotating cycle with Year 1 sand being placed on Bogue Banks and (possibly) Shackleford Banks, while Years 2 & 3 material will be placed on nearshore berms, Brandt Island, and the ODMDS depending on sand quality. The USACE has also stated that the DMMP will likely allow the County to pay “the delta costs” for placement of material during Years 2 & 3, so the overall total amount of sand from Beaufort Inlet may range from 228,000 cy/yr – 635,000 cy/yr based on the outcome of the DMMP. **If sand during Year 1 is ultimately placed on Shackleford Banks as well, it will be imperative that the County be allowed to place "delta sand" on the beach during Years 2 & 3 as desired to help meet the overall need.** For the purposes of the Master Plan, it is assumed that the overall amount of sand that will be available for beach placement on Bogue Banks will be somewhere in the middle at **400,000 cy/yr** on average.



Range	Shoaling Rate (C.Y./Year)
Range A Suitable	630,500.00
Range A Unsuitable	118,500.00
Range B	171,000.00
Cutoff	324,500.00
Range C Suitable	80,500.00
Range C East eg Unsuitable	86,000.00
West Leg	28,000.00
Northwest Leg	80,000.00
Total Annual Anticipated Shoaling (Beach Quality Sand) (CY/Year)	1,206,500.00
Total Annual Projected Sand Requirements (CY/Year)	907,400
Quantity Potentially Available (Annually)	295,100.00
Quantity Potentially Available (3 year cycle)	897,300

Figure 8-9: Placement Options from USACE DMMP

8.7.1.2 Bogue Inlet

There are two sources of beach compatible material within the Bogue Inlet complex. The first is the AIWW crossing which is also under USACE control. This area is dredged via pipeline dredge every 2 to 3 years, yielding an average volume of 44,000 cy placed on the western end of Emerald Isle at "the Point." This practice is expected to continue in perpetuity.

The second source of beach compatible material is the inlet throat itself. Navigation depths in the inlet have been met in the past mainly through sidecast dredging with no beneficial use of the dredged material. However, infrastructure near the Point was so threatened in the late 1990s and early 2000s that the Town of Emerald Isle and Carteret County developed an inlet relocation project to move the main channel back to a more central location away from the shorelines of Bogue Banks and Bear Island. Much work/study was done to determine the preferred inlet location (CP&E, 2004) and dimensions to not alter the inlet's tidal prism.

It is envisioned that dredged material from the Bogue Inlet throat would be utilized as a beach nourishment sand source only as part of potential future channel relocation projects, if and when such projects are required. This material within the inlet throat has been shown to be beach compatible during the past inlet relocation project as well as during analysis of recent vibracores (see Section 3.6.2.1.5). In order to estimate the approximate frequency of the need to relocate the inlet channel, a "safe box" was developed within which Bogue Inlet channel is proposed to be allowed to travel without triggering engineering activity. When the channel moves outside of the "safe box," it is proposed that relocation action should be considered.

The "safe box" extents were developed based on the studies of the historical shoreline and ebb channel centerline data discussed in Chapter 6.0. Figure 8-10 depicts the proposed "safe box" overlain on the historical channel centerlines. The channel constructed as part of the 2005 relocation project is shown in dashed blue lines. First, the inlet shorelines were studied and the eastern/western edges of the box were drawn at locations where historically infrastructure or vegetation areas had been threatened within 2-3 years. Secondly, the inlet ebb channel locations were studied. The eastern edge of the "safe box" was then drawn at a location beyond which it appears the channel historically became unstable and rapidly migrated to the east. This is a pattern that needs to be avoided due to the serious threat it proposes to Emerald Isle infrastructure. The western edge of the "safe box" was drawn at a distance from the stable vegetation on Bear Island that is approximately the same as the distance from the eastern edge to the nearest structures at the Point.

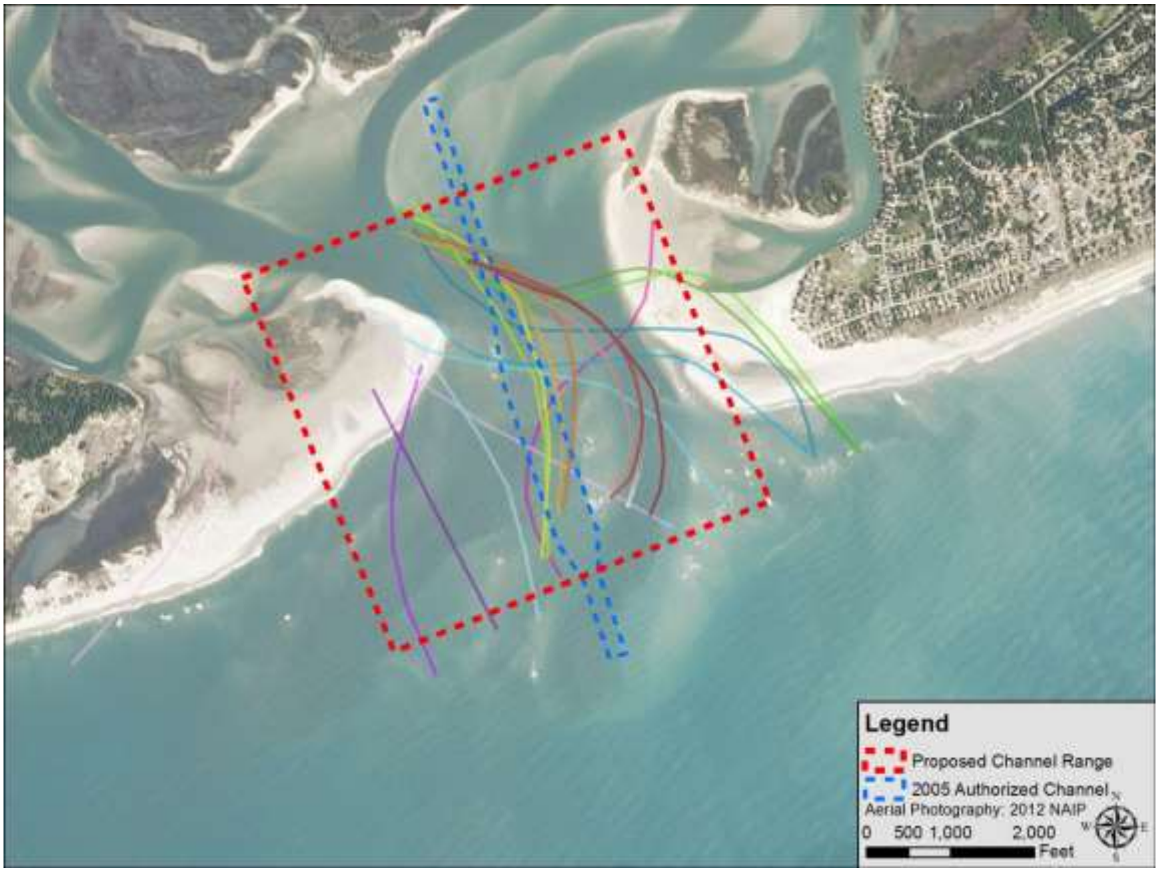


Figure 8-10: Proposed Channel Range

Based on recent USACE navigation surveys, the current eastern edge of the channel is approximately 590 ft away from the edge of the "safe box." The eastern edge of the channel has moved approximately 170 ft/yr since the 2005 relocation until the last couple of years where it has slowed to approximately 80-120 ft/yr. If this pattern continues, the inlet would likely need to be relocated within the next 5-10 years. Figure 8-11 shows the current channel alignment in relation to the proposed "safe box" and the 2005 authorized channel. The edge of the "safe box" on the Emerald Isle side is approximately 1100 ft from the nearest structure. While it may appear that this distance is conservative, it is important to note that once the channel has reached this point in the past, the movements became accelerated and structures may be threatened within a couple of years. Please also note that the reasoning of the "safe box" as well is to keep the behavior of the inlet relatively predictable. By keeping the inlet within the "safe box," natural processes are allowed until the inlet shape/location becomes such that the adjacent inlet areas become unstable.

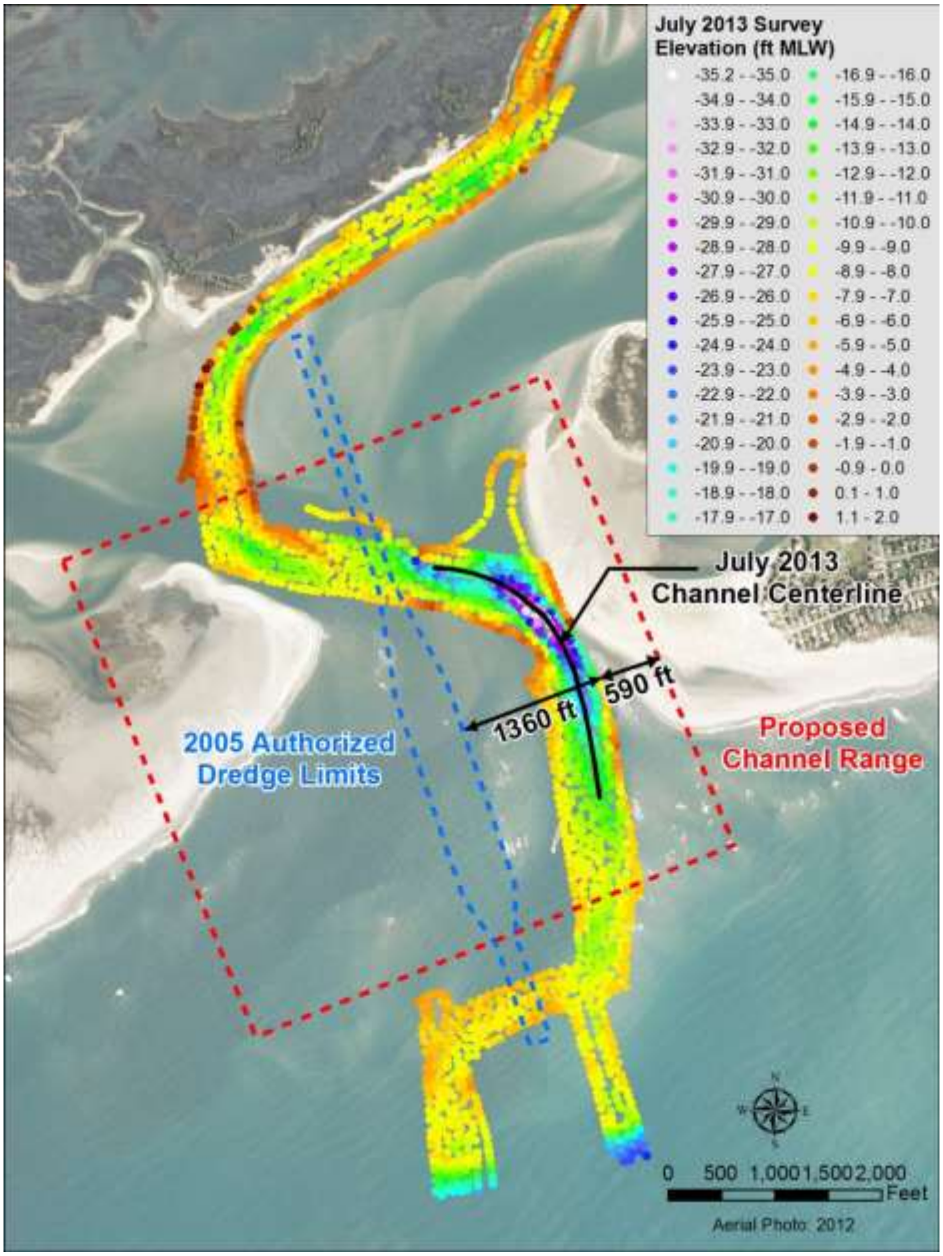


Figure 8-11: Bogue Inlet Current Channel Alignment

A program of numerical model simulations was then envisioned to confirm or revise (i.e. potentially narrow) the limits of the proposed “safe box”. The numerical model results do not indicate a channel position, rotation, or combination of parameters that suggest the initially proposed “safe box” should be revised (see Appendix A).

Based on these analytical results and the numerical modeling studies in Chapter 6.0, it would appear that the inlet relocation may need to occur every 10-15 years on average, but this number could be less or more depending on storms and changing inlet morphology. Based on current surveys of the inlet and the past project, it is estimated that about 850,000 cy of material would be available from Bogue Inlet every 10 years.

As for the effectiveness of utilizing inlet management as a way to protect the infrastructure near the Point, the Crystal Ball results were again re-examined and separate runs were made to see if the inlet shoulder volume change behavior was more variable before the inlet was moved versus after. The results were tabulated for the Bogue Inlet Reach (Transects 1-8) above elevations +1.1, -5, and -12 ft NAVD. The models were run for both the pre/during project years (1999-2005) as well as post project years (Case 1 - 2006-2012, and Case 2- 2008-2012 (to give a couple years adjustment after the project). The results showed that the range of computed annualized volume change did decrease after the inlet was relocated. The range of volume change above +1.1 ft was reduced by 40%, 23% for -5 ft, and 54% for -12 ft NAVD. The plot for -12 ft is shown below. This analysis shows that measurable reductions in inlet shoulder volume change variability can be realized using inlet relocation as a soft solution to protect adjacent inlet infrastructure and habitat with the secondary benefit of providing a needed sand source for storm protection.

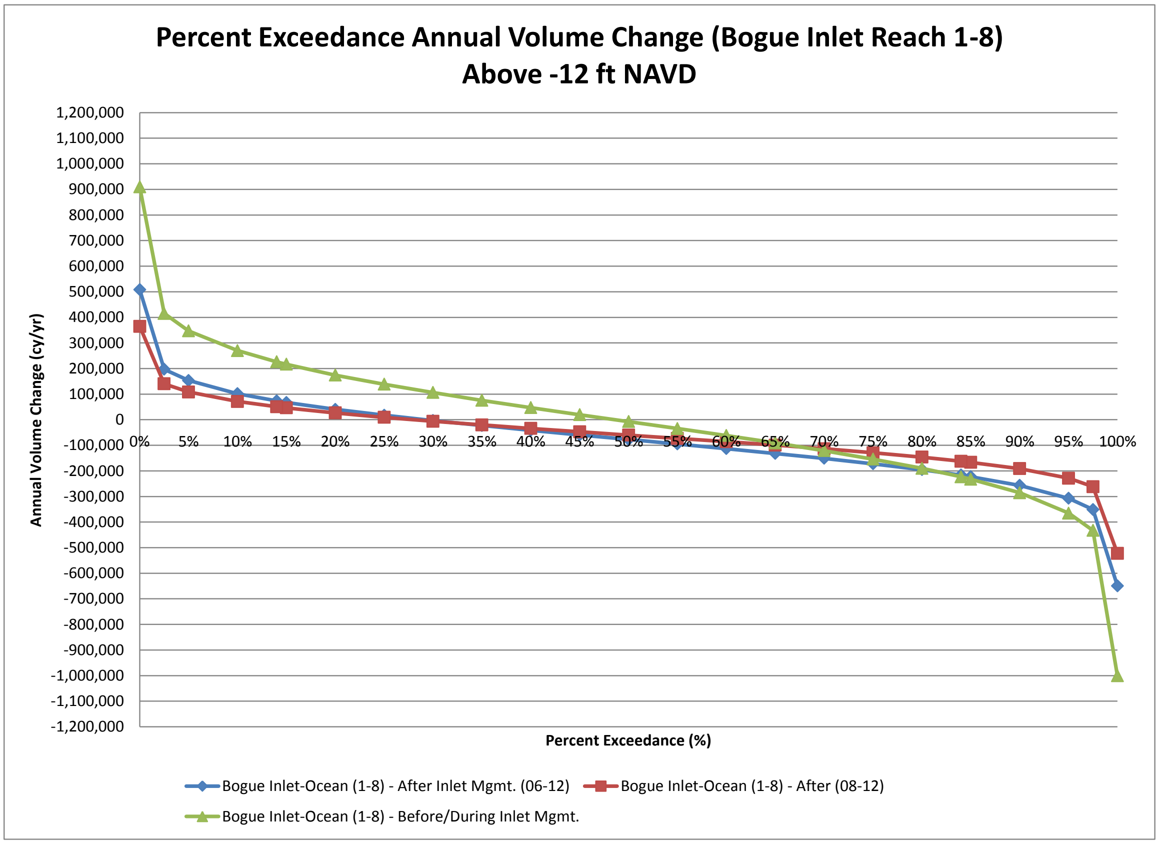


Figure 8-12: Modeled Inlet Volume Change Variability Before and After Bogue Inlet Relocation Project

8.7.1.3 Summary

In summary, non-structural inlet management is needed at both Beaufort Inlet and Bogue Inlet to meet the overall project needs. Management of these inlets will provide needed protection to the adjacent inlet shoulder volumes and infrastructure while providing the secondary benefit of a needed sand source to meet the 50-yr project sediment needs.

In addition to the upland, AIWW, and offshore borrow sources, Bogue and Beaufort Inlets could also provide material on a cyclical basis as they regularly shoal and have to be dredged for navigation purposes. **These renewable borrow areas could potentially provide approximately 25,130,000 cy over 50 years, as shown in Table 8-10, which, by itself, is not enough to cover the 50 year need.**

Table 8-10: Volume of Renewable Potential Borrow Areas (Coastal Tech, 2013)

Area	Section	Volume	Dredging Frequency	50 yr Total
MHC Outer Harbor	Cutoff+Range A to STA 110	400,000 cy (assumed)	1 years	20,000,000
Bogue Inlet	Inlet Relocation	850,000 cy	10 years	4,250,000
	AIWW Crossing	44,000 cy	2.5 years	880,000
			Totals:	**25,130,000**

However, if all mentioned sources are incorporated (upland, AIWW, offshore, and inlets) approximately 50,253,057 cy of material would be available and would meet or come very close to meeting the 50-year sediment need of 45 Mcy to 49.8 Mcy (46.8 to 51.6 Mcy with potential sea level change). The total volume available when the renewable and non-renewable sources are combined is tabulated in Table 8-11.

Table 8-11: Total Volume Available

Source	50-Yr Total Volume (cy)
Renewable	25,130,000
Non-Renewable	25,123,057
TOTAL	**50,253,057**

8.7.2 Structural Inlet Management

In addition to soft inlet solutions, it was decided that structural inlet management should also be considered given the new rules in the legislature allowing pilot terminal groin structures in four (4) locations. This section includes a desktop examination of the historical shoreline position and change rate in an effort to identify the area of influence Bogue Inlet has on the adjacent Bogue Banks shoreline. Three terminal groin configurations were developed and their effects on the adjacent Bogue Banks shoreline were analyzed using two different methods. The objective of this analysis is to determine the appropriate length of terminal groin for Bogue Inlet and show its effects on the Bogue Banks shoreline. The Bear Island shoreline was not analyzed because the terminal groin lengths considered were relatively short and their influence would not extend the more than 4,000 feet across the inlet's shoals to Bear Island. Based on past studies, the primary sediment source for the eastern end of Bear Island is the ebb-shoal and not the sediment bypassing from Bogue Banks across Bogue Inlet.

8.7.2.1 Historical Shorelines and Shoreline Change

A review of historical shoreline data in the vicinity of Bogue Inlet was conducted to understand the long-term shoreline change trends within this region and the shoreline response to Bogue Inlet. Digitized shorelines were obtained for a number of historical and recent dates and analyzed using GIS methods. The shorelines used in this analysis are listed in Table 8-12.

Table 8-12: Bogue Inlet Historical Shorelines

Data Collection Date	Surveyor
1871	USGS
1933	USGS
November 1949	NC DCM
November 12, 1958	NC DCM
August 1, 1971	NC DCM
1973	USGS
August 11, 1976	NC DCM
July 9, 1987	NC DCM
June 17, 1992	NC DCM
1997	USGS
June 26, 1998	NC DCM
June 15, 1999	Coastal Science and Engineering
May 15, 2002	UNC Institute of Marine Sciences
February 2003	UNC Institute of Marine Sciences
September 19, 2003	NC DCM
August 30, 2004	NC DCM
May 2006	Coastal Science and Engineering
May 2007	Coastal Science and Engineering
July 2008	Geodynamics, LLC
July 11, 2009	NC DCM
June 15, 2010	Geodynamics, LLC
June 1, 2011	Geodynamics, LLC
April 11, 2012	Geodynamics, LLC

These shorelines and transects where shoreline change was calculated are shown in Figure 8-13. Information related to engineering projects in the Bogue Banks area was compiled and is important to note when analyzing the shoreline change rate. The engineering activities log was compiled from previous work and Table 4-9 presents all engineering activities including beach nourishment and structure construction completed for the entire Bogue Banks shoreline between 1961 and 2013.

Figure 8-13: Bogue Inlet Historical Shorelines

The Bogue Banks beach monitoring program's established baseline and transects were used for this analysis. The distance from the baseline to the shoreline was measured along each transect. Shoreline change rates were computed by dividing the change in shoreline position by the amount of time between each data set. The results from the shoreline change analysis are shown in Figure 8-14. A large variation in the shoreline change rates exists due to the influence of Bogue Inlet within the first quarter mile between Transects 1 and 4. This variation diminishes farther east of the inlet and reaches a relative equilibrium at Transect 10. Therefore, Transect 10 was noted as the farthest point east along the Bogue Banks shoreline that is effected by Bogue Inlet and was noted in the follow section as the terminating point that was considered for estimating updrift effects.

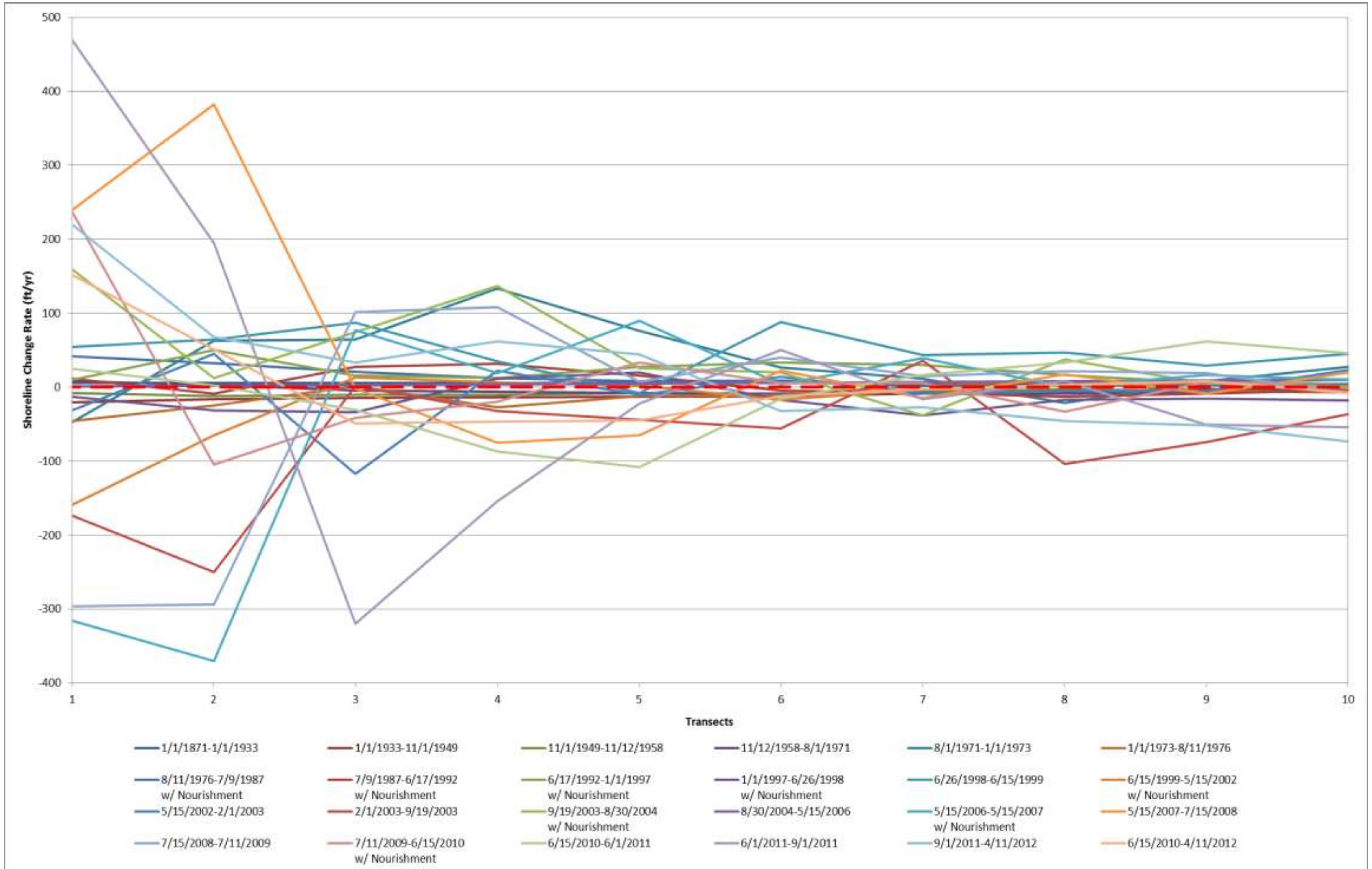


Figure 8-14: Shoreline Change Analysis Results

8.7.2.2 Function of a Terminal Groin

Terminal groins are structures built at the end of littoral cells to reduce shoreline erosion due (in this case) to inlet processes by conserving sand along the end of the beach. These structures extend into the nearshore zone and act as a barrier to the longshore transport of sediment, and they are often constructed on the updrift side of a tidal inlet. Once the terminal groin fills with sediment – as the beach accretes to the end of the groin and is called a *fillet* – additional sand will bypass the structure and enter the tidal inlet. The proper design of a terminal groin permits the longshore transport of sand around and over the structure once the beach fillet is has developed. Commonly, terminal groin construction is done in combination with beach nourishment so that the groin does not capture existing sand reservoirs. During high wave energy events, the beach along the fillet often erodes and the sand is mobilized. Once depositional wave conditions return and the normal longshore transport system is reestablished, the fillet is reconstructed by natural processes.

8.7.2.3 Shoreline Erosion Associated with Terminal Groin

Bogue Inlet is a highly dynamic system where the seaward extents of the shoreline can change rapidly. The inlet channel migrated 1,350 feet eastward in just 5 years between 1987 and 1992, to a position within 342 feet of the Bogue Banks shoreline at the Point. Therefore, a terminal groin was evaluated as a last line of defense if the inlet begins to migrate back eastward towards these homes and the inlet shoreline threatens them.

Two different methods were used to model the formation of the fillet due to the potential construction of a terminal groin on the updrift side of Bogue Inlet. The first is based on the average shoreline change rates found for similar structures from the recent Terminal Groin Study performed for the State of North Carolina (M&N, 2010). The second method uses the analytical model of shoreline evolution for a littoral barrier as described in Dean and Dalrymple (2002). Both methods were used to determine the displacement of the August 1971 shoreline and the April 2012 shoreline caused by three different groin lengths of 1000 feet, 1250 feet, and 1500 feet, as shown below in Figure 8-15. Please note that the terminal structure was envisioned to connect to the bulkhead along the Coast Guard Channel to protect the structures as well as prevent flanking. The August 1971 shoreline was included in this analysis to show the effects on the shoreline if it were to return to a threatening state at some point in the future. The April 2012 shoreline was included to show the effects of a terminal groin on the most current and representative shoreline position.

Figure 8-15: Terminal Groin Options with August 1971 Shoreline and April 2012 Shoreline

8.7.2.4 <u>Method 1: Based on Terminal Groin Study (M&N, 2010)</u>

The purpose of this section is to summarize methodology presented in the Terminal Groin Study by Moffatt & Nichol and describe how it is applied at Bogue Inlet.

8.7.2.4.1 Description of Method

The Terminal Groin Study assessed the effectiveness and impacts of terminal groins at five study sites along the southeastern Atlantic and Gulf coasts. This region was chosen since these coastal areas are most likely to be similar to North Carolina in terms of the physical setting and environmental influences. Assessing the shoreline behavior and changes in the vicinity of the structures ultimately provides one of the best tools to assess the impact of the terminal groins. In order to quantify the impacts of the terminal groins, shoreline changes were calculated in the vicinity of the terminal groins at each of the five study sites, which consisted of both long and short terminal groins as well as non-permeable (non-leaky) and permeable (leaky) structures. The length and type of each structures are listed in Table 8-13.

Table 8-13: Five Study Sites from Terminal Groin Study

Groin	Length (ft)	Type
Oregon Inlet, NC	1500	Non-leaky
Fort Macon, NC	1530	Non-leaky
Captiva Island, FL	350	Non-leaky
John's Pass, FL	460	Non-leaky
Amelia Island, FL	1500	Leaky

The permeable structure was designed to reduce the longshore transport rate while allowing sediment to pass through the structure in efforts to mitigate adverse effects along the adjacent spit. The only mode of sediment bypass for the non-permeable structures is around the end of the groin.

All five of these sites have sand management activities, including beach nourishment, as part of the overall project. A ratio was found correlating the amount of beach volume placed to shoreline change enabling shoreline change rates without the effects of nourishment to be estimated. These ratios are listed in Table 8-14.

Table 8-14: Ratio of Nourishment Volume to Shoreline Change

Groin	Ratio of Volume Placed to Shoreline
Oregon Inlet	1.41
Fort Macon	1.01
Captiva Island	1.25
John's Pass	0.74
Amelia Island	0.91

Shoreline data for both pre- and post-construction of the terminal groins was collected where available. The rates of shoreline change for a distance of three miles along the adjacent shoreline were computed for each site. The groins presented were not all constructed on the updrift side of the inlet. Due to the high variability within the first mile of the terminal groin, shoreline change rates were calculated every quarter mile. The difference in shoreline change rate was then taken between pre- and post-construction to yield a net shoreline change rate. These values were also calculated with and without nourishment. The resulting shoreline change values for Oregon Inlet and Fort Macon were averaged to produce a composite response for a non-leaky long groin with an effective groin length of 1500 feet. Similarly, Captiva Island and John's Pass were averaged to produce a composite response for a non-leaky short groin with an effective groin length of 405 feet. These results for the difference in shoreline change rate with and without nourishment effects are shown in Figure 8-16 and Figure 8-17 respectively. The long groins with and without the effects of nourishment have a large effect on the within the first half mile then quickly decay in the subsequent miles. The short groin has a minimal effect on the shoreline over the entire length.

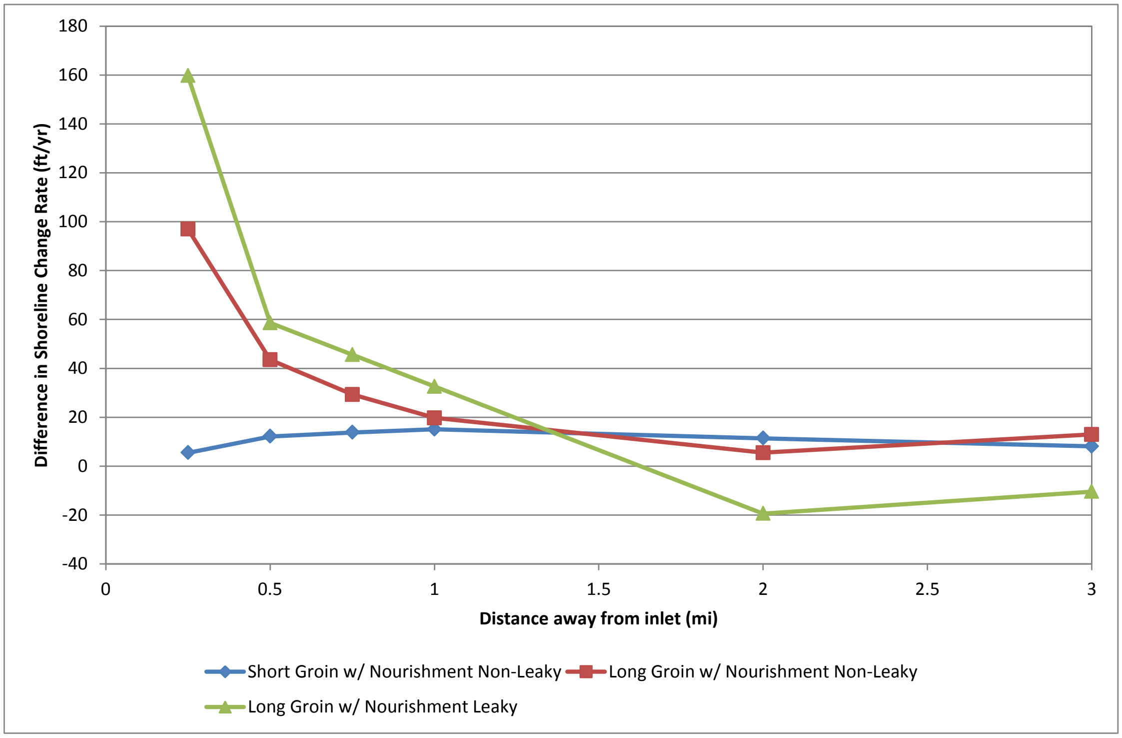


Figure 8-16: Difference in Shoreline Change Rate With Nourishment Effects

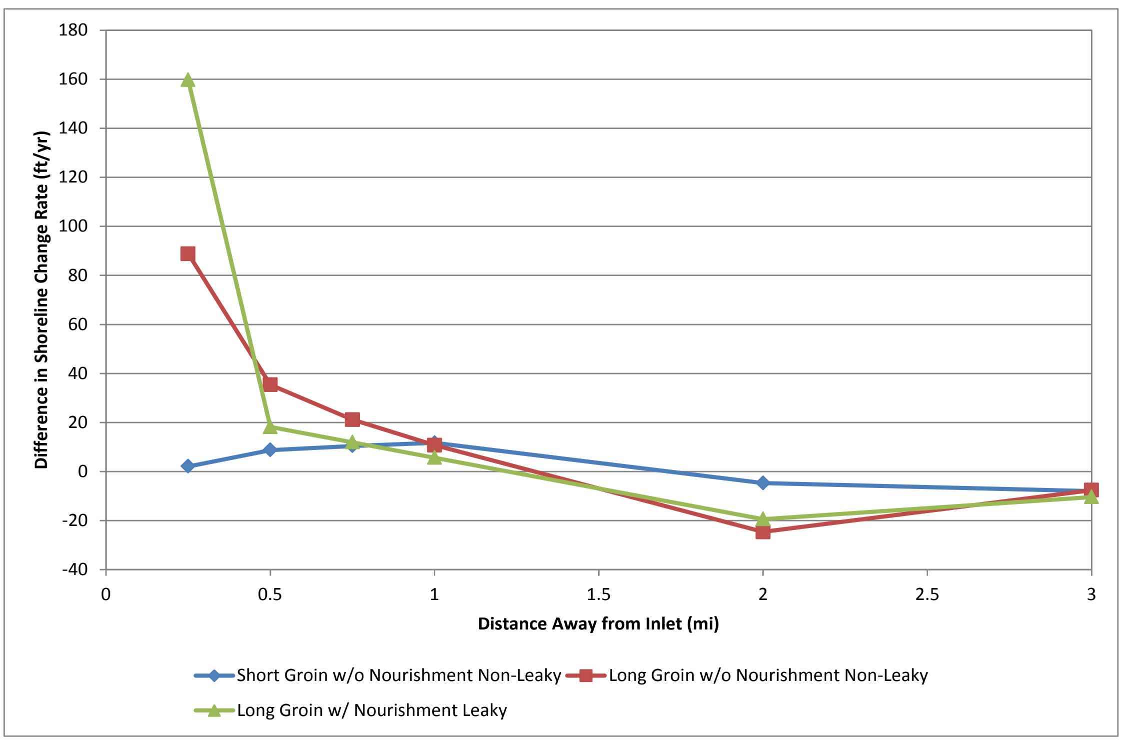


Figure 8-17: Difference in Shoreline Change Rate Without Nourishment Effects

8.7.2.4.2 Application at Bogue Inlet

The shoreline change rate in the first quarter mile was used to find the time it would take for each shoreline fill each of the three terminal groin lengths. That time was then used to find the displacement in shoreline using the rates in Figure 8-16 and Figure 8-17 along the remainder of the shoreline. The shoreline displacement due to the 1250 foot groin was found by interpolating the shoreline change rates between the long groin (1500 feet) and the short groin (405 feet). The shoreline displacement found for all three groin lengths was applied to the 1971 and 2012 Bogue Banks shorelines yielding the possible range in effects based on the original shoreline position as shown in Figure 8-18. The effects from the 1250 foot groin are minimal on the updrift shoreline and rejoin with the original shoreline around Transect 4. The effects from the 1500 foot groin are seen farther updrift of the inlet with negative effects (shoreline recession) between Transects 8 and 10. From this method, the 1250 foot groin performed reasonably within the immediate vicinity of the inlet, with minimal effects on the shoreline updrift of Transect 4.

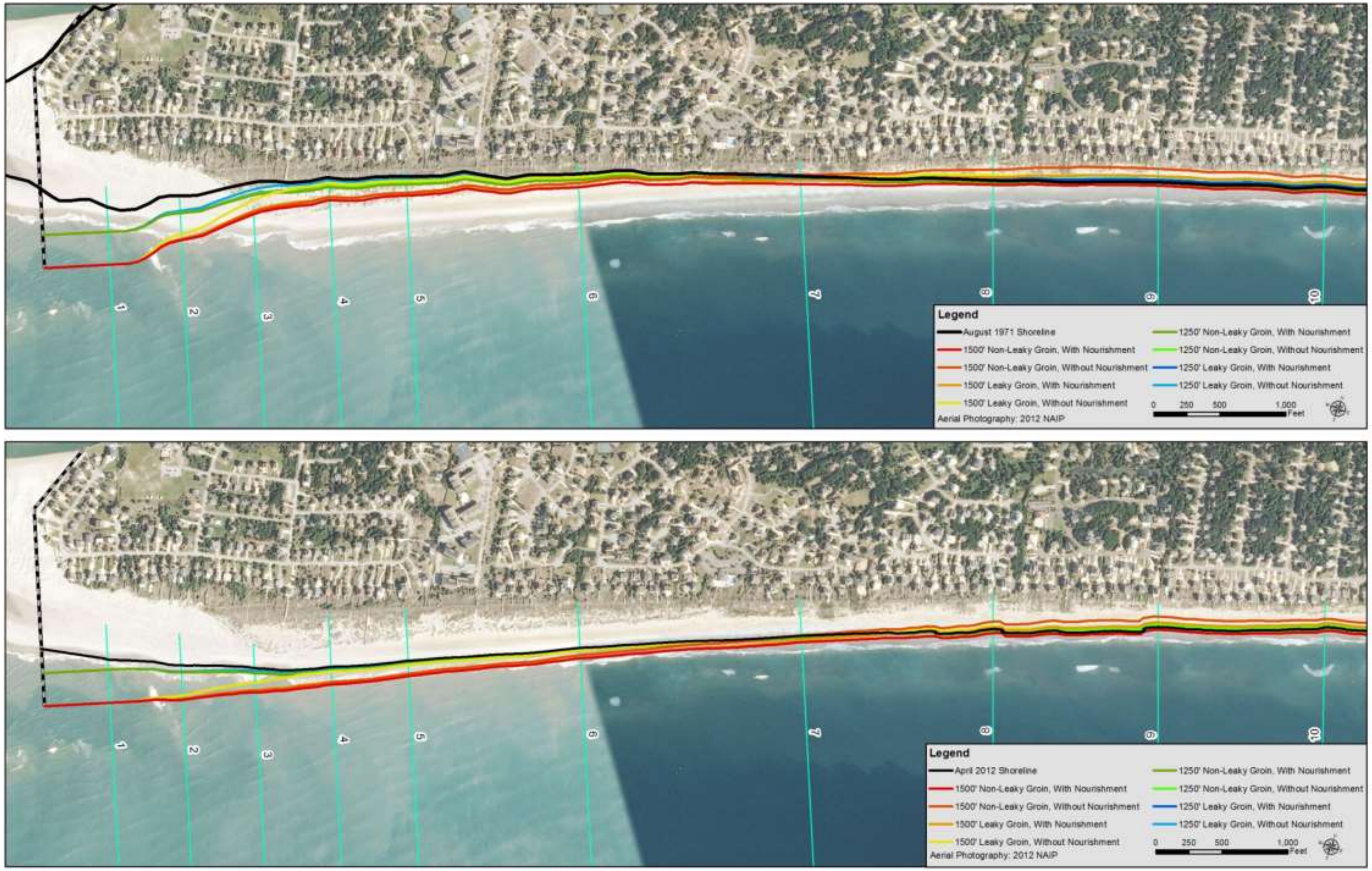


Figure 8-18: Method 1 Results for August 1971 and April 2012 Shorelines

8.7.2.5 Method 2: Analytical Solution

The purpose of this section is to summarize methodology used to solve the analytical solution for the shoreline evolution at a littoral barrier and describe how it is applied at Bogue Inlet.

8.7.2.5.1 Description of Method

To estimate the shoreline changes updrift of the example terminal groin, an analytical prediction of shoreline change at a littoral barrier was calculated by the following equation (Dean and Dalrymple, 2002):

$$y(x,t) = \pm\left[\sqrt{\frac{4Gt}{\pi}}e^{-x^2/4Gt} - |x|erfc\left(|x|\sqrt{4Gt}\right)\right]\tan\delta_b$$

where, y is the change in shore perpendicular distance, x is the distance away from the structure, t is the time at which the shoreline is calculated, G is the longshore diffusivity, erfc is the complementary error function, and δ_b is the breaking wave angle. This equation was solved for the time of incipient bypassing, where the shoreline fillet builds up to the end of the three structures. The assumptions made to solve this equation were an impermeable structure, a characteristic breaking wave height, and a background longshore transport rate.

The analytical solution does not take into account wave diffraction due to the presence of the ebb-tide delta. Wave diffraction is important to shoreline evolution around a tidal inlet (Work and Dean, 1990). This process would be necessary to include in a future detailed analysis of this system if a terminal groin were to be designed in detail for construction.

8.7.2.5.2 Application at Bogue Inlet

Two cases were defined based on the net transport rate modeled by Olsen (2004) and the results of the GENESIS modeling in the vicinity of Bogue Inlet performed in this present study. Olsen (2004) showed that the annual longshore transport 15,000 feet from the inlet was approximately 450,000 cy/yr. The GENESIS modeling from the present report found an annual longshore transport rate at the inlet of approximately 550,000 cy/yr. The net direction of longshore transport in this region is to the west. The two cases used in this analysis are listed below in Table 8-15. Each case used a characteristic breaking wave height of 2.8 feet (0.85 meters). This wave height represents approximately the 50th percentile wave height at a position just outside Bogue Inlet from a 1998 – 2012 long-term simulation using the regional wave transformation model.

Table 8-15: Annualized Longshore Transport Rate Cases

Case	Longshore Transport Rate
Q1	500,000
Q2	600,000

The results from this analysis were applied to the August 1971 and the April 2012 shorelines and are shown in Figure 8-19. The difference between the two longshore transport cases is minimal with Q2 having slightly less of an impact updrift of the inlet for each of the groin lengths. The shorelines produced for the 1971 shoreline show a larger impact updrift of the inlet for the 1250 and 1500 foot groin lengths, which was expected because of the larger distance required to fill the groin. The original position of the April 2012 shoreline extended out past the 1000 foot terminal groin; therefore, the terminal groin would essentially hold the current shoreline position. The resulting shoreline from the 1250 foot groin rejoined with the original April 2012 shoreline between Transects 6 and 7. The 1250 foot groin performed with minimal effects on the shoreline updrift of Transect 6.

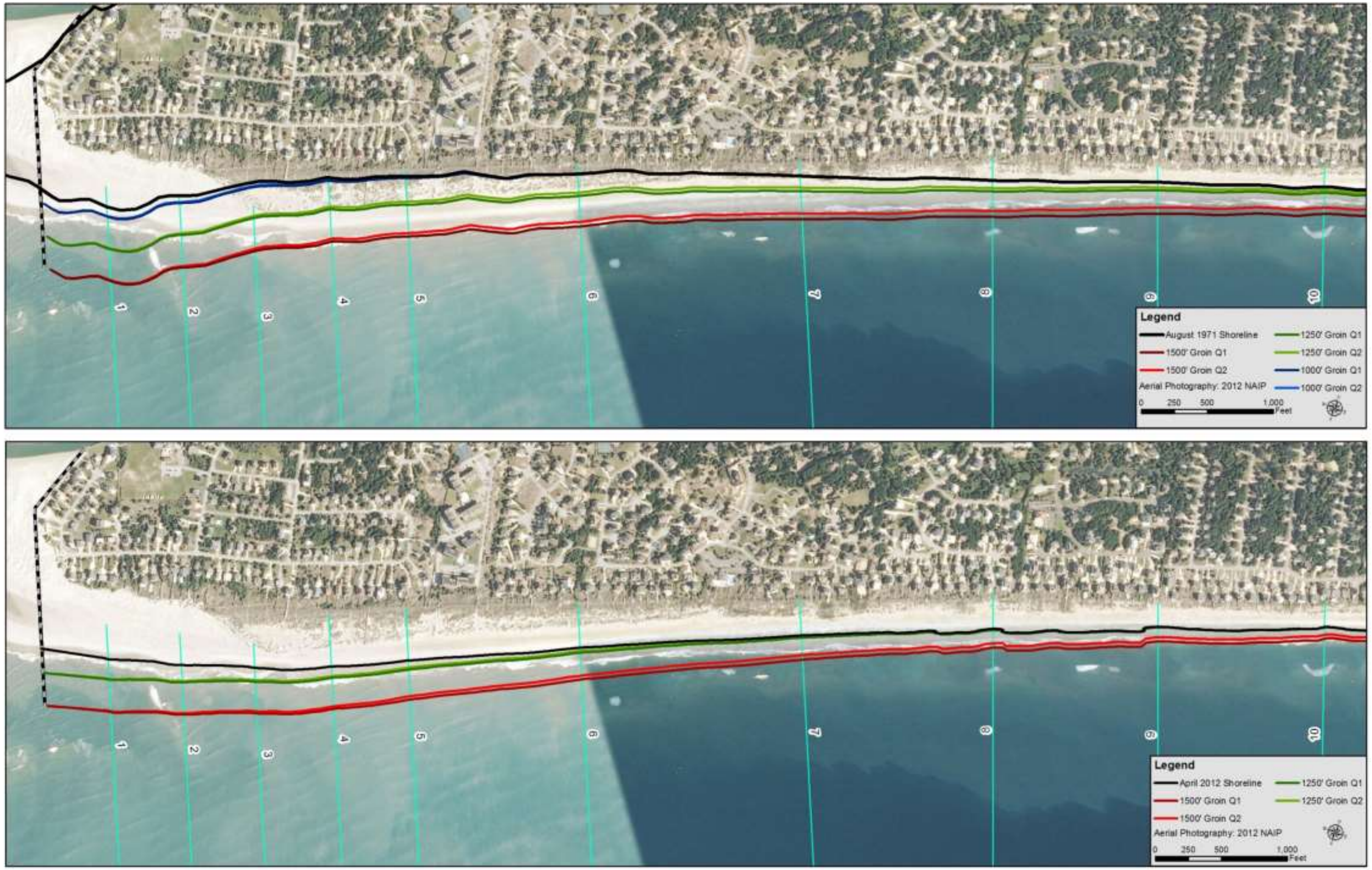


Figure 8-19: Method 2 Results for August 1971 and April 2012 Shorelines

8.7.2.6 Nourishment Reduction

The purpose of this section is to define the reduction in nourishment need for the Bogue Banks shoreline adjacent to Bogue Inlet due to the construction of a terminal groin and develop an estimate of potential nourishment cost savings as a result of terminal groin construction. This reduction was found based on the analysis performed in the Terminal Groin Report (M&N, 2010).

The five sites from the Terminal Groin Report were Oregon Inlet, Fort Macon, Amelia Island, Captiva Island, and St. John's Pass. These sites were analyzed based volume change within the first two miles as well as groin length in order to identify the most compatible sites to Bogue Inlet. The volume change at Amelia Island, Captiva Island, and St. John's pass was highly variable and the groin lengths were much shorter than the one proposed at Bogue Inlet. Therefore, these sites were removed from the analysis. The volume change and groin length of the remaining two sites, Oregon Inlet and Fort Macon, would best represent a potential 1250' terminal groin at Bogue Inlet and the reduction was found based on the following analysis.

The total volume change for each site, before and after terminal groin construction, was found over the first two miles of the adjacent shoreline. All nourishment events were removed from the volume change records so that the background volume change rates were analyzed. The percent change was then found due to the construction of the terminal groin. A positive value indicates a reduction in volume loss. The percent change from each site was averaged to yield a representative reduction. This reduction is directly correlated to the reduction in nourishment need per year.

8.7.2.6.1 Oregon Inlet

Volume change data prior to the construction of the terminal groin at Oregon Inlet was available from 1949 to 1980 and 1984 to 1988. These two data sets were pro-rated over the 35 year record to give one combined data set prior to terminal groin construction. Volume change data after the construction of the terminal groin was available between 1997 and 2007. The total volume change from this data set was compared over the first two miles of the Pea Island shoreline and the percent change was calculated to analyze the change in sediment loss due to the terminal groin. For Oregon Inlet, the sediment loss was decreased by 43%, as shown in Table 8-16.

Table 8-16: Volume Change Without Nourishment – Pea Island (cy/yr)

Distance from Inlet (mi)	0 - 0.25	0.25 - 0.5	0.5 - 0.75	0.75 - 1	1 - 2	Total 0-2
Pre: 1949 - 1980	*-193,147*	*-47,638*	*-26,432*	*-16,255*	*-62,578*	
Pre: 1984 - 1988	*-417,272*	*-169,950*	*-134,769*	*-76,673*	*-170,340*	
Pre: Pro-rated	-218,761	-61,617	-38,813	-23,160	-74,894	-417,245
Post: 1997 - 2007	-423	-5,666	-17,027	-21,592	-192,638	-237,346
Percent Change						**43.1%**

8.7.2.6.2 Fort Macon

Volume change data prior to the construction of the terminal groin at Fort Macon was available between 1933 and 1946. The volume change data after the construction of the terminal groin was available between 1971 and 2004. The total volume change from this data set was compared over the first two miles of the Bogue Banks shoreline and the percent change was calculated to analyze the change in sediment loss due to the terminal groin. For Fort Macon, the sediment loss was decreased by 65%, as shown in Table 8-17.

Table 8-17: Volume Change Without Nourishment – Fort Macon (cy/yr)

Distance from Inlet (mi)	0 - 0.25	0.25 - 0.5	0.5 - 0.75	0.75 - 1	1 - 2	Total 0-2
Pre: 1933 - 1946	-97,737	-77,677	-52,840	-33,886	13,607	-248,533
Post: 1971 - 2004	1,135	-13,419	-16,630	-16,971	-40,132	-86,017
Percent Change						**65.4%**

8.7.2.6.3 Summary

These two cases were averaged together to produce a representative reduction in the volume change of **54.3%**. The annualized erosion rate for Bogue Banks within the first 2 miles of Bogue Inlet (Transects 1 – 11) is -44,852 cy/yr. Applying this reduction factor, the annualized erosion rate would be reduced by 24,485 cy/yr. This reduction in volume loss will reduce the nourishment need by **24,334 cy/yr** along the Bogue Banks shoreline. Given that the proposed terminal groin length would be roughly 83% of the Fort Macon and Oregon Inlet terminal groin, the expected reduction in volume would be **20,278 cy/yr**. If a leaky groin were ultimately required to be built, the reduction would likely be less. Nonetheless, at $12/cy (assumed pipeline project), the nourishment reduction benefit could be up to $243,340/yr.

8.7.2.7 <u>Overall Findings</u>

From the results of this analysis, the 1250 foot terminal groin was chosen to best suit the needs of shoreline management at Bogue Inlet. The effects of this length groin updrift of the inlet are minimal while providing a last resort protection to the homeowners adjacent to the inlet. The results from the two methods described above are shown in Figure 8-20. Given concerns about the spit, it is expected that the 1250 ft option would continue to require nourishment and that at least a portion of the groin would be designed to be porous to allow some sediment transport through the structure.

The influences of a potential terminal groin on the morphology of the adjacent beach and inlet shorelines were investigated using the local 2-D model of Bogue Inlet. Two iterations of the representative tide and wave time series (discussed in Appendix A as Simulation Package A) were run for a model starting condition including the 1250 foot terminal groin built into surveyed 2005 inlet bathymetry. The results of this simulation were compared to a simulation without the terminal groin. The "without groin" surface was subtracted from the "with groin" surface, and the resulting difference in bed elevation is shown in Figure 8-21.

The model indicated that some accretion of the eastern inlet shoulder and spit in the simulation without the terminal groin. For that reason, the model run with the terminal groin did not show much beach and nearshore elevation difference compared to the "without groin" run. The primary difference in morphology that did appear with the groin is an increase in elevation on the inlet side of the groin. The model showed an increase in bed elevation of between 0.25 and 0.35 meters (0.8 to 1.1 feet) over an distance the equivalent of 950 feet, with an area of approximately 22 acres.

This result indicates that the presence of a 1250 foot terminal groin at this location on the eastern shoulder of Bogue Inlet would not be likely to have an erosional impact on the spit currently existing between The Point and the waters of Bogue Inlet.

Minor differences are shown within the Bogue Inlet ebb channel, where the "with groin" model shows the channel becoming slightly deeper on its western edge. The model simulation does not indicate adverse impacts on Bear Island.

The groin is estimated to reduce the nourishment need by **20,278 cy/yr** along the Bogue Banks shoreline based on the annual erosion rate in the vicinity of the inlet and the reduction in erosion seen at Oregon Inlet and Fort Macon after structures were built at these locations. If a leaky groin were ultimately required to be built, the reduction would likely be less. Nonetheless, at $12/cy (assumed pipeline project), the nourishment reduction benefit could be up to $243,340/yr.

Figure 8-20: 1250 ft Groin

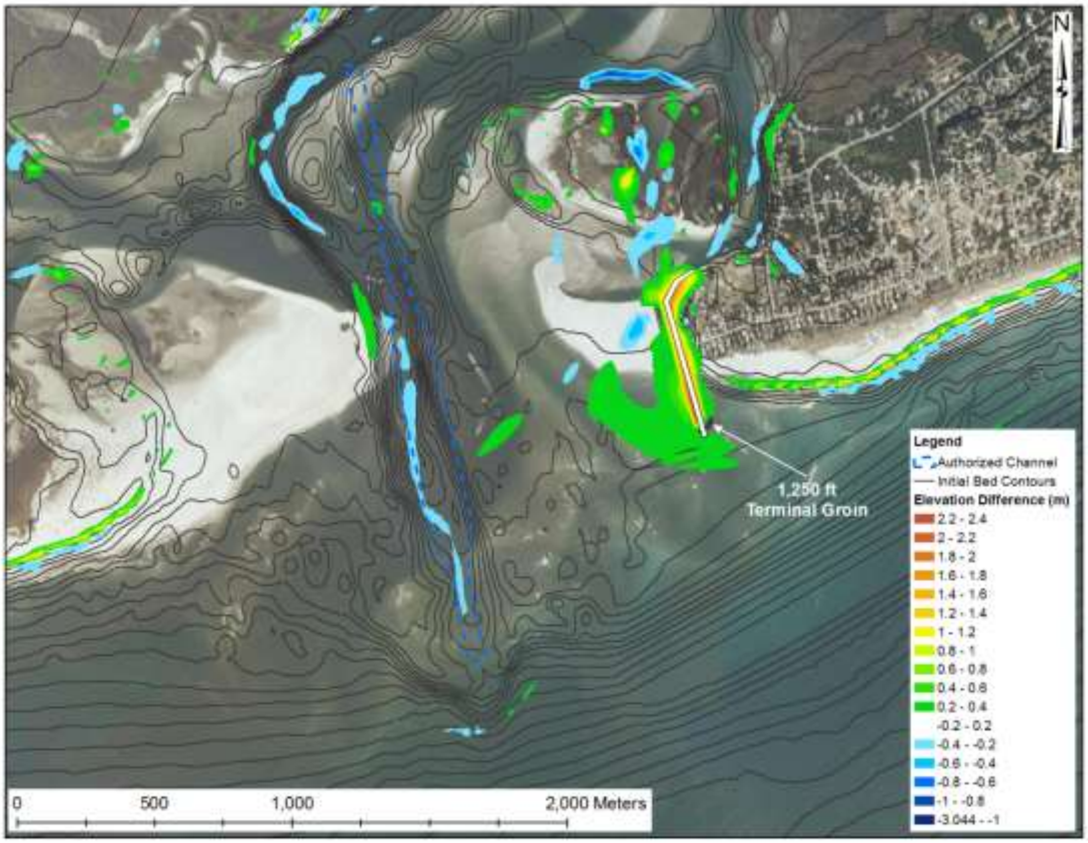


Figure 8-21: Model Simulated Difference in Bed Elevation With Terminal Groin

8.7.2.8 <u>Cost</u>

Based on similar designs of terminal groin structures and the current structure cross-section at Fort Macon, the expected cost per linear foot of groin is expected to be $3,000 – $4,000. This would entail an initial cost of $3.8- 5.0M and would still require ongoing beach nourishment costs as well to be sure that the effects on adjacent shorelines are minimal. As discussed in a previous section, the reduction in nourishment costs could reach $243,340 per year. Using this result, the terminal groin structure would pay for itself in 15-20 years. **However, given that Bogue Inlet would still have to be relocated to ensure that the terminal groin were never undermined and therefore inlet management would still have to be completed, this alternative was dropped from further consideration.** Given the historical behavior of the inlet and its past history of moving considerably along the inlet corridor from Bear Island to the Point at Emerald Isle, the terminal groin itself could not be counted on alone to provide adequate inlet stability. Given the past behavior at the Point, it would be impossible to say that inlet management would never be required even if a terminal groin were built.

8.7.3 Structural and Non-Structural Inlet Management (Hybrid Approach)

Lastly, given the above findings, a hybrid approach was also considered utilizing inlet relocation and construction of a terminal groin at Bogue Inlet. Again, since the inlet studies completed to date by CPE and M&N show that the inlet stability and the behavior of the inlet movement is more related to the interplay of all the complex hydrodynamics of the inlet itself, all the backchannels (White Oak, Bogue Sound, etc.) and the ebb shoals, it is believed that non-structural inlet management must be completed whether a terminal groin structure is needed or not. Therefore, the decision to move forward with the addition of a terminal groin structure then becomes a decision as to whether the relative increase in inlet stability and possible reductions in beach nourishment need are worth the additional expense. At this time, the analyses to date show that the Town of Emerald Isle and the County would need to raise an additional $4 - 5.0M to build the terminal groin structure and would take 15-20 years to pay for itself in reductions in nourishment costs. Since the inlet shoulders volume change variability has been approximately cut in half since the inlet has been relocated, and the additional monies would require special bonding or many years or reallocation of beach nourishment funding, it was decided that it would be most prudent to drop this alternative from further consideration. It was decided that the most prudent path forward would be to utilize non-structural inlet management since it has proven to be so successful thus far. If storms or other conditions warrant, a separate environmental document could be completed at a later date for inclusion of a terminal groin structure at Bogue Inlet. Also, since the current laws only allow four (4) terminal structures to be permitted and four (4) are already being planned, it was decided that this option may not be feasible from a legal perspective. Therefore, it was dropped from further consideration.

8.8 Alternative Cost Comparison

A cost estimate for each the finalized alternatives was developed based on various criteria including nourishment costs, relocation costs, and structure costs, as well as lost property value and tax revenue. The following presents a description of the cost analysis for each alternative. It should also be noted that the amount of material placed in Atlantic Beach for the nourishment costs is equivalent to the volume of material planned for placement, not the actual volume need. Please also note that all costs are based on current values simply multiplied over a 50 year period – no effects of inflation and/or interest were considered. Lastly, it should also be noted that each alternative with planned, engineered nourishment/inlet management had the same estimate for storm erosion costs given the uncertainty of this factor and since it is expected that FEMA funds will be utilized for these storm recovery efforts given the fact that the Towns of Emerald Isle, Indian Beach/Salter Path, and Pine Knoll Shores along Bogue Banks have developed an engineered beach.

<u>No Action Alternative</u>

As stated previously, this alternative consists of continued nourishment by the USACE on Atlantic Beach using material from Morehead City Harbor (MHC) and at the Point adjacent to Bogue Inlet using material from the Bogue Inlet AIWW crossing. Given that under this alternative, infrastructure at the Point would likely be threatened in the future, two (2)

Bogue Inlet relocation projects were also included in this alternative. Given the recent behavior of the Bogue Inlet Channel (moving ~170 ft/yr during the first 9 years and ~100 ft/yr over the last few), it is estimated that the channel would be up against infrastructure at the point every 20-25 years after a relocation project. Therefore, it could be expected to occur twice over a 50 year period. This would provide a total of approximately 1.7Mcy (850,000 cy/event) and this volume would meet the need of both the Bogue Inlet and Emerald Isle West reaches over the project life (~1.5 Mcy).

It is expected that limited nourishment at hotspots within Emerald Isle and Pine Knoll Shores based on historical losses would also be completed. The hotspot areas are shown in **Figure 8-22** below and were identified after computing background erosion rates (subtracting out nourishment effects) for monitoring profiles across the island.

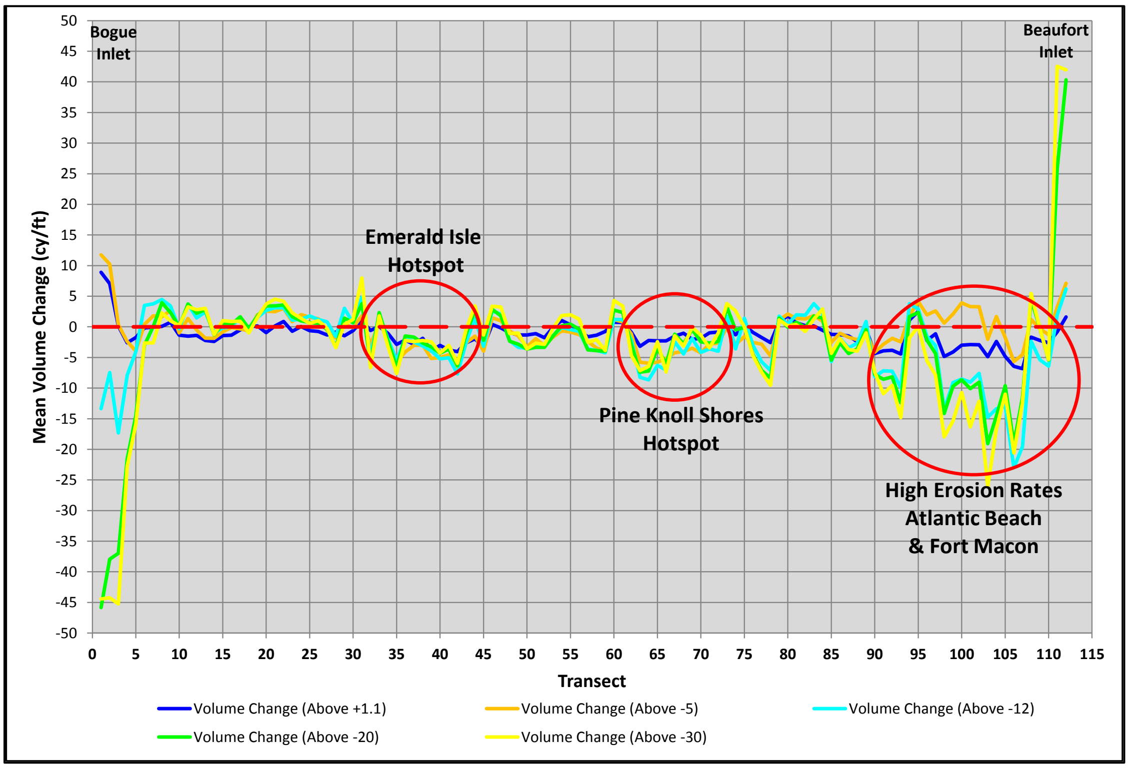


Figure 8-22: Bogue Banks Mean Volume Change Rate (Background Rate with Nourishment Subtracted Out)

After the hotspot areas above were identified, an annual loss rate for those areas of 90,542 cy was computed utilizing the same procedures outlined in Section 4.2.2 in the Engineering Report. Given mob/demob costs, it is expected that these hotspot areas would be nourished with a ~1Mcy project that would occur once every ~11 years. This entire nourishment cost for this alternative is estimated to be approximately $330.4 million over the next 50 years.

In addition to the cost of nourishment, there would be a number of properties at risk of due to the absence of nourishment to keep up with the background erosion rates for a majority of the island and storm erosion for the entire island. Based on the using the 2004 NC Division of Coastal Management shoreline erosion rates (selected since this erosion rate would only have MHC and Bogue Inlet AIWW nourishment activities within it – the most recent shoreline erosion rates would have nourishment effects across the entire island), it was determined that there were oceanfront 226 properties at risk in this alternative over the next 50 years (annual raw rate multiplied by 50 years). Please note that the properties at risk within the Bogue Inlet and Emerald Isle West reaches were set to zero since the amount of sand provided by the AIWW maintenance and the two Bogue Inlet relocation projects was more than adequate to meet the need.

It should also be noted that the number of properties at risk for the Emerald Isle – East (81) and Pine Knoll Shores (184) reaches computed by this method were reduced based on the ratio of nourishment volume provided for the hotspot areas versus the required nourishment volume for the reach (75% and 51%, respectively) to end up with the final values of 61 properties at risk for Emerald Isle-East and 94 properties at risk for Pine Knoll Shores. The average oceanfront property value along Bogue Banks was determined to be approximately $1.7 million (see Table 8-4 of Engineering Report). Based on these numbers, lost property value could total $392.9 million. In addition to the lost property value, annual tax revenue would also be lost. Based on the tax rates for municipalities along Bogue Banks, approximately $96.6 million in tax revenue would be lost over 50 years. See **Table 8-18** below for a summary of this alternative.

The cost of nourishment as well as lost property value and tax revenue totals $819.8 million over the next 50 years for the No Action Alternative.

Table 8-18: No Action Alternative Cost Summary

Average Oceanfront Property Value	$1,738,184
Average Non Oceanfront Property Value	$287,158

PROPERTY VALUE/TAX REVENUE				
Management Reach	**Number of Properties at Risk**	**Total Property Value ($)**	**Tax Rate (County + Local)**	**50 yr Tax Revenue ($)**
Bogue Inlet	0	$0	0.455	$0
Emerald Isle - West	0	$0	0.455	$0
Emerald Isle - Central	24	$41,716,421	0.455	$9,490,486
Emerald Isle - East	61	$106,029,237	0.455	$24,121,651
Indian Beach/Salter Path	47	$81,694,658	0.515	$21,036,374
Pine Knoll Shores	94	$163,389,316	0.513	$41,909,360
	226	$392,829,633	0.492	$96,557,871

NOURISHMENT				
Source	**Placement Location**	**Volume (cy/yr)**	**Unit Cost ($/cy)**	**50 yr Total Cost ($)**
Bogue Inlet AIWW	Bogue Inlet	20,200	$15.00	$15,150,000
Bogue Inlet, Upland, AIWW, Offshore	Bogue Inlet	24,652	$15.00	$18,489,000
Bogue Inlet, Upland, AIWW, Offshore	Emerald Isle West	6,334	$15.00	$4,750,500
Upland, AIWW, Offshore	Emerald Isle East	47,604	$15.00	$35,703,000
Upland, AIWW, Offshore	Pine Knoll Shores	42,938	$12.25	$26,299,525
MCH	Atlantic Beach	400,000	$11.50	$230,000,000
		541,728		$330,392,025

	50 yr Volume (cy)	Unit Cost ($/cy)	50 yr Total Cost ($)
Storm Erosion	0	$13.25	$0

ALTERNATIVE 1 COST	
Nourishment Cost (Background Erosion)	$330,392,025
Nourishment Cost (Storm Erosion)	$0
Lost Property Value	$392,829,633
Lost Tax Revenue	$96,557,871
TOTAL	**$819,779,529**

<u>Relocation/Abandonment Alternative</u>

This alternative consists of continued nourishment by the USACE on Atlantic Beach using material from Morehead City Harbor and at the Point adjacent to Bogue Inlet using material from the Bogue Inlet AIWW crossing. This nourishment would cost approximately $245.2 million over the next 50 years.

In addition to the cost of nourishment, there would be a number of properties at risk of due to the absence of nourishment to keep up with the background erosion rates. Based on the using the 2004 NC Division of Coastal Management shoreline erosion rates (selected since this erosion rate would only have MHC and Bogue Inlet AIWW nourishment activities within it – the most recent shoreline erosion rates would have nourishment effects across the entire island), it was determined that there were oceanfront 434 structures at risk in this alternative over the next 50 years (annual raw rate multiplied by 50 years). However, this alternative seeks to relocate the threatened structures to vacant lots, saving some of the property value and tax revenue from being lost completely. Bogue Banks currently has 114 vacant oceanfront lots and almost 1,500 vacant non-oceanfront lots potentially available for relocation. Therefore, 114 of the 451 at risk structures could potentially be relocated to other oceanfront lots, saving the property value and tax revenue of those structures. The remaining 337 structures would have to be relocated to non-oceanfront lots causing the property value and tax revenue to decrease. The average non-oceanfront property value along Bogue Banks was determined to be approximately $287,000. Based on these numbers, lost property value could total $489.0 million. In addition to the lost property value, annual tax revenue would also be lost. Based on the tax rates for municipalities along Bogue Banks, approximately $118.6 million in tax revenue would be lost over 50 years. Also, relocation of each of the structures would cost approximately $75,000 for a total of $33.8 million for all 451 structures ($75,000 per relocation based on discussions with house movers with experience with beach homes). See **Table 8-19** below for a summary of this alternative.

The cost of nourishment, lost property value and tax revenue, and relocation costs total $886.5 million over the next 50 years for the Relocation/Abandonment Alternative.

Table 8-19: Relocation/Abandonment Alternative Cost Summary

Average Oceanfront Property Value	$1,738,184
Average Non Oceanfront Property Value	$287,158

Vacant Oceanfront Lots	114
Vacant Non Oceanfront Lots	1,498

PROPERTY VALUE/TAX REVENUE				
Management Reach	**Number of Properties at Risk**	**Total Property Value**	**Tax Rate (County + Local)**	**50 yr Tax Revenue ($)**
Bogue Inlet	82	$142,531,106	0.455	$32,425,827
Emerald Isle - West	33	$57,360,079	0.455	$13,049,418
Emerals Isle - Central	24	$41,716,421	0.455	$9,490,486
Emerald Isle - East	81	$140,792,922	0.455	$32,030,390
Indian Beach/Salter Path	47	$81,694,658	0.515	$21,036,374
Pine Knoll Shores	184	$319,825,896	0.513	$82,035,342
	451	$783,921,082	0.485	$190,067,837

Relocation Type	**Number of Properties**	**Original Property Value ($**	**Relocated Property Value ($**	**Lost Property Value ($)**	**Avg Tax Rate**	**50 yr Original Tax Revenue ($)**	**50 yr Relocated Tax Revenue**	**Lost Tax Revenue ($)**
Homes to be Relocated Oceanfront	114	$198,153,001	$198,153,001	$0	0.485	$48,043,755	$48,043,755	$0
Homes to be Relocated Non Oceanfront	337	$585,768,081	$96,772,158	$488,995,923	0.485	$142,024,082	$23,463,171	$118,560,911
	451	$783,921,082	$294,925,158	$488,995,923		$190,067,837	$71,506,926	$118,560,911

RELOCATION COST			
	Number of Properties	**Unit Cost ($/property)**	**Total Cost ($)**
Number of Properties	451	$75,000	$33,825,000

NOURISHMENT				
Source	**Placement Location**	**Volume (cy/yr)**	**Unit Cost ($/cy)**	**50 yr Total Cost ($)**
Bogue Inlet AIWW	Bogue Inlet	20,200	$15.00	$15,150,000
MCH	Atlantic Beach	400,000	$11.50	$230,000,000
		420,200		$245,150,000

	50 yr Volume (cy)	**Unit Cost ($/cy)**	**50 yr Total Cost ($)**
Storm Erosion	0	$13.25	$0

ALTERNATIVE 2 COST	
Nourishment Cost (Background Erosion)	$245,150,000
Nourishment Cost (Storm Erosion)	$0
Relocation Cost	$33,825,000
Lost Property Value	$488,995,923
Lost Tax Revenue	$118,560,911
	$886,531,834

Nourishment Only Alternative

This alternative consists of continued nourishment by the USACE on Atlantic Beach using material from Morehead City Harbor and at the Point adjacent to Bogue Inlet using material from the Bogue Inlet AIWW crossing as well as nourishment of Emerald Isle East, Indian Beach/Salter Path, and Pine Knoll Shores using material from upland/offshore sources only (i.e. no Bogue Inlet material). This nourishment would cost approximately $385.6 million over the next 50 years. It is also approximated that erosion from storms over the next 50 years would require approximately 27.2 million cy of material (maximum value - see Section 4.2.2 of Engineering Report), costing roughly $360.4 million.

In addition to the cost of nourishment, there would be a number of properties at risk of due to the absence of nourishment to keep up with the background erosion rates. Based on the modeled shoreline position (model results were used since nourishment was incorporated within this alternative), it was determined that there were 122 structures at risk over the next 50 years in this alternative due to unavailable material from Bogue Inlet management (please note that longshore transport is from east to west along most of Bogue Banks which explains why the number of structures at risk would drop even for western areas not receiving direct nourishment from Bogue Inlet relocation projects). The average oceanfront property value along Bogue Banks was determined to be approximately $1.7 million. Based on these numbers, lost property value could total $212.1 million. In addition to the lost property value, annual tax revenue would also be lost. Based on the tax rates for municipalities along Bogue Banks, approximately $48.2 million in tax revenue would be lost over 50 years. See **Table 8-20** below for a summary of this alternative.

The cost of nourishment as well as lost property value and tax revenue totals $1.006 billion over the next 50 years for the Nourishment Only alternative.

Table 8-20: Nourishment Only Alternative Cost Summary

Average Oceanfront Property Value	$1,738,184
Average Non Oceanfront Property Value	$287,158

PROPERTY VALUE/TAX REVENUE				
Management Reach	**Number of Properties at Risk**	**Total Property Value ($)**	**Tax Rate (County + Local)**	**50 yr Tax Revenue ($)**
Bogue Inlet	66	$114,720,158	0.455	$26,098,836
Emerald Isle - West	33	$57,360,079	0.455	$13,049,418
Emerals Isle - Central	23	$39,978,237	0.455	$9,095,049
Emerald Isle - East	0	$0.00	0.455	$0
Indian Beach/Salter Path	0	$0.00	0.515	$0
Pine Knoll Shores	0	$0.00	0.513	$0
	122	$212,058,474	0.455	$48,243,303

NOURISHMENT				
Source	**Placement Location**	**Volume (cy/yr)**	**Unit Cost ($/cy)**	**50 yr Total Cost ($)**
Bogue Inlet AIWW	Bogue Inlet	20,200	$15.00	$15,150,000
Upland, AIWW, Offshore	Emerald Isle East	63,744	$15.00	$47,808,000
Upland, AIWW, Offshore	Indian Beach/Salter Path	62,567	$13.00	$40,668,550
Upland, AIWW, Offshore	Pine Knoll Shores	84,795	$12.25	$51,936,938
MCH	Atlantic Beach	400,000	$11.50	$230,000,000
		631,306		$385,563,488

	50 yr Volume (cy)	Unit Cost ($/cy)	50 yr Total Cost ($)
Storm Erosion	27,200,000	$13.25	$360,400,000

ALTERNATIVE 3 COST	
Nourishment Cost (Background Erosion)	$385,563,488
Nourishment Cost (Storm Erosion)	$360,400,000
Lost Property Value	$212,058,474
Lost Tax Revenue	$48,243,303
	$1,006,265,265

<u>Nourishment with Non-Structural Inlet Management Alternative</u>

This alternative consists of continued nourishment by the USACE on Atlantic Beach using material from Morehead City Harbor and at the Point adjacent to Bogue Inlet using material from the Bogue Inlet AIWW crossing as well as nourishment of Emerald Isle West, Emerald Isle Central, Emerald Isle East, Indian Beach/Salter Path, and Pine Knoll Shores using material from offshore sources and the relocation of Bogue Inlet as needed. This nourishment would cost approximately $427.5 million over the next 50 years. It is also approximated that erosion from storms over the next 50 years would require approximately

27.2 million cy of material (maximum value - see Section 4.2.2 of Engineering Report), costing roughly $360.4 million. See **Table 8-21** below for a summary of this alternative.

This nourishment plan seeks to protect all of the structures along Bogue Banks, meaning that no property value or tax revenue would be lost.

The cost of nourishment totals $787.9 million over the next 50 years for this alternative.

Table 8-21: Nourishment with Non-Structural Inlet Management Alternative Cost Summary

Average Oceanfront Property Value	$1,738,184
Average Non Oceanfront Property Value	$287,158

PROPERTY VALUE/TAX REVENUE				
Management Reach	**Number of Properties at Risk**	**Total Property Value ($)**	**Tax Rate (County + Local)**	**50 yr Tax Revenue ($)**
Bogue Inlet	0	$0	0.455	$0
Emerald Isle - West	0	$0	0.455	$0
Emerals Isle - Central	0	$0	0.455	$0
Emerald Isle - East	0	$0	0.455	$0
Indian Beach/Salter Path	0	$0	0.515	$0
Pine Knoll Shores	0	$0	0.513	$0
	0	$0		$0

NOURISHMENT				
Source	**Placement Location**	**Volume (cy/yr)**	**Unit Cost ($/cy)**	**50 yr Total Cost ($)**
Bogue Inlet AIWW	Bogue Inlet	20,200	$15.00	$15,150,000
Bogue Inlet, Upland, AIWW, Offshore	Bogue Inlet	24,652	$15.00	$18,489,000
Bogue Inlet, Upland, AIWW, Offshore	Emerald Isle West	6,334	$15.00	$4,750,500
Bogue Inlet, Upland, AIWW, Offshore	Emerald Isle Central	24,983	$15.00	$18,737,250
Upland, AIWW, Offshore	Emerald Isle East	63,744	$15.00	$47,808,000
Upland, AIWW, Offshore	Indian Beach/Salter Path	62,567	$13.00	$40,668,550
Upland, AIWW, Offshore	Pine Knoll Shores	84,795	$12.25	$51,936,938
MCH	Atlantic Beach	400,000	$11.50	$230,000,000
		687,275		$427,540,238

	50 yr Volume (cy)	**Unit Cost ($/cy)**	**50 yr Total Cost ($)**
Storm Erosion	27,200,000	$13.25	$360,400,000

ALTERNATIVE 4 COST	
Nourishment Cost (Background Erosion)	$427,540,238
Nourishment Cost (Storm Erosion)	$360,400,000
Lost Property Value	$0
Lost Tax Revenue	$0
	$787,940,238

<u>Nourishment with Structural Inlet Management Alternative</u>

This alternative consists of continued nourishment by the USACE on Atlantic Beach using material from Morehead City Harbor and at the Point adjacent to Bogue Inlet using material from the Bogue Inlet AIWW crossing as well as nourishment of Emerald Isle East, Indian Beach/Salter Path, and Pine Knoll Shores using material from offshore sources only (i.e. no Bogue Inlet material from relocation). This nourishment would cost approximately $385.6 million over the next 50 years. It is also approximated that erosion from storms over the next 50 years would require approximately 27.2 million cy of material (maximum value - see Section 4.2.2 of Engineering Report), costing roughly $360.4 million.

This alternative also includes construction of a terminal groin at Bogue Inlet. The cost of construction would be approximately $4.4 million.

There would still be a number of properties at risk of due to the absence of nourishment to keep up with the background erosion rates. Based on the modeled shoreline position (model results used since nourishment and a terminal groin were incorporated within this alternative), it was determined that there were 103 structures at risk in Alternative 5 over the next 50 years. The average oceanfront property value along Bogue Banks was determined to be approximately $1.7 million. Based on these numbers, lost property value could total $179.0 million. In addition to the lost property value, annual tax revenue would also be lost. Based on the tax rates for municipalities along Bogue Banks, approximately $40.7 million in tax revenue would be lost over 50 years. See **Table 8-22** below for a summary of this alternative.

The cost of nourishment, construction of a terminal groin, and lost property value and tax revenue totals $970.1 million over the next 50 years for this alternative.

Table 8-22: Nourishment with Inlet Management Alternative Cost Summary

Average Oceanfront Property Value	$1,738,184
Average Non Oceanfront Property Value	$287,158

PROPERTY VALUE/TAX REVENUE				
Management Reach	**Number of Properties at Risk**	**Total Property Value ($)**	**Tax Rate (County + Local)**	**50 yr Tax Revenue ($)**
Bogue Inlet	47	$81,694,658	0.455	$18,585,535
Emerald Isle - West	33	$57,360,079	0.455	$13,049,418
Emerals Isle - Central	23	$39,978,237	0.455	$9,095,049
Emerald Isle - East	0	$0	0.455	$0
Indian Beach/Salter Path	0	$0	0.515	$0
Pine Knoll Shores	0	$0	0.513	$0
	103	$179,032,974	0.455	$40,730,002

NOURISHMENT				
Source	**Placement Location**	**Volume (cy/yr)**	**Unit Cost ($/cy)**	**50 yr Total Cost ($)**
Bogue Inlet AIWW	Bogue Inlet	20,200	$15.00	$15,150,000
Upland, AIWW, Offshore	Emerald Isle East	63,744	$15.00	$47,808,000
Upland, AIWW, Offshore	Indian Beach/Salter Path	62,567	$13.00	$40,668,550
Upland, AIWW, Offshore	Pine Knoll Shores	84,795	$12.25	$51,936,938
MCH	Atlantic Beach	400,000	$11.50	$230,000,000
		631,306		$385,563,488

	50 yr Volume (cy)	**Unit Cost ($/cy)**	**50 yr Total Cost ($)**
Storm Erosion	27,200,000	$13.25	$360,400,000

TERMINAL GROIN			
	Length (ft)	**Unit Cost ($/ft)**	**Total Cost ($)**
Terminal Groin	1250	$3,500	$4,375,000

ALTERNATIVE 5 COST	
Nourishment Cost (Background Erosion)	$385,563,488
Nourishment Cost (Storm Erosion)	$360,400,000
Structure Cost	$4,375,000
Lost Property Value	$179,032,974
Lost Tax Revenue	$40,730,002
	$970,101,464

Overall Cost Summary

As can be seen from **Table 8-23** below, the preferred alternative, Alternative 4, has the lowest overall cost over the next 50 years of each option mainly due to the fact that it is the only option that provides enough sediment to meet the needs of all of Bogue Banks shorelines over the next 50 years.

Table 8-23: Overall Cost Summary Alternative Comparison

SUMMARY TABLE							
Alternative	Background Erosion Nourishment Cost ($)	Storm Erosion Nourishment Cost ($)	Relocation Cost ($)	Structure Cost ($)	Lost Property Value ($)	Lost Tax Revenue ($)	Total Cost ($)
No Action	$330,392,025	$0	N/A	N/A	$392,829,633	$96,557,871	$819,779,529
Relocation/Abandonment	$245,150,000	$0	$33,825,000	N/A	$488,995,923	$118,560,911	$886,531,834
Nourishment Only	$385,563,488	$360,400,000	N/A	N/A	$212,058,474	$48,243,303	$1,006,265,265
Nourish/Non-Struct Inlet Mgmt	$427,540,238	$360,400,000	N/A	N/A	$0	$0	$787,940,238
Nourish/Struct Inlet Mgmt	$385,563,488	$360,400,000	N/A	$4,375,000	$179,032,974	$40,730,002	$970,101,464

8.9 Preferred Alternative

8.9.1 Nourishment Volumes and Renourishment Interval

Therefore, based on the above analyses, the preferred alternative is Beach Nourishment with Non-structural Inlet Management. This is the only option that provides adequate sand sources to provide and maintain a 25-yr event LoP for all of Bogue Banks as well as provide adequate infrastructure and habitat protection along the Bogue Inlet shoulders. Based upon the analysis results in Chapter 7.0, revised nourishment triggers for -12 ft NAVD shall be utilized as shown below in Table 8-24. The resulting management reaches are on average 2-3 miles long with the exception of the Pine Knoll Shores and Atlantic Beach management reaches which are somewhat longer and cover the entire Town in each case. For the proposed management reaches, the weighted trigger is 233 cy/ft with triggers varying from 211 cy/ft for Emerald Isle Central to 266 cy/ft for portions of Emerald Isle West (Table 8-24).

Table 8-24: Revised Calculated Trigger Volumes Above -12 ft NAVD88 for Various RP Events

Reach	Reach Length (ft)	50-yr, -12 ft Trigger (cy)	25-yr, -12 ft Trigger (cy)	Adjusted 25-yr, -12 ft Trigger (cy)	Preliminary -12 ft Trigger (cy)	-12 ft 2011 Volume (cy)
Bogue Inlet (1-8)	7,432	238	103	238	235	389
Emerald Isle West - A (9-11)	4,056	282	230	230		277
Emerald Isle West - B (12-22)	14,283	319	272	272	266	295
Emerald Isle West - C (23-25)	4,005	323	242	242		303
Emerald Isle Central - A (26-32)	10,428	237	213	213	211	292
Emerald Isle Central - B (33-36)	5,374	277	207	207		262
Emerald Isle East - A (37-44)	8,814	268	214	214	221	242
Emerald Isle East - B (45-48)	4,406	299	235	235		264
Indian Beach/Salter Path - West (49-52)	5,275	243	216	216	224	263
Indian Beach/Salter Path - East (53-58)	7,575	241	229	229		298
Pine Knoll Shores - West (59-65)	9,063	235	196	196	211	253
Pine Knoll Shores - East - A (66-70)	6,564	271	218	218		240
Pine Knoll Shores East - B (71-76)	8,251	287	222	222		262
Atlantic Beach - West (77-81)	5,388	269	225	225	254	281
Atlantic Beach - Central (82-89, 91-96)	13,771	375	248	248		291
Atlantic Beach - Circle (90)	1,006	408	364	364		330
Atlantic Beach - East (97-102)	6,011	318	276	276		384
TOTAL	**121,702**					
AVERAGE		**288**	**230**	**238**	**233**	**290**
					Weighted	

To estimate the time when the next round of nourishment projects will be needed, the 2011 volumes above -12 ft NAVD were assumed to erode at the annualized loss rate until the trigger would be reached. This was completed for both the individual subreaches as well as the management reaches and results are presented in Table 8-25 and Table 8-26.

Table 8-25: Estimated Years Until First Round of Nourishment Projects – Individual Subreach Basis

Reach	Reach Length (ft)	Preliminary -12 ft Trigger (cy)	-12 ft 2011 Volume (cy)	Years to 25 yr Trigger 50%	Years to 25 yr Trigger 55%	Years to 25 yr Trigger 60%	Years to 25 yr Trigger 65%	Years to 25 yr Trigger 70%	Years to 25 yr Trigger 75%	Years to 25 yr Trigger 85%
Bogue Inlet (1-8)	7,432	238	389	28	18	13	10	8	7	5
Emerald Isle West - A (9-11)	4,056	230	277	36	19	13	10	7	6	4
Emerald Isle West - B (12-22)	14,283	272	295	68	68	68	68	68	21	8
Emerald Isle West - C (23-25)	4,005	242	303	156	156	26	14	9	7	4
Emerald Isle Central - A (26-32)	10,428	213	292	59	59	30	20	15	12	8
Emerald Isle Central - B (33-36)	5,374	207	262	27	17	13	10	8	7	5
Emerald Isle East - A (37-44)	8,814	214	242	6	5	4	4	3	3	2
Emerald Isle East - B (45-48)	4,406	235	264	6	4	3	2	2	2	1
Indian Beach/Salter Path - West (49-52)	5,275	216	263	5	4	3	3	3	2	2
Indian Beach/Salter Path - East (53-58)	7,575	229	298	64	33	22	16	13	10	7
Pine Knoll Shores - West (59-65)	9,063	196	253	38	23	16	13	10	8	6
Pine Knoll Shores - East - A (66-70)	6,564	218	240	6	5	4	3	3	3	2
Pine Knoll Shores East - B (71-76)	8,251	222	262	7	6	5	4	3	3	2
Atlantic Beach - West (77-81)	5,388	225	281	51	51	26	17	12	10	6
Atlantic Beach - Central (82-89, 91-96)	13,771	248	291	6	6	5	4	4	4	3
Atlantic Beach - Circle (90)	1,006	364	330	-3	-2	-2	-1	-1	-1	-1
Atlantic Beach - East (97-102)	6,011	276	384	13	11	10	9	8	7	5
TOTAL	**121,702**									
AVERAGE				**34**	**28**	**15**	**12**	**10**	**6**	**4**

Table 8-26: Estimated Years Until First Round of Projects – Management Reach Basis

Reach	Reach Length (ft)	Management Reach Length (ft)	Preliminary -12 ft Trigger (cy)	-12 ft 2011 Volume (cy)	Years to 25 yr Trigger 50%	Years to 25 yr Trigger 55%	Years to 25 yr Trigger 60%	Years to 25 yr Trigger 65%	Years to 25 yr Trigger 70%	Years to 25 yr Trigger 75%	Years to 25 yr Trigger 85%
Bogue Inlet (1-8)	7,432	11,488	235	349	29	18	13	10	8	7	5
Emerald Isle West - A (9-11)	4,056										
Emerald Isle West - B (12-22)	14,283	18,288	266	297	90	90	90	49	19	11	6
Emerald Isle West - C (23-25)	4,005										
Emerald Isle Central - A (26-32)	10,428	15,802	211	282	45	36	22	16	12	10	7
Emerald Isle Central - B (33-36)	5,374										
Emerald Isle East - A (37-44)	8,814	13,220	221	250	6	5	4	3	3	2	2
Emerald Isle East - B (45-48)	4,406										
Indian Beach/Salter Path - West (49-52)	5,275	12,850	224	284	12	10	8	7	6	5	4
Indian Beach/Salter Path - East (53-58)	7,575										
Pine Knoll Shores - West (59-65)	9,063	23,878	211	253	12	9	7	6	5	4	3
Pine Knoll Shores - East - A (66-70)	6,564										
Pine Knoll Shores East - B (71-76)	8,251										
Atlantic Beach - West (77-81)	5,388	26,176	254	312	9	8	7	6	5	5	4
Atlantic Beach - Central (82-89, 91-96)	13,771										
Atlantic Beach - Circle (90)	1,006										
Atlantic Beach - East (97-102)	6,011										
TOTAL	**121,702**	**121,702**									
AVERAGE			**233**	**288**	**29**	**25**	**22**	**14**	**8**	**6**	**4**
			weighted	weighted							

Based on these above tables, it appears that 5-7 years will pass before various reaches are in need of nourishment from either approach. Please recall that results for the higher % exceedance include storm effects. Based on the proposed management reaches, the Emerald Isle East reach will likely require nourishment first with other reaches following depending on future storm effects. This timing will allow the County and Towns to be proactive in maintaining the required nourishment triggers as well time to replenish over $7 M of local funds that were spent recently for the Post-Irene Renourishment Project. Therefore, this time indicates how long before the "sediment bank" along Bogue Banks can sustain additional erosion or "debits" before additional "credits" or nourishments are needed to maintain the required 25-yr event LoP for the engineered beach.

As for future renourishment intervals and placement areas, a preliminary estimate was made based on past projects, whereas a future re-nourishment placement of 25 cy/ft is assumed and the annualized loss rates described previously for the 50% exceedance were used to determine how many years would pass before the 25 cy/ft would erode away. This analysis assumes that the "sediment bank" described above has been allowed to reach the 25-yr triggers along Bogue Banks and the County and Towns would then be in a mode of active continuous management. If quiet years or storm years are experienced, the renourishment intervals could be longer or shorter periods of time. However, this approach will be useful from a planning and funding perspective – and should reflect average future long term renourishment intervals – as an assurance that the Master Plan is financially sustainable.

Once the years for the average 25 cy/ft placement rate to erode away were calculated for each reach, it was found that most of the results for the reaches were close to multiples of 3 years (i.e., 3, 6, 9, etc. years). The results were then tabulated and classified into the various 3, 6, and 9 year renourishment cycles and the required volumes calculated. Table 8-27, Figure 8-23, and Figure 8-24 show the results as well as the preliminary proposed projects over the next 50 years. Please note that the nourishment volume approximates the need for background erosion only. It is expected that named storm losses will be handled separately through FEMA reimbursement projects.

Again, it is VERY IMPORTANT to note that the results are based upon average background erosion rates across the island. Storm effects and other factors could DRASTICALLY alter future nourishment requirements. The plan will nourish areas as they reach the nourishment triggers via gradual erosion or in response to future storms which of course cannot be predicted. However, the results presented in Table 8-27, Figure 8-23, and Figure 8-24 are useful for overall long term planning and budgeting purposes.

Table 8-27: Renourishment Intervals and Preliminary Projects Based on Detailed Subreach and Management Reach Approaches

Year	Detailed Subreach Nourishment Volume (cy)	Management Reach Nourishment Volume (cy)	Nourishment Project (Yr)
2019	640,332	686,067	3
2022	1,686,018	1,839,351	6
2025	1,163,781	967,920	9
2028	1,686,018	1,839,351	6
2031	640,332	686,067	3
2034	2,209,467	2,121,204	6,9
2037	640,332	686,067	3
2040	1,686,018	1,839,351	6
2043	1,163,781	967,920	9
2046	1,686,018	1,839,351	6
2049	640,332	686,067	3
2052	2,209,467	2,121,204	6,9
2055	640,332	686,067	3
2058	1,686,018	1,839,351	6
2061	1,163,781	967,920	9
2064	1,686,018	1,839,351	6
TOTAL	**21,228,045**	**21,612,609**	

Figure 8-23: Detailed Subreach Nourishment Plan

Figure 8-24: Management Reach Nourishment Plan

Based on the results above, one can see that some reaches will require more sand than others based on localized and regional erosion patterns. The inlet/dredging effects at Atlantic Beach and Bogue Inlet as well as the hotspots at Pine Knoll Shores-East and Emerald Isle-East are apparent and reflect the greater need for future nourishment, while historically sand receiving areas at Emerald Isle-Central and West will require less sand comparatively. The Management Reach nourishment plan will likely be the one most closely followed in the future, but again, storms and other factors will likely override the above approach in reality. It should also be noted that the results above do not include the storm need volume. It is assumed that these projects will be funded by FEMA once the new nourishment triggers and engineered beach with the 25-year return period event LoP have been accepted by FEMA.

While it is expected that a volumetric trigger will be utilized in the future to determine when nourishment action takes place, plots of the minimum MHW line position based on the volumetric triggers were plotted and can be seen in Appendix F. The maximum expected advance fill templates equating to the min/max range of 25-50 cy/ft is also shown. It is important to note that these lines were generated using the representative profiles and transect specific conditions may be different. None the less, the plots are instructive and useful for permitting purposes.

8.9.2 Borrow Sources

The total volume available when the upland sources, AIWW disposal areas, and the offshore sources are combined is presented in Table 8-28. The total non-renewable volume available from these sources is 25,123,057 cy. The overall sediment need for Bogue Banks over the 50 year planning horizon based on the analytical/empirical analysis is between 45.0 and 49.8 Mcy (46.8 to 51.6 Mcy for moderate sea level change). Therefore, the volume of the combined upland, AIWW, and offshore sources will not be enough to meet the 50 year need by itself.

Table 8-28: Summary of Non-Renewable Potential Borrow Areas

Area	Total Volume (cy)
Sand Mines	1,380,700
AIWW Disposal Areas	1,288,800
Offshore Sources	22,453,557
TOTAL	**25,123,057**

In addition to the upland, AIWW, and offshore borrow sources, Bogue and Beaufort Inlets could also provide material on a cyclical basis as they regularly shoal and have to be dredged by the USACE for navigation purposes. These renewable borrow areas could potentially provide approximately 25,130,000 cy over 50 years, as shown in Table 8-29, which, by itself, is not enough to cover the 50 year need.

Table 8-29: Volume of Renewable Potential Borrow Areas (Coastal Tech, 2013)

Area	Section	Volume	Dredging Frequency	50 yr Total
MHC Outer Harbor	Cutoff+Range A to STA 110	400,000 cy (assumed)	1 years	20,000,000
Bogue Inlet	Inlet Relocation	850,000 cy	10 years	4,250,000
	AIWW Crossing	44,000 cy	2.5 years	880,000
			Totals:	**25,130,000**

However, if all mentioned sources are incorporated (upland, AIWW, offshore, and inlets) approximately 50,253,057 cy of material would be available and would meet the 50-year sediment need of 45 Mcy to 49.8 Mcy (46.8 to 51.6 Mcy with moderate sea level change). The total volume available when the renewable and non-renewable sources are combined is tabulated in Table 8-30.

Table 8-30: Total Volume Available

Source	50-Yr Total Volume (cy)
Renewable	25,123,057
Non-Renewable	25,123,057
TOTAL	**50,253,057**

The MBNP and Preferred Alternative include the following elements:

- Sand from <u>offshore sources</u> (1st priority), <u>inlet sources</u> (2nd priority) and <u>upland sources</u> (3rd priority) is proposed to be excavated and placed on the beach. These <u>primary sand sources</u> are sufficient to maintain the design beach at a 25-year LoP with advance fill varying from 25 to 50 cubic yards per foot – depending upon actual future erosion rates and available funding.

- Renourishment events are expected to be required at 3, 6, and 9 year intervals starting in 2019 - based upon average background erosion rates. Actual renourishment events will be dependent upon actual erosion, and available funding – including FEMA funding in response to future storms for which the timing and severity cannot be reasonably predicted.

- Sand obtained from the USACE maintenance dredging of the Morehead City Harbor Channel and Bogue Inlet AIWW "crossings" is proposed to be used as part of the <u>primary sand sources</u>; maintenance dredging is proposed to be performed by the USACE under their permit authority, but USACE dredging and beach-fill placement are assumed to continue and are an integral part of the MBNP.

- If the main channel at Bogue Inlet migrates outside the "safe box", the main channel is proposed to be relocated by the Applicant, Carteret County, to the location constructed in 2005 with the excavated material used to nourish the beach as part of the primary sand sources.

8.9.3 Modeling of Preferred Alternative in GENESIS-T

The preferred alternative was modeled by the calibrated GENESIS-T model using the April 2012 as the initial shoreline. The model was run for just under 18 years with expected future nourishments to allow for each of the nourishment cycles (3 yr, 6 yr, and 9 yr) to run at least one full series of nourishment events. At year 18, all 3 cycles would potentially be ready for nourishment again. Comparison of the shorelines just before the year 18 nourishment and the initial shoreline represents whether the preferred alternative has enough planned future nourishment to at least maintain the initial April 2012 conditions, if not build the shoreline out some distance. The full results of the preferred alternative run in GENESIS can be seen in Appendix E. As can be seen from the results, most of the shoreline either matches the initial shoreline position or exists seaward of the initial shoreline position. There are two areas in particular where the final GENESIS shoreline is landward of the initial shoreline: 1) Emerald Isle Central and East (Transects 34-40) and 2) Pine Knoll Shores (Transects 60-68). Figure 8-25 and Figure 8-26 show examples of these areas. It is in these areas that particular attention should be paid during nourishment projects. Instead of applying the same template across the entire reach being nourished, it is possible that these areas may need slightly more sand than the remainder of the reach being nourished. However, that will depend on beach conditions at the time of nourishment and the determination of how much material is needed to provide equivalent protection across the nourishment reach based on volume rather than equivalent beach width. It is important to note that the final shoreline in other portions of these reaches exists seaward of the initial conditions so there may be material to spare if certain areas aren't performing as well. It should be noted that the modeled shoreline near Bogue Inlet (Transects 8-18) also appears to require additional material. However, performance of this area is not likely to be predicted accurately in GENESIS due to the multiple forces at work near the inlet – beyond longshore transport. On the other hand, the amount of accretion shown nearest the inlet (Transects 1-7) is likely equivalent to the extra erosion seen along the adjacent reach so the mass balance of material indicates that this area will likely achieve the MBNP goals.

Figure 8-25: Example GENESIS Preferred Alternative Results (Emerald Isle East)

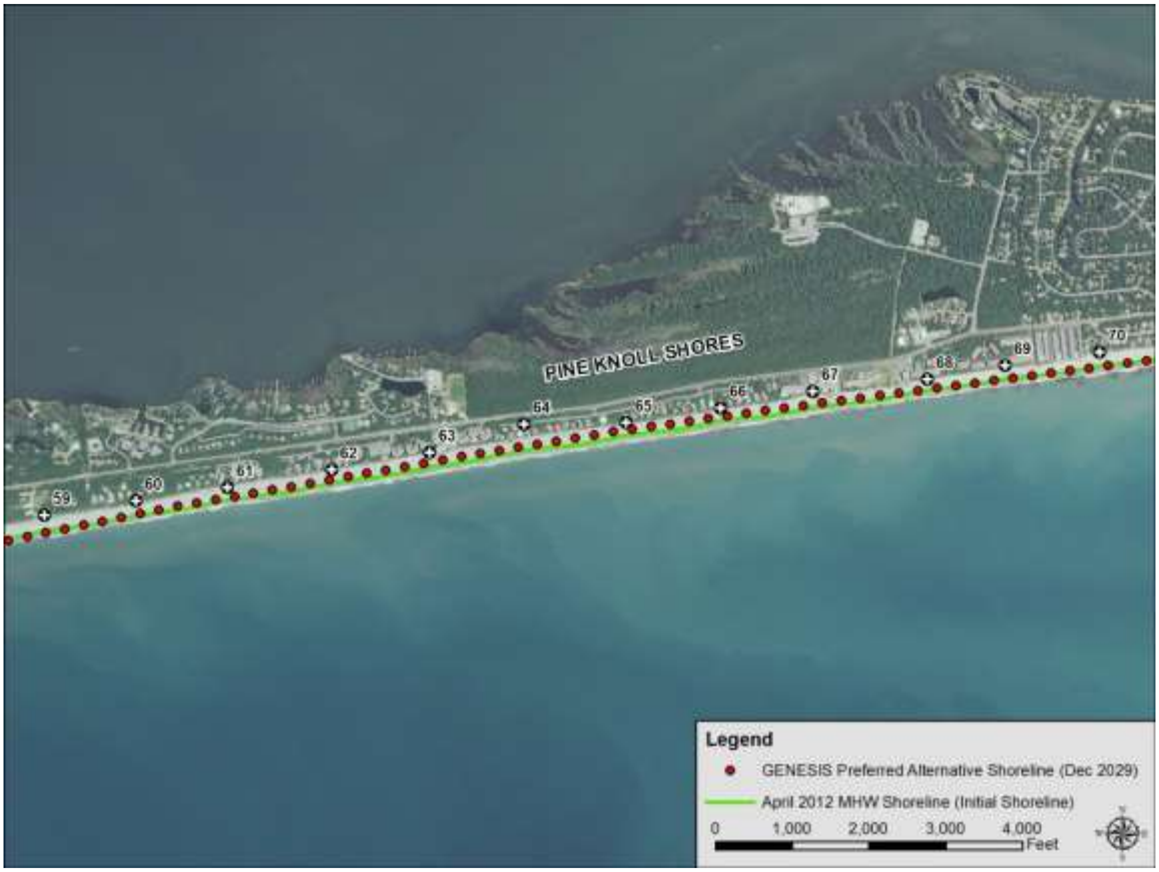


Figure 8-26: Example GENESIS Preferred Alternative Results (Pine Knoll Shores)

8.9.4 Funding of the Preferred Alternative and Static Line Exception Requirements

With the individual Towns and County funding streams, various scenarios were investigated to determine the long-term financial sustainability of the MBNP. Please see Appendix G for a detailed discussion of the Town and County funding streams – as historically collected from property and occupancy taxes.

First, dredging/placement unit costs were developed from past projects (rates include mob/demob).

- Emerald Isle – Combination of Pipeline and Hopper - $12 - $18/ cy – Avg. = $15/cy
- Indian Beach /Salter Path – All Hopper - $13/cy
- Pine Knoll Shores – All Hopper - $12.25/cy
- Atlantic Beach – Combination of Hopper and Pipeline - $11.50 cy – USACE Project Good To Circle – 60% - Prorated Unit Rate for Entire Volume = $4/cy

Utilizing the annualized volume needs estimated as part of the preferred option and the above unit rates, an annualized estimate of funding need was developed. As can be seen in Table 8-31, utilizing a 25% Town/75% County split would likely not be sustainable for the County fund since annual need would be roughly $3.4 M while $2.4 M is likely to be generated. This scenario also require less cost share overall from the Towns than is currently being generated. However, a scenario with a 33% Town/67% County cost share was also run and the results look much more equitable between the two funding streams. The annualized need versus funds raised for the Towns is quite close to the current funding levels with the exception of Atlantic Beach which does not currently have a dedicated funding source. However, given the possible range of outcomes from the ongoing DMMP, the numbers in this table could become less or more. It appears that it will be important for Atlantic Beach to revisit the idea of a dedicated funding source after the DMMP is finalized. As for the County annual need versus funding level, the need is still higher ($3.1 M vs. $2.4M) but the fund currently has $5.7M in reserve and it is expected that 6 years will pass before the next project is needed. This should allow adequate time for the reserve to build up to a point to where the County fund is also sustainable long-term. The intra-local agreement signed by all the Towns and County also requires them to meet the funding needs even if new taxes or one-time loans are required.

Table 8-31: Annualized Estimate of Funding

				25% Town/75% County Cost Share				33% Town/67% County Cost Share		
Town	Annual Volume Loss (cy)	% of Total Annual Volume Loss	Avg. Placement Unit Cost Per Town	Annual Town Cost ($)	Annual County Cost ($)	% of Total Annual County Cost	Annually Generated Taxes for Beach Nourishment	Annual Town Cost ($)	Annual County Cost ($)	% of Total Annual County Cost
Emerald Isle	139,913	31%	$15.00	$524,674	$1,574,021	46%	$675,000	$692,569	$1,406,126	46%
Indian Beach/Salter Path	62,567	14%	$13.00	$203,343	$610,028	18%	$282,406	$268,412	$544,959	18%
Pine Knoll Shores	84,795	19%	$12.25	$259,685	$779,054	23%	$316,500	$342,784	$695,955	23%
Atlantic Beach	164,945	36%	$4.00	$164,945	$494,835	14%	TBD	$217,727	$442,053	14%
TOTAL	452,220				$3,457,938				$3,089,093	
					Avg. Annual County Tax Generated Over Next 6 Years = $2,440,664					

If the above results were then just multiplied out over the next 50 years, the preferred plan needs would be fairly equal to the current funding levels at the 33% Town/67% County split as summarized below:

- **Annual Total Cost = $4.61 M/yr * 50 yr = $230.5 M**
- **Annual Total Revenue = $3.93 M/yr * 50 yr = $196.6 M**

Thus, if all the variables (dredging/placement costs, tax revenue, etc.) escalate at the same rate, the 50-yr master plan will be 85% funded overall = $196.6M/$230.5M (*assumes Atlantic Beach starts generating taxes and participates in the master plan). If Atlantic Beach declines to participate in the master plan due to adequate sand placement from the Morehead City Harbor Project, the 50-yr master plan will be 94% funded overall = $185.7M/$197.5M.

Of course, the above analysis is simplistic so a more formal cash flow analysis was completed as well. The cash flow analysis utilized the same assumptions as the Static Line Reports submitted to the state in 2010. These assumptions were reviewed and were found to still be valid with recent trends as well (especially with the economic recovery and the Sheraton opening back up).

- Dredging Cost Increases = 2% Annually
- Interest Gained on Accounts = 2% Annually
- Accommodations and Tax Growth = 4% Annually

As can be seen from analyses in Appendix G, the Town and County current funding levels are expected to be sustainable for 20 years into the future.

Again, it is VERY IMPORTANT to note that the results above are based upon average erosion rates across the island. Storm effects and other factors could drastically alter future nourishment requirements. It is also important to note that the all the previous funding analyses are based upon background erosion rates and that FEMA funding is expected to cover the named storm (hurricane) induced erosion as has been done in the past. In summary, the plan will nourish areas as they reach the nourishment triggers as well as in response to future storms which of course cannot be predicted.

Given the preferred plan is sustainable for 20 yrs, the recommendation is to track expenditures over next 5-10 years and adjust then as needed. Finally, it should be noted that all the above analyses does not include any State or Federal funding above that which is expected for the Morehead City Harbor Project and as required to maintain the ICWW near Bogue Inlet. Any additional funds from these sources would extend the long-term sustainability of the project.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Carteret County, the Carteret County Beach Commission, and the Shore Protection Office (SPO) seek to provide long-term, sustaining management of Bogue Banks beaches. In 2001, by state legislation, the Carteret County Beach Commission was established, and a room occupancy tax (ROT) for funding beach nourishment and related functions was put in place mainly as a response to the hurricanes of the 1990's (Bertha, Fran and Floyd) and subsequent storms. Carteret County intends to maintain Bogue Banks beaches via implementation of this proposed Master Beach Nourishment Plan (MBNP) with guidance from the SPO and oversight by the Beach Commission.

Carteret County is specifically seeking federal and state permits to allow implementation of this MBNP as a non-federal shoreline protection and inlet management project over a multi-decadal period to preserve Bogue Banks' tax base, infrastructure, and tourist oriented economy. An inter-local agreement was developed and executed by each municipality on Bogue Banks creating an effective and efficient approach for a long-term and sustainable implementation of this MBNP.

The proposed program incorporates actions within multiple oceanfront municipalities to nourish recipient beaches, via use of multiple sand sources, over a multi-decadal timeline with revolving nourishment-project events. This MBNP identifies engineering design elements including: sand volumes required to yield the desired level of protection throughout Bogue Banks; sand volume triggers to initiate nourishment events; sand borrow source locations, volumes, quality, and viability; the expected capacity of the recipient beaches for nourishment; and the projected timing of nourishment events. A primary MBNP goal is to offset natural and anthropogenic erosion effects by optimizing use of existing high quality borrow sources to nourish prioritized recipient beaches to provide a spatially-equivalent level of protection to upland property along Bogue Banks.

In the process of completing past projects and monitoring, Bogue Banks has developed a large and impressive dataset that was the underpinning of all the analyses. Major findings of these datasets and the analyses completed for the MBNP are listed below.

<u>Waves and Water Levels</u>

Offshore significant wave heights are greater than 4.5 m (14.8 feet) between 15% and 25% of the time in the NDBC and WIS data sets. The vast majority of waves approach from the east-northeast through south-southwest directions. The NDBC buoys' measured wave data indicate a noticeably higher percentage of waves occurring from east through southeast, while the longer term model hindcast WIS record indicates a more even spread of wave occurrence between east and south-southwest.

While this difference is subtle, the percentage of occurrence of waves from east-northeast through east-southeast is relevant: The wave transformation model indicates that Cape Lookout and the associated shoals provide a degree of wave energy sheltering to Shackleford Banks and the eastern reaches of Bogue Banks. This effect appears to be at least partly responsible for gradients in longshore transport that affect shoreline evolution along Bogue Banks.

There are two tide gages in the area with a long-term station at Beaufort (NOAA facility at Pivers Island) and an open coast one at Atlantic Beach. The mean tide range at the Atlantic Beach Triple-S Pier tide gauge is approximately 117% of the mean tide range at the Beaufort tide gauge. The ratio of measured water levels Atlantic Beach to those at Beaufort increases to just over 120% (in general) for significant coastal storm surge events.

Beach Topography and Nearshore Bathymetry

Carteret County has a relatively rich beach profile and bathymetry dataset. Beach profile monitoring has been performed on a consistent basis since 1999, with the BBBNMP officially starting in 2004. A more recent focus has been placed on inlet bathymetry as both Bogue and Beaufort Inlets play an important role in the condition of Carteret County beaches. Detailed multibeam surveys have been performed at both inlets in addition to some offshore work at the Morehead City Harbor ODMDS.

Sediment Resource Data

Before the series of nourishment projects which took place along Bogue Banks in the 2000's, native beach data was been collected by the USACE as well as CSE. These projects indicated a native grain size anywhere from 0.2 mm to 0.3 mm (0.30 mm used for this study). The native beach characteristics and parameters identified by the North Carolina Administrative Code "Technical Standards for Beach Fill Projects" (15A NCAC 07H .0312) are presented in Table 9-1.

Table 9-1: Native Beach Characteristics and Rule Parameters

Characteristic	2001 Native	Rule Requirements	Required Borrow Site Parameters
Fines <#230	Reported: 0%, Assumed: <1%	<1% + 5%	≤ 6%
Sand (> #230 & <#10)	Reported at 98.68%	-	-
Granular (>#10 & < #4)	Reported combined at 1.32%, Assumed 0.7% each	0.7% + 5%	≤ 6%
Gravel (>#4)		0.7% + 5%	≤ 6%
Calcium Carbonate	Reported at 15-20%	20% + 15%	≤ 35%

Offshore/borrow source sediment data has also been collected to support identification of borrow areas for the various nourishment projecst that have occurred along Bogue Banks. These cores exist in the offshore borrow areas (A1, A2, B1, and B2) used for the Bogue Banks Restoration Project as well as the Morehead City ODMDS which was used for the most recent Post-Irene Renourishment Project. Both inlets (Bogue and Beaufort) and the AIWW have also been sampled and used as sediment sources in the past. Additional research into other areas offshore of Bogue Banks (Area Y and Area Z) was also performed in an attempt to find additional nourishment material, especially for Emerald Isle. In the end, it was found that adequate sediment resources are available for the project.

<u>Past Engineering Activities</u>

Carteret County has a rich nourishment history dating back to the 1970s with dredge disposal from the Morehead City Harbor channel to eastern Bogue Banks. Since then, Bogue Banks has also undergone nourishment at the Point from Bogue Inlet, various post-storm restoration projects, and a few USACE sanctioned projects. Figure 9-1 shows the location and quantities of each of the nourishment activities.

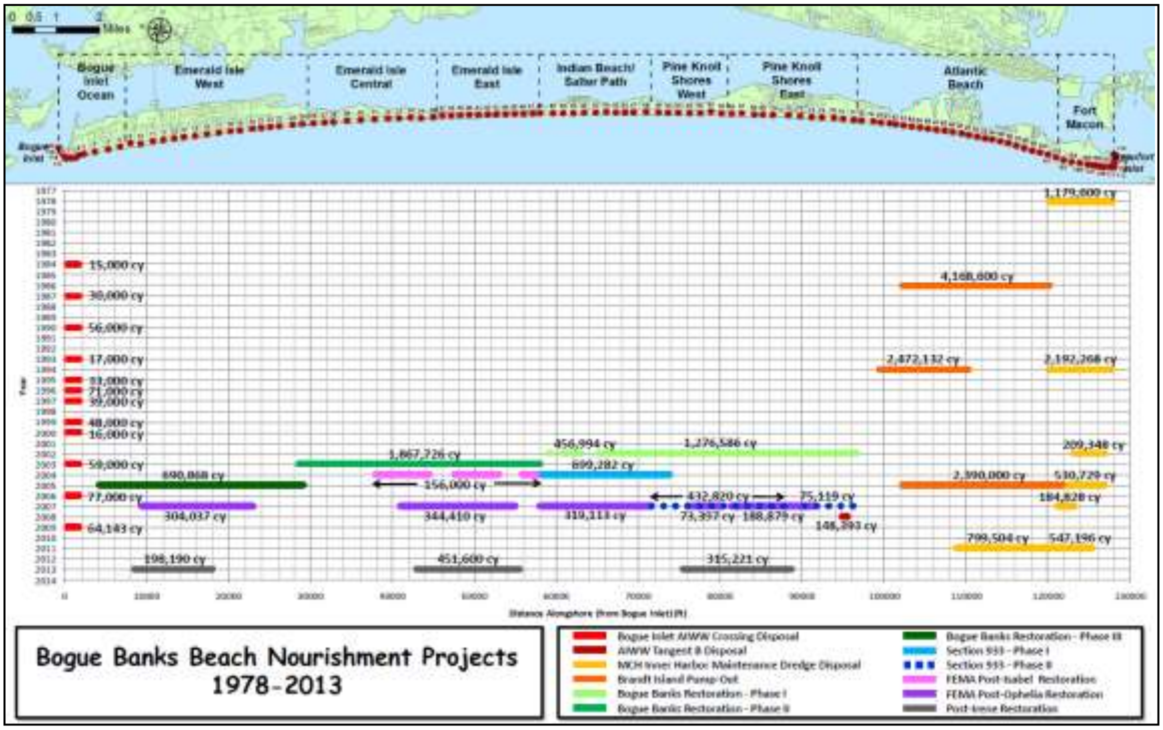


Figure 9-1: Bogue Banks Beach Nourishment History

<u>Analytical Analyses</u>

The first stage of the analytical/empirical analysis of historical data was to assess volumetric change over the period of 1999 to 2013 (13 years). Various beach profile volumes and changes were calculated over various time periods as the data allowed.

A statistical analysis of the above data was completed as well using the Crystal Ball modeling software.

For comparative purposes, the Crystal Ball analysis results were tabulated and compared to the annualized sediment need determined by the USACE for its 50-yr project. When one compares the results of these analyses to those of the USACE for the 50-yr Study, it became apparent that the results for the 50% probability were the closest match to the USACE Preferred NED plan which was developed with the complex BEACH-FX model and was optimized to provide an optimal benefit/cost ratio for shoreline protection along Bogue Banks over 50 years.

The analysis shows an overall annual background erosion loss along Bogue Banks (without Fort Macon) of roughly 452,200 cy with a 50-yr nourishment need of 22.6 Mcy just to keep up with historical erosion patterns. Again, the estimate compares favorably to the USACE estimate of approximately 356,247 cy/yr and a 50 year need of 17.8 Mcy.

To complete the analysis, the overall dataset was restricted to the three years which covered Hurricanes Isabel, Ophelia, and Irene to estimate potential hurricane storm losses. Based on the results, it is expected that the need for a given storm may range between 1.4 – 1.7 Mcy. Given that storms have occurred once every three years or so, the storm need over 50 years may range between 22.4 – 27.2 Mcy, which is equivalent to the background erosion loss/need.

Also, from Table 9-2, the overall annual loss rate (for the period of 1999-2012) has been approximately 500,000 cy/yr. Therefore, the Crystal Ball analyses is likely somewhat conservative, but the County would rather be sure that the Master Plan meets the expected needs for beach nourishment over the next 50 years.

Table 9-2: Average Annual Background Erosion Rate

Reach	Length (ft)	Volume Change Above -12 ft NAVD88 (cy) (1999-2012)	Nourishment Volume (cy)	Background Erosion (cy)	Average Annual Background Erosion Rates (cy/ft/yr)
Bogue Inlet-Ocean	7,432	-212,839	59,272	-272,111	-3
Emerald Isle West	22,344	811,451	935,633	-124,182	0
Emerald Isle Central & East	29,022	1,231,310	2,368,136	-1,136,826	-3
Indian Beach/Salter Path	12,850	693,714	1,358,842	-665,128	-4
Pine Knoll Shores	23,878	1,084,840	2,311,741	-1,226,901	-4
Atlantic Beach	26,176	1,323,201	3,189,504	-1,866,303	-5
Fort Macon State Park	6,691	314,190	1,472,101	-1,157,911	-13
Total	**128,393**	**5,245,869**	**11,695,229**	**-6,449,360**	**-3.86**

Therefore, the overall (background and storm) sediment need over the 50 year planning horizon based on the analytical/empirical analysis is between 45.0 and 49.8 Mcy. Accounting for USACE guidelines for sea level change, the value increases to 46.8 to 51.6 Mcy.

<u>Numerical Modeling</u>

Beach profiles respond most significantly to elevated water levels and waves associated with storms. Storm-induced beach profile evolution simulations were conducted for representative survey transects in each reach / subreach using the SBEACH numerical model. The model was calibrated to observed beach profile morphology from the 2005 pre- and post-Ophelia data set and verified using the 2011 pre- and post-Irene data set.

The primary purpose of the beach profile evolution numerical modeling is to assess the level of protection from storm surge and waves afforded by the beach and dune system – in existing conditions and with different project alternatives. The level of protection afforded is determined as the profile's ability to resist breaching and severe overtopping during extreme storm events of a certain annual probability of exceedance (stated as return period, the inverse of this probability). Dune integrity was assessed using results from beach profile change simulations in the SBEACH computational model. For the existing conditions simulations, SBEACH was run with initial profiles from the June 2011 survey data. The post-storm beach and dune profiles resulting from the SBEACH simulations were inspected and coastal engineering judgment applied to develop conclusions regarding the level of protection afforded by the existing profiles. For forward-looking nourishment project alternatives, the SBEACH initial profile was modified to increase dune height, dune width, and/or beach berm width until the profile performed acceptably in the storm return period being assessed.

To investigate longshore transport patterns, GENESIS-T was used. GENESIS (Generalized Model for Simulating Shoreline Change) is designed to simulate long-term shoreline change based on spatial and temporal differences in longshore sediment transport induced primarily by wave action. The GENESIS modeling system allows for a number of user-specified inputs including wave inputs, initial shoreline positions, coastal structures and their characteristics, and beach fills; all of which aid in the calculation of sediment transport and shoreline change.

The model output matched the measured shoreline position fairly well in some areas and not in others. The calibration shoreline was a close match in Emerald Isle, including the hotspot areas of Emerald Isle East (Transects 35-46). The model also performed very well in Atlantic Beach (Transects 78-102). The model slightly underestimates the erosion in much of Pine Knoll Shores, although it performs well at the hotspot around Transect 65. The model does not perform as well in Indian Beach/Salter Path and Beaufort Inlet, where it substantially underestimates the erosion. For the verification run, the model output matched the measured shoreline position fairly well in some areas and not in others. The verification model performed best in Emerald Isle West, Pine Knoll Shores, and Atlantic Beach. It slightly underestimated the erosion at Emerald Isle Central and East as well as Indian Beach/Salter Path.

<u>Hotspots Investigation</u>

Based on a review of the analytical volumetric background change results, it was apparent that there are erosional hotspots with increased and more wildly varying erosion rates (as compared to the entire island) at the Atlantic Beach, Pine Knoll Shores-East, Indian Beach/Salter Path, Emerald Isle-East and Bogue Inlet reaches.

These findings were further confirmed and with the various subreaches utilized during the Crystal Ball analyses as well as the USACE study. As can be seen from the Table 9-3, apparent hotspots are present at Bogue Inlet, both Emerald Isle-East subreaches, Indian Beach/Salter Path-West, both Pine Knoll Shores East subreaches, as well as most of

Atlantic Beach. The Bogue Inlet and Atlantic Beach subreaches were not unexpected given the inlet effects within these areas. Therefore, the remainder of the hotspot areas were studied using a detailed numerical model to determine if possible causes could be determined.

Table 9-3: USACE and Crystal Ball Analyses Denoting Hotspots

Reach	Reach Length (ft)	USACE Annual Renourishment (cy)	-5 ft Annual Loss 50% (cy)	-12 ft Annual Loss 50% (cy)	-16 ft Annual Loss 50% (cy)
Bogue Inlet (1-8)	7,432	-19,228	-18,555	-39,468	-134,450
Emerald Isle West - A (9-11)	4,056	-24,225	318	-5,384	-3,004
Emerald Isle West - B (12-22)	14,283	-16,233	26,970	33,886	45,035
Emerald Isle West - C (23-25)	4,005	-295	7,128	6,254	7,218
Emerald Isle Central - A (26-32)	10,428	-5,245	2,913	-982	19,080
Emerald Isle Central - B (33-36)	5,374	-2,133	-6,347	-10,890	-11,250
Emerald Isle East - A (37-44)	8,814	-22,025	-24,000	-40,472	-73,944
Emerald Isle East - B (45-48)	4,406	-8,410	-14,088	-23,272	-12,302
Indian Beach/Salter Path - West (49-52)	5,275	-18,144	-34,982	-54,380	-35,560
Indian Beach/Salter Path - East (53-58)	7,575	-23,753	-5,706	-8,187	-25,398
Pine Knoll Shores - West (59-65)	9,063	-31,057	-14,833	-13,726	-12,095
Pine Knoll Shores - East - A (66-70)	6,564	-19,056	-15,605	-24,709	-32,204
Pine Knoll Shores East - B (71-76)	8,251	-31,562	-27,929	-46,360	-85,297
Atlantic Beach - West (77-81)	5,388	-26,533	567	-125	-4,475
Atlantic Beach - Central (82-89, 91-96)	13,771	-52,361	-78,963	-96,718	-150,104
Atlantic Beach - Circle (90)	1,006	-4,280	-10,397	-12,948	-22,234
Atlantic Beach - East (97-102)	6,011	-51,707	-25,279	-49,398	-48,566
TOTAL ANNUAL VOLUME CHANGE	**121,702**	**-356,247**	**-238,788**	**-386,879**	**-579,550**

Before the modeling commenced, a review of available multibeam surveys in the hotspot areas was also completed to determine if localized bathymetric features were present that may affect these areas. After review of available data, a detailed multibeam survey was found that included a portion of the area contained within the Emerald Isle East hotspot. As can be seen in Figure 9-2, there appear to be some dredge cuts in deeper water offshore of Transects 37 & 38 that may allow some increased wave energy to influence this area. However, more interesting and likely more important are the features that can be seen offshore of Transects 41-43 in both deeper water and shallow areas as well which show "fingers" of deeper water that reach toward the shore (and hence would allow increased wave energy to reach the shoreline in this area). It is important to note that this area is centered at Transect 42 which is located at 12th Street within Emerald Isle. This particular location has been one of the most erodible areas of all of Bogue Banks. This data points to the relative importance of localized bathymetric/geologic features on shoreline behavior.

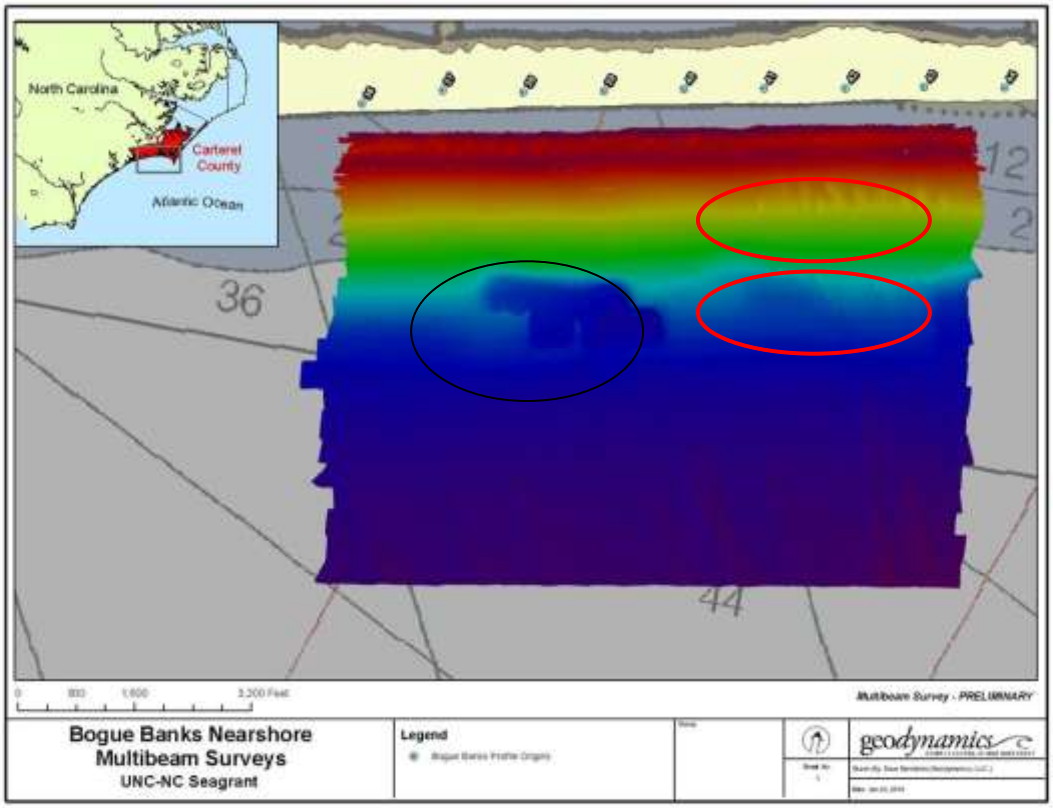


Figure 9-2: Detailed Multibeam Survey of Area Within Emerald Isle East Hotspot

This finding also then supported the use of a detailed model to investigate the hotspot areas and to try and develop an understanding of potential underlying causes.

A separate local scale model of hydrodynamic, wave, and sediment transport processes was developed for the majority of Bogue Banks, from regular monitoring survey Transect 13 in the west to Transect 84 in the east. The model was used to investigate likely causes of an erosional hotspot along a segment of Emerald Isle shoreline historically observed between Transects 30 and 50 and 66 to76.

The wave transformation model results indicate a significant gradient in mean annual wave energy along Bogue Banks, with wave energy increasing from west to east. This result alone would indicate that gradients in sediment transport-causing wave energy may be responsible for the increased erosion seen in the middle portions of Bogue Banks.

The sediment transport component of the model results further indicates gradients in net accumulated alongshore transport that would result in greater removal of sediment from these hotspot areas than is supplied by the updrift reaches.

The alongshore transport gradient observed in the local model results is believed to be primarily due to the increased wave energy affecting the shoreline in the western reaches. This increased was energy at both hotspots is believed to be due to a combination of wave sheltering effects of Cape Lookout as well as localized bathymetry patterns.

Bogue Inlet

In addition to studying the historical hotspots along Bogue Banks and their effect on nourishment volume needs along Bogue Banks, the behavior of Bogue Inlet is also very important to the study from an infrastructure protection perspective. While Beaufort Inlet is also very important to Bogue Banks and has far reaching implications concerning its management, the management of Beaufort Inlet is governed by a Federal Navigation Project, and hence is not subject to County dredging, being a deep draft navigation project associated with a port.

An analytical study of Bogue Inlet channel morphology was conducted using historical aerial imagery from 1938 – 2011. The study was conducted by defining and then measuring a small set of geometric parameters such as the position and alignment of the main ebb channel and the two landward channels connecting Bogue Inlet with Bogue Sound and the White Oak River. The analytical study component indicated extreme variability in the ebb channel position and alignment from 1938 to approximately 1987, while from 1987 – 2004 the channel moved consistently eastward and maintained a counterclockwise (CCW) alignment relative to a hypothetical "straight line" through the middle of the inlet. Since the ebb channel was relocated in 2005 to an approximate straight alignment at a mid-inlet lateral position, the ebb channel has again migrated eastward, though at a lesser rate than seen in the 1987 – 1992 migration. The post-relocation channel also has not yet realigned to a consistent CCW orientation, but currently has a CCW alignment landward and CW alignment seaward of the defined Reference Line. The analytical study component appears to indicate that the ebb channel will eventually migrate further east and that the ebb channel may need to be relocated again at some future date.

A product of the initial analytical study is a proposed area, or "safe box," within which the main channel of Bogue Inlet would be allowed move, without triggering engineering intervention. The limits of the "safe box" were set so that sunsequent channel migration did not threaten adjacent inlet shorelines/infrastructure by erosion within 3 years (in order to provide adequate time for an inlet relocation project to occur)

A program of numerical model simulations was then envisioned to confirm or revise (i.e. potentially narrow) the limits of the proposed "safe box". The dynamically coupled wave, flow, sediment transport, and bathymetry change (morphodynamic) model simulations were run for several idealized (schematized) inlet channel configurations. The model simulations were intended to provide an indication of whether there is a certain (approximate) lateral position, channel orientation, or combinations of both which, once reached, may speed up (or inhibit recovery from) migration of the channel to unacceptable positions near Bogue Banks or Bear Island.

The schematized inlet configuration simulations generally indicated that – from most of the starting inlet geometries – the main channel would tend to migrate back toward the center of the inlet and prefer a generally normal alignment similar to the Authorized Channel.

The numerical model results do not indicate a channel position, rotation, or combination of parameters that suggest that proposed "safe box" should be refined.

Therefore, it appears that the use of the "safe box" determined from the analytical analysis (Section 6.3) is a prudent approach to provide infrastructure protection for adjacent inlet shorelines. It also appears that the 2005 Authorized Channel dimension and location are valid. A slight improvement that may provide longer timeframes for stability appears to be to rotate the 2005 Authorized Channel by 15 clockwise (CW) as shown in Figure 9-3. Additional information and studies outlining the design of the 2005 Authorized Channel can be found in the 2004 CP&E report (CP&E, 2004).

Figure 9-3: Example 2005 Authorized Channel Rotated 15 Degrees

Based on recent USACE navigation surveys, the current eastern edge of the channel is approximately 590 ft away from the edge of the "safe box". The eastern edge of the channel has moved approximately 170 ft/yr since the 2005 relocation and has slowed in recent years to 80-120 ft/yr. If this pattern continues, the inlet would likely need to be relocated within the next 5-10 years. Figure 9-4 shows the current channel alignment in relation to the proposed "safe box" and the 2005 authorized channel. The edge of the "safe box" on the Emerald Isle side is approximately 1100 ft from the nearest structure. While it may appear that this distance is conservative, it is important to note that once the channel has reached this point in the past, the movements became accelerated and structures may be threatened within a couple of years. Please also note that the reasoning of the "safe box" as well is to keep the behavior of the inlet relatively predictable. By keeping the inlet within the "safe box", natural processes are allowed until the inlet shape/location becomes such that the adjacent inlet areas become unstable.

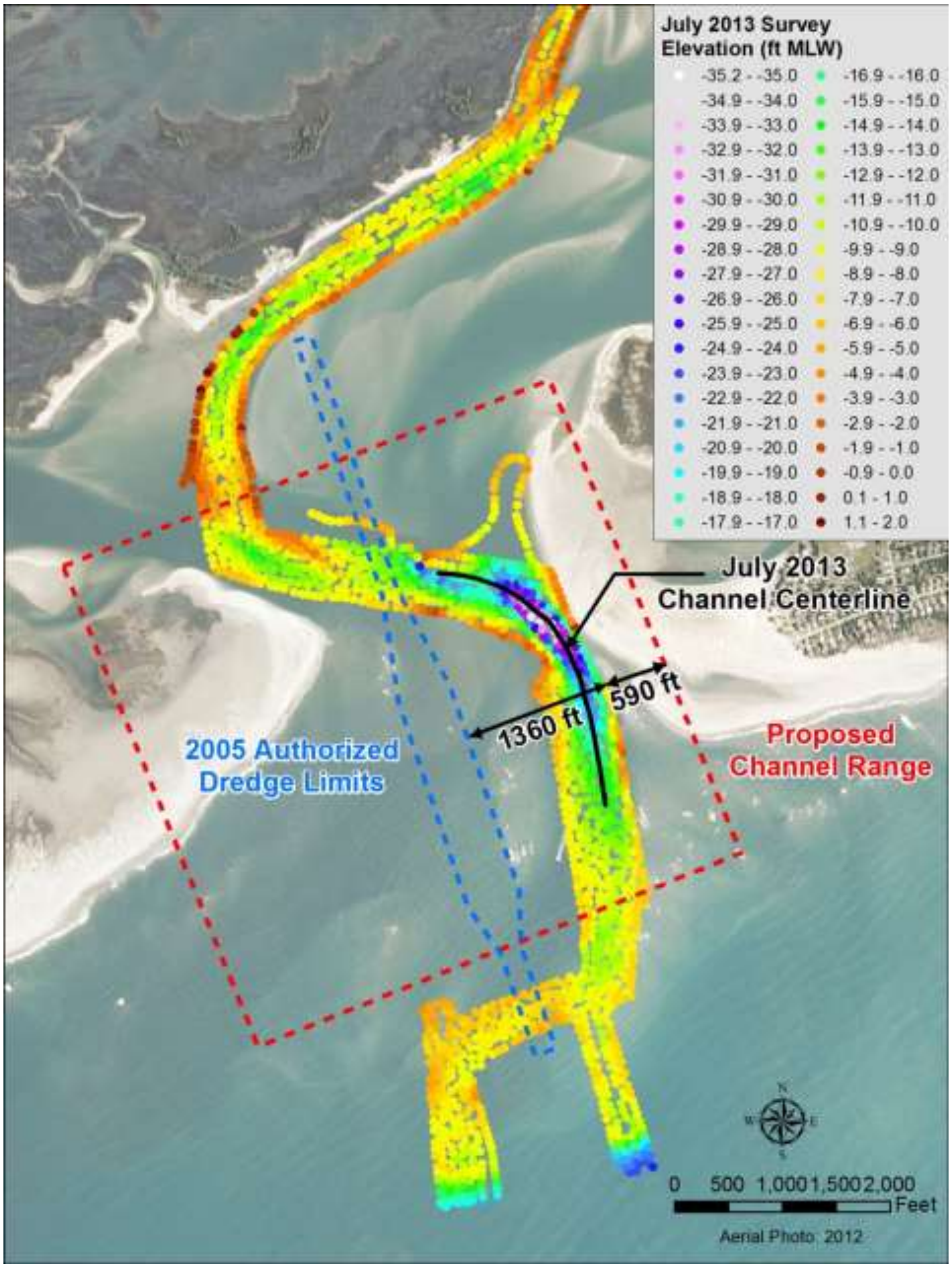


Figure 9-4: Bogue Inlet Current Channel Alignment

<u>Level of Protection and Nourishment Trigger Determination</u>

In addition to the study of Bogue Inlet to determine an optimal solution for protection of infrastructure adjacent to the inlet, the overall beach nourishment need to provide adequate protection for infrastructure along Bogue Banks was also needed.

While the Crystal Ball analysis outlined in Section 4.2 provided a good estimate of the long term needs to maintain the beaches in their current state (approximately 452,220 cy/yr and 22.6 Mcy over the 50 year project) and this estimate matched well with the USACE estimate of approximately 356,347 cy/yr and 17.8 Mcy over 50 years, the overall level of protection across the island had not been quantified by anyone to date.

In fact, a key element of the project purpose is to provide an equivalent level of protection (LoP) to upland structures across all of Bogue Banks – **not equal sand, but equal protection**. This LoP determination would also be critical in developing new nourishment triggers for the island; the current trigger is set at 225 cy/ft across the whole island for the volume from the landward top of dune out to -12 ft NAVD88

As outlined in the previous sections, the current beach profiles are adequate to provide protection for a 25-yr event, while some targeted dune building in various reaches would be required to provide protection for a 50-yr event. As stated previously, a project of approximately 2.2 Mcy would be needed to provide this 50-yr event level of protection.

While this initial project does seem feasible it is important to note that the project would likely cost between $22 - $27.5M based on recent dredging/placement costs. Since this project cost would likely be borne mainly by the County and Towns, the amount of time that it would take to raise this level of funds at current funding streams would be 5 – 7 years. Since current funding streams are needed to meet the overall maintenance requirements, providing a LoP for a 50-yr event across the entire island was determined to not be feasible, and therefore a 25-yr event LoP was selected. The County and Towns could always work toward a 50-yr level of protection if an unusual number of quiet years were to be experienced, but it was decided that it would be most prudent to select the 25-yr event LoP. Figure 9-5 also shows the difference in the volume trigger above the -12 ft elevation (volume from top of landward dune out to -12 ft NAVD) that would be needed for a 50-yr event versus the 25-yr event and the volume available in the 2011 survey (before Hurricane Irene). It should be noted that all of these calculations were also completed for the +1.1, -5, -12, -16 and -20 ft elevations. However, when considering the fact that nourishment projects usually place material out to the -12 ft elevation and the fact that the USACE preferred alternative annual beach need matched our estimates for the -12 ft elevation, it was decided that the -12 ft elevation should be used to determine the appropriate triggers for the LoP. Another reason to use the -12 ft NAVD elevation is the 13-yr history of data and comfort in using this elevation by the County and Towns as well as FEMA.

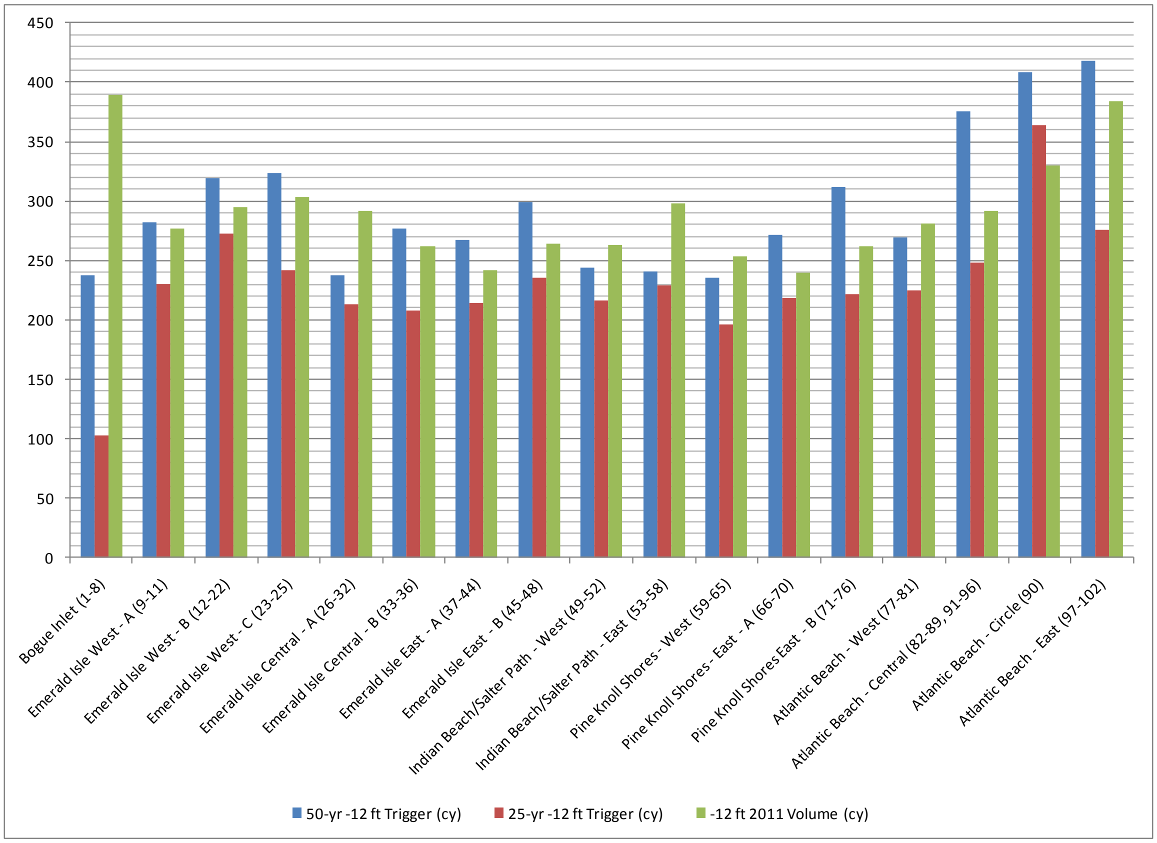


Figure 9-5: 50-yr Event Trigger vs. 25-yr Event Trigger vs. 2011 Volume (-12 ft NAVD88)

With the 25-yr event selected as the finalized level of protection, the development of nourishment triggers could be completed. Again, it is important to note that the potential of triggers at all of the computation elevations was considered, but ultimately the elevation of -12 ft NAVD was selected due to reasons stated earlier.

The resulting overall average is 238 cy/ft (see Table 9-4). This result makes sense in the fact that the 225 cy/ft original trigger was based on profile volumes in Atlantic Beach (which had weathered the hurricanes well) AFTER the hurricanes. It would only make sense that the PRE-storm volume would be higher and given that the past hurricanes over the last decade have had roughly 1.2 -1.5 Mcy this would mean that the prestorm volume was approximately 10-13 cy/ft higher than the 225 cy/ft after the event. Therefore, the overall average of 238 cy/ft for the entire island was determined to be very reasonable.

Nonetheless, while determination of the individual subreach triggers was needed, it would not be practicable to have individual nourishment actions be dictated by a single subreach while adjacent subreaches would not require sand placement. Therefore, the individual subreaches were re-examined to determine which subreaches should be grouped together for management reach determination. As can be seen from Table 9-4, the Bogue Inlet subreach is similar to the Emerald Isle West – A subreach and so on. The table shows the proposed management reaches and the weighted trigger volume above -12 ft NAVD based on the subreach lengths. The resulting management reaches are on average 2-3 miles long with the exception of the Pine Knoll Shores and Atlantic Beach management reaches which are somewhat longer and cover the entire Town in each case. For the proposed management reaches, the weighted trigger is 233 cy/ft with triggers varying from 211 cy/ft for Emerald Isle Central to 266 cy/ft for portions of Emerald Isle West.

Table 9-4: Revised Calculated Trigger Volumes Above -12 ft NAVD88 for Various RP Events

Reach	Reach Length (ft)	50-yr, -12 ft Trigger (cy)	25-yr, -12 ft Trigger (cy)	Adjusted 25-yr, -12 ft Trigger (cy)	Preliminary -12 ft Trigger (cy)	-12 ft 2011 Volume (cy)
Bogue Inlet (1-8)	7,432	238	103	238	235	389
Emerald Isle West - A (9-11)	4,056	282	230	230		277
Emerald Isle West - B (12-22)	14,283	319	272	272	266	295
Emerald Isle West - C (23-25)	4,005	323	242	242		303
Emerald Isle Central - A (26-32)	10,428	237	213	213	211	292
Emerald Isle Central - B (33-36)	5,374	277	207	207		262
Emerald Isle East - A (37-44)	8,814	268	214	214	221	242
Emerald Isle East - B (45-48)	4,406	299	235	235		264
Indian Beach/Salter Path - West (49-52)	5,275	243	216	216	224	263
Indian Beach/Salter Path - East (53-58)	7,575	241	229	229		298
Pine Knoll Shores - West (59-65)	9,063	235	196	196	211	253
Pine Knoll Shores - East - A (66-70)	6,564	271	218	218		240
Pine Knoll Shores East - B (71-76)	8,251	287	222	222		262
Atlantic Beach - West (77-81)	5,388	269	225	225	254	281
Atlantic Beach - Central (82-89, 91-96)	13,771	375	248	248		291
Atlantic Beach - Circle (90)	1,006	408	364	364		330
Atlantic Beach - East (97-102)	6,011	318	276	276		384
TOTAL	**121,702**					
AVERAGE		**288**	**230**	**238**	**233**	**290**
					Weighted	

Engineering Alternatives Considered

Multiple alternatives were considered to meet the project need including, No Action (Status Quo), Relocation/Abandonment, the USACE 50-yr project, Beach Nourishment Only (With Various Sources), and Beach Nourishment with Inlet Management (Non-structural and Structural).

The status quo will not provide any material to Indian Beach/Salter Path and Emerald Isle which have significant long term needs. The small amount of AIWW dredge material is also not adequate to meet the long-term needs of the area immediately adjacent to Bogue Inlet. **Therefore, the status quo option is not feasible and will not meet the project purpose and need.**

The relocation/abandonment option would consider relocating damaged/threatened structures to other portions of the island. Based on the County data, while only 8.3% of the parcels on Bogue Banks are oceanfront, they constitute 35.4% of the tax value. While some of that value might be translated to the 2nd row lots, the overall effect on the County and Town tax bases would be truly devastating, not to mention the effects on tourism with a narrow beach and structure waiting to be relocated. Assuming a combined tax rate of $0.45/$100 (County and Town), the annual loss in tax revenue for these structures would be over $10 million. This does not include the costs to the homeowner to relocate. In addition, many of the oceanfront parcels include hotels, large condo buildings, townhouses, and other multiple-dwelling units. Vacant lots large enough to accommodate these are not available on the remainder of the island for relocation. Even if it were possible, the cost of relocation/rebuilding would also be staggering. Even assuming a lot and building price of $500,000, the cost to relocate all oceanfront lots would be $666 million. Given that the average oceanfront lot value is $1.7 million, a more reliable cost would be $1 million/lot, equaling $1.3 billion. **Given the level of cost, the relocation/abandonment alternative was deemed to not be feasible and does not meet the project purpose and need.**

The USACE Coastal Storm Damage Reduction Study has developed a National Economic Development (NED) plan based on a cost/benefit analysis of beach nourishment and the associated economic value of the protection (i.e. reduction of storm damages) and recreation provided. The plan was developed using the economic model Beach-*fx* which takes into account the value of damaged infrastructure vs. the cost of nourishment. While the project is still in the planning phase, a tentative NED plan has been identified. Initial construction would require approximately 2.45 Mcy of material based upon initial conditions set by the June 2009 profiles (due to study timeline). The renourishment cycle would be every three years following initial construction and require approximately 1.07 Mcy of sand. Over the course of 50 years, this would call for approximately 19.55 Mcy of material. The project provides an estimated average annual $11,511,000 in coastal storm damage reduction benefits and $3,432,000 in recreational benefits at an average annual cost of $6,583,500 per year. This is a benefit/cost ratio of 2.3 to 1. **While the project has moved forward with completion of the feasibility study, it is questionable whether the project will ever be funded or implemented. Therefore, this project cannot be counted on to meet the project purpose and need and was dropped from further consideration.** However, if the project ever were to be funded, the County would adjust this plan to supplement the USACE project where needed.

Beach nourishment alone is also not a viable option using only upland, AIWW and other offshore sources. The total volume available when the upland sources, AIWW disposal areas, and the offshore sources are combined is presented in Table 9-5. The total non-renewable volume available from these sources is 25,123,057 cy. The overall sediment need for Bogue Banks over the 50 year planning horizon based on the analytical/empirical analysis is between 45.0 and 49.8 Mcy (46.8 to 51.6 Mcy for moderate sea level change). **Therefore, the volume of the combined upland, AIWW, and offshore sources will also not be enough to meet the 50 year need.**

Table 9-5: Summary of Non-Renewable Potential Borrow Areas

Area	Total Volume (cy)
Sand Mines	1,380,700
AIWW Disposal Areas	1,288,800
Offshore Sources	22,453,557
TOTAL	**25,123,057**

However, beach nourishment with inlet management (non-structural) is a viable alternative that does meet the project's purpose and need.

In summary, non-structural inlet management is needed at both Beaufort Inlet and Bogue Inlet to meet the overall project needs. Management of these inlets will provide needed protection to the adjacent inlet shoulder volumes and infrastructure while providing the secondary benefit of a needed sand source to meet the 50-yr project sediment needs.

In addition to the upland, AIWW, and offshore borrow sources, Bogue and Beaufort Inlets could also provide material on a cyclical basis as they regularly shoal and have to be dredged for navigation purposes. **These renewable borrow areas could potentially provide approximately 25,130,000 cy over 50 years, as shown in Table 9-6, which also, by itself, is not enough to cover the 50 year need.**

Table 9-6: Volume of Renewable Potential Borrow Areas (Coastal Tech, 2013)

Area	Section	Volume	Dredging Frequency	50 yr Total
MHC Outer Harbor	Cutoff+Range A to STA 110	400,000 cy (assumed)	1 years	20,000,000
Bogue Inlet	Inlet Relocation	850,664 cy	10 years	4,250,000
	AIWW Crossing	44,000 cy	2.5 years	880,000
			Totals:	**25,130,000**

However, if all mentioned sources are incorporated (upland, AIWW, offshore, and inlets) approximately 50,253,057 cy of material would be available and would meet the 50-year sediment need of 45 Mcy to 49.8 Mcy (46.8 to 51.6 Mcy for moderate sea level change). The total volume available when the renewable and non-renewable sources are combined is tabulated in Table 9-7.

Table 9-7: Total Volume Available

Source	50-Yr Total Volume (cy)
Renewable	25,130,000
Non-Renewable	25,123,057
TOTAL	**50,253,057**

As for structural inlet management, based on similar designs of terminal groin structures and the current structure cross-section at Fort Macon, the expected cost per linear foot of groin is expected to be $3,000 – $4,000. This would entail an initial cost of $3.8- 5.0M and would still require ongoing beach nourishment costs as well to be sure that the effects on adjacent shorelines are minimal. The groin is estimated to reduce the nourishment need by **20,278 cy/yr** along the Bogue Banks shoreline based on the annual erosion rate in the vicinity of the inlet and the reduction in erosion seen at Oregon Inlet and Fort Macon after structures were built at these locations. If a leaky groin were ultimately required to be built, the reduction would likely be less. Nonetheless, at $12/cy (assumed pipeline project), the nourishment reduction benefit could be up to $243,340/yr. Therefore, the terminal groin would take 15-20 years to pay for itself in reductions in nourishment costs. **Given that Bogue Inlet would still have to be relocated to ensure that the terminal groin were never undermined and therefore inlet management would still have to be completed, this alternative was dropped from further consideration.** Given the historical behavior of the inlet and its past history of moving considerably along the inlet corridor from Bear Island to the Point at Emerald Isle, the terminal groin itself could not be counted on alone to provide adequate inlet stability. Given the past behavior at the Point, it would be impossible to say that inlet management would never be required even if a terminal groin were built.

Lastly, given the above findings, a hybrid approach was also considered utilizing inlet relocation and construction of a terminal groin at Bogue Inlet. Again, since the inlet studies completed to date by CPE and M&N show that the inlet stability and the behavior of the inlet movement is more related to the interplay of all the complex hydrodynamics of the inlet itself, all the backchannels (White Oak, Bogue Sound, etc.) and the ebb shoals, it is believed that non-structural inlet management must be completed whether a terminal groin structure is needed or not. Therefore, the decision to move forward with the addition of a terminal groin structure then becomes a decision as to whether the relative increase in inlet stability and possible reductions in beach nourishment need are worth the additional expense. At this time, the analyses to date show that the Town of Emerald Isle and the County would need to raise an additional $4 - 5.0M to build the terminal groin structure. Since the inlet shoulders volume change variability has been approximately cut in half since the inlet has been relocated, and the additional monies would require special bonding or many years or reallocation of beach nourishment funding, it was decided that it would be most prudent to drop this alternative from further consideration. It was decided by the County and the Town of Emerald Isle that the most prudent path forward would be to utilize non-structural inlet management since it has proven to be so successful thus far. If storms or other conditions warrant, a separate environmental document could be completed at a later date for inclusion of a terminal groin structure at Bogue Inlet. Also, since the current laws only allow four (4) terminal structures to be permitted and four (4) are already being planned, it was decided that this option may not be feasible from a legal perspective. Therefore, it was dropped from further consideration.

Preferred Alternative

Therefore, based on the above analyses, the preferred alternative is Beach Nourishment with Non-structural Inlet Management. This is the only option that provides adequate sand sources to provide a 25-yr event LoP for all of Bogue Banks as well as provide adequate infrastructure and habitat protection along the Bogue Inlet shoulders. Based on the analysis results in Chapter 7.0, revised nourishment triggers for -12 ft NAVD shall be utilized as shown below in the table. The resulting management reaches are on average 2-3 miles long with the exception of the Pine Knoll Shores and Atlantic Beach management reaches which are somewhat longer and cover the entire Town in each case. For the proposed management reaches, the weighted trigger is 233 cy/ft with triggers varying from 211 cy/ft for Emerald Isle Central to 266 cy/ft for portions of Emerald Isle West (Table 9-8).

Table 9-8: Revised Calculated Trigger Volumes Above -12 ft NAVD88 for Various RP Events

Reach	Reach Length (ft)	50-yr, -12 ft Trigger (cy)	25-yr, -12 ft Trigger (cy)	Adjusted 25-yr, -12 ft Trigger (cy)	Preliminary -12 ft Trigger (cy)	-12 ft 2011 Volume (cy)
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Atlantic Beach - Circle (90)	1,006	408	364	364		330
Atlantic Beach - East (97-102)	6,011	318	276	276		384
TOTAL	**121,702**					
AVERAGE		**288**	**230**	**238**	**233**	**290**
					Weighted	

Again, it is VERY IMPORTANT to note that the results are based upon average background erosion rates across the island. Storm effects and other factors could DRASTICALLY alter future nourishment requirements. The plan will nourish areas as they reach the nourishment triggers via gradual erosion or in response to future storms which of course cannot be predicted. However, the results presented in Table 9-9, Figure 9-6, and Figure 9-7 are useful for overall long term planning and budgeting purposes.

Table 9-9: Renourishment Intervals and Preliminary Projects Based on Detailed Subreach and Management Reach Approaches

Year	Detailed Subreach Nourishment Volume (cy)	Management Reach Nourishment Volume (cy)	Nourishment Project (Yr)
2019	640,332	686,067	3
2022	1,686,018	1,839,351	6
2025	1,163,781	967,920	9
2028	1,686,018	1,839,351	6
2031	640,332	686,067	3
2034	2,209,467	2,121,204	6,9
2037	640,332	686,067	3
2040	1,686,018	1,839,351	6
2043	1,163,781	967,920	9
2046	1,686,018	1,839,351	6
2049	640,332	686,067	3
2052	2,209,467	2,121,204	6,9
2055	640,332	686,067	3
2058	1,686,018	1,839,351	6
2061	1,163,781	967,920	9
2064	1,686,018	1,839,351	6
TOTAL	**21,228,045**	**21,612,609**	

Figure 9-6: Detailed Subreach Nourishment Plan

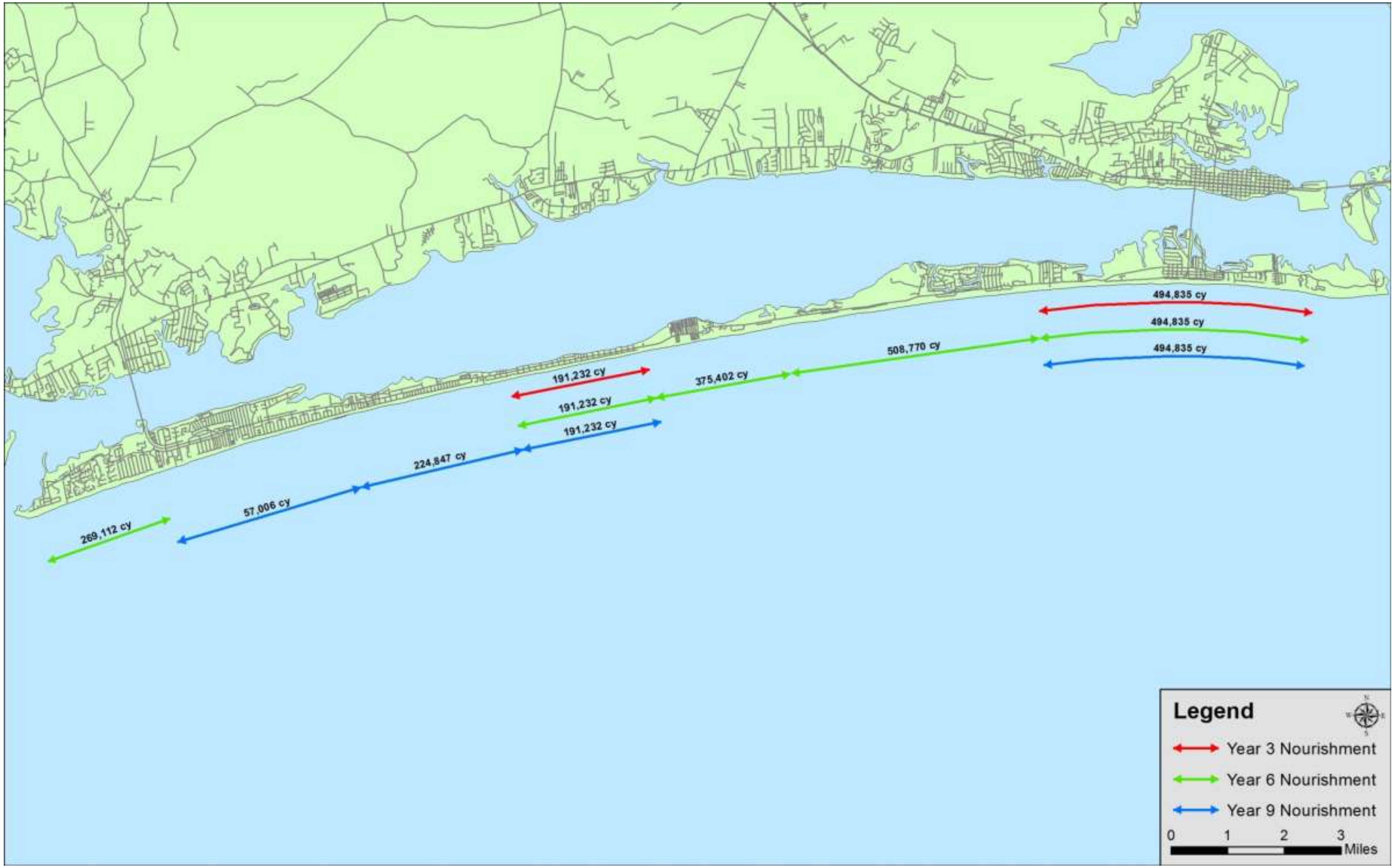

Figure 9-7: Management Reach Nourishment Plan

Based on the results above, one can see that some reaches will require more sand than others based on localized and regional erosion patterns. The inlet/dredging effects at Atlantic Beach and Bogue Inlet as well as the hotspots at Pine Knoll Shores-East and Emerald Isle-East are apparent while historically sand receiving areas at Emerald Isle-Central and West will require less sand comparatively. The Management Reach nourishment plan will likely be the one most closely followed in the future, but again, storms and other factors will likely override the above approach in reality.

The MBNP and Preferred Alternative include the following elements:

- Sand from offshore sources (1st priority), inlet sources (2nd priority) and upland sources (3rd priority) is proposed to be excavated and placed on the beach. These primary sand sources are sufficient to maintain the design beach at a 25-year LoP with advance fill varying from 25 to 50 cubic yards per foot – depending upon actual future erosion rates and available funding.

- Renourishment events are expected to be required at 3, 6, and 9 year intervals starting in 2019 - based upon average background erosion rates. Actual renourishment events will be dependent upon actual erosion, and available funding – including FEMA funding in response to future storms for which the timing and severity cannot be reasonably predicted.

- Sand obtained from the USACE maintenance dredging of the Morehead City Harbor Channel and Bogue Inlet AIWW "crossings" is proposed to be used as part of the primary sand sources; maintenance dredging is proposed to be performed by the USACE under their permit authority, but USACE dredging and beach-fill placement are assumed to continue and are an integral part of the MBNP.

- If the main channel at Bogue Inlet migrates outside the "safe box", the main channel is proposed to be relocated by the Applicant, Carteret County, to the location constructed in 2005 with the excavated material used to nourish the beach as part of the primary sand sources.

Funding

Numerous analyses were completed to determine the sustainability of funding for the Master Plan. Analyses on an annual, long-term (covers 85-94% of the need), and cash-flow perspective were completed. In each case, current funding streams are quite close to providing the long-term financial need for the project. The cash flow analyses showed the shortest sustainable timeframe with the project requiring additional funding 20 years from now.

Again, it is VERY IMPORTANT to note that the results are based upon average background erosion rates across the island. Storm effects and other factors could DRASTICALLY alter future nourishment requirements. The plan will nourish areas as they reach the nourishment triggers via gradual erosion or in response to future storms which of course cannot be predicted. It is also important to note that the all the funding analyses are for the background erosion rates and that FEMA funding is expected to cover the named storms (hurricane) erosion as has been done in the past. In summary, the plan will nourish areas as they reach the nourishment triggers as well as in response to future storms which of course cannot be predicted.

Given the preferred plan is sustainable for 20 yrs, the recommendation is to track expenditures over next 5-10 years and adjust then as needed. Finally, it should be noted that all the above analyses does not include any State or Federal funding above that which is expected for the Morehead City Harbor Project and as required to maintain the ICWW near Bogue Inlet. Any additional funds from these sources would extend the long-term sustainability of the project.

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