INTEGRATED FEASIBILITY REPORT AND ENVIRONMENTAL IMPACT STATEMENT

COASTAL STORM DAMAGE REDUCTION

BOGUE BANKS, CARTERET COUNTY

NORTH CAROLINA

APPENDIX A

Coastal Engineering

US Army Corps
of Engineers
Wilmington District

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Appendix A: Coastal Engineering

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1.1 Introduction

1.1.1 Project Overview

The U.S. Army Corps of Engineers (USACE) Wilmington District (District) is conducting a storm damage reduction study for the Bogue Banks (Carteret County) shoreline. The study area includes the majority of Bogue Banks, approximately 23 miles, from Bogue Inlet on the west to the western end of Fort Macon on the east (Figure 1). Communities included within the study area are Atlantic Beach, Pine Knoll Shores, Salter Path, Indian Beach and Emerald Isle. A portion of Fort Macon State Park on the eastern end of the barrier island is also included within the study area. The ultimate goal of the project is to formulate the beach maintenance plan for Bogue Banks over the next 50 years that maximizes net economic benefits and is feasible from both an environmental and constructability standpoint.

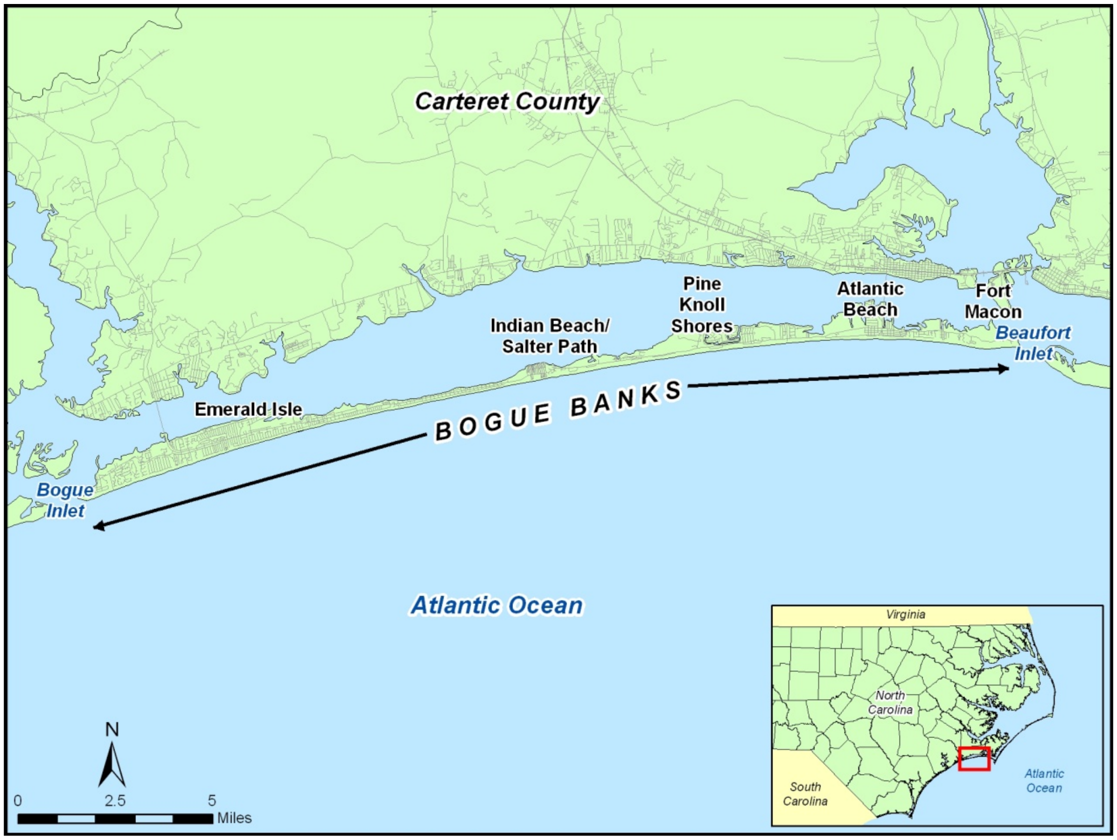


Figure 1: Project Location

The Beach-fx software was utilized to analyze the physical performance of storm damage reduction alternatives in the Bogue Banks study area as well as the economic benefits and costs. Beach-fx is an event-based, Monte Carlo life cycle simulation tool capable of estimating storm damage along coastal zones caused by erosion, flooding, and wave impact. The software also calculates the economic benefits and costs associated with the alternatives. Inputs are required from meteorology, coastal morphology, economics, and management processes. Within Beach-fx, data elements are stored in a relational database where rules for applying the data elements are inherent in the program (Gravens et. al. 2007). The data necessary to run a Beach-fx project provide a full description of the coastal area under study. The software requires an inventory of structures susceptible to damage, a set of historically-based possible storms that can impact the area, the estimated morphology response of the beach to each storm in the storm set, and damage-driving parameters for estimating inundation, erosion, and wave impact damages on the structures. The collection of beach profile responses to various historical storms was developed using SBEACH (Storm induced BEAch CHange), a cross-shore beach morphology program within the CEDAS (Coastal Engineering Design & Analysis System) package.

The unit of analysis in a shoreline storm damage reduction project is the shoreline area. Within the Beach-fx planning context, the project is divided into reaches, which are defined as contiguous, morphologically homogeneous areas. Reaches are defined and grouped by profile, or cross sections of the beach which characterize the beach morphology. Each reach contains a given number of lots and each lot contains one or more damage element, such as a residential home or nonresidential structure.

The purpose of this appendix is to describe, in detail, the Coastal Engineering input driving the Beach-fx software for the Bogue Banks study area. This includes developing the representative reaches for the Bogue Banks study area, a historical storm suite, historic shoreline change conditions, and profile response to the array of storm events using SBEACH.

1.1.2 Longshore Sediment Transport

As part of the June 2001 Section 111 study (USACE, 2001) a sediment transport study was conducted for Bogue and Shackleford Banks. Results from the study show that the east end of Bogue Banks, between the east town limit of Atlantic beach and Beaufort Inlet, have a high degree of variability resulting from complex wave transformation across the ebb tide delta of Beaufort Inlet. The predominant direction of net littoral transport on Bogue Banks near Beaufort Inlet is to the east, while the remainder of the island experiences net transport to the west. The location of the reversal in net transport is located approximately 2.3 miles west from the shoulder of Beaufort Inlet. Sediment transport along Shackleford Banks is primarily toward the west, or Beaufort Inlet. Net transport is highest near the shoulder of the inlet flowing west. Transport rates decrease with increased distance from the inlet to a point 3.2 miles east of the inlet where potential transport is calculated to be nearly zero. East of this point the transport rates are lower and more erratic varying between easterly and westerly transport up to 6 miles east of the inlet. The remaining approximate half mile of the island experiences eastward net transport toward Barden Inlet.

2.1 Data Requirements

This section provides a description of the data collected to populate the Beach-fx databases and to execute the Bogue Banks Storm Damage Reduction Study as well as all assumptions inherent in the methodology.

2.1.1 Profiles

Coastal process models require a detailed characterization of the beach profile (distances vs. elevation). A simplified representation, or profile, is required for Beach-fx and depicts the following shore features: dune width, dune height, dune slope, foreshore slope, upland elevation, upland width, berm width, and berm height. For the Bogue Banks study area, the shoreline is defined by thirteen unique profile areas, grouped as shown in Figure 2. A schematic of the simplified Beach-fx profile is provided in Figure 3. Figures 4 through 16 provide the generalized representative cross shore for the existing condition (current conditions) for Profiles 1 to 13, respectively. The process for developing the idealized profiles is described in detail in Section 3 of this appendix.

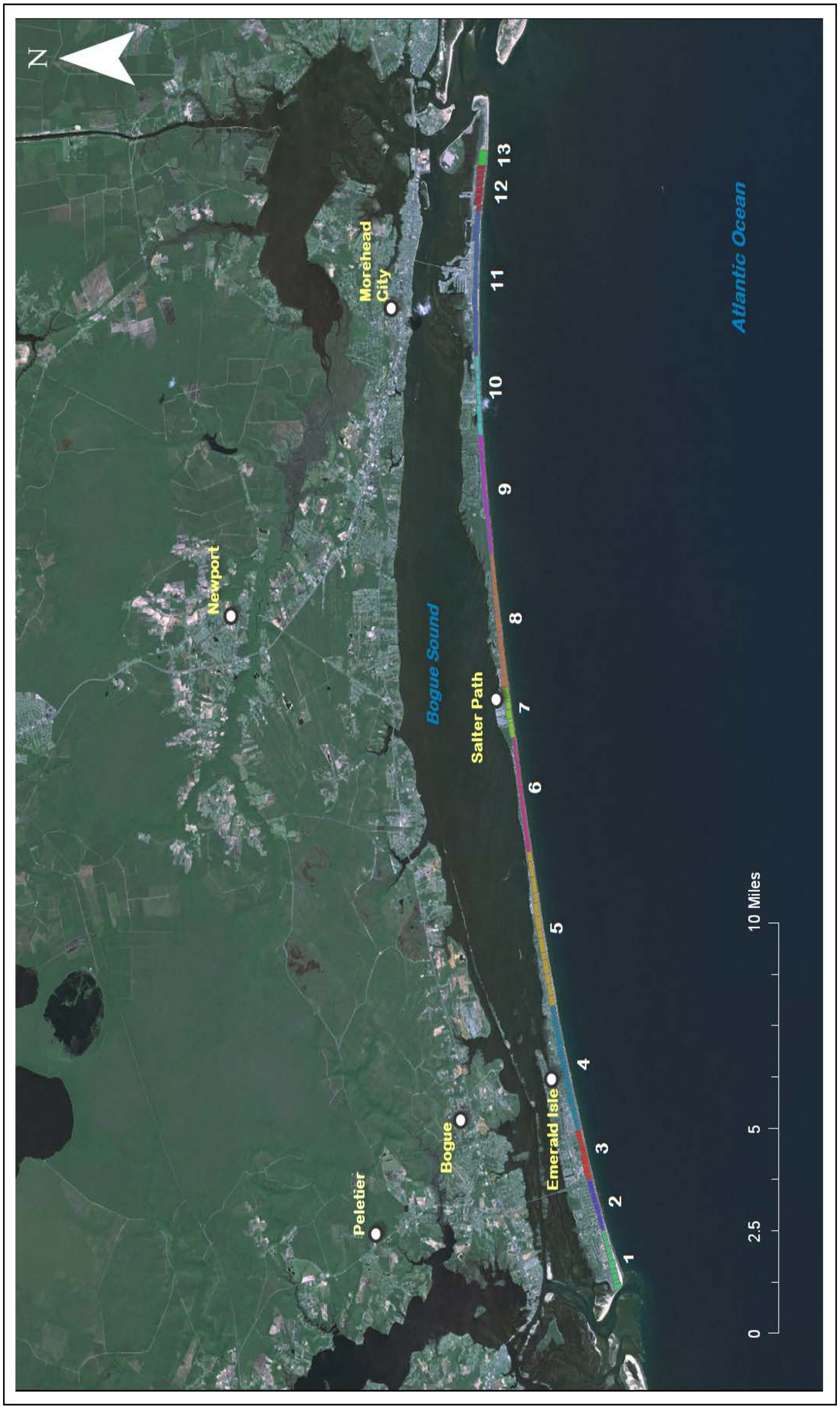


Figure 2: Representative profile areas 1 to 13 along the Bogue Banks study area

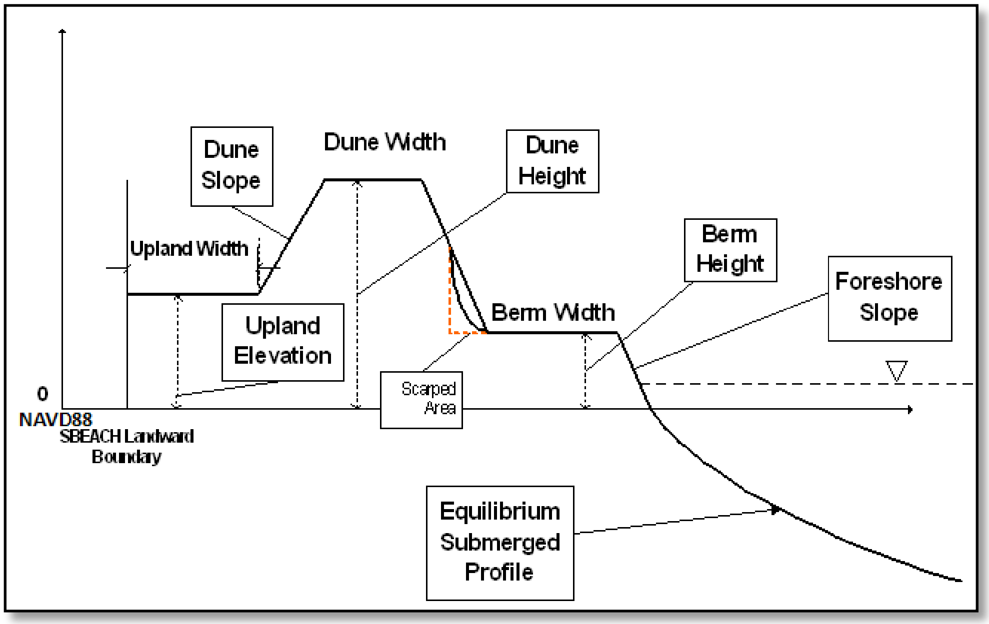


Figure 3: Simplified Beach Profile Required by Beach-fx

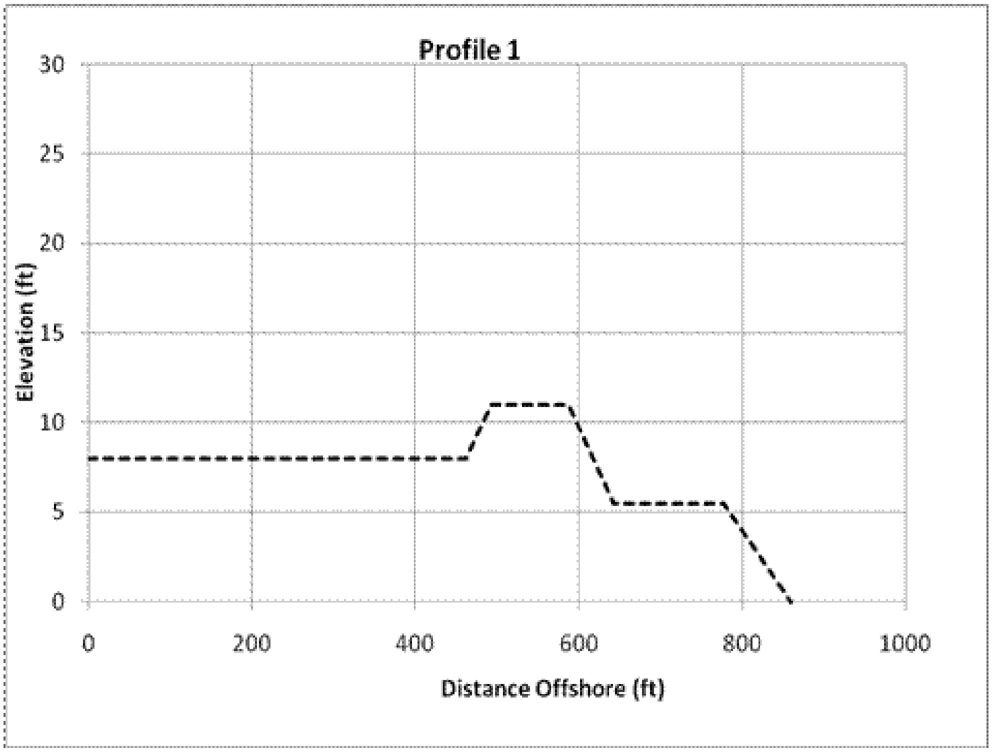


Figure 4: Generalized Cross Shore Morphology for Profile 1

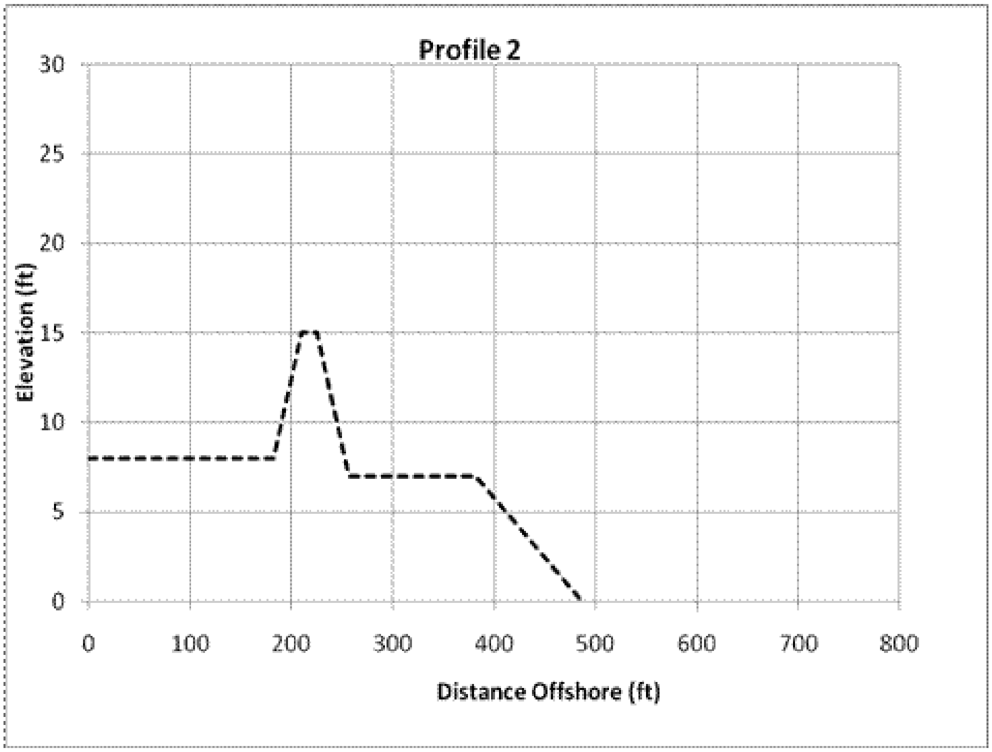


Figure 5: Generalized Cross Shore Morphology for Profile 2

Figure 6: Generalized Cross Shore Morphology for Profile 3

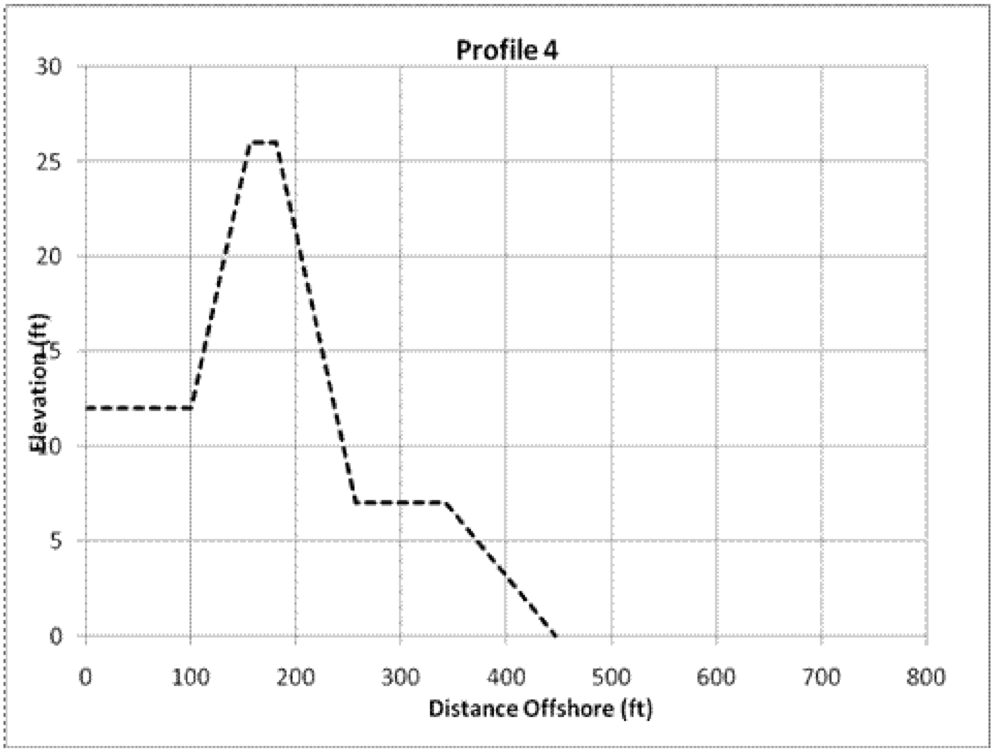


Figure 7: Generalized Cross Shore Morphology for Profile 4

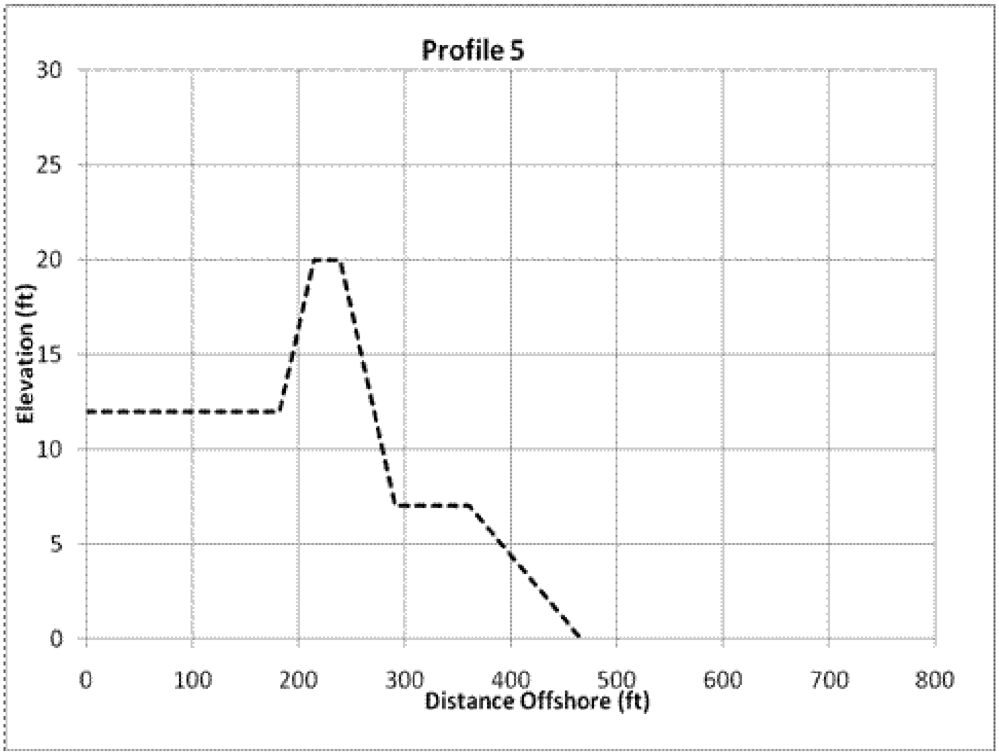


Figure 8: Generalized Cross Shore Morphology for Profile 5

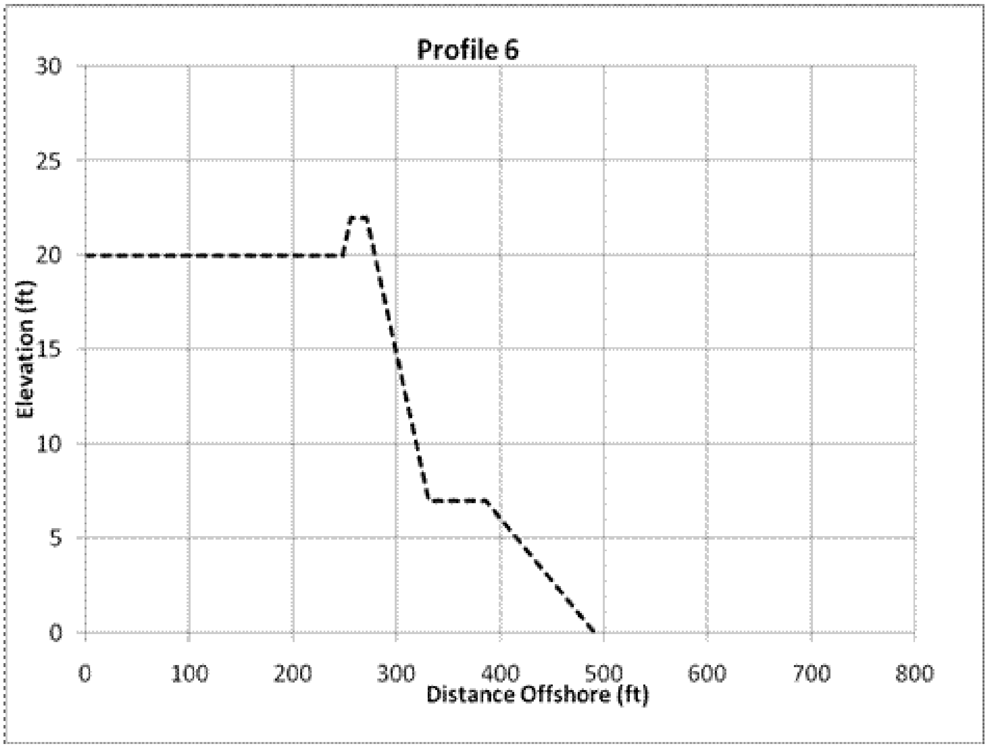


Figure 9: Generalized Cross Shore Morphology for Profile 6

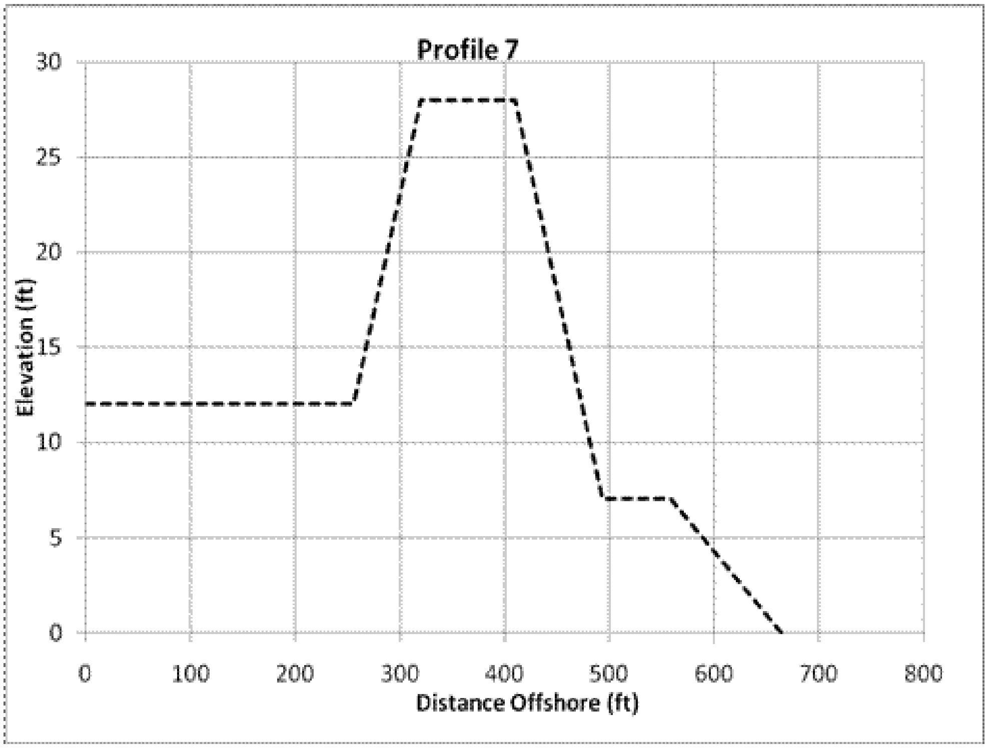


Figure 10: Generalized Cross Shore Morphology for Profile 7

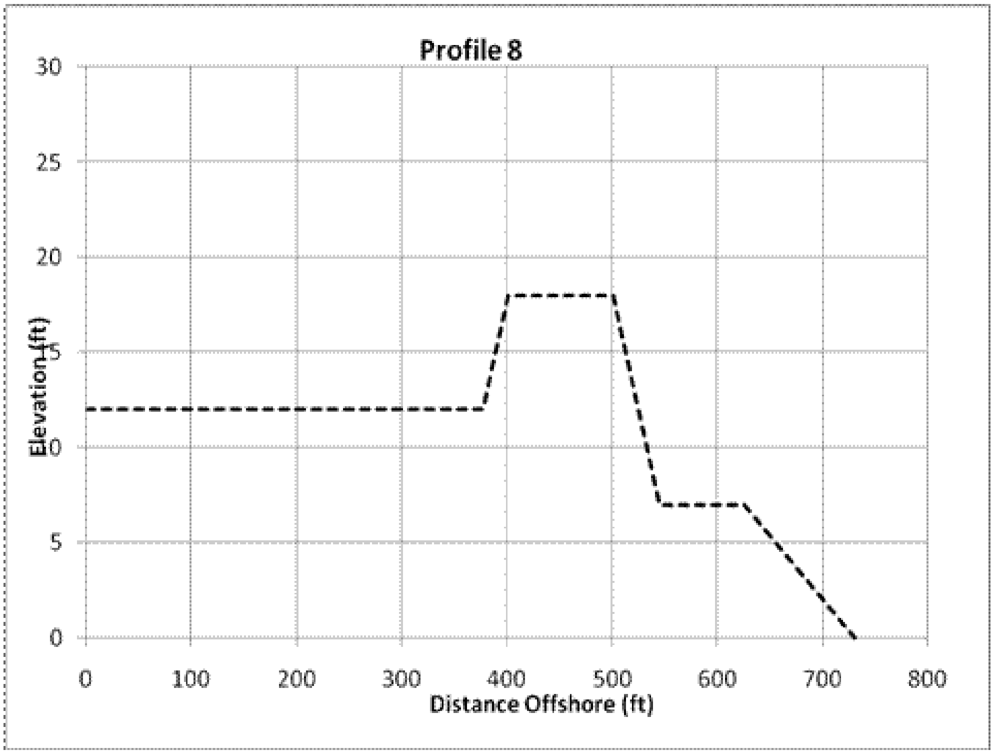


Figure 11: Generalized Cross Shore Morphology for Profile 8

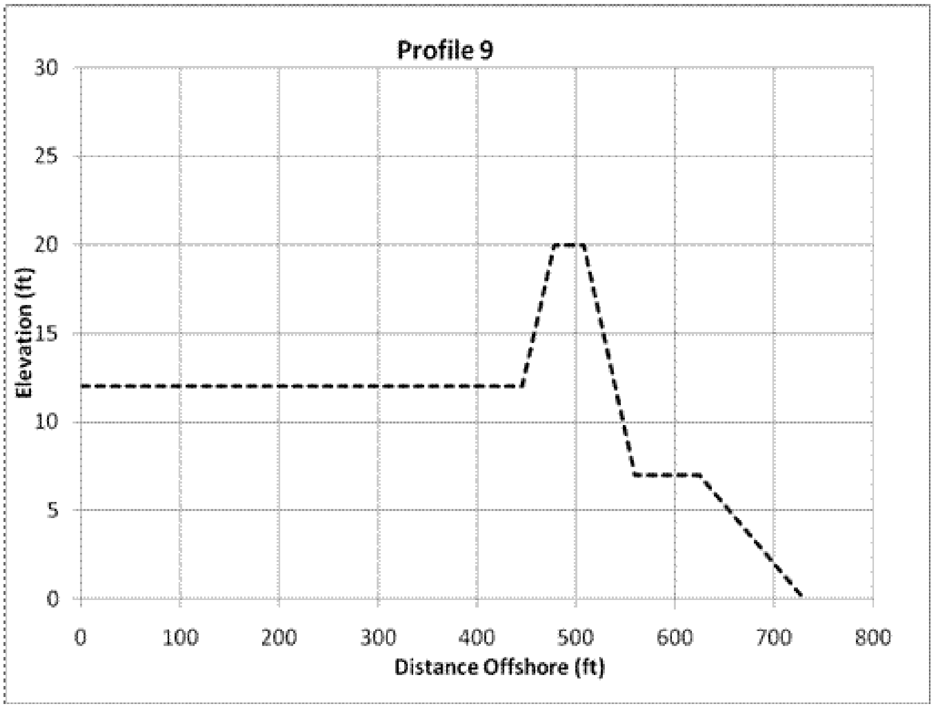


Figure 12: Generalized Cross Shore Morphology for Profile 9

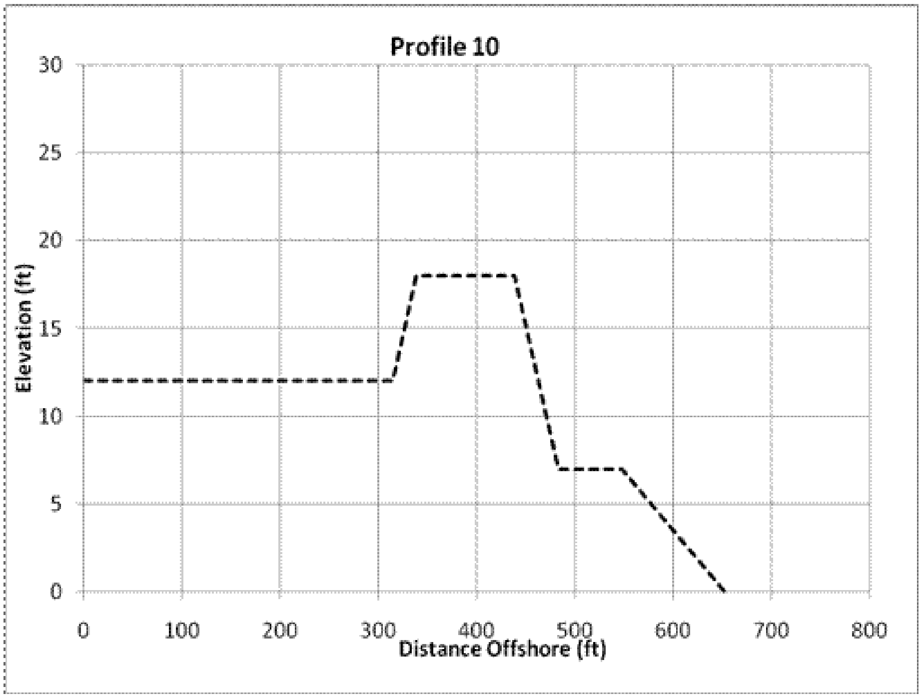


Figure 13: Generalized Cross Shore Morphology for Profile 10

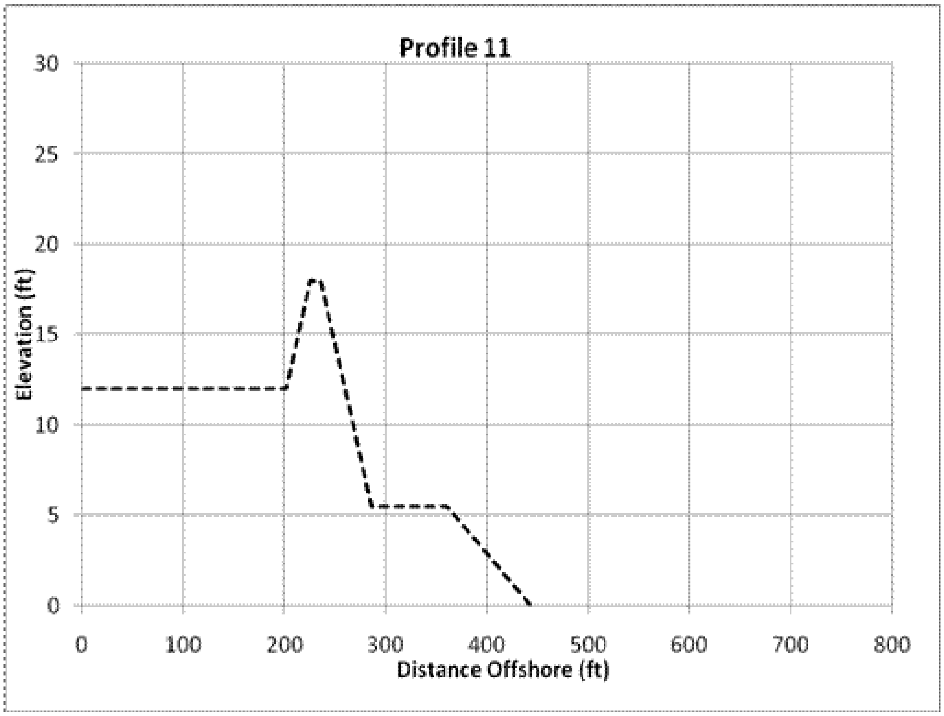


Figure 14: Generalized Cross Shore Morphology for Profile 11

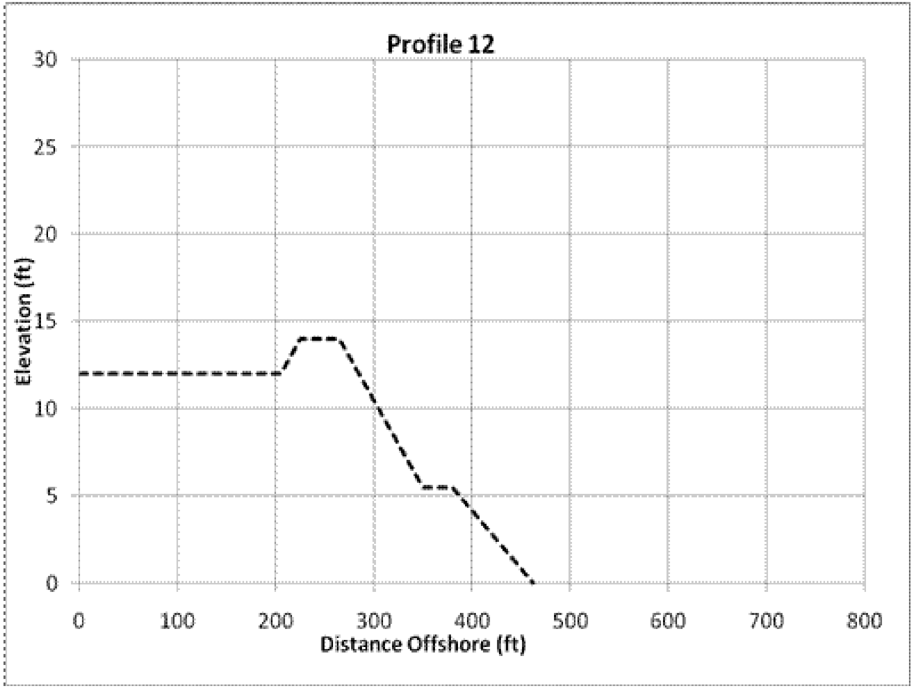


Figure 15: Generalized Cross Shore Morphology for Profile 12

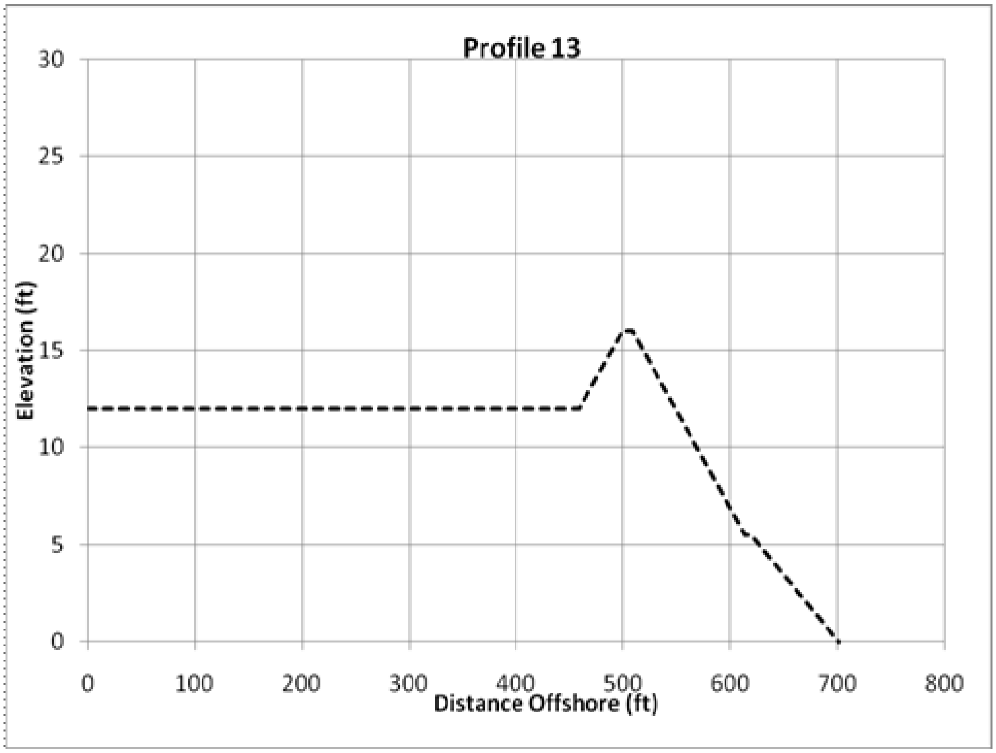


Figure 16: Generalized Cross Shore Morphology for Profile 13

2.1.2 Reaches

Reaches are contiguous stretches of the shoreline that share a common morphological makeup with a particular profile (Rogers et. al. 2009). The Bogue Banks study area is divided into 118 reaches that correspond with Profiles 1 to 13, as shown in Table 1. The following data are reach specific within Beach-fx: applied erosion rate, back-bay flooding, planned nourishment, emergency nourishment, flooding threshold, control line offset (threshold distance from the lot centroid to the seaward toe of the dune at which lots in the reach will be marked as condemned prohibiting the rebuilding of damage elements in that lot), and berm width recovery factor. For calibrating Beach-fx, reach-specific historic erosion rates are also needed, as discussed in Section 2.2.

No back-bay flooding or emergency nourishment is assumed in the study area. The berm width recovery factor is assumed at 95 percent for Reaches 1 to 117. The berm width recovery factor was adjusted to 99% for reach 118 during the calibration process.

Profile	Reaches
1	1-10
2	11-15
3	16-21
4	22-29
5	30-42
6	43-52
7	53-58
8	59-73
9	74-85
10	86-92
11	93-110
12	111-117
13	118

Table 1: Reach/Profile Cross Reference

Control line offsets differ in the study area depending upon structure square footage. According to the state legal requirements, structures less than 5,000 square feet (sq ft) have a minimum setback factor equal to 30 times the erosion rate from the vegetation line. Structures between 5,000 and 10,000 sq ft have a minimum setback factor equal to 60 times the erosion rate from the vegetation line. As structures increase in size to 100,000 sq ft or greater, the erosion standard increases incrementally, reaching a maximum setback of 90 times the erosion rate. The minimum erosion rate is set at 2 feet per year (ft/yr). Thus, it was necessary to analyze the weighted average control line offset for each reach. Assumptions were made regarding the average square footage of structure types in the study area. High rise hotels were assumed to fall within the 90 times erosion rate category. Club houses, apartments/condos, 1 to 2 story motels, warehouses, and large footprint single-family homes were assumed to fall within the 60 times erosion rate category. All other structures were assumed to fall within the 30 times erosion rate category. Given these assumptions, a weighted setback factor was calculated for each reach. This value was multiplied by the historical erosion rate in the reach (no less that 2) to determine the Reach specific weighted average control line offset input for Beach-fx.

2.1.3 Lots

In Beach-fx, a lot is an organizational container used by the software for damage elements and are designed in a way that best fits the specific study need. The following data are Lot specific: type (residential or vacant), lot description (typically address), armoring status and additional armoring specific data.

There were 1,847 lots created for the study area and no lot armoring is assumed within the study area. An example lot from Reach 1 is shown in Figure 17. The boundary of Reach 1 is red while lot boundaries within the reach are black. The blue dots represent damage elements.

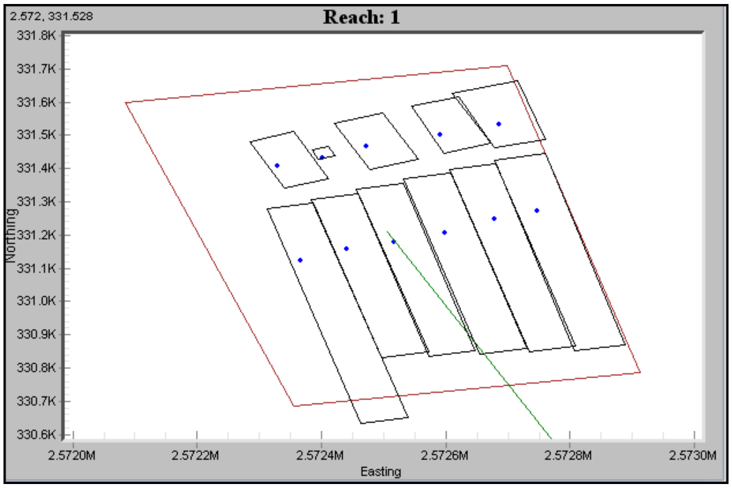


Figure 17: Lots within Reach 1

2.1.4 Damage Elements

A damage element is any physical structure that can endure storm damages, including a residential home, deck, pool, restaurant, pier house, etc. Damage elements are represented by X,Y coordinates in Beach-fx. Damage elements types, or categories, are defined by the user and are project specific. Foundation and construction categories for damage elements are also project specific and defined by the user. Critical vertical erosion amounts that compromise the structure are defined by foundation type. Damage element specific data include: type, description (typically address) foundation type, construction type, armor data, coordinates, number of rebuilds allowed, and triangular distributions of content value, structure value, rebuilding time, and first floor elevation.

For the Bogue Banks study area, the above mentioned data requirements were collected for nearly 2,000 damage elements by the Wilmington District. Construction types include wood or masonry, with all but one structure being built of wood. Foundation types include slab, 8-foot deep pile, or 16-foot pile with critical erosion amounts of 0.5, 4, and 8 feet, respectively. Nearly 80 percent of damage elements in the study area are built upon 8-foot deep piles. Damage element type codes cover the range of structures in the study area, as shown in Table 2.

Code	Description	Code	Description
SF1	1 story SF on slab	SF1_SM	SF 1 story on piles with small footprint
SF2	2 story SF on slab	SF2_SM	SF 2 story on piles with small footprint
MF1	apartments/condos	SF1_LG	SF 1 story on piles with large footprint
CondoHOA	condo, HOA	SF2_LG	SF 2 story on piles with large footprint
MOBHM	mobile home	POOLH	pool house, garage
HOTEL	hotel or hi-rise	STRT	street / highway
MOTEL	motel (1 to 2 stories)	PARK	parking lot
OFFIC	office Building	DECK	decks
POOL_TEN	swimming pool, tennis court	DUNE	dune walkovers
CLUB	private club	PU_ACC	public access--improved
RESTU	restaurant	WAREH	storage building / warehouse
BAR	tavern	PIERHOUSE	pier house or storage

Table 2: Damage Element Types

Quality checks were performed on the damage elements through the coordinate checking process in Beach-fx. Data discrepancies were investigated using GIS and resolved as appropriate. As a result of the coordinate checking process in Beach-fx, several errors were identified within the damage element database. Approximately 100 damage elements were reported by Beach-fx as not falling within the assigned lot and/or reach. These errors were investigated using GIS. The given damage element description (i.e. address) was compared to nearby lot addresses. In nearly all instances, the proper lot was located and the damage element coordinates were corrected accordingly. Three damage element locations could not be verified and were thus inactivated in the database. The coordinate checking process also reported incidents where the input first floor elevation was below the calculated profile elevation at that point for a given damage element. The cause of this error is likely due to the generalization of reach elevation. These errors were corrected by adjusting the given damage element elevation to be an appropriate distance above the profile elevation of the reach in which it falls. Additionally, the coordinate check revealed that 142 damage elements are located landward of the SBEACH line and thus never experience damage in the model. These damage elements were marked as inactive in the database.

After rectifying the damage element errors, the Bogue Banks study area has 1,764 active damage elements remaining. A summary of these damage elements by type are provided in Table 3. Large footprint single-family homes constitute the majority of the structures in the study area. Total structure values for all damage elements are estimated at $714.8 million and total contents are valued at $290.6 million for a total $1 billion in property that could potentially be damaged from incoming storms.

Damage Element Type	Count	Sum of Structure Value (ML*)	Sum of Contents Value (ML)	Sum of Total Value (ML)
BAR	1	123,600	51,418	175,018
CLUB	7	3,181,200	1,233,024	4,414,224
CondoHOA	2	1,200,000	480,000	1,680,000
HOTEL	3	3,435,600	3,698,654	7,134,254
MF1	12	44,882,400	17,952,960	62,835,360
MOBHM	4	1,290,000	620,040	1,910,040
MOTEL	14	8,824,800	3,991,560	12,816,360
OFFIC	4	353,700	355,723	709,423
PARK	13	7,044,100	3,039,400	10,083,500
PIERHOUSE	6	1,058,400	1,767,528	2,825,928
POOL_TEN	37	2,858,400	428,760	3,287,160
POOLH	2	2,526,000	444,576	2,970,576
RESTU	5	1,077,600	1,788,816	2,866,416
SF1	56	5,145,600	2,058,240	7,203,840
SF1_LG	451	71,716,920	28,686,768	100,403,688
SF1_SM	111	27,562,950	11,025,180	38,588,130
SF2	92	50,412,000	20,164,800	70,576,800
SF2_LG	802	367,432,848	146,923,790	514,356,638
SF2_SM	137	112,862,940	45,097,416	157,960,356
UA	2	1,200,000	480,000	1,680,000
WAREH	3	597,600	298,800	896,400
Grand Total	1,764	714,786,658	290,587,453	1,005,374,111

*ML = most likely

Table 3: Damage Element Summary Data

2.1.5 Meteorological Data

The project area is impacted by both tropical and extra-tropical (also called “nor’easter”) storm events. An analysis of historical storm climatology resulted in identification of 35 tropical storms from 1893 to 1999 giving an annual probability of tropical storm occurrence of 0.33. Twenty-three extra-tropical storms occurred from 1978 to 1992 giving an annual probability of extra-tropical storm occurrence of 1.44. These 58 historical storms, shown by arrival date in Figure 18, were expanded to a plausible storm suite consisting of 696 storms by combining the historical storm surge hydrograph with three statistically defined tidal ranges (high, mean, and low) and combining the storm surge hydrograph at four phases of the astronomical tide such that peak surge is aligned at high tide, mid-tide rising, mid-tide falling, and low tide. In terms of relative probability of occurrence, those plausible storms associated with mean tidal ranges are given a relative probability of 2 whereas those storms associated with high and low tidal ranges are given a relative probability of 1.

Beach-fx requires specification of user defined storm seasons. Using the historical storms dataset, six seasons were defined and probabilities for tropical and extra-tropical storms were calculated. Minimum inter-storm arrival times were also calculated and the maximum allowable tropical and extra-tropical storms within a season were set. These data are provided in Table 4.

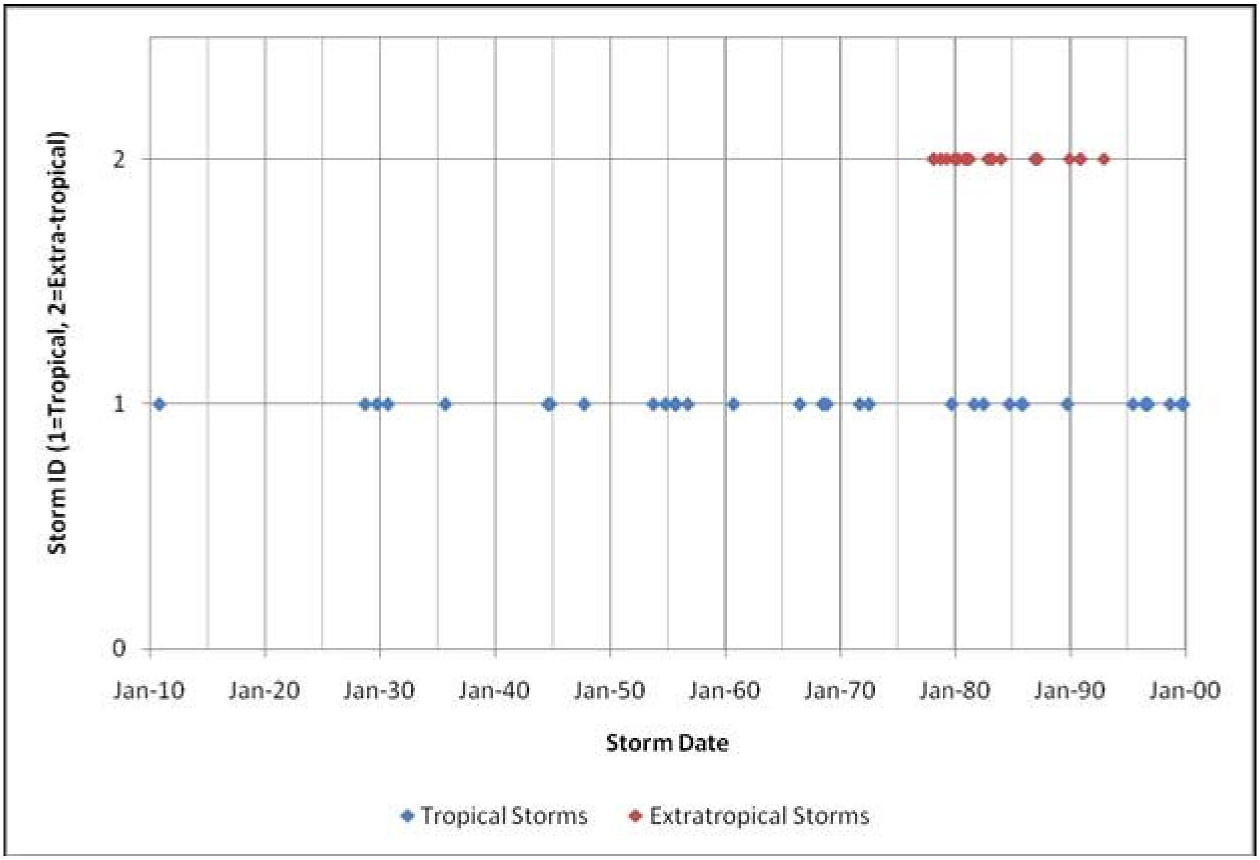


Figure 18: Historical Storm Dataset

Season	Probability Extra-Tropical	Probability Tropical	Min Storm Arrival	Max Extra-Tropical	Max Tropical
Jan-Mar	0.688	0.000	13	3	0
Apr-May	0.000	0.000	30	0	0
Jun-Aug	0.000	0.113	5	0	2
Sept	0.063	0.132	17	1	1
Oct	0.125	0.075	30	1	1
Nov-Dec	0.563	0.009	24	2	1

Table 4: Storm Seasons

2.1.6 Coastal Processes Model Data

A shoreline damage reduction study requires inputs from a coastal process model that captures how the beach responds to wave action and water levels caused by storms as well as long-term processes. For the Bogue Banks project, the Storm Induce Beach Change model (SBEACH) was executed external to the Beach-*fx* environment. The beach profile responses estimated in the SBEACH simulations are used to populate the Shore Response Database (SRD) in Beach-*fx*. Details on the SRD development are provided in Section 3.

2.1.7 Damage Functions

Damage functions are used within Beach-*fx* to estimate storm-induced damages sustained by the damage elements. Damages are estimated separately for the structure and contents of each impacted damage element. Damages are caused by three processes: erosion, inundation, and wave attack. Beach-*fx* has an inherent set of rules for combining damages when multiple damage processes produce damages to a structure or contents during a storm event (see Rogers et. al. 2009, page 47).

Damage functions are user-defined within Beach-*fx*. Damage function types and definitions are included but the specific functions must be developed and defined for each project. A specific damage function must be assigned to each combination of damage element type, foundation type, and construction type. These functions are expressed as a percent of the structure or content valuation compromised. In all, the Wilmington District developed 23 damage functions, as shown in Table 5. Triangular distributions were developed for each of the damage functions representing minimum, most likely, and maximum values at each point along the X-axis. These damage functions are where uncertainties of the model area accounted for using a Monte Carlo analysis. Illustration of each damage function developed for Bogue Banks can be found in the Economic Appendix, Appendix B.

Function	Function Description Group Description	X-axis	Y-axis
ERODP1MCON	Erosion - Pile 16 - MF - Contents	% Footprint compromised	Fractional damage to contents or structure
ERODP1SCON	Erosion - Pile 16 - SF - Contents		
EROPILECON	Erosion - Pile Foundations - Contents		
EROSHLCON	Erosion - Shallow Foundation - Contents		
ERODP1MSTR	Erosion - Deep Piles 1 Floor Medium - Structures		
ERODP1SSTR	Erosion - Deep Piles 1 Floor Small - Structures		
ERODP2LSTR	Erosion - Deep Piles 2 Floors Large - Structures		
ERODP2MSTR	Erosion - Deep Piles 2 Floors Medium - Structures		
ERODP2SSTR	Erosion - Deep Piles 2 Floors Small - Structures		
ERODP3MSTR	Erosion - Deep Piles 3 Floors Medium - Structures		
ERODP4LSTR	Erosion - Deep Piles 4 Floors Large - Structures		
ERODP4SSTR	Erosion - Deep Piles 4 Floors Small - Structures		
ERODP5LSTR	Erosion - Deep Piles 5 Floors Large - Structures		
EROPILESTR	Erosion - Pile Foundation - Structures		
EROSHLSTR	Erosion - Shallow Foundation - Structures	Water depth above 1st floor	
2SNBC	Innundation - 1 - 2 story - Contents		
4SNBC	Innundation - 4 story - Contents		
INUM4FL	Innundation - 4 - 5 floors - Structures		
INUNALLSTR	Innundation - All Structures up to 3 floors- Structures		
WAVENPC	Wave - Not On Piles - Contents		
WAVEPC	Wave - On Piles - Contents		
WAVENPS	Wave - Not On Piles - Structures		
WAVEPS	Wave - On Piles - Structures		

Table 5: Damage Functions for Bogue Banks

2.1.8 Existing Management Measures

Within the Bogue Banks area, no emergency nourishment is assumed to occur. No property is assumed to be armored. Thus, no existing management measures beyond existing regulatory requirements are assumed in the analysis.

2.1.9 Sea Level Rise

Beach-fx allows for sea level rise to be specified for a project. For the Bogue Banks project, sea level rise was set at 0.0084 ft/yr (2.57 mm/yr). This rate is based on the long term sea level rise measurement calculated at the Beaufort Inlet NOAA Tide gauge as shown in Figure 19.

In addition to the base model run using the historic sea level rise trend for the area, Beach-fx allows for relative sea level rise curves to be simulated in compliance with Engineering Circular 1165-2-212. This circular requires that "Potential relative sea-level change must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence". Relative sea level rise is a combination of the global sea level changes, due to thermal expansion and deglaciation, and local geologic changes in land elevation resulting in uplift or submergence. The relative sea level rise curves were calculated for NRC curves I and III and are displayed in Figure 20 along with the projected rise based on the measured historic rate at the Beaufort Inlet NOAA gauge. To incorporate these curves into the sea level rise analysis using Beach-FX a representative rate based on these curves was chosen. This rate was selected by calculating the projected sea level rise 30 years from the project base line year of 2010 and computing an average of this rise by dividing by 30. The representative sea level rise rates used in Beach-FX were 0.0341 ft/yr for Curve III and 0.0145 ft/yr for Curve I.

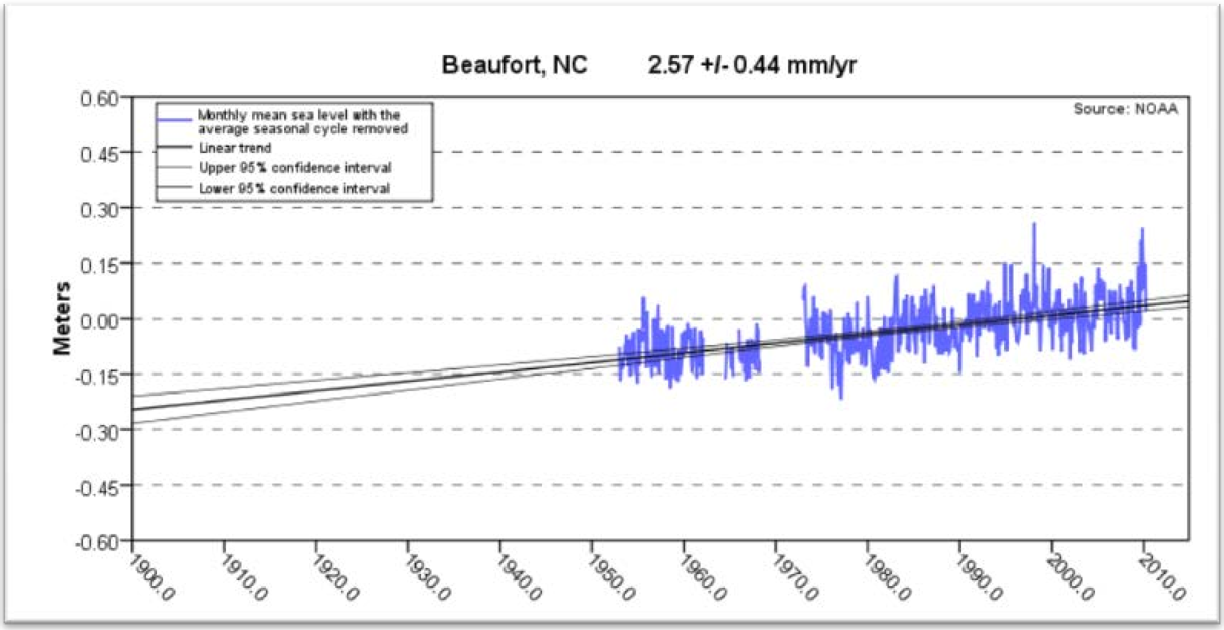


Figure 19 Long Term NOAA Tidal Gauge at Beaufort Inlet, NC

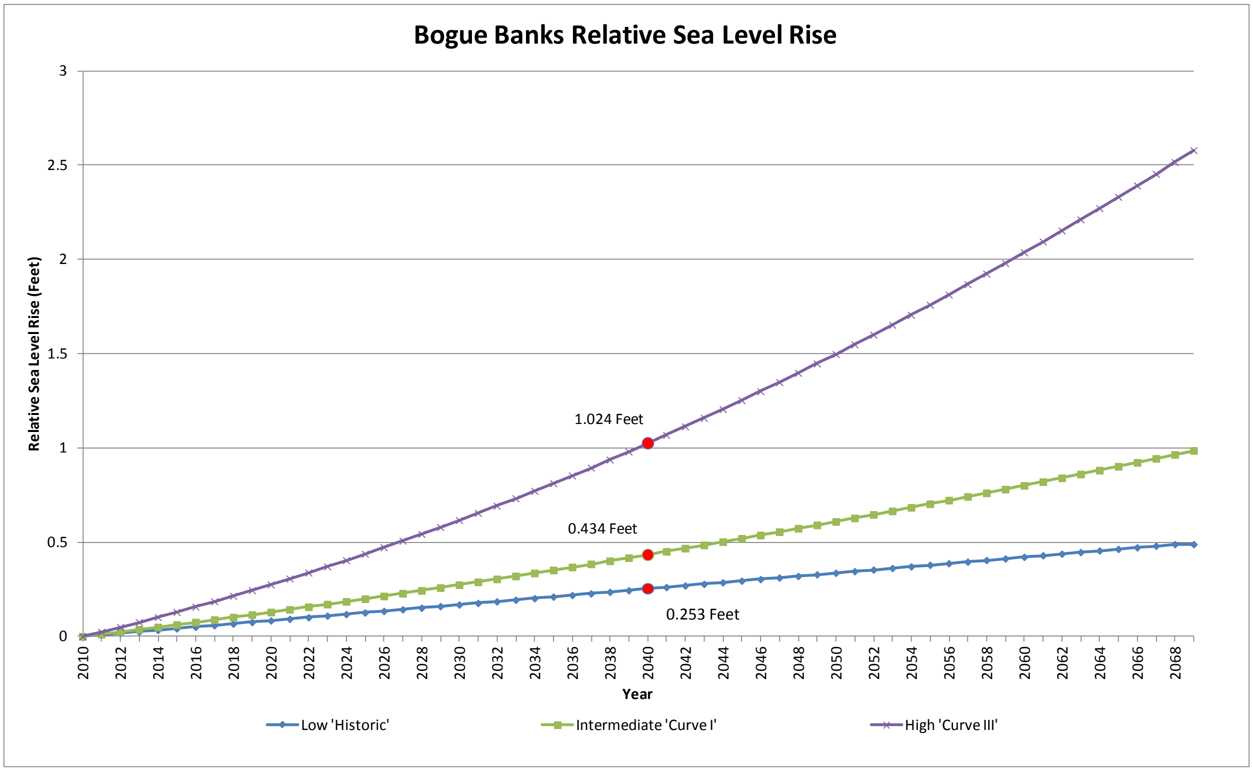


Figure 20 Bogue Banks Relative Sea Level Rise

2.1.10 Planned Nourishment

Development of planned nourishment alternatives requires data beyond the explanation of the existing conditions in the study area. The present implementation of planned nourishment within Beach-fx involves nourishment triggers expressed as a percent of specified nourishment template values along with a target nourishment interval, start date, mobilization threshold, and mobilization costs. Beach-fx requires inputs for these data as well as nourishment blackout windows, planform rate of change caused by the nourishment, production rate, borrow to placement ratio, and reach nourishment processing order. This section provides the planned nourishment assumption for the Bogue Banks study area.

The triggers used to initiate project nourishment were defined as 0.75 for berm width, 0.90 for dune width, and 0.85 for dune height. Model runs were completed with nourishment target intervals defined at 3, 4, and 5 years with a start date of January 1, 2019 and the mobilization threshold assumed at 1. Project-level mobilization costs are assumed for two hoppers at $3,200,000 and no mobilization costs are assumed at the reach level. Borrow to placement ratios for the study area are specified at the reach level and are shown in Table 6.

Due to the size of the storm response database file the project was divided into four roughly equal segments with the results summarized outside the Beach-fx environment. A summary of these data are provided in Table 6.

Reach Number	Planned Nourishment Alternative Name	Unit Placement Cost	Borrow To Placement Ratio	Production Rate	Berm Width Planned Nourishment Trigger	Dune Width Planned Nourishment Trigger	Dune Height Planned Nourishment Trigger
1	NED_3YRCYCLE	7.6	1.09603	27851.93	0.75	0.9	0.85
2	NED_3YRCYCLE	7.6	1.09603	27851.93	0.75	0.9	0.85
3	NED_3YRCYCLE	7.6	1.09603	27851.93	0.75	0.9	0.85
4	NED_3YRCYCLE	7.6	1.09603	27851.93	0.75	0.9	0.85
5	NED_3YRCYCLE	7.6	1.09603	27851.93	0.75	0.9	0.85
6	NED_3YRCYCLE	7.6	1.09603	27851.93	0.75	0.9	0.85
7	NED_3YRCYCLE	7.6	1.09603	27851.93	0.75	0.9	0.85
8	NED_3YRCYCLE	7.6	1.09603	27851.93	0.75	0.9	0.85
9	NED_3YRCYCLE	7.53	1.09603	28646.00	0.75	0.9	0.85
10	NED_3YRCYCLE	7.53	1.09603	28646.00	0.75	0.9	0.85
11	NED_3YRCYCLE	7.53	1.09603	28646.00	0.75	0.9	0.85
12	NED_3YRCYCLE	7.53	1.09603	28646.00	0.75	0.9	0.85
13	NED_3YRCYCLE	7.53	1.09603	28646.00	0.75	0.9	0.85
14	NED_3YRCYCLE	7.53	1.09603	28646.00	0.75	0.9	0.85
15	NED_3YRCYCLE	7.53	1.09603	28646.00	0.75	0.9	0.85
16	NED_3YRCYCLE	7.53	1.05324	28646.00	0.75	0.9	0.85
17	NED_3YRCYCLE	7.53	1.05324	28646.00	0.75	0.9	0.85
18	NED_3YRCYCLE	7.53	1.05324	28646.00	0.75	0.9	0.85
19	NED_3YRCYCLE	7.53	1.05324	28646.00	0.75	0.9	0.85
20	NED_3YRCYCLE	7.53	1.05324	28646.00	0.75	0.9	0.85
21	NED_3YRCYCLE	7.6	1.05324	27851.93	0.75	0.9	0.85
22	NED_3YRCYCLE	7.6	1.05324	27851.93	0.75	0.9	0.85
23	NED_3YRCYCLE	7.6	1.05324	27851.93	0.75	0.9	0.85
24	NED_3YRCYCLE	7.6	1.05324	27851.93	0.75	0.9	0.85
25	NED_3YRCYCLE	8.14	1.05324	26103.79	0.75	0.9	0.85
26	NED_3YRCYCLE	8.14	1.04802	26103.79	0.75	0.9	0.85
27	NED_3YRCYCLE	8.14	1.04802	26103.79	0.75	0.9	0.85
28	NED_3YRCYCLE	8.4	1.04802	24583.72	0.75	0.9	0.85
29	NED_3YRCYCLE	8.4	1.04802	24583.72	0.75	0.9	0.85
30	NED_3YRCYCLE	8.4	1.04802	24583.72	0.75	0.9	0.85
31	NED_3YRCYCLE	8.4	1.04802	24583.72	0.75	0.9	0.85
32	NED_3YRCYCLE	8.4	1.04802	24583.72	0.75	0.9	0.85
33	NED_3YRCYCLE	8.76	1.04802	23977.24	0.75	0.9	0.85
34	NED_3YRCYCLE	8.76	1.04802	23977.24	0.75	0.9	0.85
35	NED_3YRCYCLE	8.76	1.04802	23977.24	0.75	0.9	0.85
36	NED_3YRCYCLE	8.76	1.04802	23977.24	0.75	0.9	0.85
37	NED_3YRCYCLE	8.76	1.05042	24204.81	0.75	0.9	0.85
38	NED_3YRCYCLE	8.76	1.05042	24204.81	0.75	0.9	0.85
39	NED_3YRCYCLE	8.76	1.05042	24204.81	0.75	0.9	0.85
40	NED_3YRCYCLE	8.76	1.05042	24204.81	0.75	0.9	0.85
41	NED_3YRCYCLE	8.76	1.05042	24204.81	0.75	0.9	0.85
42	NED_3YRCYCLE	8.76	1.05042	24204.81	0.75	0.9	0.85
43	NED_3YRCYCLE	8.76	1.05252	24204.81	0.75	0.9	0.85
44	NED_3YRCYCLE	8.76	1.05252	24204.81	0.75	0.9	0.85
45	NED_3YRCYCLE	8.67	1.05252	24394.08	0.75	0.9	0.85
46	NED_3YRCYCLE	8.67	1.05252	24394.08	0.75	0.9	0.85
47	NED_3YRCYCLE	8.67	1.05252	24394.08	0.75	0.9	0.85
48	NED_3YRCYCLE	8.67	1.05252	24394.08	0.75	0.9	0.85
49	NED_3YRCYCLE	8.67	1.05252	24394.08	0.75	0.9	0.85
50	NED_3YRCYCLE	8.76	1.05252	24204.81	0.75	0.9	0.85
51	NED_3YRCYCLE	8.76	1.05252	24204.81	0.75	0.9	0.85
52	NED_3YRCYCLE	8.76	1.05252	24204.81	0.75	0.9	0.85
53	NED_3YRCYCLE	8.76	1.05252	24204.81	0.75	0.9	0.85
54	NED_3YRCYCLE	8.76	1.05252	24204.81	0.75	0.9	0.85
55	NED_3YRCYCLE	8.76	1.05252	24204.81	0.75	0.9	0.85
56	NED_3YRCYCLE	8.94	1.05252	23749.66	0.75	0.9	0.85
57	NED_3YRCYCLE	8.94	1.05252	23749.66	0.75	0.9	0.85
58	NED_3YRCYCLE	8.94	1.05252	23749.66	0.75	0.9	0.85
59	NED_3YRCYCLE	8.94	1.05252	23749.66	0.75	0.9	0.85
60	NED_3YRCYCLE	8.94	1.05252	23749.66	0.75	0.9	0.85

Table 6: Reach Specific Planned Nourishment Assumptions

Reach Number	Planned Nourishment Alternative Name	Unit Placement Cost	Borrow To Placement Ratio	Production Rate	Berm Width Planned Nourishment Trigger	Dune Width Planned Nourishment Trigger	Dune Height Planned Nourishment Trigger
61	NED_3YRCYCLE	8.94	1.05252	23749.66	0.75	0.9	0.85
62	NED_3YRCYCLE	9.03	1.05252	23294.52	0.75	0.9	0.85
63	NED_3YRCYCLE	9.03	1.05252	23294.52	0.75	0.9	0.85
64	NED_3YRCYCLE	9.03	1.05252	23294.52	0.75	0.9	0.85
65	NED_3YRCYCLE	9.03	1.05252	23294.52	0.75	0.9	0.85
66	NED_3YRCYCLE	9.03	1.05252	23294.52	0.75	0.9	0.85
67	NED_3YRCYCLE	9.03	1.05042	23294.52	0.75	0.9	0.85
68	NED_3YRCYCLE	9.03	1.05042	23294.52	0.75	0.9	0.85
69	NED_3YRCYCLE	9.46	1.05042	22419.48	0.75	0.9	0.85
70	NED_3YRCYCLE	9.46	1.05042	22419.48	0.75	0.9	0.85
71	NED_3YRCYCLE	9.46	1.05042	22419.48	0.75	0.9	0.85
72	NED_3YRCYCLE	9.46	1.05042	22419.48	0.75	0.9	0.85
73	NED_3YRCYCLE	9.46	1.05042	22419.48	0.75	0.9	0.85
74	NED_3YRCYCLE	9.7	1.05042	21539.71	0.75	0.9	0.85
75	NED_3YRCYCLE	9.7	1.05042	21539.71	0.75	0.9	0.85
76	NED_3YRCYCLE	9.7	1.05042	21539.71	0.75	0.9	0.85
77	NED_3YRCYCLE	9.7	1.05042	21539.71	0.75	0.9	0.85
78	NED_3YRCYCLE	9.7	1.05042	21539.71	0.75	0.9	0.85
79	NED_3YRCYCLE	9.7	1.05042	21539.71	0.75	0.9	0.85
80	NED_3YRCYCLE	9.55	1.10707	22204.56	0.75	0.9	0.85
81	NED_3YRCYCLE	9.55	1.10707	22204.56	0.75	0.9	0.85
82	NED_3YRCYCLE	9.55	1.10707	22204.56	0.75	0.9	0.85
83	NED_3YRCYCLE	9.55	1.10707	22204.56	0.75	0.9	0.85
84	NED_3YRCYCLE	9.55	1.10707	22204.56	0.75	0.9	0.85
85	NED_3YRCYCLE	9.4	1.10707	22849.34	0.75	0.9	0.85
86	NED_3YRCYCLE	9.4	1.10707	22849.34	0.75	0.9	0.85
87	NED_3YRCYCLE	9.4	1.10707	22849.34	0.75	0.9	0.85
88	NED_3YRCYCLE	9.4	1.10707	22849.34	0.75	0.9	0.85
89	NED_3YRCYCLE	8.94	1.10707	23749.66	0.75	0.9	0.85
90	NED_3YRCYCLE	8.94	1.10707	23749.66	0.75	0.9	0.85
91	NED_3YRCYCLE	8.94	1.10707	23749.66	0.75	0.9	0.85
92	NED_3YRCYCLE	8.94	1.10707	23749.66	0.75	0.9	0.85
93	NED_3YRCYCLE	8.94	1.10707	23749.66	0.75	0.9	0.85
94	NED_3YRCYCLE	8.76	1.06965	24204.81	0.75	0.9	0.85
95	NED_3YRCYCLE	8.76	1.06965	24204.81	0.75	0.9	0.85
96	NED_3YRCYCLE	8.76	1.06965	24204.81	0.75	0.9	0.85
97	NED_3YRCYCLE	8.76	1.06965	24204.81	0.75	0.9	0.85
98	NED_3YRCYCLE	8.76	1.06965	24204.81	0.75	0.9	0.85
99	NED_3YRCYCLE	8.76	1.06965	24204.81	0.75	0.9	0.85
100	NED_3YRCYCLE	8.67	1.06965	24583.72	0.75	0.9	0.85
101	NED_3YRCYCLE	8.67	1.06965	24583.72	0.75	0.9	0.85
102	NED_3YRCYCLE	8.67	1.06965	24583.72	0.75	0.9	0.85
103	NED_3YRCYCLE	8.67	1.06965	24583.72	0.75	0.9	0.85
104	NED_3YRCYCLE	8.67	1.06965	24583.72	0.75	0.9	0.85
105	NED_3YRCYCLE	8.67	1.06965	24583.72	0.75	0.9	0.85
106	NED_3YRCYCLE	8.67	1.06965	24583.72	0.75	0.9	0.85
107	NED_3YRCYCLE	8.67	1.41164	24583.72	0.75	0.9	0.85
108	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85
109	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85
110	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85
111	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85
112	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85
113	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85
114	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85
115	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85
116	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85
117	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85
118	NED_3YRCYCLE	8.67	1.41164	24394.08	0.75	0.9	0.85

Table 6: Reach Specific Planned Nourishment Assumptions (continued)

2.2 Beach-fx Calibration

Calibration of the Beach-*fx* model is essential to ensure that the morphology behavior is representative of the reaches of the study area (Rogers et. al. 2009). In the absence of nourishment activities, the simulated shoreline rate of change should, on average and over multiple iterations, equal the historical rate of shoreline change. Calibration of Beach-*fx* is achieved through an iterative simulation process in which a balance is reached between three interrelated model specifications: storm climatology, post-storm berm width recovery, and the applied erosion rate. It was found that convergence of the model outputs was achieved at approximately 275 iterations and based on this each of the model runs consisted of 300 iterations (Figure 21a). The goal of the calibration process is to determine the proper combination of these inputs that will result in the target historical erosion rate.

The Beach-*fx* calibration process involves two preliminary steps followed by third step that requires multiple simulation runs. These steps were successfully completed for the Bogue Banks study area. First, the role of the applied erosion rate was confirmed by creating a simulation in which there were no storms and the only process causing the shoreline to change was the applied erosion rate. In the second step, the estimated the shoreline rate of change due to storm processes only was determined. In this step, the combined effect of the post-storm berm width recovery and storm climatology on the erosion rate was identified by setting the applied erosion rate for all reaches to zero. The third step was to determine the applied erosion rate that will return the target historical erosion rate of change after a given number of iterations on a reach by reach basis. This was executed through a number of simulations where the input applied erosion rates were adjusted according to the output average annual erosion rate from the previous simulation.

Calibration was completed after the development of the Storm Damage Database which is discussed in detail in section three of this appendix. After a number of simulations, the proper combination of berm width recovery and applied erosion rate was determined for each reach. Berm width recovery was set at 95 percent for reaches 1 through 117 and 99 percent for reach 118. Reach 118 was initially included in the project scope; however, since there are no structures included within the reach limits it was not included in the final project layout. Figure 21 provides the calibrated average annual erosion rate compared to the target historical shoreline rate of change, thus confirming a successful calibration. Also included in Figure 21 is the data used as the applied erosion rate within Beach-fx during calibration.

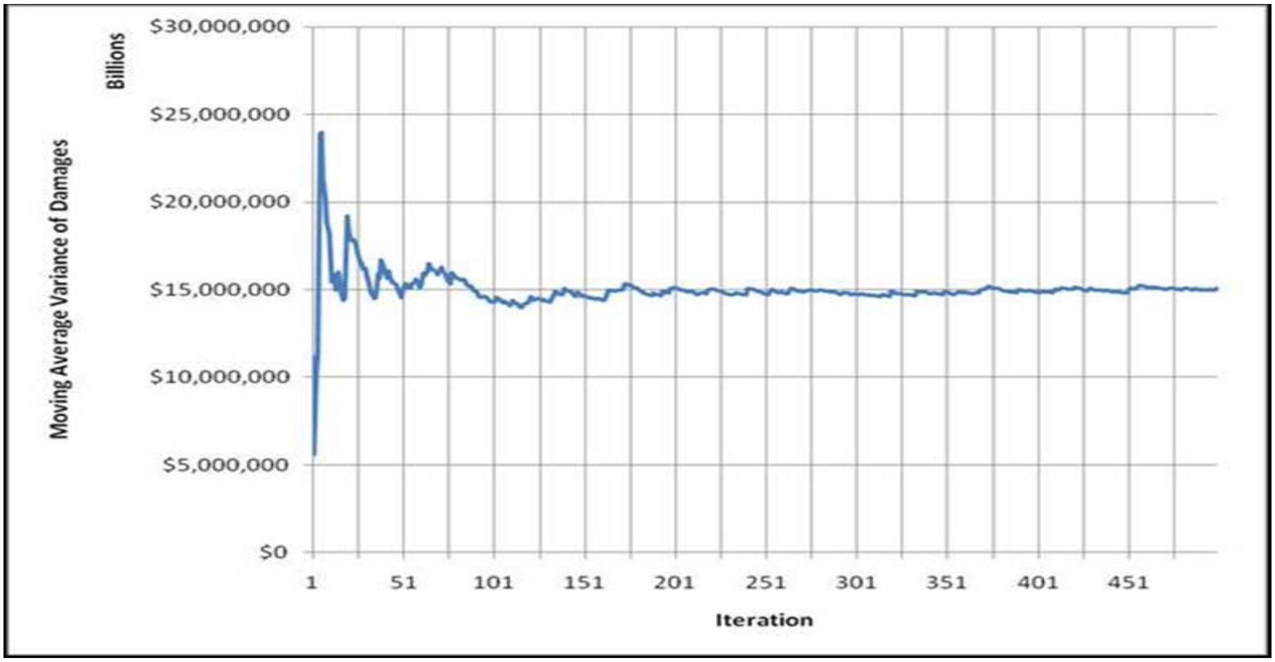


Figure 21a: Model Iterations for Convergence

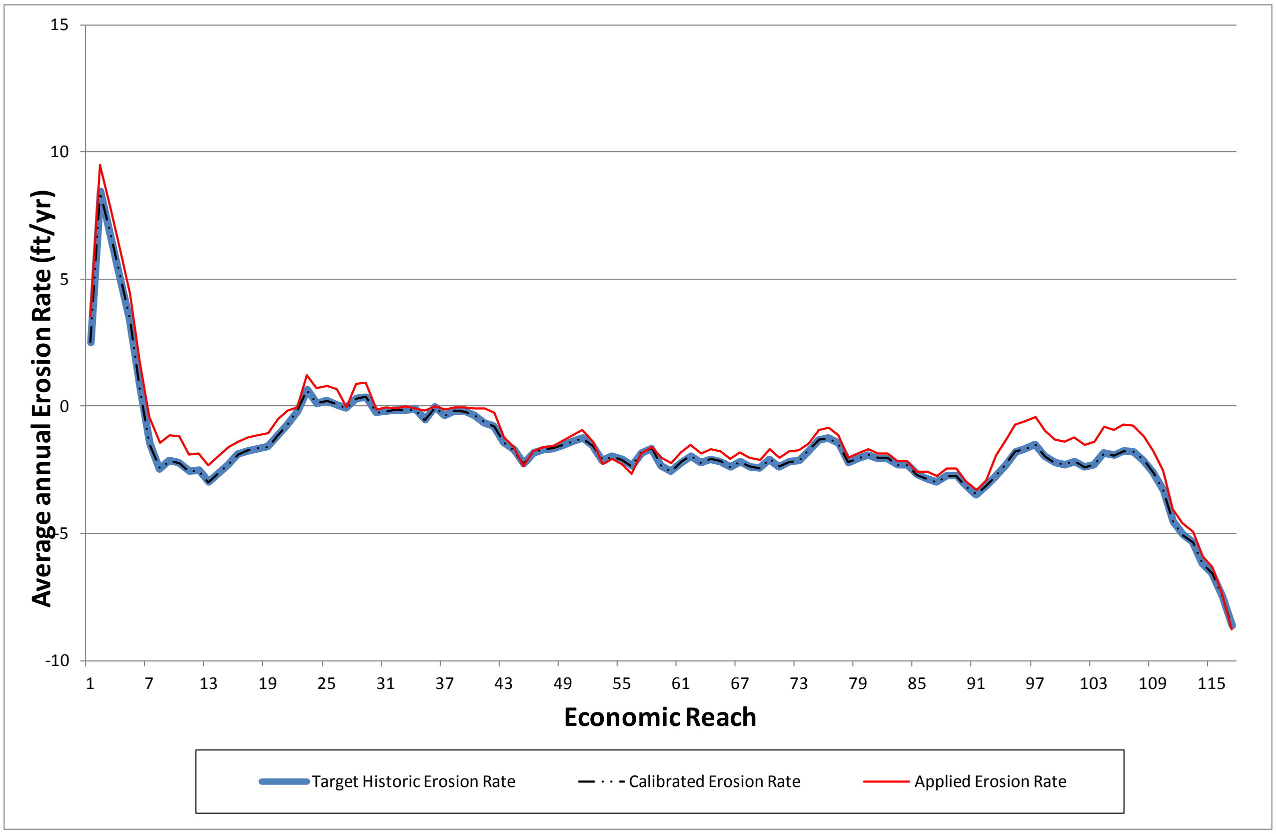


Figure 21: Confirmation of Beach-*fx* Calibration

3.1 SBEACH Data Requirements

This section provides details on the data collection and methodology employed to develop the storm response database (SRD) within the Beach-fx context that stores beach profile responses to various historical storms for lookup. Historical and current data sets applicable to Bogue Banks were collected, which would be necessary in the development of the storm response database as described here. These data include historical beach nourishment projects, historical erosion rates, current beach profile data, native beach sediment data, historical storm data, and economic data.

3.1.1 Historical Beach Nourishment Projects

Multiple data sources were consulted to develop a beach nourishment database for Bogue Banks, encompassing historical beach nourishment projects from 1978 to 2009. Sources included The Western Carolina Program for the Study of Developed Shorelines, North Carolina Sea Grant (Spencer Rogers), and the Carteret County Shore Protection Office. Table 7 shows the historical beach nourishment project locations, volumes, and descriptions. The historical beach nourishment projects were used to determine background erosion rates of the study area, which are required for calibration of Beach-fx and were used in discretization of the study area, as discussed in section 3.1.2 below.

3.1.2 Erosion Rates

The most recent set of erosion rates developed by the North Carolina Division of Coastal Management (DCM) was downloaded from the coastal hazards GIS data portion of the DCM website (http://dcm2.enr.state.nc.us/Maps/chdownload.htm). Using the digitized shorelines from a historical database compiled by DCM, long term erosion rates were calculated every 50 meters along the shoreline. Shoreline change was calculated based on the distance between the earliest shoreline archived (typically from the 1940s) and the 1998 shoreline. Raw erosion rates were then calculated by dividing the distance between the two shorelines by the numbers of years between them. The 1998 raw erosion rates calculated by DCM are presented in Figure 22.

Fiscal Year	Placement Location	Volume (cy)	Project Description
1978	Fort Macon	1,179,600	Dredge Disposal to Eastern Bogue Banks (MCH Inner Habor Maintenance)
1984	Western Emerald Isle	15,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
1986	Atlantic Beach	4,168,600	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)
1987	Western Emerald Isle	30,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
1989	Emerald Isle	45,399	USACE Navigation Dredging
1990	Western Emerald Isle	56,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
1993	Western Emerald Isle	17,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
1994	Fort Macon	2,192,268	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)
1994	Atlantic Beach	2,472,132	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)
1995	Western Emerald Isle	33,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
1996	Western Emerald Isle	71,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
1997	Western Emerald Isle	39,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
1999	Western Emerald Isle	48,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
2000	Western Emerald Isle	16,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
2002	Fort Macon	209,348	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)
2002	Indian Beach (reach 1)	456,994 (total)	Bogue Banks Restoration - Phase I -R1
2002	Indian Beach (reach 2)	456,994 (total)	Bogue Banks Restoration - Phase I -R2
2002	Pine Knoll Shores (reach 3)	1,276,586	Bogue Banks Restoration - Phase I -R3
2003	Western Emerald Isle	59,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
2003	Eastern Emerald Isle	1,867,726	Bogue Banks Restoration - Phase II
2004	Eastern Emerald Isle (east reach)	156,000 (total)	Isabel Sand Replenishment-East Reach
2004	Eastern Emerald Isle (mid reach)	156,000 (total)	Isabel Sand Replenishment-Mid Reach
2004	Eastern Emerald Isle (west reach)	156,000 (total)	Isabel Sand Replenishment-West Reach
2004	Indian Beach/Salter Path	699,282	Section 933 - Phase I
2005	Fort Macon	530,729	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)
2005	Atlantic Beach	2,390,000	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)
2005	Western Emerald Isle	690,868	Bogue Banks Restoration-Phase III
2006	Western Emerald Isle	77,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle
2007	Emerald Isle (reach 1)	262,080	Ophelia Sand Replenishment-Reach 1
2007	Emerald Isle (reach 2)	307,080	Ophelia Sand Replenishment-Reach 2
2007	Indian Beach/Salter Path (reach 3)	298,604	Ophelia Sand Replenishment-Reach 3
2007	Pine Knoll Shores (reach 4)	59,560	Ophelia Sand Replenishment-Reach 4
2007	Pine Knoll Shores (reach 5)	180,236	Ophelia Sand Replenishment-Reach 5
2007	Pine Knoll Shores	920,000	Section 933-Phase II
2007	Fort Macon	211,000	Dredge Disposal to Eastern Bogue Banks (MCH Inner Harbor Maintenance)
2009	Western Emerald Isle	74,000	Dredge Disposal from Bogue Inlet AIWW Crossing to Western Emerald Isle

Table 7 Historic Beach Nourishment Activities

The 1998 erosion rates calculated by DCM are influenced by multiple nourishment projects completed prior to 1998. Areas of Bogue Banks which may be affected are western Emerald Isle, Atlantic Beach, and Fort Macon. According to the beach nourishment database (Table 7) approximately 306,400 cy of material was used in beach nourishment projects along western Emerald Isle prior to 1998. Approximately 10,012,600 cy of material was placed along Atlantic Beach and Fort Macon prior to 1998 (3,371,868 cy along Fort Macon and 6,640,732 cy along Atlantic Beach). This nourishment material influences the rates calculated in these areas by creating artificial accretion or reduced apparent erosion. For the purposes of this project, erosion rates calculated by DCM were adjusted in these areas to account for accretion added by nourishment projects, resulting in the natural background erosion rate to be used in Beach-fx. Adjustments were made by dividing the total amount of material placed in each region prior to 1998 by the length over which it was placed and the number of years over which the original shoreline change was calculated. The resulting value, in cy/ft/yr, was then divided by a factor of 1.0 cy/ft which is an approximation of the relationship between the volume of material lost or gained (cy) and the corresponding response of the shoreline change (ft) in this region. Therefore, for every 1.0 cy of material lost (or gained), the shoreline erodes 1 ft (or accretes 1 ft). Using this coefficient allows for the volume of nourishment material (cy) prior to 1998 to be converted to shoreline accretion (ft). Since much of the nourishment material would have been spread along the beach, through natural littoral processes, by the time the 1998 shoreline was digitized, a diffusion factor was used to account for material from the nourishment projects being transported to the adjacent shoreline. It was calculated that the half life of each of the projects was reached before 1998. Therefore, 50 percent of the original nourishment amount for each project was spread along adjacent shorelines while the other 50 percent remained within the original project limits. The accretion provided by the nourishment projects at each 50 m transect was then subtracted from the DCM raw rates to get the background erosion rate.

The adjusted erosion rates are presented in Figure 23 and plotted against the original raw erosion rates in Figure 24. The adjusted erosion rates were used as a key basis for discretizing the study area for SBEACH modeling. They were also used as Beach-fx input and calibration information for each economic reach.

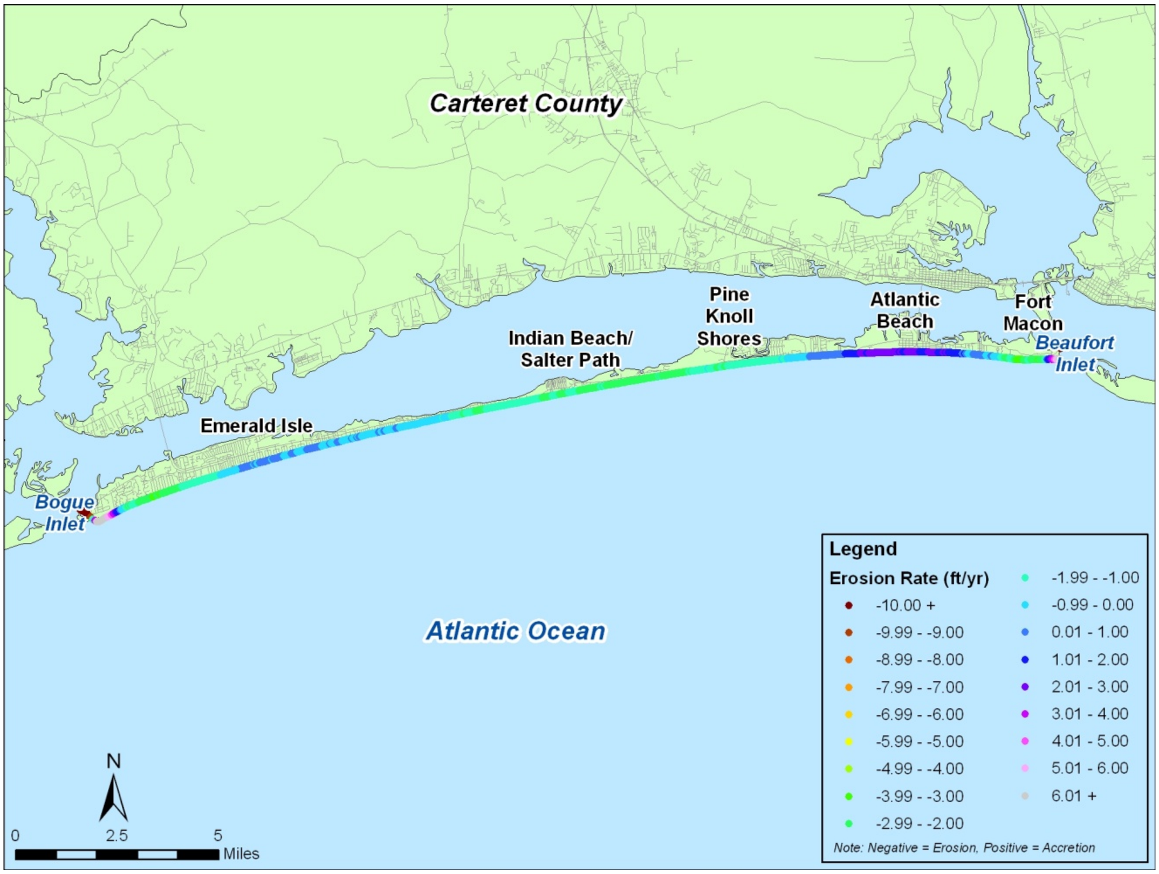


Figure 22: 1998 DCM Raw Erosion Rates

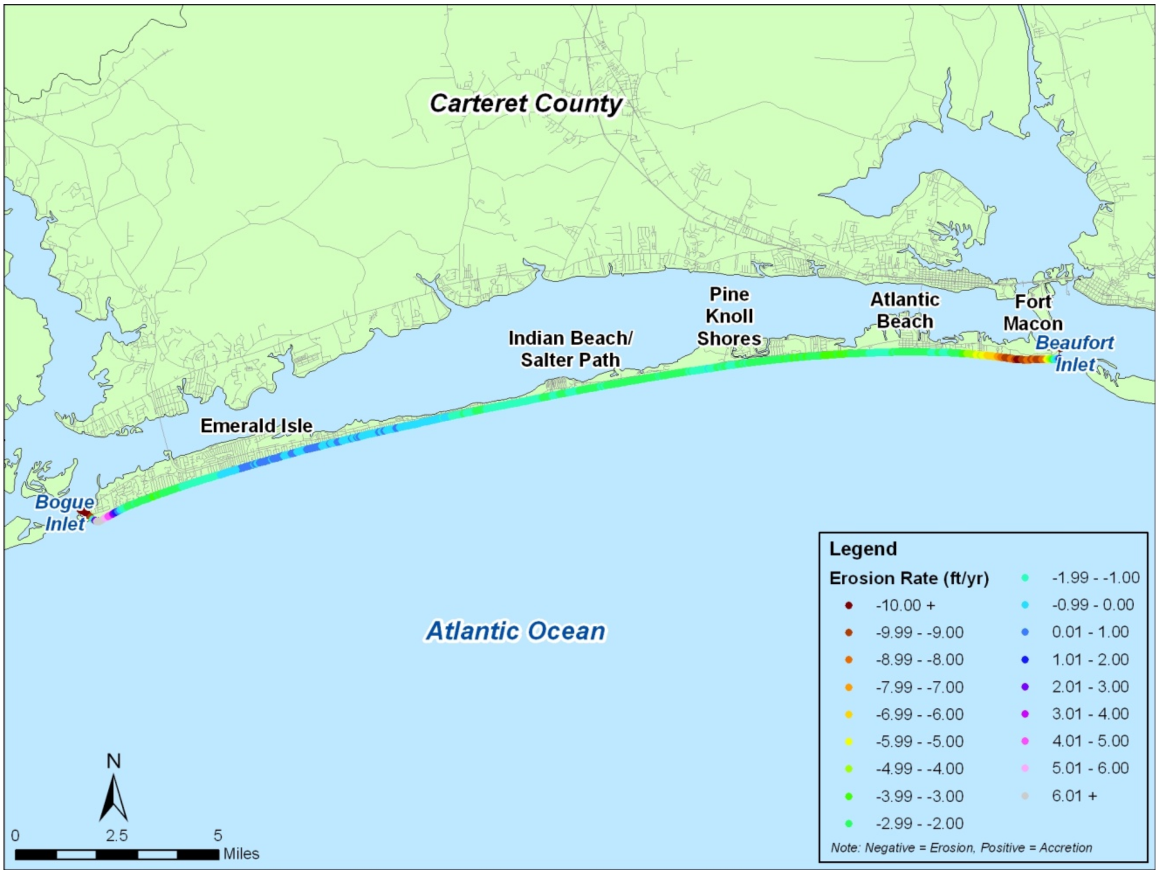


Figure 23: Adjusted Erosion Rates

Figure 24: Raw and Adjusted Erosion Rates

3.1.3 Survey Profile Data

As part of the Carteret County funded Bogue Banks Beach and Nearshore Mapping Program (BBBNMP), beach surveys are performed along Bogue Banks each spring/summer. Most recently, the beach was surveyed in June 2009 by Geodynamics. From Bogue Inlet to Beaufort Inlet, 112 transects were surveyed with a spacing of approximately 1000 ft. Both topographic and hydrographic data were collected at each transect. The survey was referenced in NAD 1983 State Plane North Carolina (ft), with a vertical datum of NAVD 1988. The location of the program transects and their associated regions are presented in Figure 25. The most recent set of data (June 2009) served as the basis from which representative profiles were developed for the existing conditions SBEACH model.

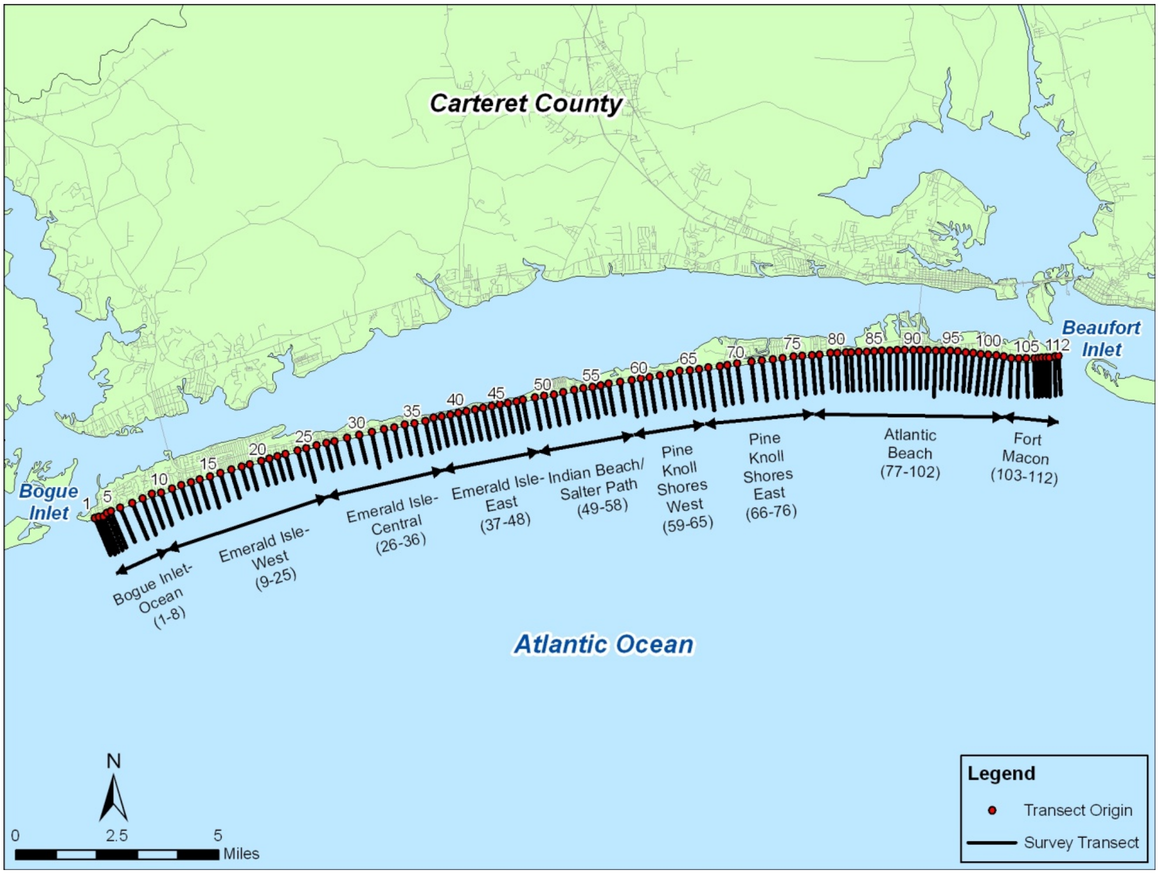


Figure 25: BBBNMP Survey Transect Locations and Regions

3.1.4 Sediment Data

In 2001, sediment along Bogue Banks was sampled by the USACE to determine native grain size. The results are presented in Table 8. This set of data served as the basis for determination of grain size input for SBEACH. Greater detail regarding sediment analysis is available within the Appendix C (Geotechnical Appendix) of this report.

Region	Native Grain Size (mm)
Bogue Inlet Area	0.19
West Emerlad Isle	0.19
East Emerald Isle	0.20
Indian Beach	0.20
Pine Knoll Shores	0.19
Atlantic Beach	0.19
Fort Macon	0.22

Table 8: Bogue Banks Native Mean Grain Size Data (2001)

3.1.5 Storm Data

The storm dataset used in this analysis was developed based on the storm surges identified by the Dredging Research Program (DRP-1-17, Scheffner, 1994). This research included all storm surge time-series from 1890 through 1990. These data were then supplemented with ADCIRC hindcast data to include hurricanes through 1999, including named hurricanes Bertha, Fran, Dennis, Floyd, Bonnie, and Irene. Storms within the database were selected based on the Peak Over Threshold method with the minimum wave height of 2 feet and minimum duration of 12 hours. The complete dataset contains 35 tropical storms occurring from 1893 to 1999 and 23 extratropical storms occurring from 1978 to 1992. Peak surges ranged from 0.3 ft to 16.2 ft for tropical storms and 0.4 ft to 1.4 ft for extratropical storms. Table 9 shows a list of the storms included in the dataset.

Tropical Storms		Extratropical Storms	
10/3/1893	8/27/1971	1/9/1978	3/1/1987
10/20/1910	6/21/1972	1/26/1978	12/8/1989
9/18/1928	9/5/1979 (David)	9/2/1978	11/10/1990
10/2/1929	8/20/1981	3/24/1979	12/4/1990
9/12/1930	6/19/1982	11/26/1979	12/10/1992
9/5/1935	9/12/1984 (Diana)	1/13/1980	
8/2/1944	9/27/1985 (Gloria)	3/13/1980	
10/19/1944	11/23/1985	10/24/1980	
9/24/1947	9/22/1989 (Hugo)	11/27/1980	
9/27/1953	6/6/1995	12/28/1980	
10/15/1954 (Hazel)	7/12/1996 (Bertha)	3/23/1981	
8/12/1955 (Connie)	9/6/1996 (Fran)	10/25/1982	
8/17/1955 (Diane)	10/8/1996	2/14/1983	
9/19/1955 (Lone)	8/26/1998 (Bonnie)	3/18/1983	
9/27/1956	8/30/1999 (Dennis)	12/21/1983	
9/11/1960 (Donna)	9/16/1999 (Floyd)	12/1/1986	
6/11/1966 (Alma)	10/18/1999 (Irene	1/1/1987	
10/19/1968 (Gladys)		2/16/1987	

Table 9: Storm Dataset

Wave heights and periods corresponding to the storm surge events discussed above were determined from WIS hindcast data. Combined with the water level time-series, these wave height and period time-series will serve as the storm input to SBEACH for the damage analysis.

Each storm surge hydrograph was combined with a cosine representation of the astronomical tide to generate a plausible total water level elevation. Each storm surge was combined with three representative tidal ranges (spring, mean and neap) and the peak surge elevation was aligned with four tidal phases (high tide, mid-tide falling, low tide and mid-tide rising) to create suite of 12 storms of each historical storm surge hydrograph. The result is a storm database that includes 696 storm cases used in the SBEACH modeling for the storm response database.

While this analysis does include plausible non-historical storm events in the Beach-FX analysis, it is possible for additional unforeseen extreme events to occur in the future. Extreme, non-historical storm events can have significant impacts to rubble mound coastal structures where armor unit stability is dependent of extreme wave events. Extreme events are also significant for inland flood control systems involving dams and levees. However, beach systems and coastal storm damage reduction projects involving “soft” solutions like beach nourishment are flexible and able to adjust and withstand extreme events.

Current Corps policy as outlined in The Planning Guidance Notebook (ER 1105-2-100) specifies that CSDR damage relationships are developed using actual damage data from past storm events. This policy is embodied in the Beach-FX analysis which is aimed at developing a plausible storm suite that characterizes the storm climatology at the project site. Consistent with the Walton County CSDR project, for Bogue Banks no effort was made to define or characterize extreme events rather the effort was to characterize the expected storm climatology based on the plausible storm history for the project location.

In addition to the use of the storms in SBEACH, storm data was analyzed to determine various input parameters for Beach-*fx*, as discussed in Section 2.1.6.

3.2 SBEACH Methodology

The storm response database serves as an input to the Beach-fx program. It is essentially a “look-up” table of beach profile responses to storms, to be used by Beach-fx to determine the amount of damage a particular stretch of beach may endure during a particular storm. The response of beach profiles to storms was modeled using SBEACH, an empirically based numerical simulation model which was developed by the USACE Waterways Experiment Station (WES) Coastal & Hydraulics Laboratory (CHL). The purpose of the model is to calculate two-dimensional, cross-shore beach, berm, and dune erosion under single-storm surge, wave, and wind action. The SBEACH model is based on a fundamental assumption that profile change is produced only by cross-shore processes. Therefore, longshore processes are considered uniform and neglected in calculating profile change. The most recent version of SBEACH, version 4.03, operates under CEDAS, a suite of tools developed by Veri-Tech, based on various numerical models and codes developed by CHL, now a part of the Engineering Research and Development Center (ERDC), formally WES.

The SBEACH model has potential for many applications in the coastal environment, including evaluation of design beaches for erosion and/or flood protection, evaluation of short-term beach fill performance, and preliminary input for economic analyses of beach alternatives. The main inputs to the SBEACH model include:

- Profile Data – two-dimensional description of the shoreline extending from offshore to a landward point of interest,
- Sediment Data – characterization of the average sediment size and,
- Storm Data – time dependent description of water elevation, waves, and winds (if available).
- Model Calibration Parameters – various beach characteristic and sediment transport parameters which influence beach profile change.

3.2.1 Modeling Scope

The SBEACH model provides understanding of cross shore loss of sand in the berm and/or dune following storm activity. However, SBEACH must be calibrated to the specific site conditions at which it is to be applied. For this study Hurricane Ophelia data was used for calibration since both pre- and post-storm profiles were available in addition to wave hindcast data from Oceanweather Inc. The calibrated SBEACH model was then used to evaluate the existing conditions and future response if no projects were built (without project conditions). The calibrated SBEACH model was also used to evaluate the response of various nourishment alternatives (with project conditions). Results of the without project and with project conditions were then compiled into one database, housing the responses of each of the beach profiles to various storm conditions, to be used by Beach-fx to assess damages and determine the optimal project for Bogue Banks over a 50 year project duration.

3.2.2 SBEACH Calibration Model

The SBEACH model was calibrated to reflect the storm induced impacts which occurred between surveys in May 2005 and September 2005. During this time period, Hurricane Ophelia impacted the North Carolina coast from September 5, 2005 to September 18, 2005. This storm was selected as the basis of the SBEACH calibration based on the availability of quality measured survey data and measured storm data that was not available within the established storm database discussed in Section 3.1.5. This storm event is not included in the historical storm suite used to calculate storm induced damages within Beach-FX. Calibration of SBEACH occurred subsequent to the development of the storm suite and due to project funding and time limitations the storm database was not extended to include Hurricane Ophelia and other storms between 1999 and 2005.

SBEACH is typically calibrated by establishing known inputs such as profile data, storm data, and sediment data and then adjusting the model calibration parameters, which include a number of sediment transport characteristics and other beach characteristics that influence sediment transport. Sensitivity of the model response to changes in these parameters was tested and then they were adjusted to yield the appropriate model response.

3.2.3 SBEACH Calibration Survey Profile Data

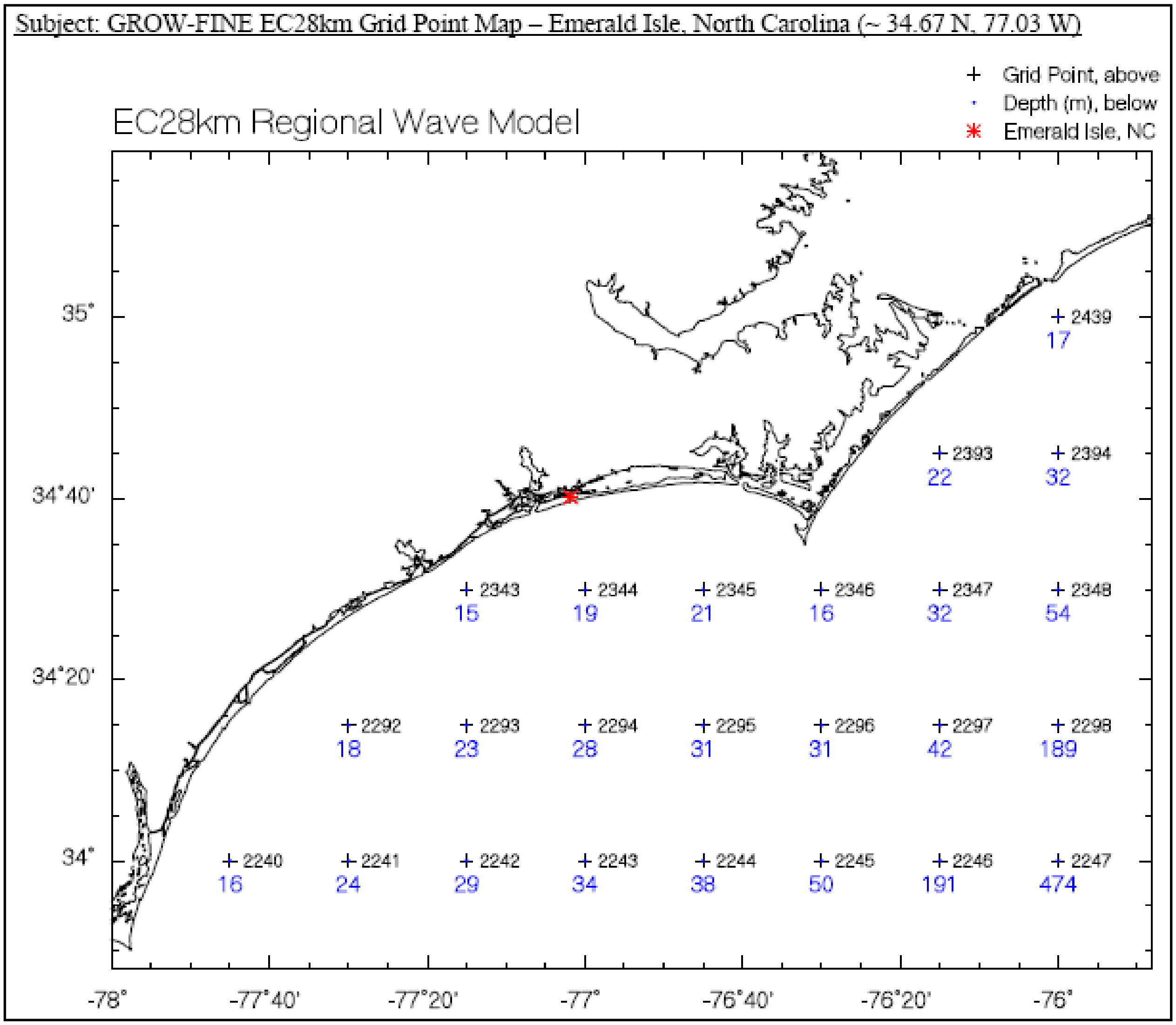
The beach profile data used for calibration was obtained from the BBBNMP. In May 2005, the annual Bogue Banks survey was completed as part of the BBBNMP. In September 2005, an additional post-storm survey was performed immediately after Hurricane Ophelia impacted the coast. This profile data was readily available from the Carteret County Shore Protection Office. The post-storm survey was performed along 29 of the 112 transects used in the BBBNMP. The measured May 2005 profile data was used as the initial beach profile for the SBEACH model input. The post-storm measured September 2005 profile was also loaded into the model to serve as a reference profile position for the model calibration.

3.2.4 SBEACH Calibration Sediment Data

According to samples taken in 2001, the native grain size of the beach ranges from 0.19 mm to 0.22 mm. Most recently, the beach was nourished in 2007 at various locations with material from the Morehead City Harbor ODMDS as part of the post-Ophelia FEMA project. This material was shown in a 2004 study to have a grain size of 0.20 mm. Therefore, for this study, the effective grain size selected for use in the SBEACH model was 0.20 mm.

3.2.5 SBEACH Calibration Storm Data

Typical storm data input for SBEACH includes storm hydrographs of total water elevation, wave conditions, and wind conditions. For this analysis, the calibration simulation involved a 13 day time series over which Hurricane Ophelia impacted the coast. Storm data was available from Oceanweather Inc. (Oceanweather) as part of their Global Reanalysis of Ocean Waves (GROW) project along the east coast. Oceanweather has developed a global long term hindcast database which has been improved and enhanced over the years in various areas including the U.S. east coast (GROW-FINE EC28km). The GROW-FINE EC28km database contains a point offshore of Emerald Isle which was used for this study (grid point 2344). Data available from this site includes wind speed and direction, wave height and direction, peak period, surge height, and current speed and direction. Figure 26 shows the location of the data point and Figure 27 shows the data retrieved from the point which was used in the SBEACH calibration model.



Subject: GROW-FINE EC28km Grid Point Map – Emerald Isle, North Carolina (~ 34.67 N, 77.03 W)

Figure 26: GROW-FINE EC28km Point Locations (Oceanweather Inc.)

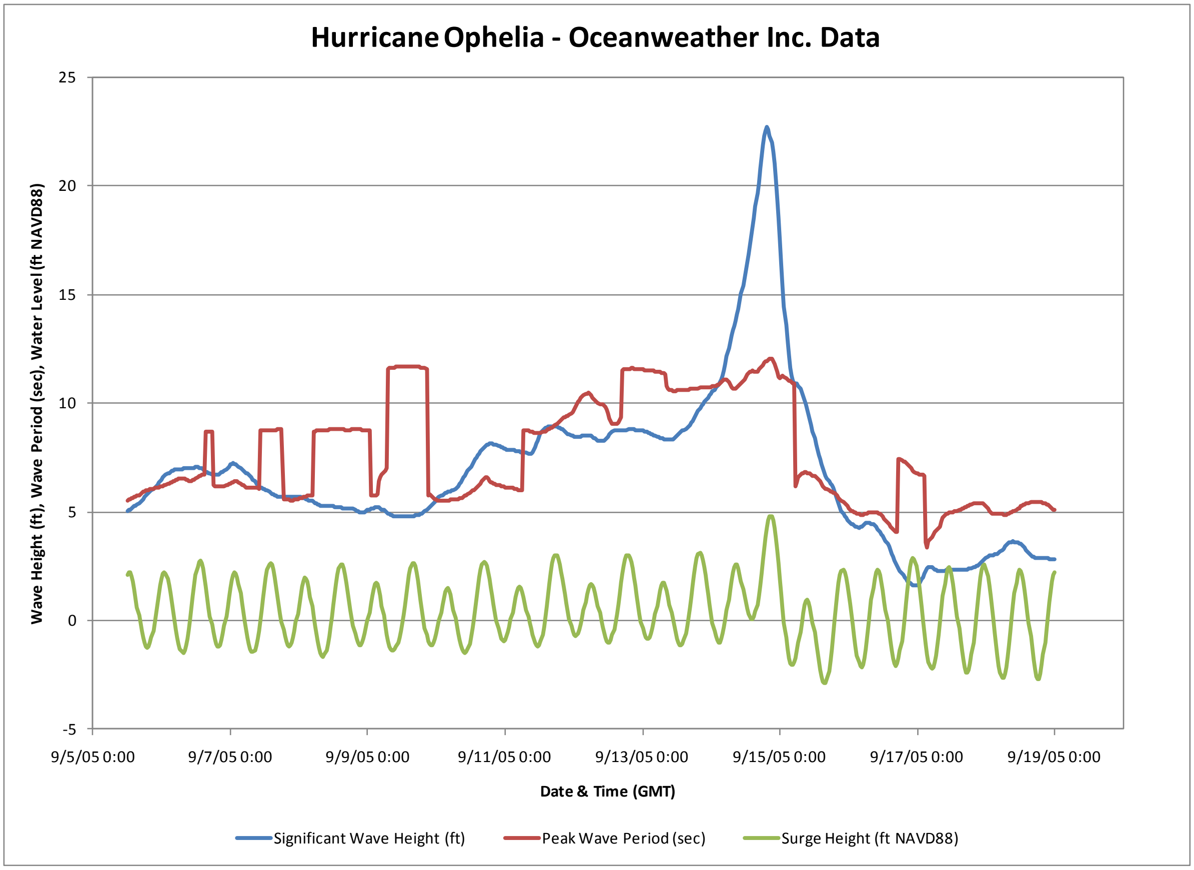


Figure 27: Grid Point 2344 Hurricane Ophelia Storm Data

3.2.6 SBEACH Calibration Parameters

SBEACH is typically calibrated by adjusting the sediment transport characteristics or beach characteristics. Sediment transport characteristics include Transport Rate Coefficient, K (m^4/N), Overwash Transport Parameter, Coefficient for Slope Dependent Term, Eps (m^2/s), Transport Rate Decay Coefficient Multiplier, and Water Temperature (°C). Beach characteristics include Landward Surf Zone Depth (ft) and Avalanche Angle (Deg).

Initially, the model was run with the default parameters. These were shown to create too much sediment transport, flattening out the beach and the outer bar. The main factor in this is the Transport Rate Coefficient, which was lowered to produce less transport of material. Other parameters changed from their defaults were the Transport Rate Decay Coefficient Multiplier, which was lowered to be in the middle of the acceptable range, and the Avalanche Angle which was set to 40 degrees and is considered a natural angle of internal friction for sand. The model calibration parameters decided on after running various model scenarios are presented in Table 10.

Beach Parameters:	Value	Units
Landward Surf Zone Depth	1	ft
Maximum Slope Prior to Avalanching	40	deg
Sediment Transport Parameters:	**Value**	**Units**
Transport Rate Coefficient	2.50E-07	m^4/N
Overwash Transport Parameter	0.005	
Coefficient for Slope-Dependent Term	0.002	m^2/S
Transport Rate Decay Coeffcient Multiplier	0.3	
Water Temperature	20	Deg C

Table 10: SBEACH Calibration Parameters

3.2.7 SBEACH Calibration Results

An example comparison of the initial profile (May 2005), final SBEACH model profile, and the measured final profile (September 2005) is shown in Figure 28 for one of the 29 transects containing pre- and post- storm profile data.

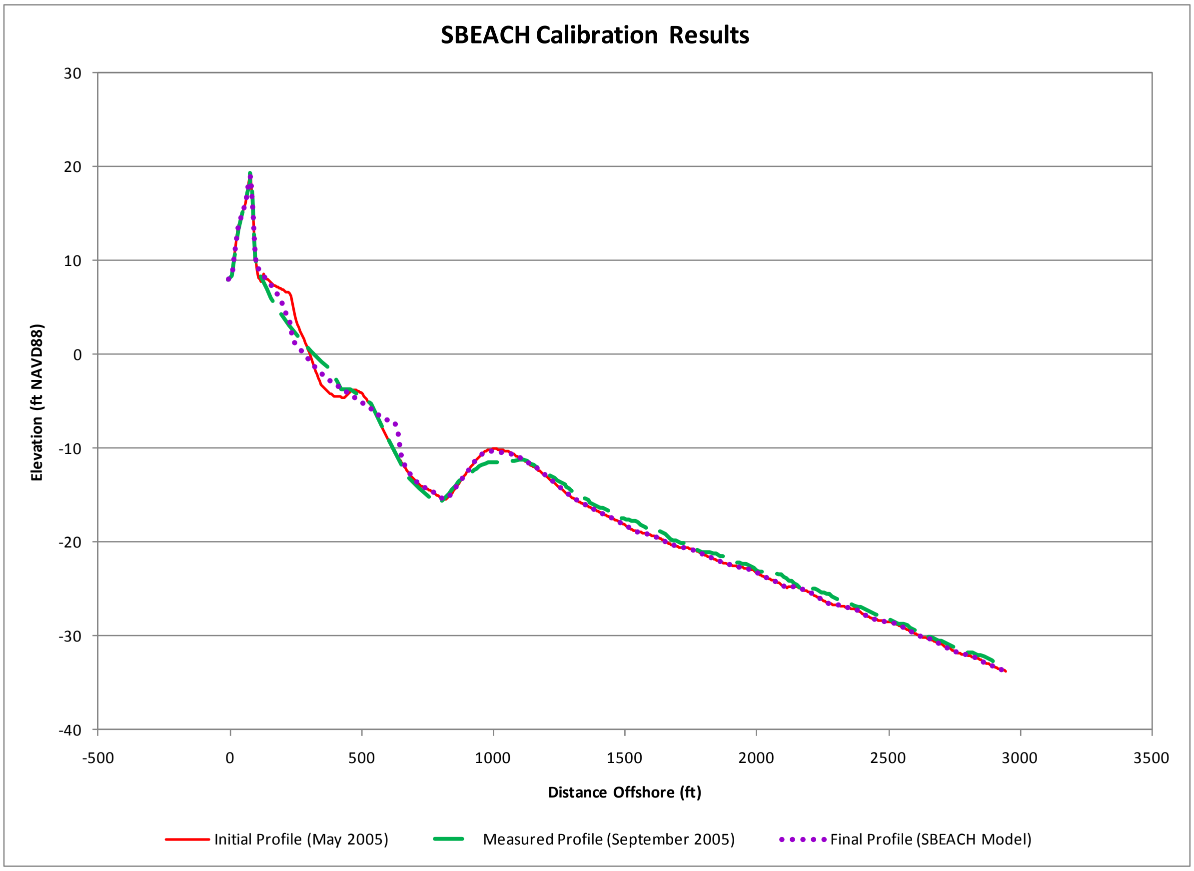


Figure 28: SBEACH Calibration Model Results

The amount of time between measured profiles (approximately 4 months) presented an issue with calibration which could only be run for Hurricane Ophelia (13 days) due to available data and the limits of SBEACH to only predict storm induced beach change. The offshore bar tends to move less in SBEACH simulations. Additionally, the SBEACH model does not account for longshore sediment transport, which may have been significant during the period modeled. However, the SBEACH model simulates change in the berm and dune region of the profile, holding offshore profiles fairly consistent over time.

3.3 SBEACH Results and Analysis

3.3.1 SBEACH Reach and Profile Development

After determining the SBEACH calibration coefficients, an existing conditions model was developed to estimate the initial cross shore beach change that Bogue Banks would experience from a variety of storms if no new projects were built. This process involved discretizing the study area into SBEACH analysis reaches, developing representative profiles for the existing conditions of each reach, idealizing the existing conditions profiles to fit within the Beach-*fx* framework, and creating an existing conditions matrix of profiles to be run in SBEACH. The corresponding results would encompass a range of beach responses that might take place over a 50 year period without any projects being built.

The study area was discretized primarily using long term erosion rates and beach profile shape. This resulted in 13 stretches of beach, known as SBEACH analysis reaches, with similar erosion rates and physical morphology. Particular attention was paid to important profile features such as dune height, berm height and width, and offshore bar location. In addition, shoreline orientation was also taken into consideration. The boundaries of each SBEACH analysis reach were made to coincide with the limits of the economic reaches provided by the USACE for ease of use in Beach-*fx*, allowing for each economic reach to be assigned to only one of the SBEACH analysis reach profiles. Figure 29 shows the limits of each SBEACH analysis reach plotted with the adjusted long term erosion rates. The survey transects from the BBBNMP located within each SBEACH analysis reach are also noted, as they will be used in development of the representative profiles for each SBEACH analysis reach as described in the following section.

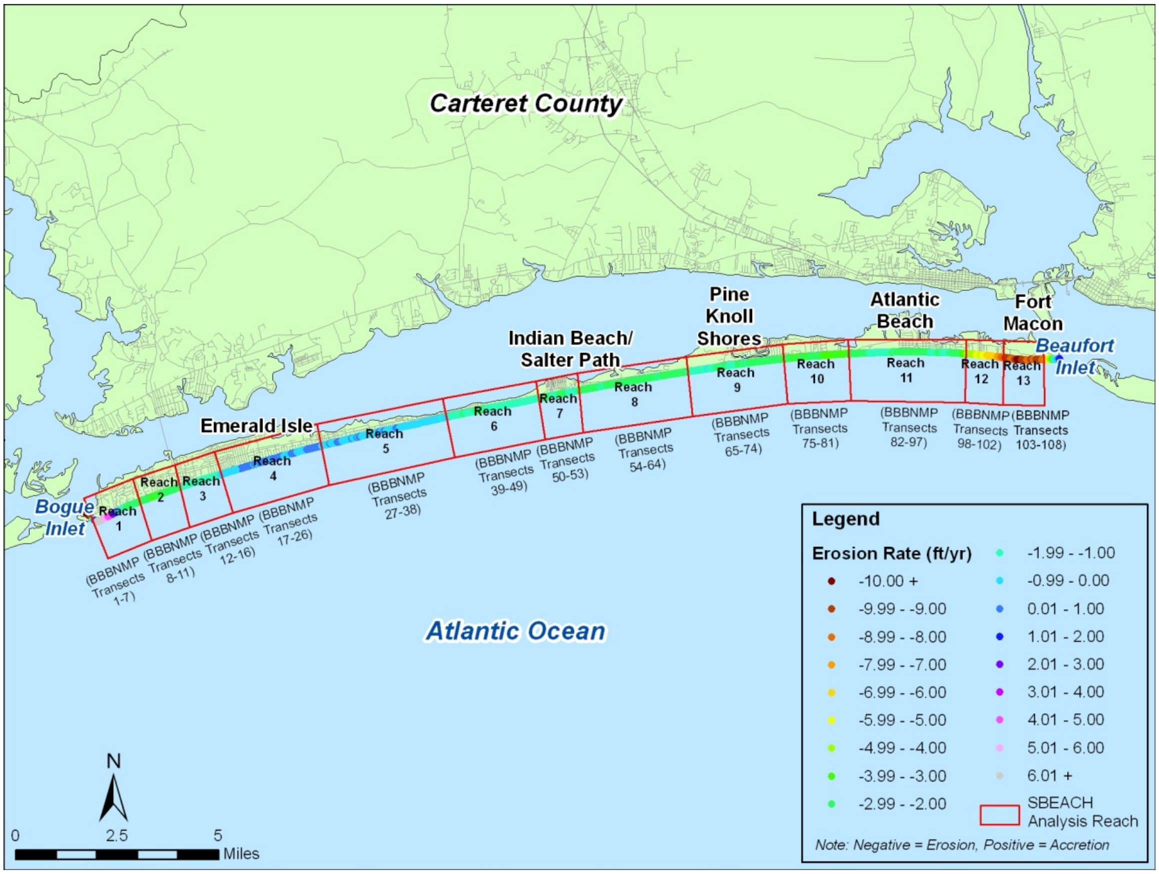


Figure 29: SBEACH Analysis Reaches

Overall average profiles were created for each of the 13 SBEACH analysis reaches using beach profile analysis tools in BMAP (Beach Morphology Analysis Package), located within the suite of CEDAS tools. BBBNMP survey profiles in each SBEACH analysis reach were split into 3 features (dune, berm/foreshore, and offshore bar) and averaged with respect to each component (Figure 30). The three components were then combined to form an overall average profile. Limitations of the survey data (not all transects went over the dune crest due to the presence of structures or dense vegetation) resulted in the averaged dune portion of the overall average profile not being representative of the dune features within each SBEACH analysis reach. Therefore, a visually inspected typical dune feature, within each SBEACH analysis reach, was selected from the raw survey data and combined with the overall average profile to create the final representative profile for each SBEACH analysis reach.

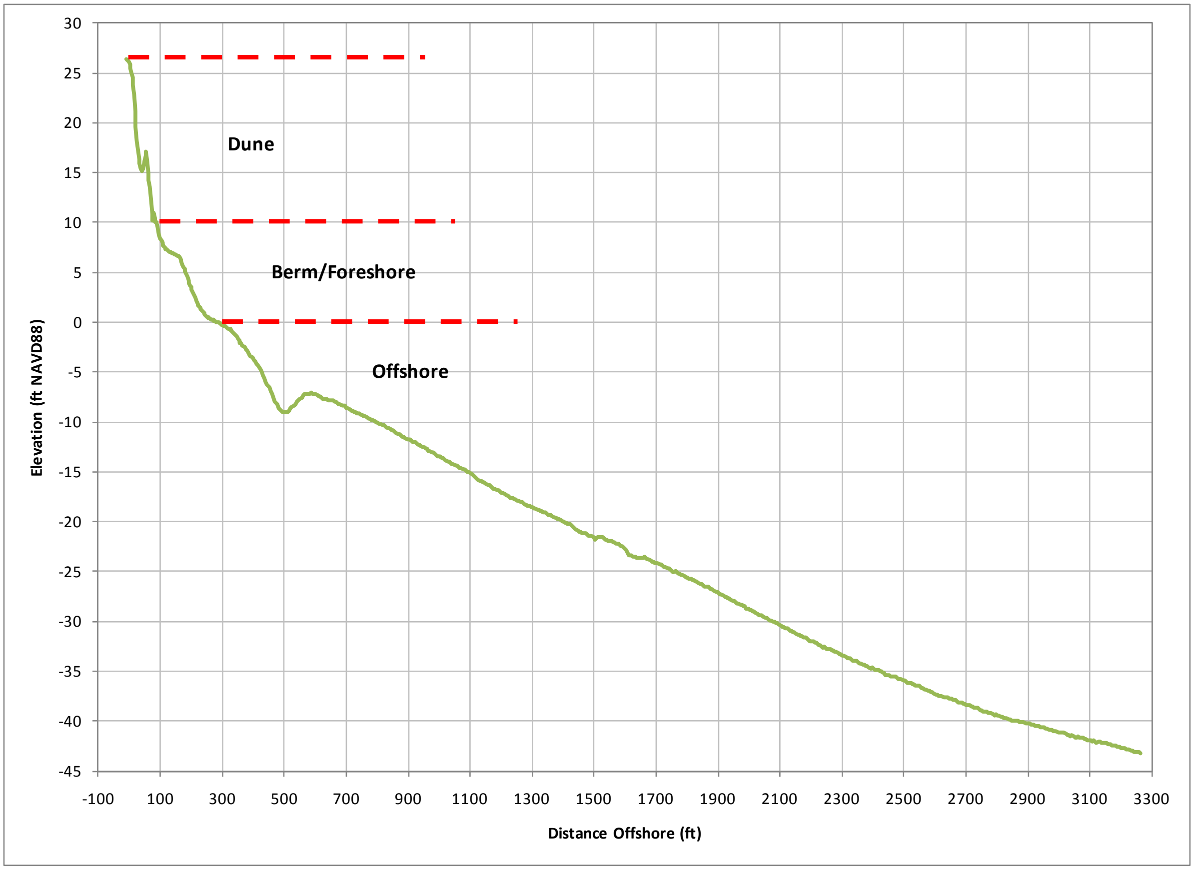


Figure 30: Profile Averaging Components

The following steps were taken to create an overall average profile and a finalized representative profile for each SBEACH analysis reach:

Step 1: Create average dune profile for each SBEACH analysis reach

- All profiles were aligned in space at an elevation representative of the dune face since not all survey profiles extended over the dune crest. This elevation ranged from +7 ft NAVD88 to +16 ft NAVD88 depending on the reach (see Table 11 for reach by reach values).
- An average was taken of the aligned profiles, creating the representative average dune feature for each reach.

Step 2: Create average berm/foreshore profile for each SBEACH analysis reach

- All profiles were aligned in space at an elevation representative of the berm/foreshore. This elevation was chosen to be +3 ft NAVD88 for all reaches.
- An average was taken of the aligned profiles, creating the representative average berm/foreshore feature for each reach.

Step 3: Create average offshore bar profile for each SBEACH analysis reach

- All profiles were aligned in space at an elevation on the seaward face of the offshore bar. This elevation ranged from -8 ft NAVD88 to -13 ft NAVD88 depending on the reach (see Table 11 for reach by reach values).
- An average was taken of the aligned profiles, creating the representative average offshore bar feature for each reach.

Step 4: Combine average profiles of all three features for each SBEACH analysis reach

- Average dune and average berm/foreshore profiles were aligned at an elevation ranging from 5.5 ft NAVD88 to 11 ft NAVD88 depending on the reach (see Table 11 for reach by reach values). A combination of the two profiles was created using everything above that elevation from the average dune profile and everything below that elevation from the average berm/foreshore profile to create “upper beach” profile.
- The “upper beach” profile was then aligned at 0 ft NAVD88 with the average offshore bar profile. A combination of the two profiles was created using everything above 0 from the “upper beach” profile and everything below 0 from the average offshore bar profile to create the “overall” average profile.

Step 5: Create a final representative profile for each SBEACH analysis reach

- Given the limitations of the survey data (landward survey extent), the dune portion of the “overall” average profile was not considered to be representative of the dune feature within many of the reaches.
- Therefore, a representative dune was selected from profiles within each reach. This dune was aligned and combined with the “overall” average profile at elevations ranging from 5.5 ft NAVD88 to 11 ft NAVD88, in accordance with the elevation previously used to combine the average dune profile with the average berm/foreshore profile (see Table 11 for reach by reach values), creating the final representative averaged profile for each analysis reach.

The average and representative profiles developed for Reaches 1 through 13 are shown in Figures 31 through 43.

Reach	Elevation Used to Align Profiles and Calculate Average Dune Profile	Elevation Used to Align Profiles and Calculate Average Berm/Foreshore Profile	Elevation Used to Align Profiles and Calculate Average Offshore Profile	Elevation Used to Combine Avg Dune & Average Berm/Foreshore (Upper Beach Profile)	Elevation Used to Combine Upper Beach Profile & Average Offshore Profile	Elevation Used to Combine Representative Dune with Overall Average Profile
Reach 1	7	3	-8.5	5.5	0	5.5
Reach 2	11	3	-8	6	0	6
Reach 3	16	3	-9	9	0	9
Reach 4	13	3	-9	10	0	10
Reach 5	14.5	3	-9	11	0	11
Reach 6	14.5	3	-11	10	0	10
Reach 7	11.5	3	-12	9	0	9
Reach 8	14.5	3	-10	9	0	9
Reach 9	13.5	3	-11	9	0	9
Reach 10	15	3	-10.5	9	0	9
Reach 11	11	3	-12	9	0	9
Reach 12	12	3	-10	9	0	9
Reach 13	14	3	-13	9	0	9

Table 11: Elevations Used to Develop Overall Average Profiles for Each Analysis Reach

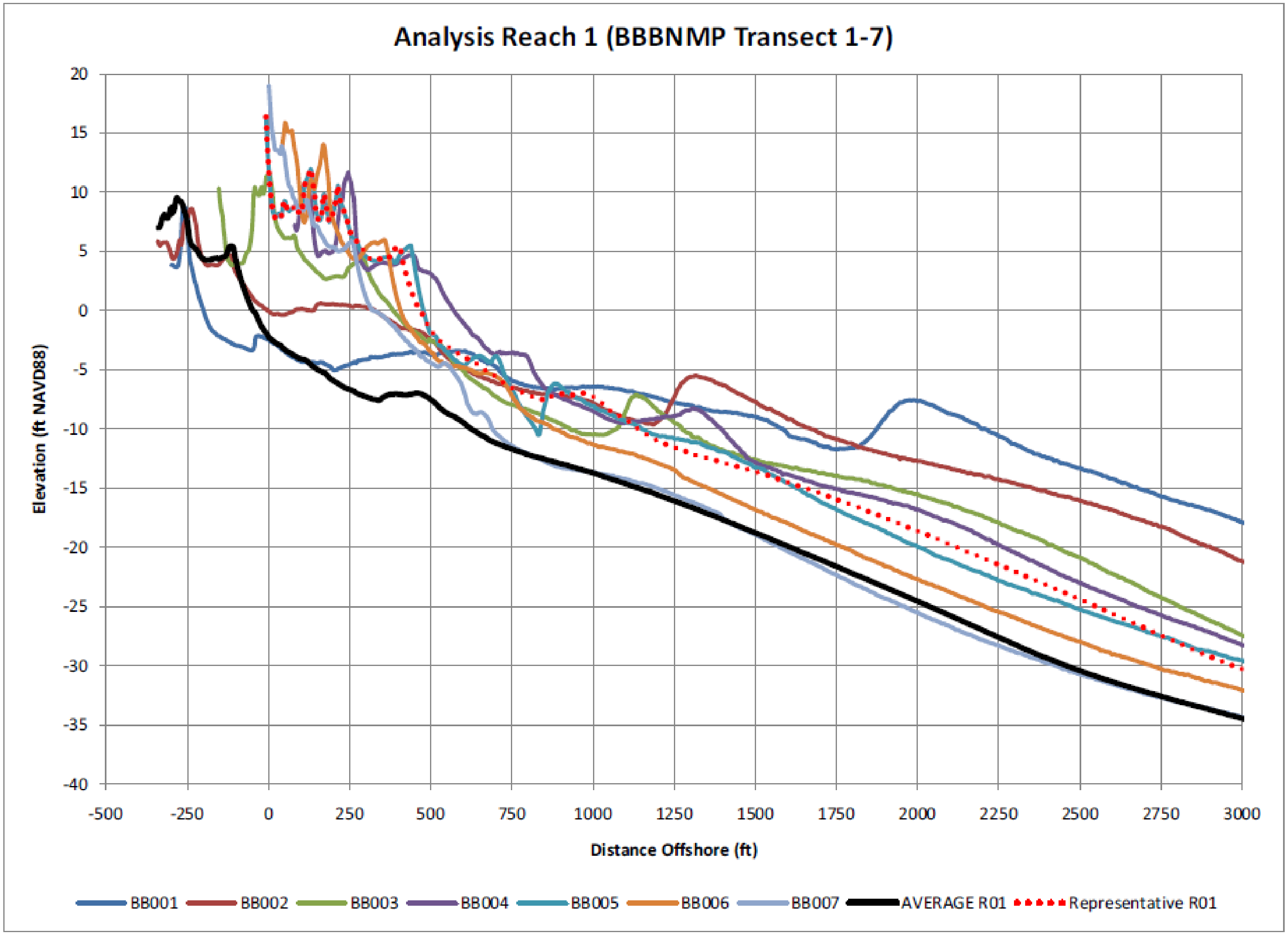


Figure 31 Reach 1 Representative Profile Development

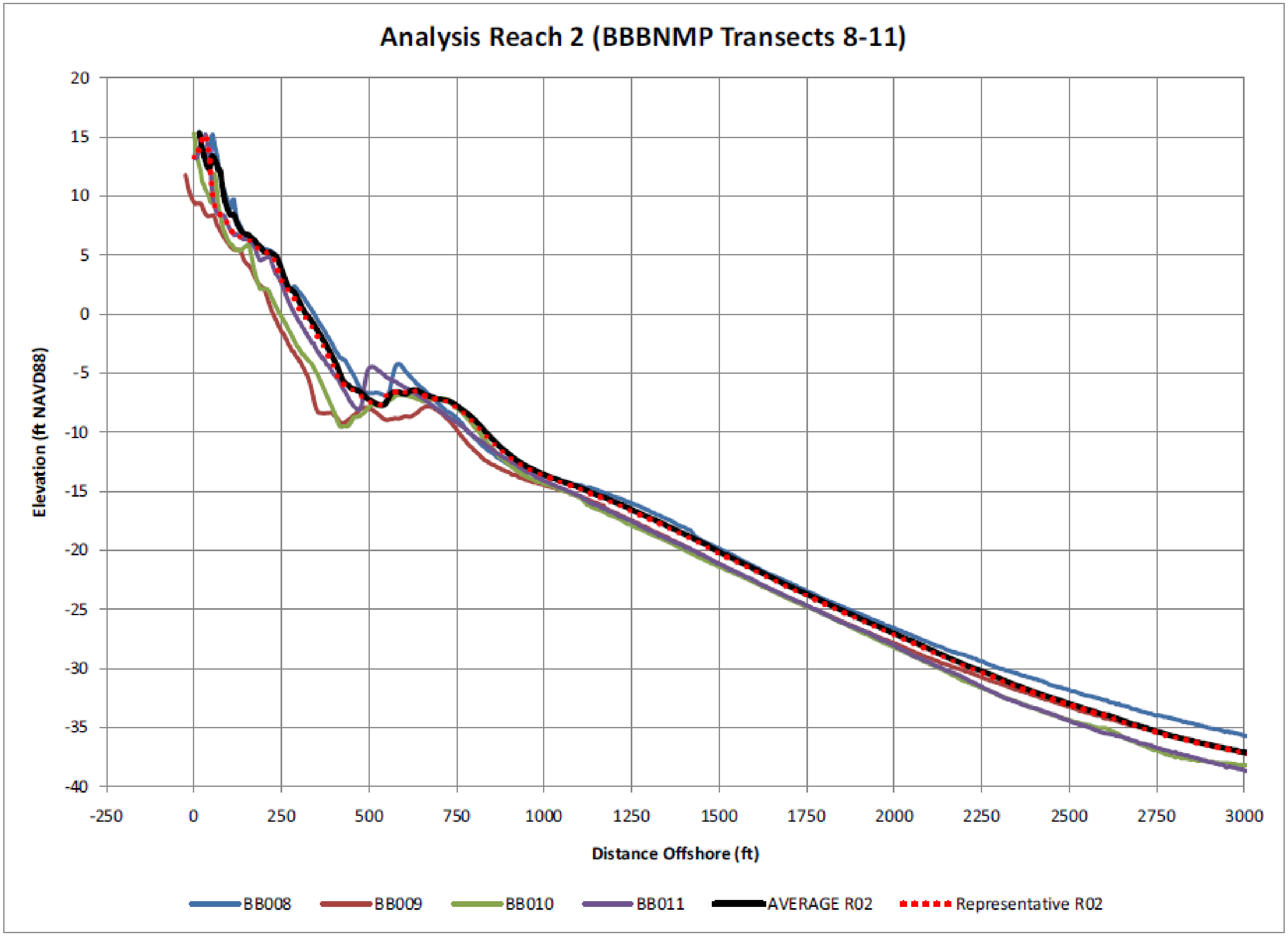


Figure 32 Reach 2 Representative Profile Development

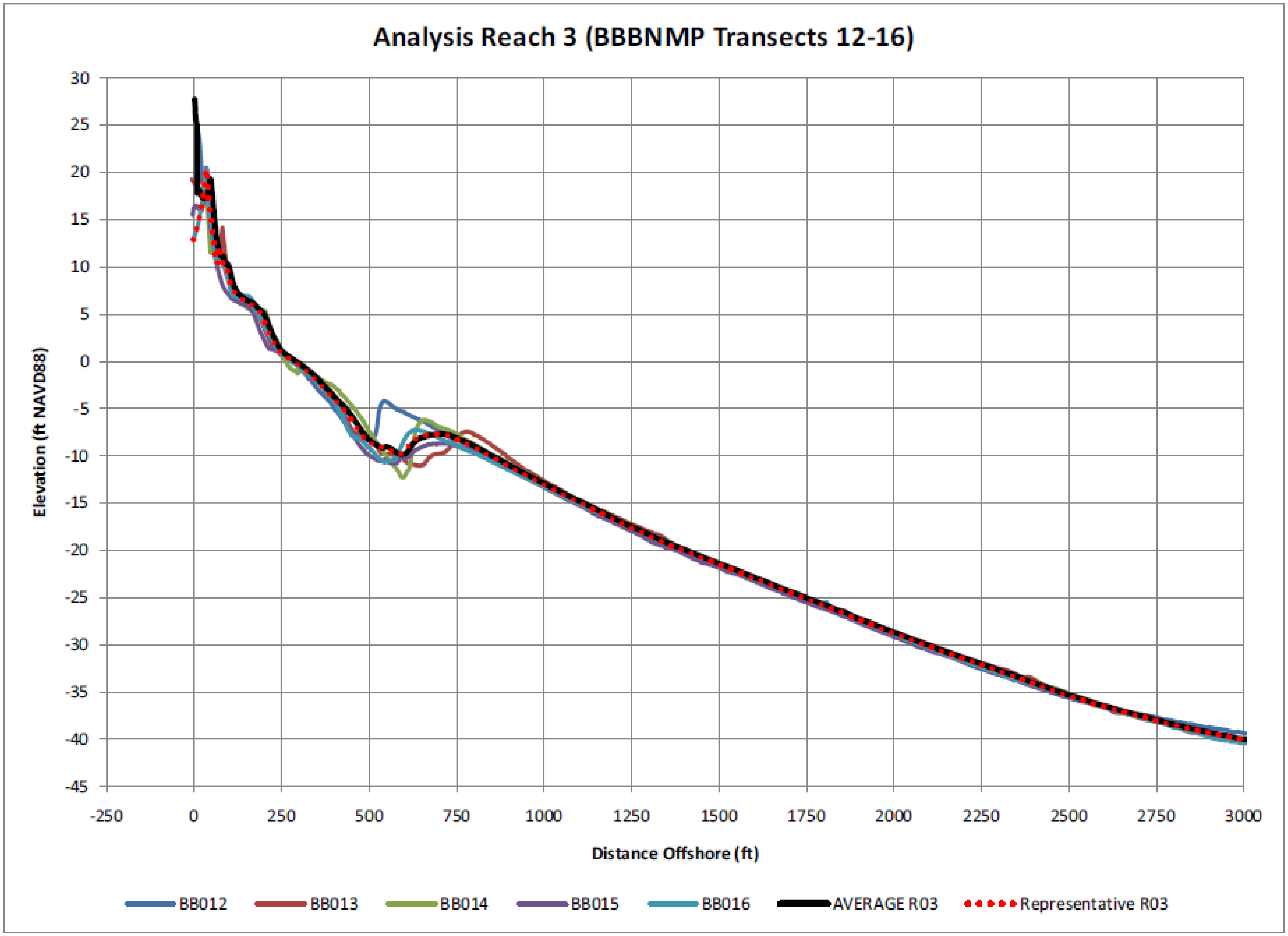


Figure 33 Reach 3 Representative Profile Development

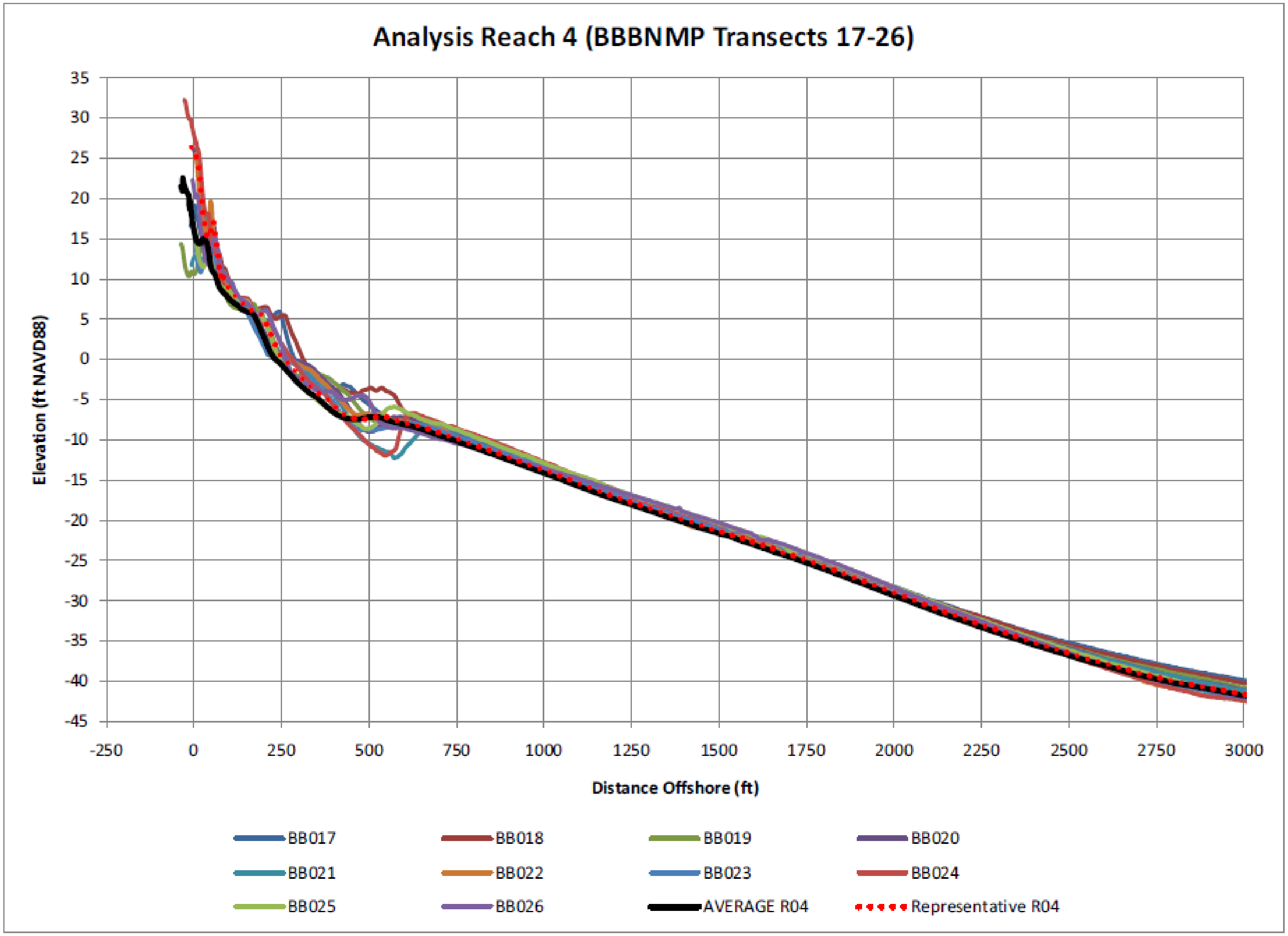


Figure 34 Reach 4 Representative Profile Development

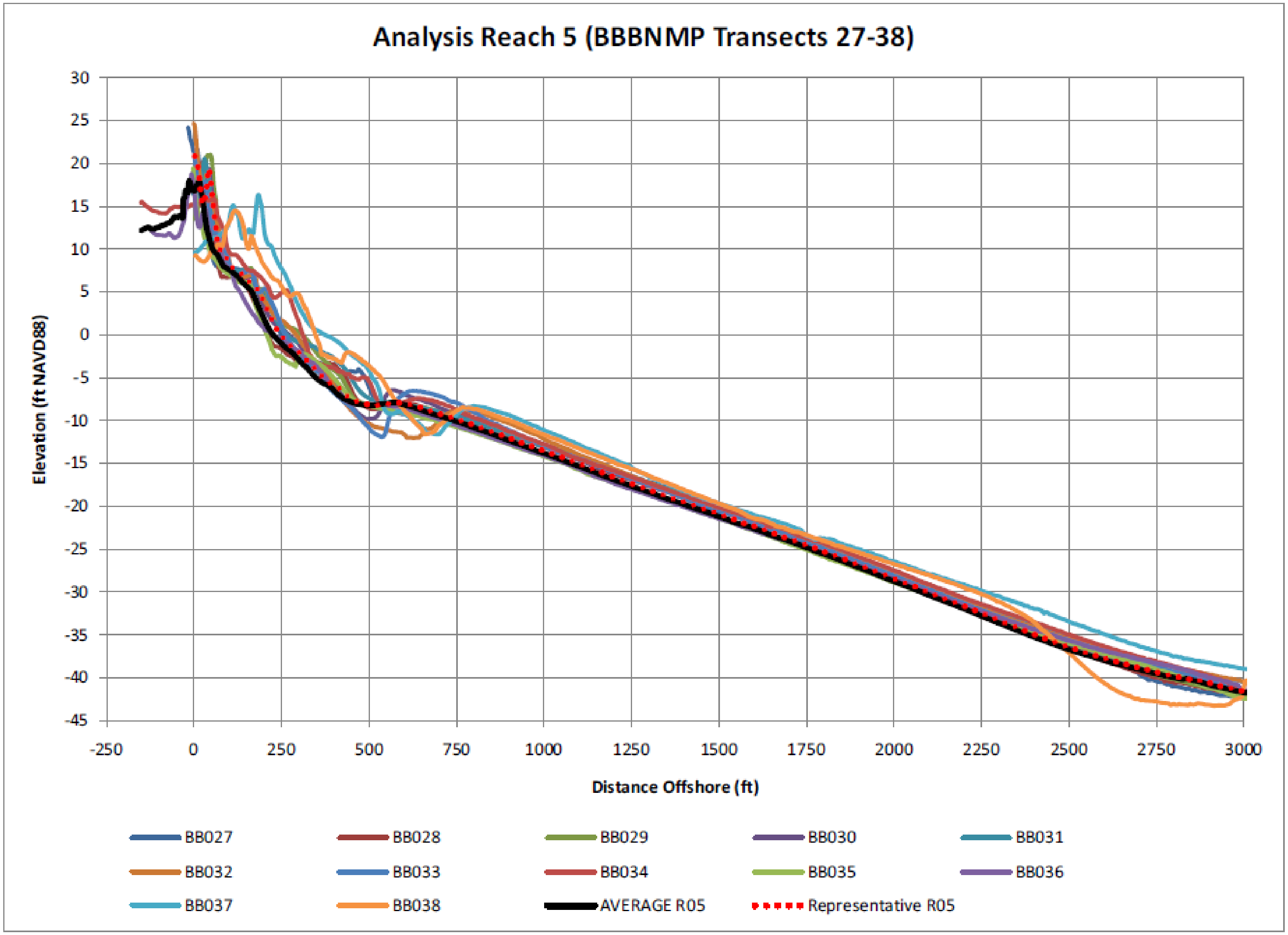


Figure 35 Reach 5 Representative Profile Development

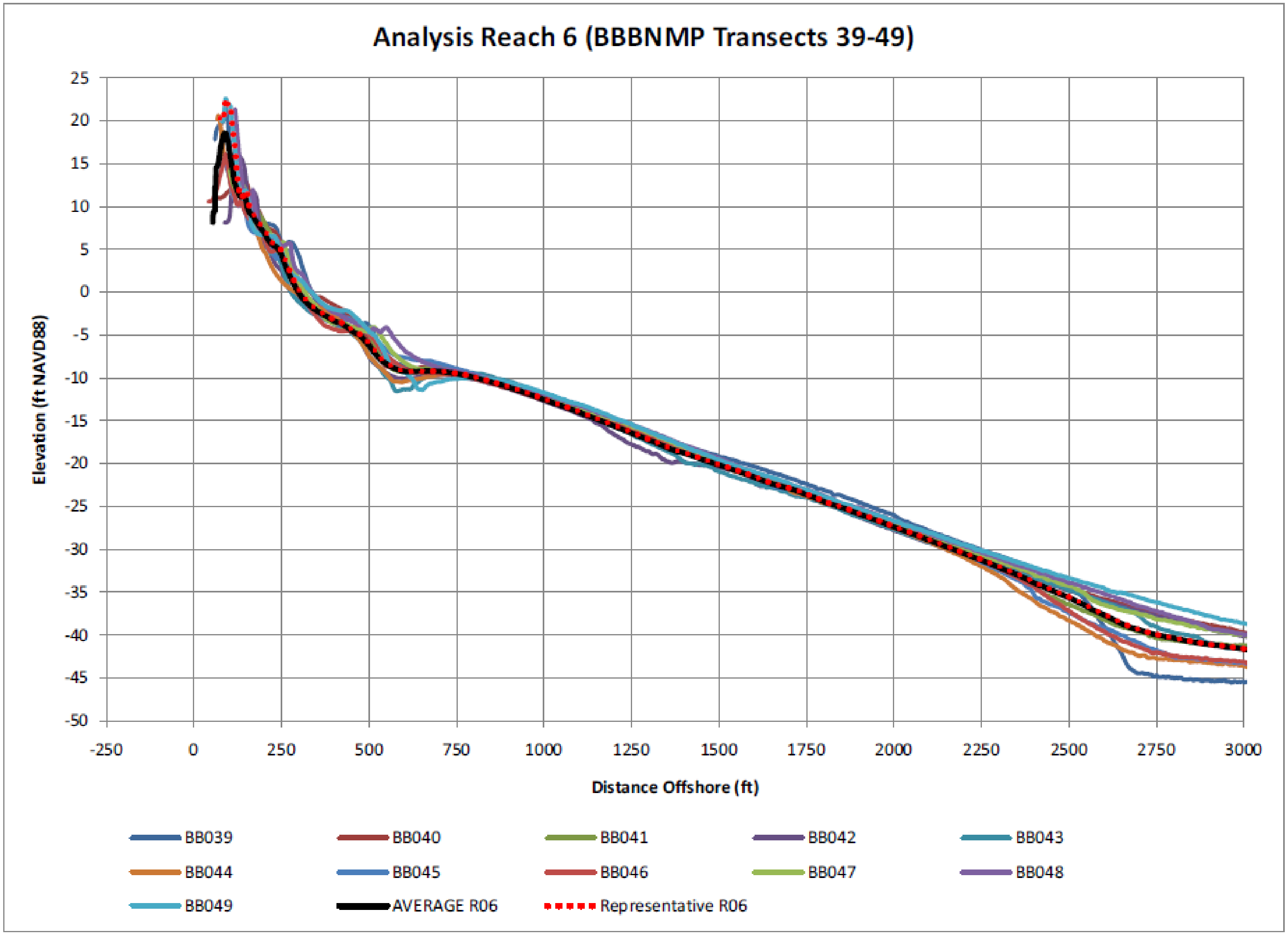


Figure 36 Reach 6 Representative Profile Development

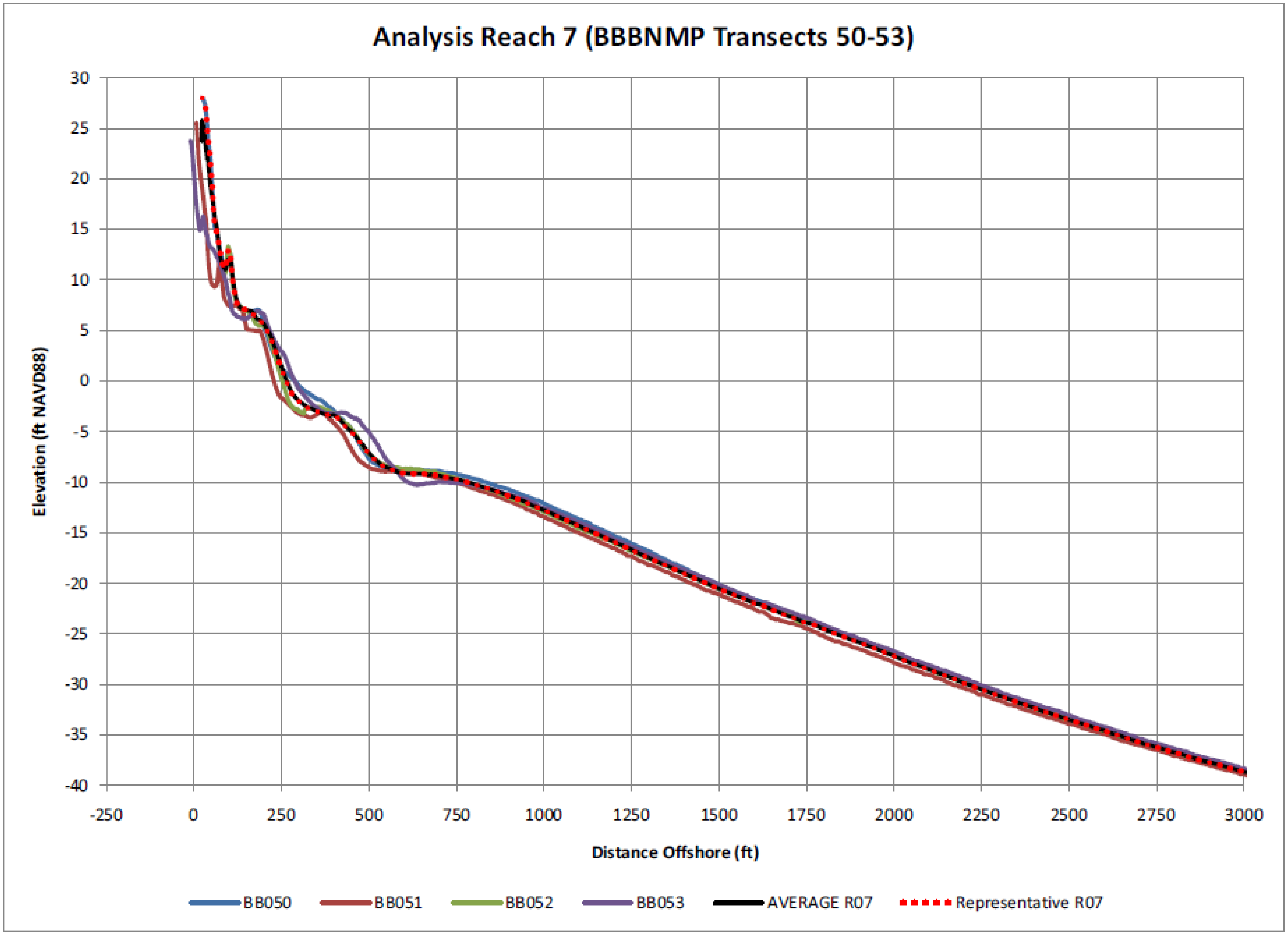


Figure 37 Reach 7 Representative Profile Development

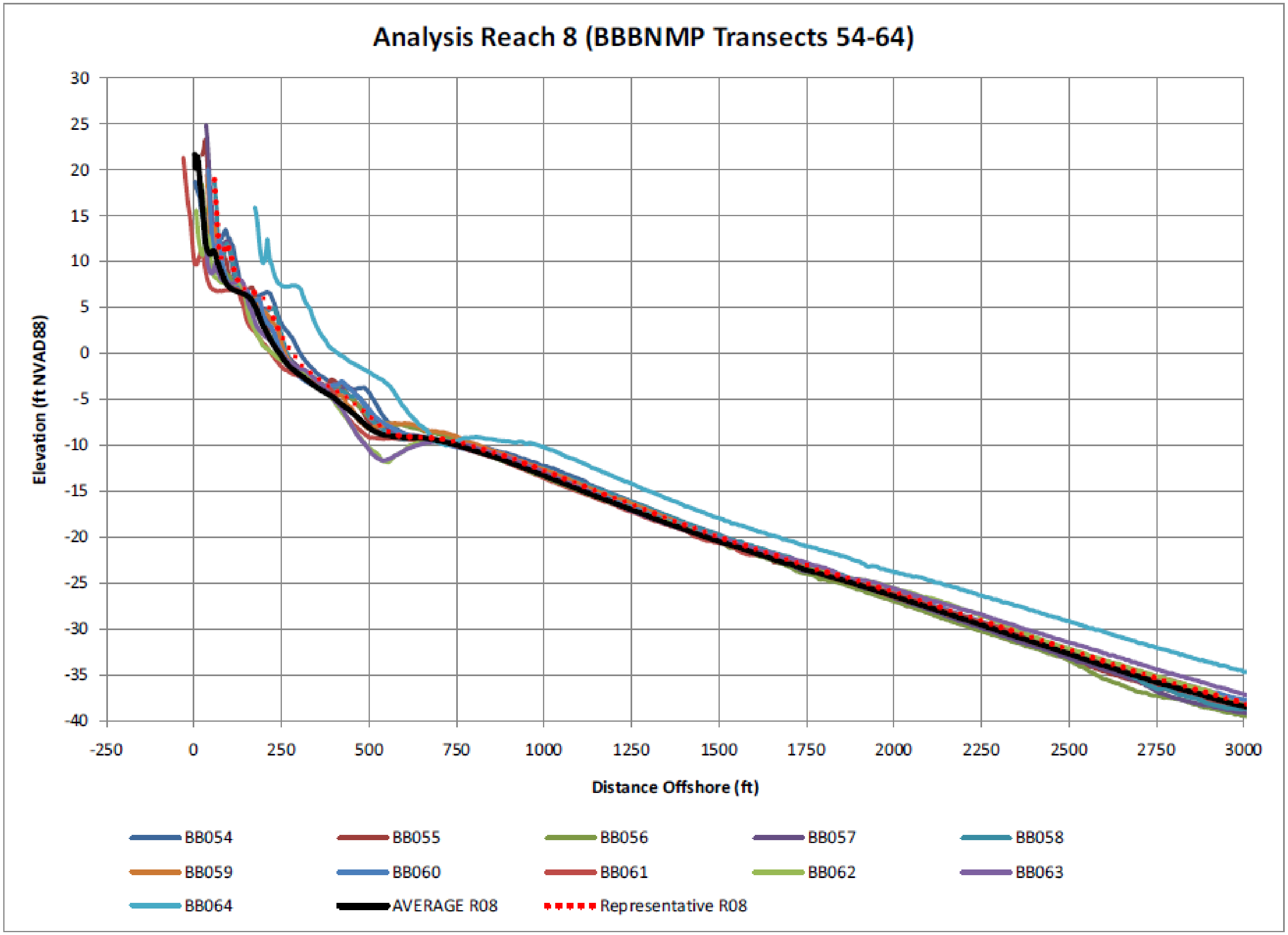


Figure 38 Reach 8 Representative Profile Development

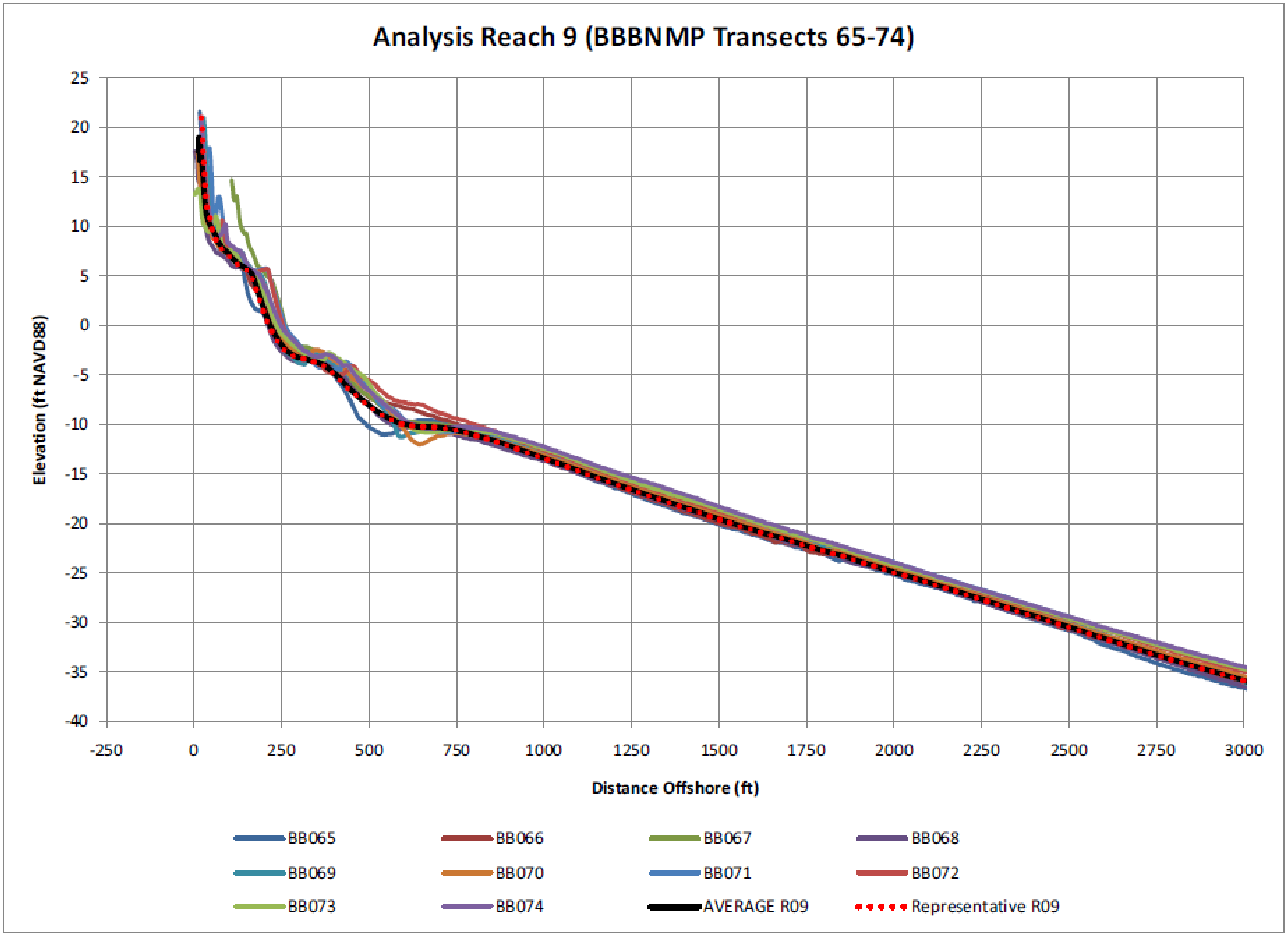


Figure 39 Reach 9 Representative Profile Development

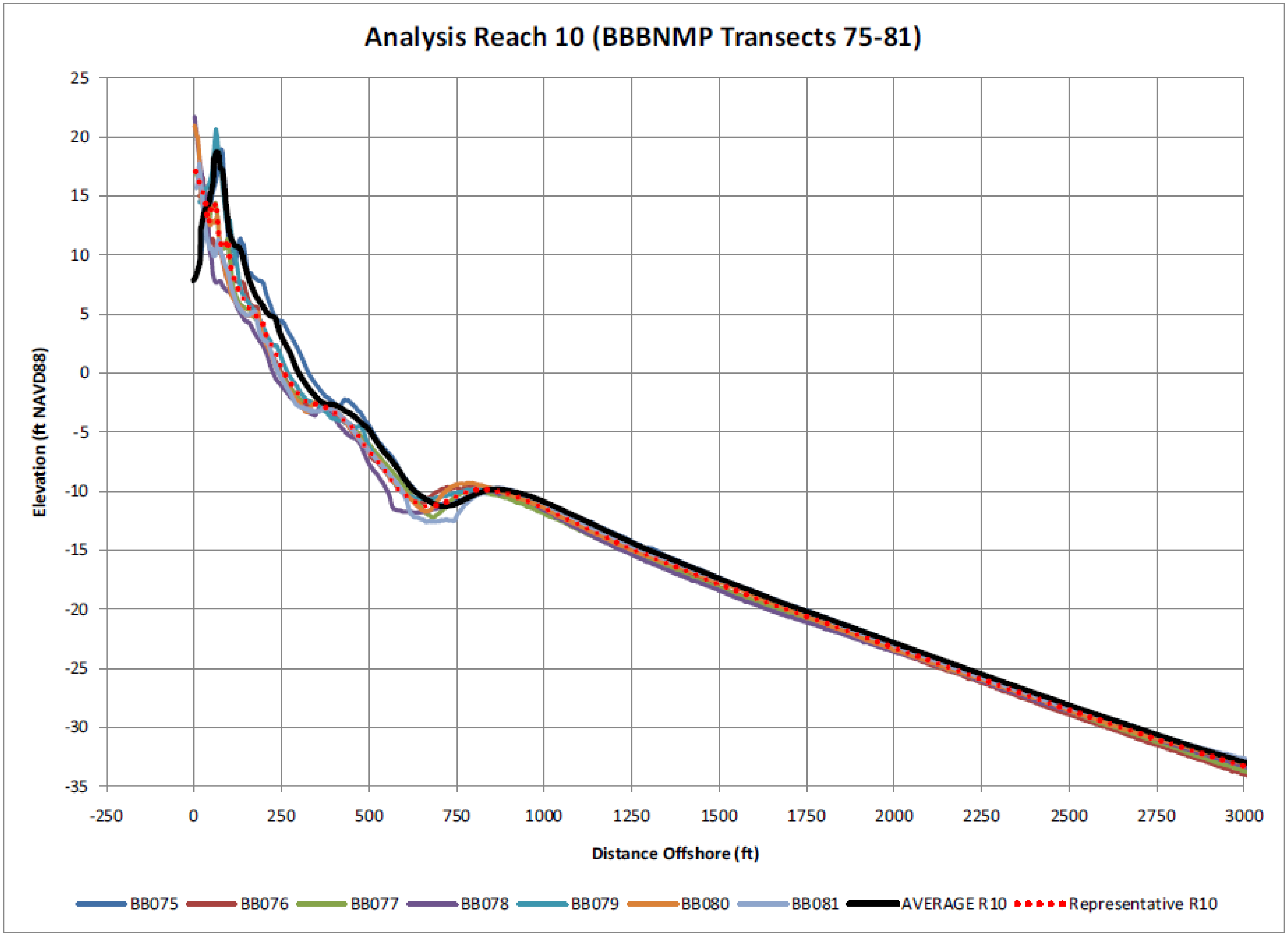


Figure 40 Reach 10 Representative Profile Development

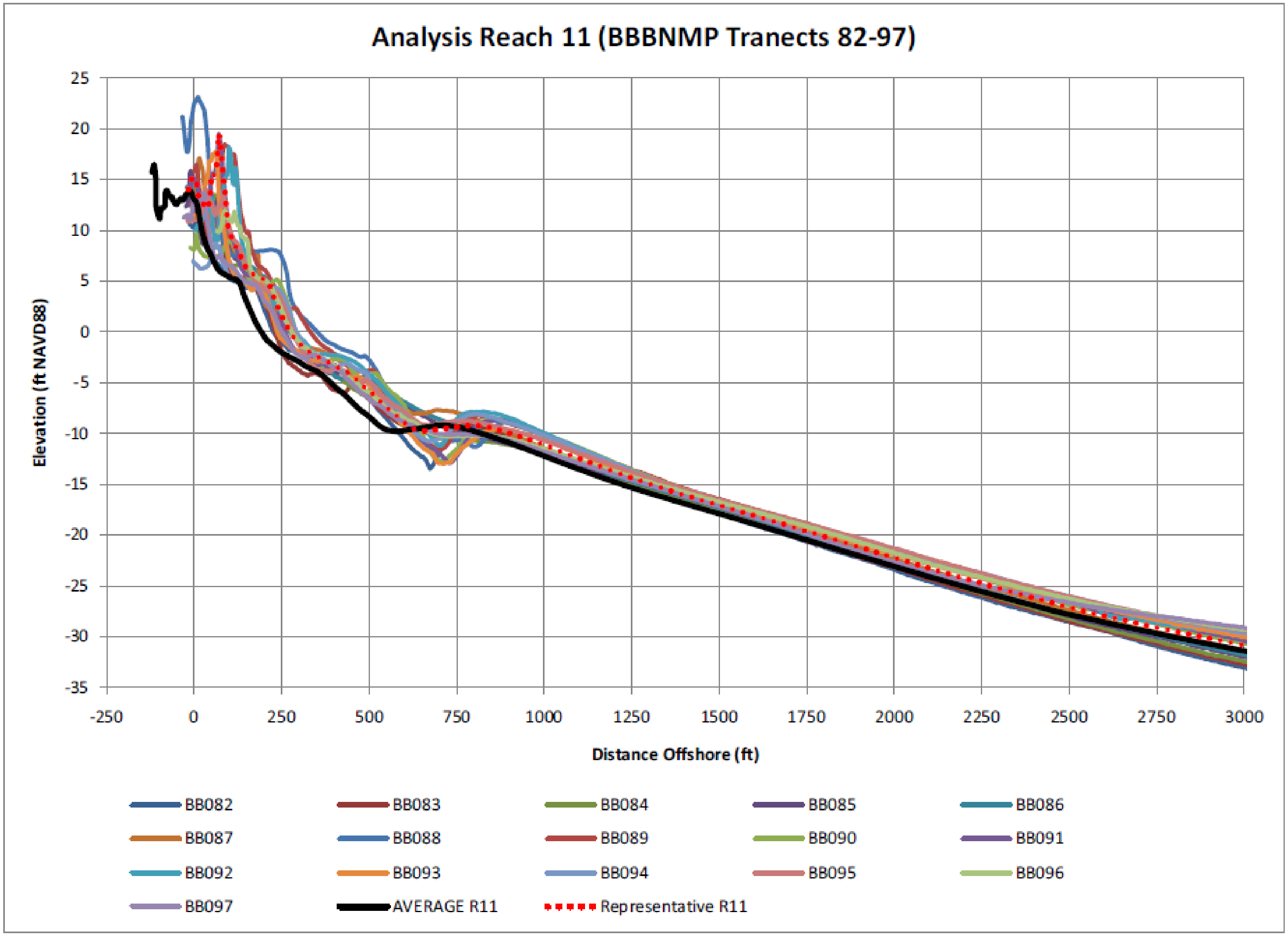


Figure 41 Reach 11 Representative Profile Development

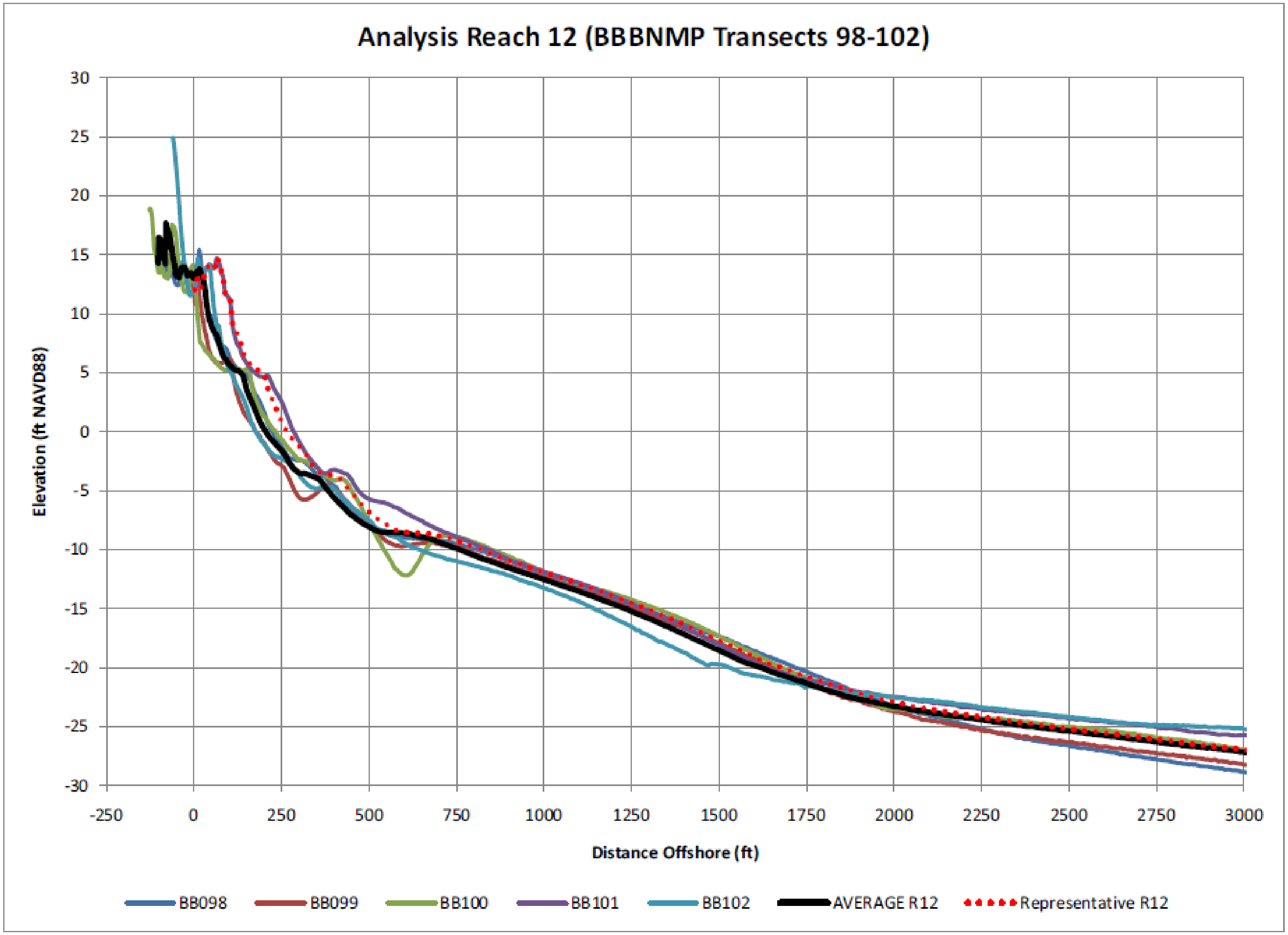


Figure 42 Reach 12 Representative Profile Development

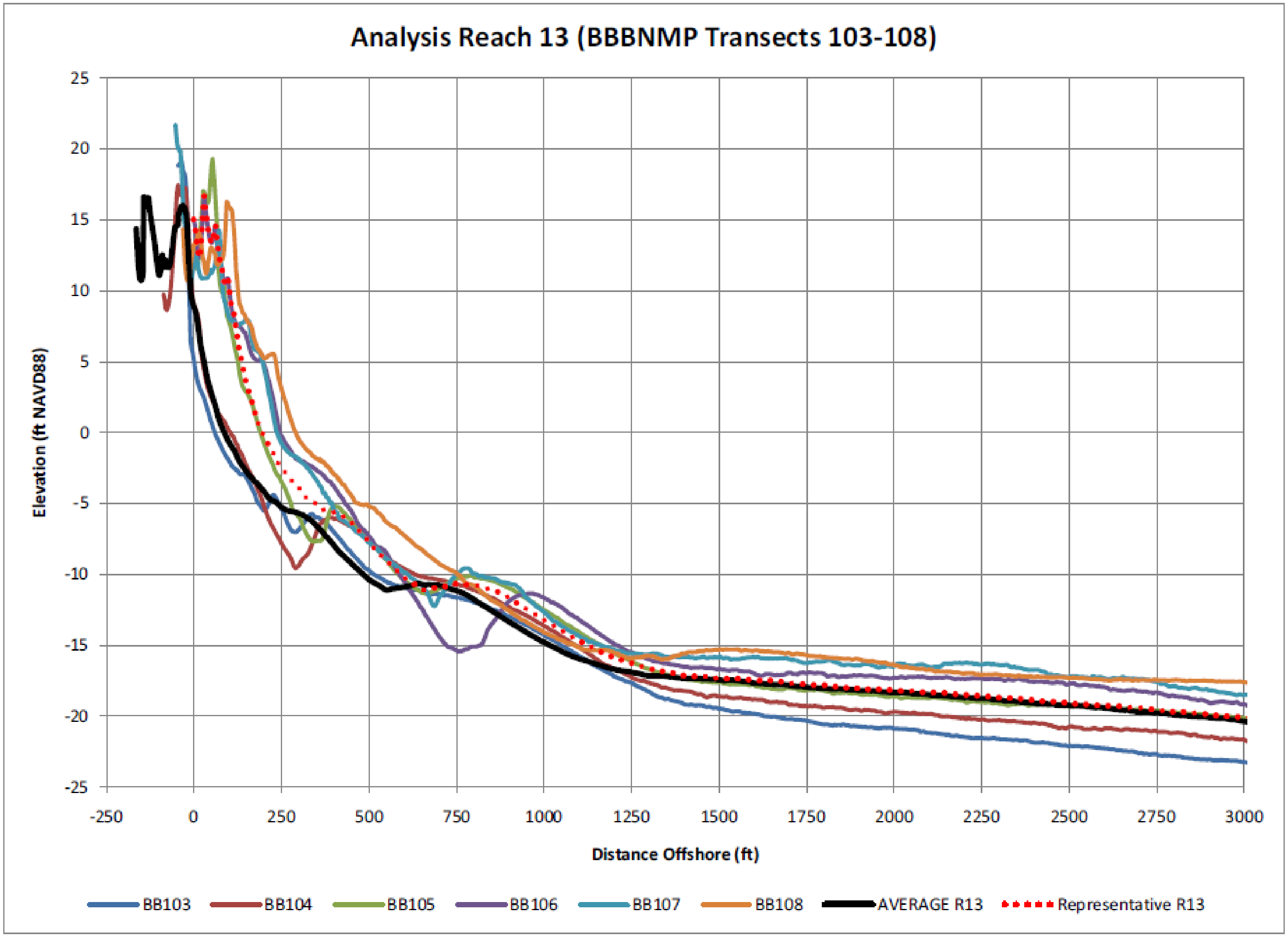


Figure 43 Reach 13 Representative Profile Development

The representative profiles for each reach were idealized to conform with the Beach-*fx* model framework, as seen earlier in this report in Figure 3. An effort was made to match dune slope, berm height, and foreshore slope across reaches to allow for ease in laying out project profiles later. However, survey data clearly shows that berm elevations and dune slopes are different near the inlets from the remainder of the beach. The idealized profile dimensions are tabulated for each SBEACH analysis reach in Table 12.

Reach	SBEACH Landward Boundary	Upland Elevation	Upland Width	Landward Dune Slope (X:1)	Dune Elevation	Dune Width	Seward Dune Slope (X:1)	Berm Height	Berm Width	Foreshore Slope (X:1)
1	-2000	8	2087.65	4	11	95	-4	5.5	135	-15
2	-2000	8	1992.50	4	15	15	-4	7	125	-15
3	-2000	12	1998.32	4	20	5	-4	7	70	-15
4	-2000	12	1928.27	4	26	25	-4	7	85	-15
5	-2000	12	1981.87	4	20	25	-4	7	70	-15
6	-2000	20	2077.96	4	22	15	-4	7	55	-15
7	-2000	12	1875.47	4	28	90	-4	7	65	-15
8	-2000	12	1937.00	4	18	100	-4	7	80	-15
9	-2000	12	1953.58	4	20	30	-4	7	65	-15
10	-2000	12	1919.61	4	18	100	-4	7	65	-15
11	-2000	12	2041.56	4	18	10	-4	5.5	75	-15
12	-2000	12	2014.62	4	14	40	-4	5.5	30	-15
13	-2000	12	1983.99	4	16	10	-4	5.5	5	-15

Table 12: Dimensions for Existing Idealized Profiles

In order to idealize the representative profiles developed for the existing conditions in each SBEACH analysis reach, contours created from 2007 LiDAR data were downloaded from the North Carolina Department of Transportation GIS website (http://www.ncdot.org/IT/gis/) to assess conditions landward of where the survey data ended. The LiDAR data was used to decide on the upland elevation and width landward of where the survey data ended. Figures 44 through 56 display the developed idealized conditions for Reaches 1 through 13.

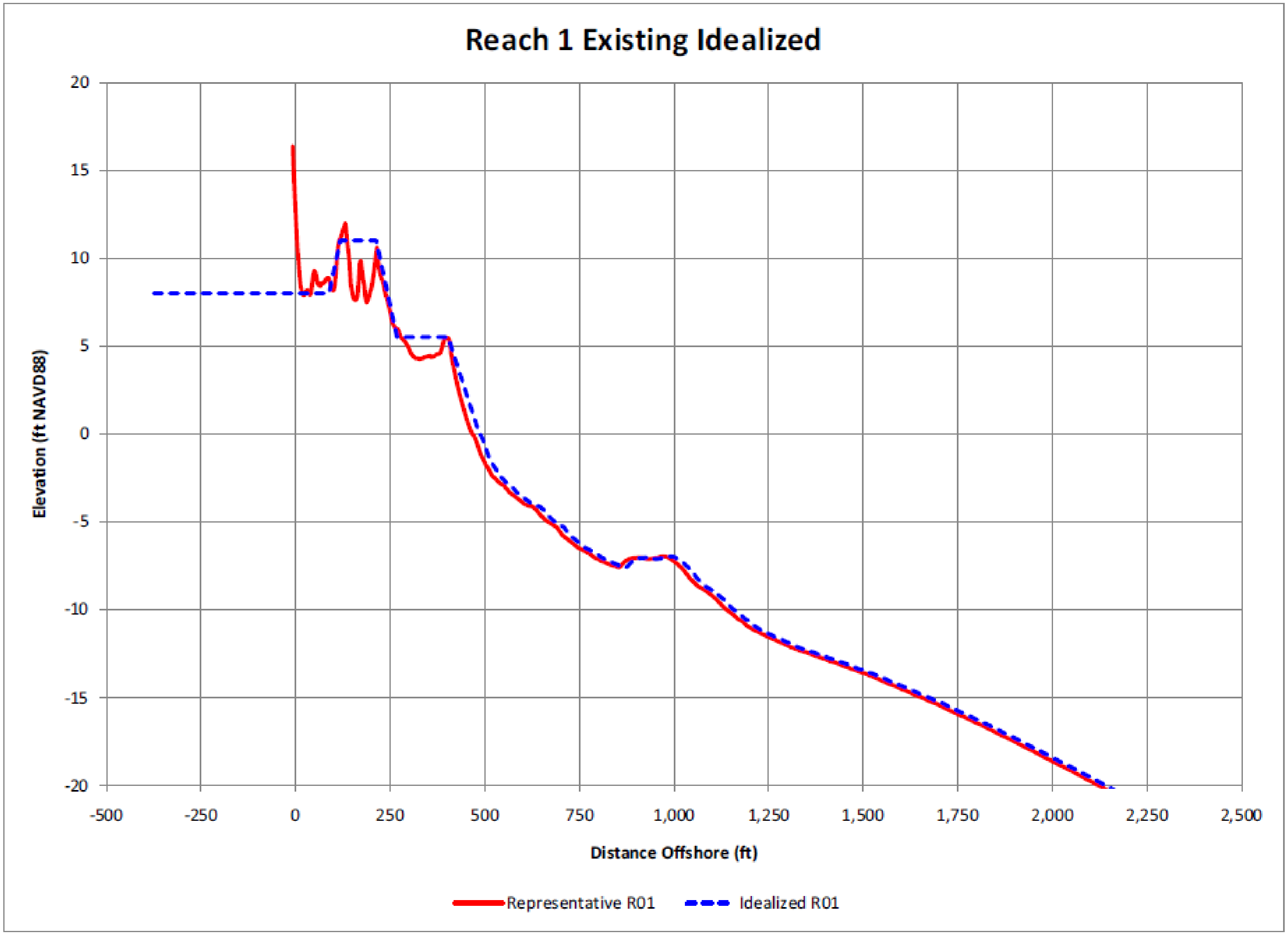


Figure 44 Reach 1 Idealized Existing Condition

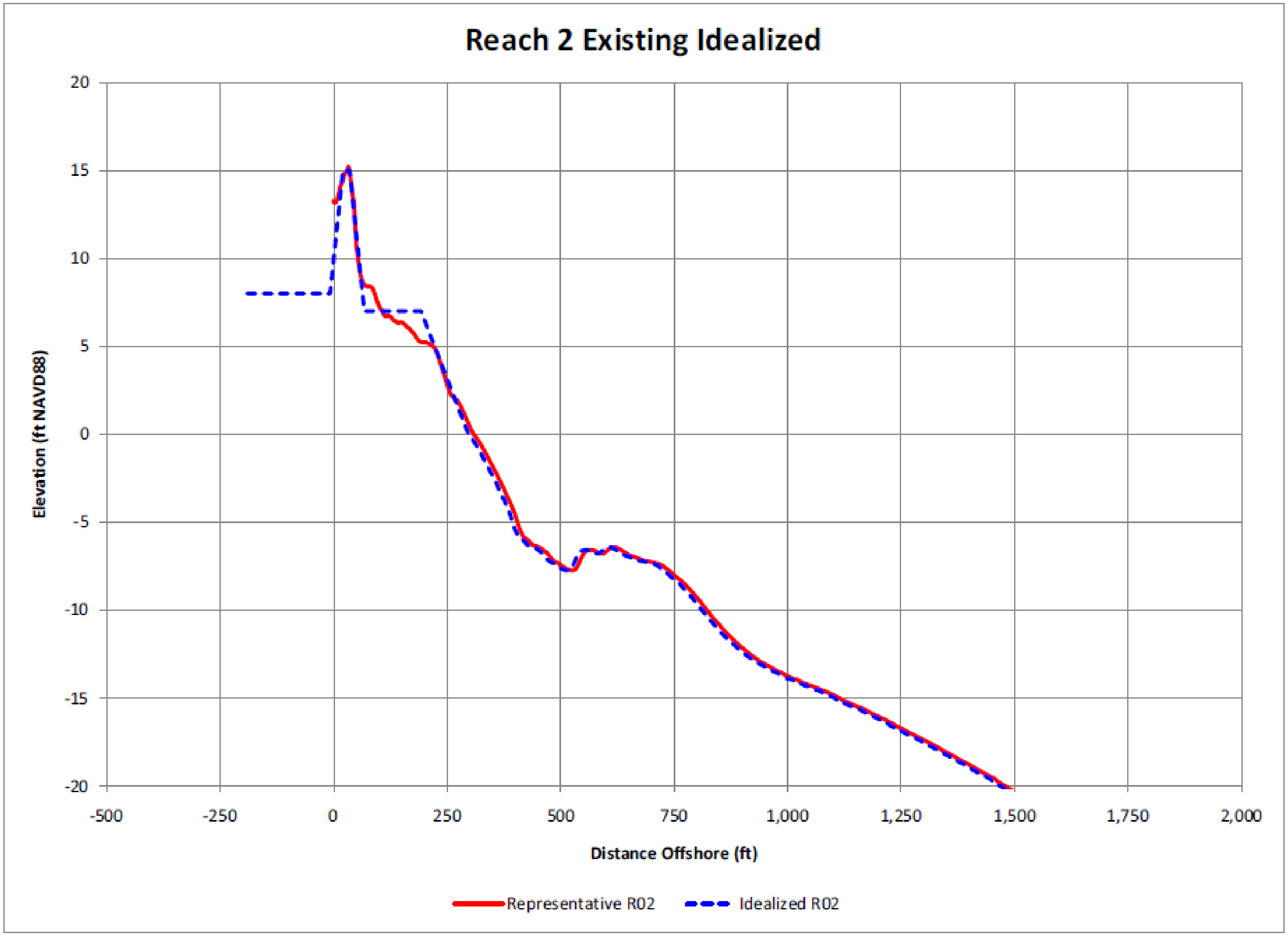


Figure 45 Reach 2 Idealized Existing Condition

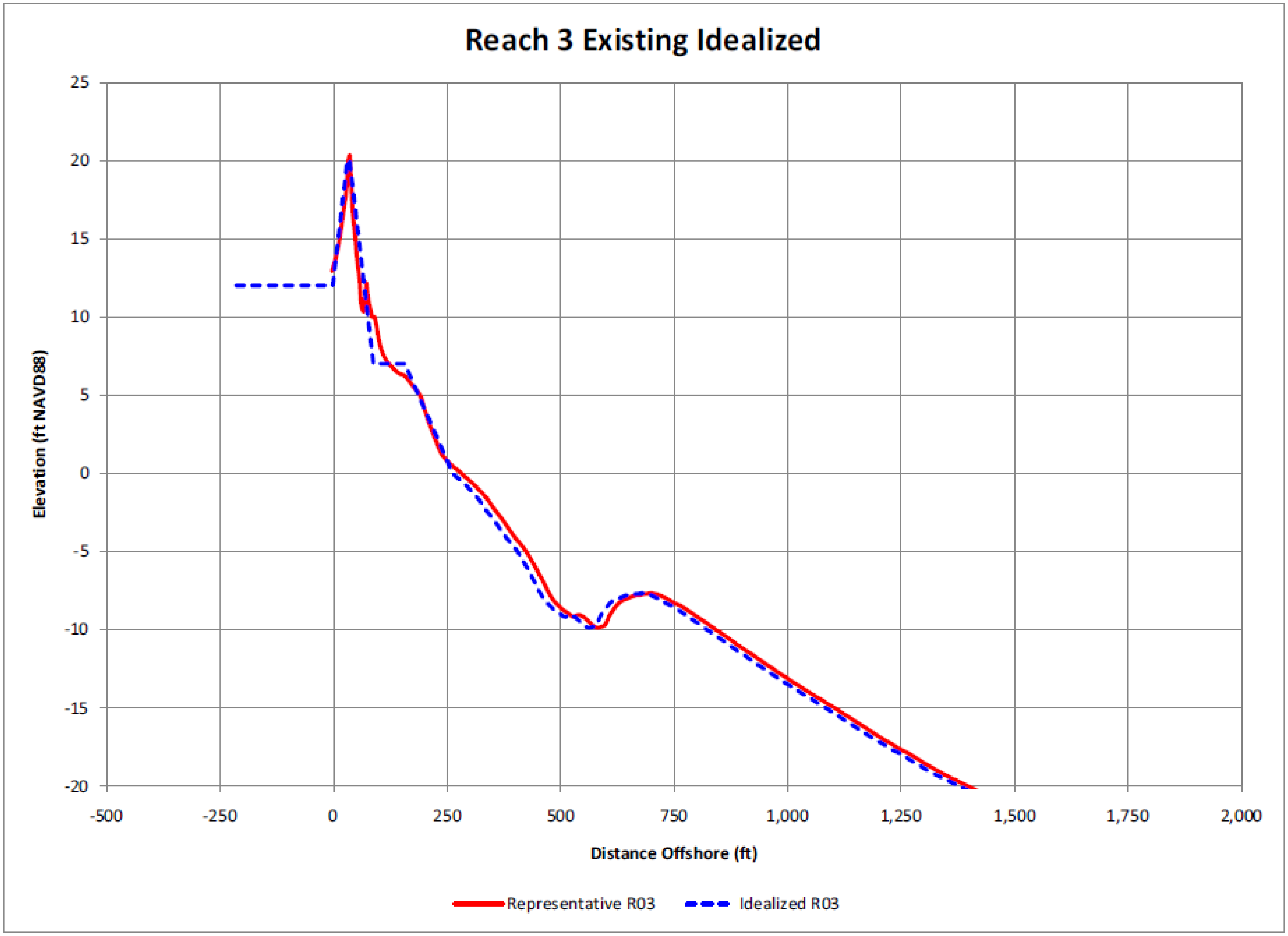


Figure 46 Reach 3 Idealized Existing Condition

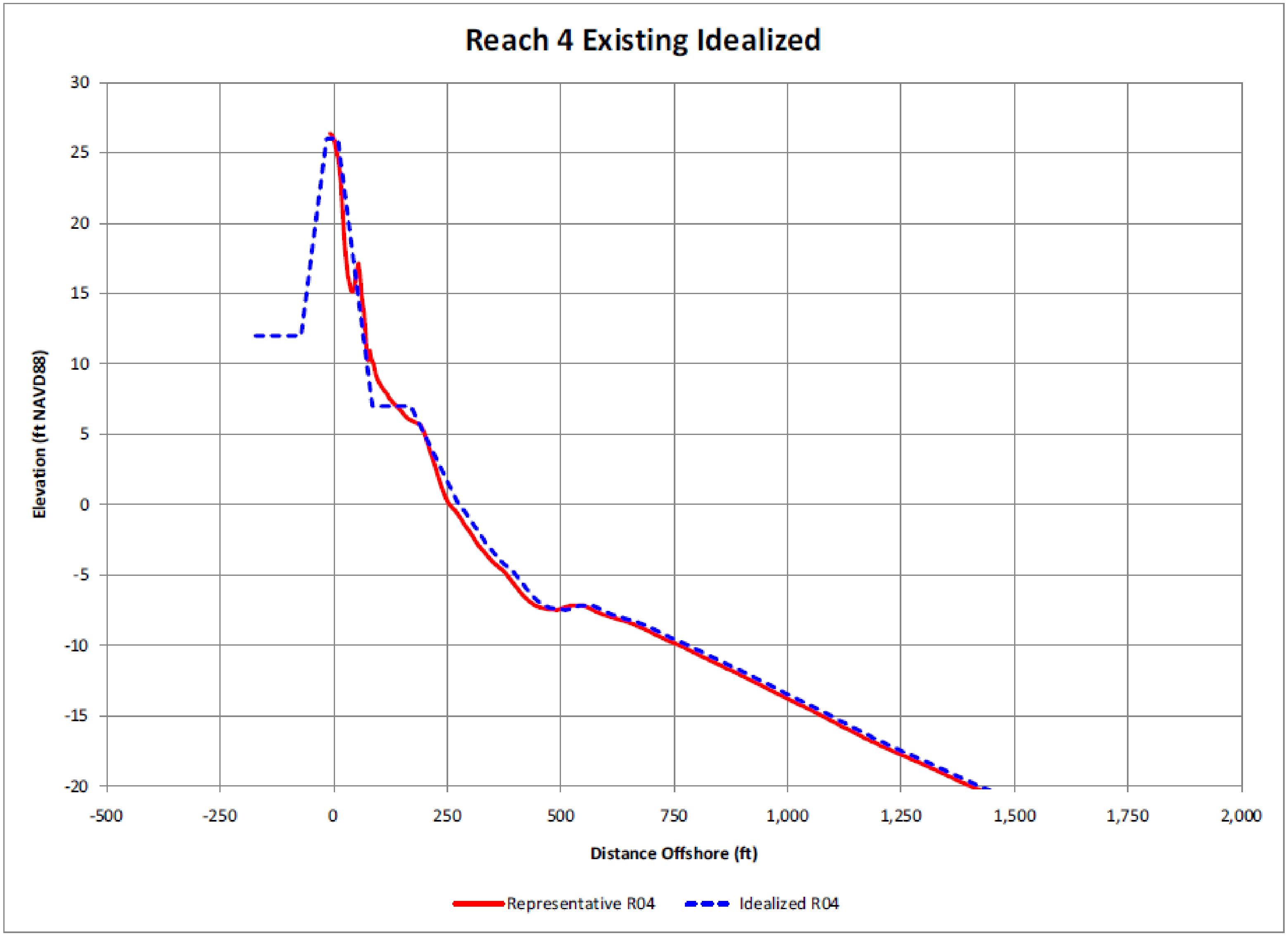


Figure 47 Reach 4 Idealized Existing Condition

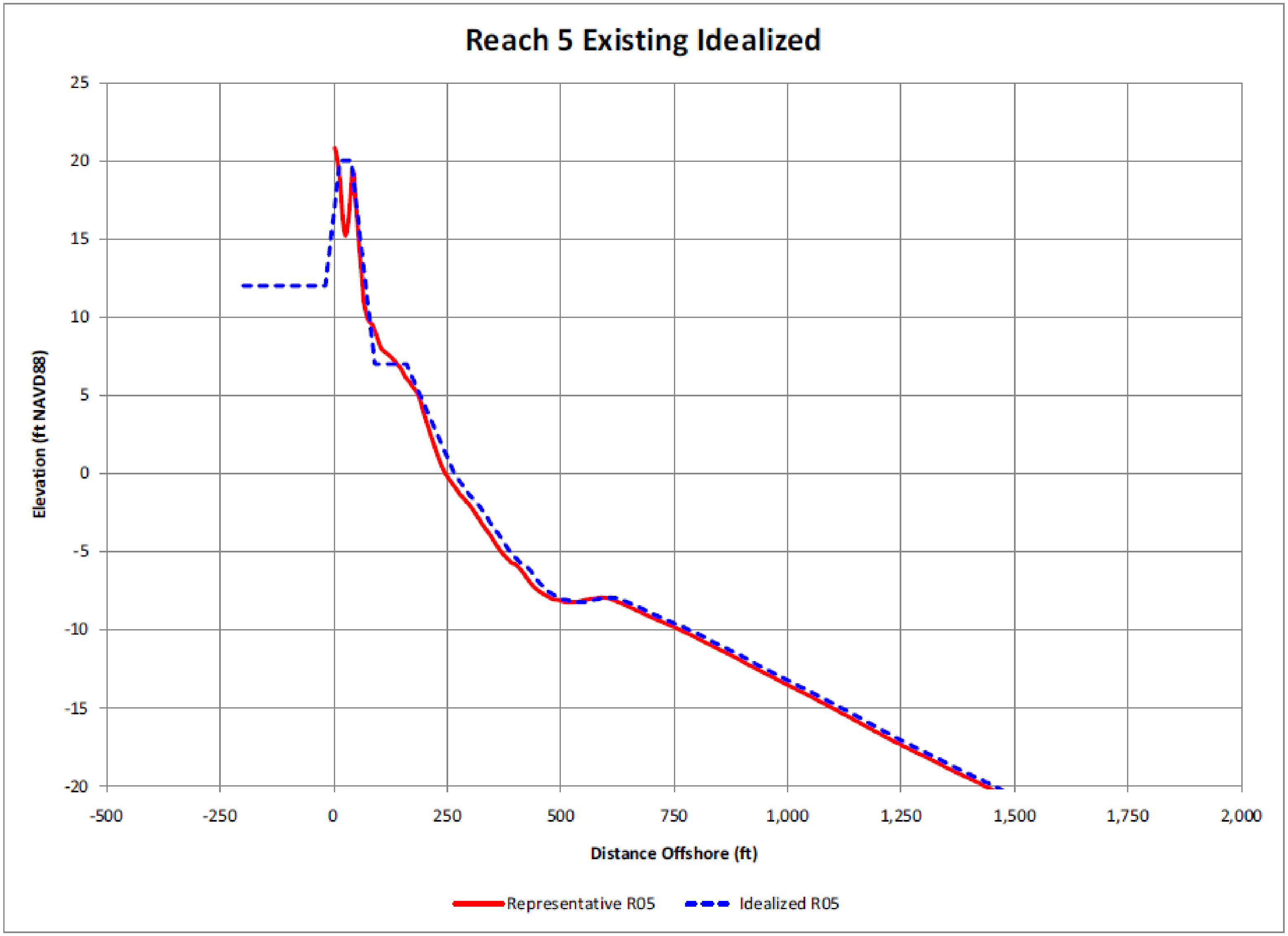


Figure 48 Reach 5 Idealized Existing Condition

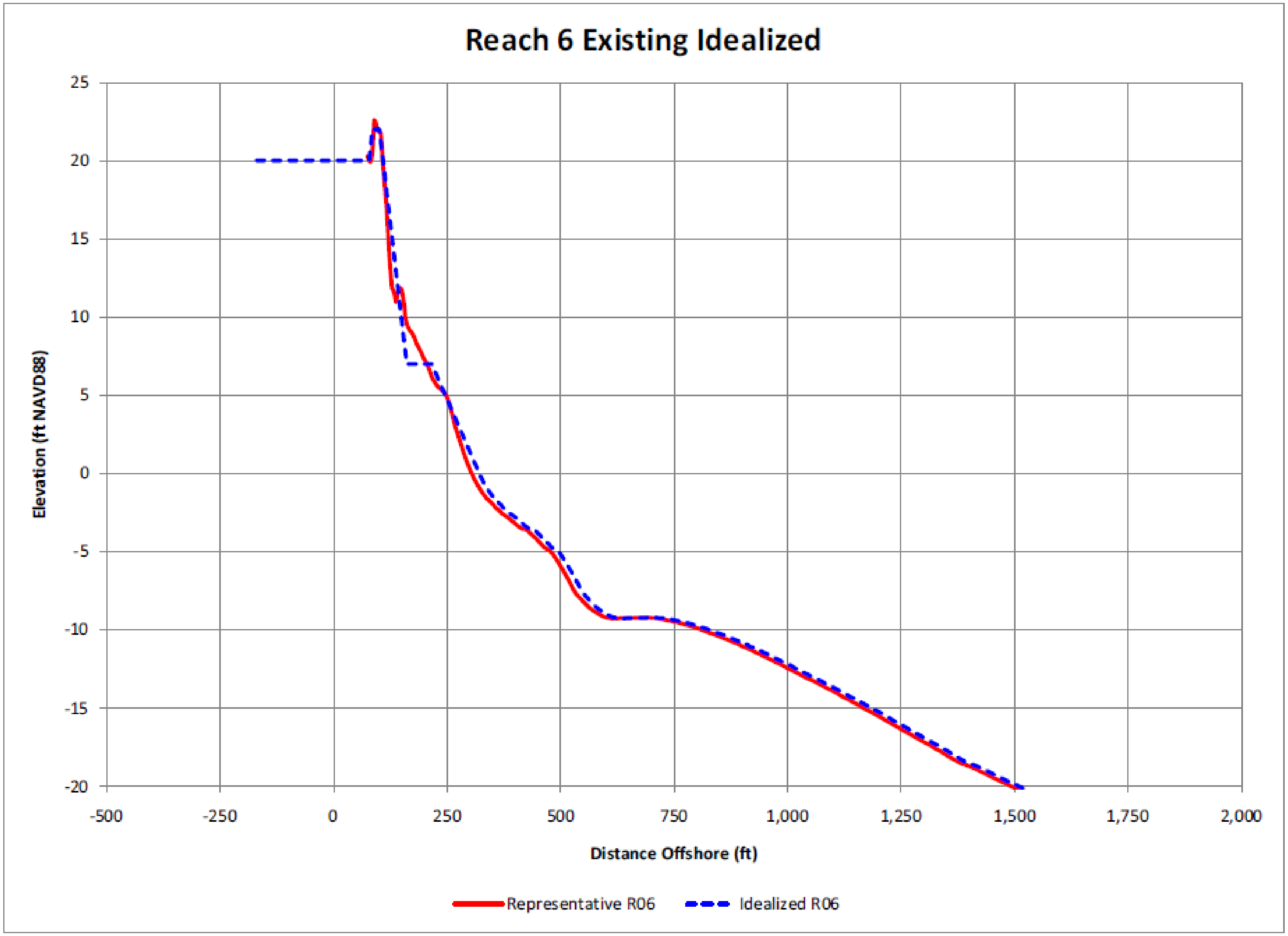


Figure 49 Reach 6 Idealized Existing Condition

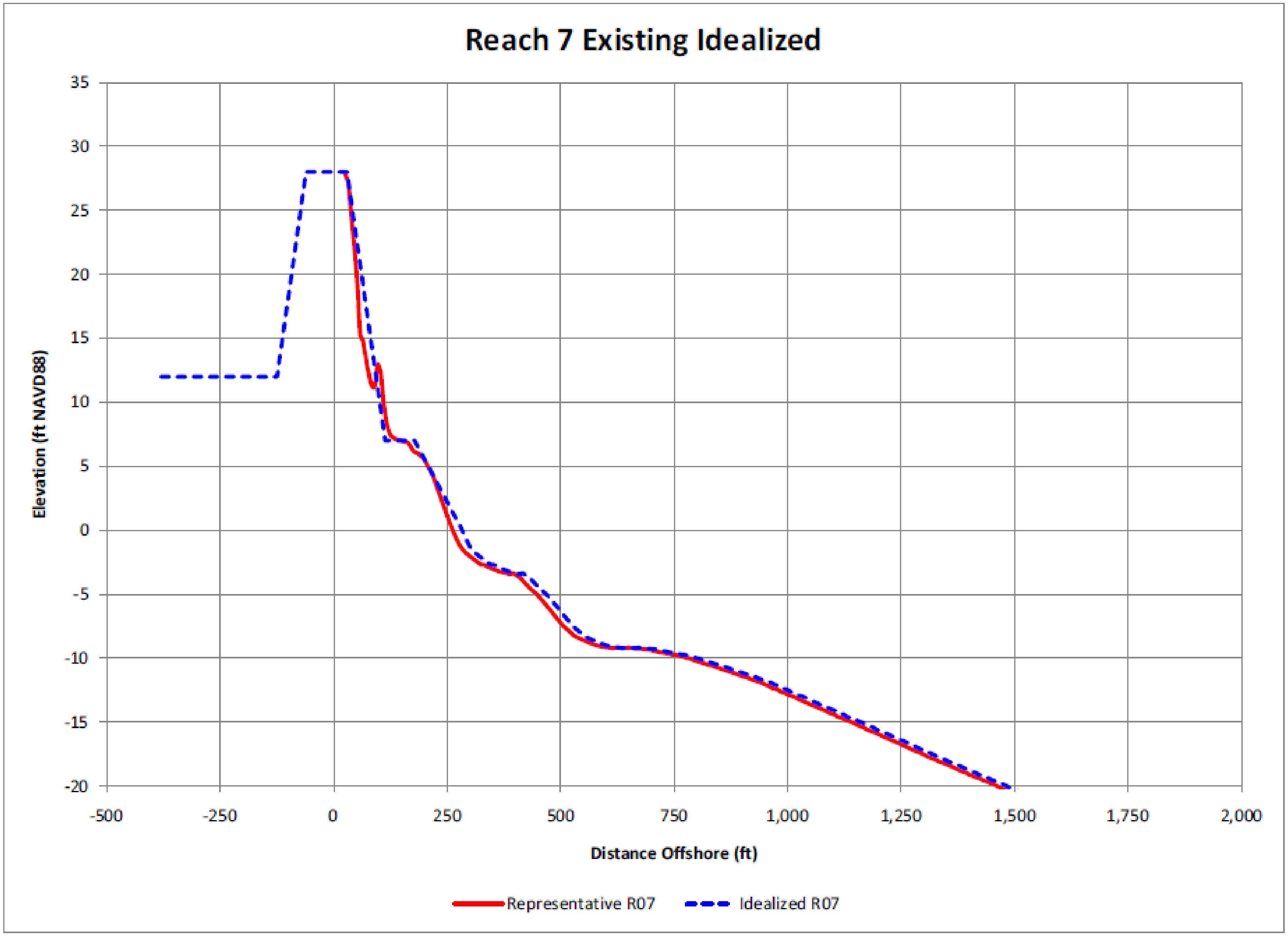


Figure 50 Reach 7 Idealized Existing Condition

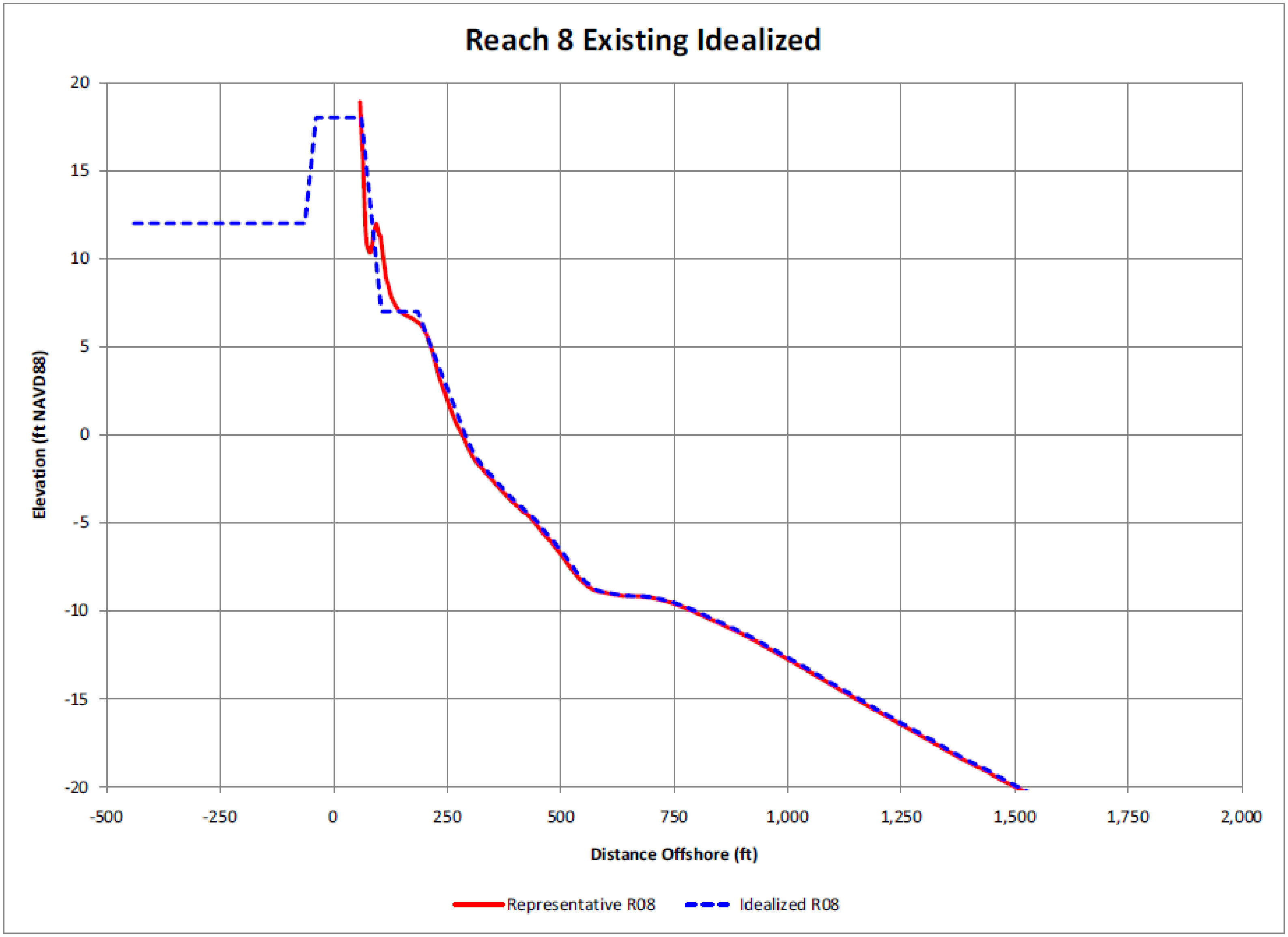


Figure 51 Reach 8 Idealized Existing Condition

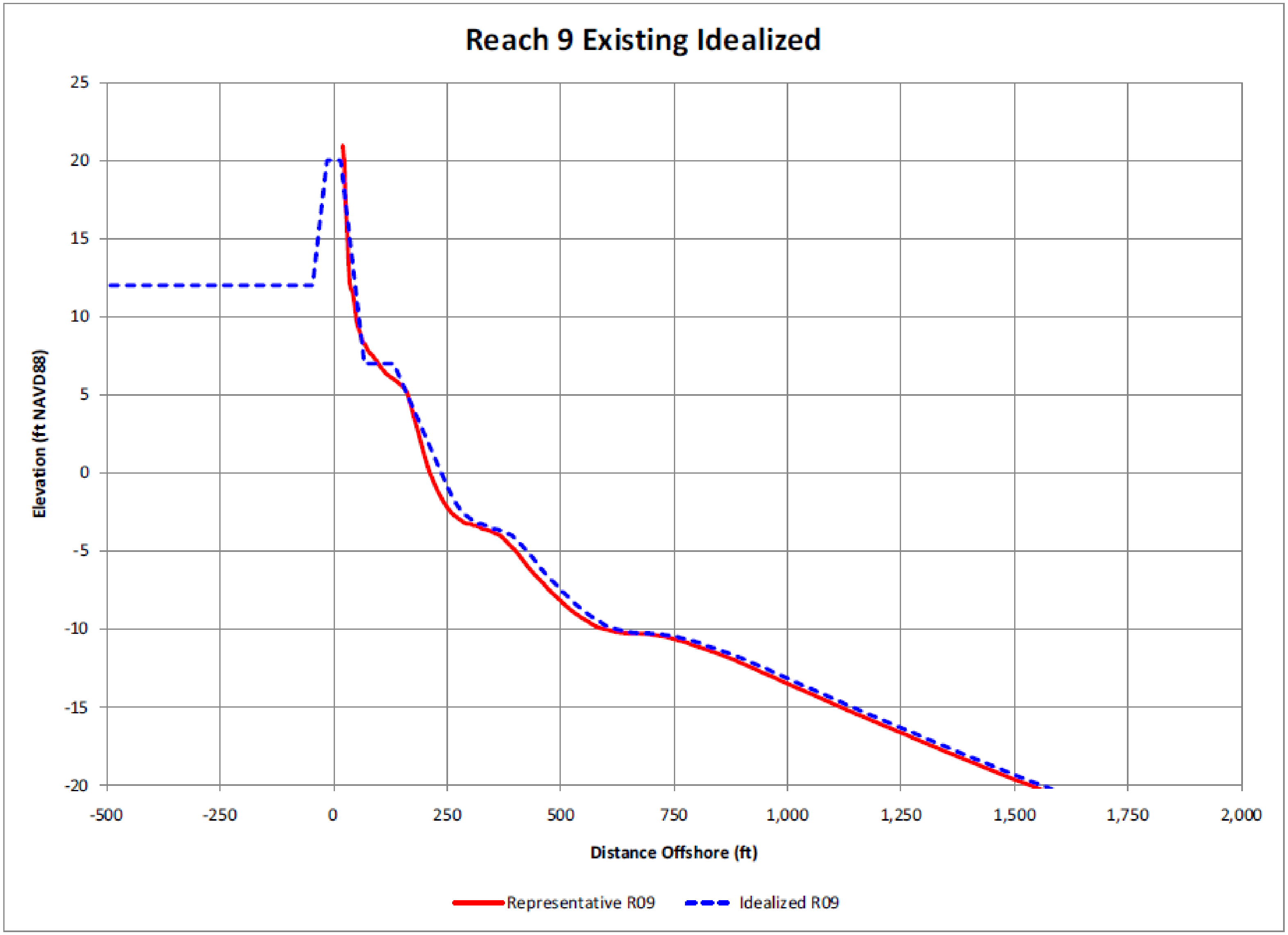


Figure 52 Reach 9 Idealized Existing Condition

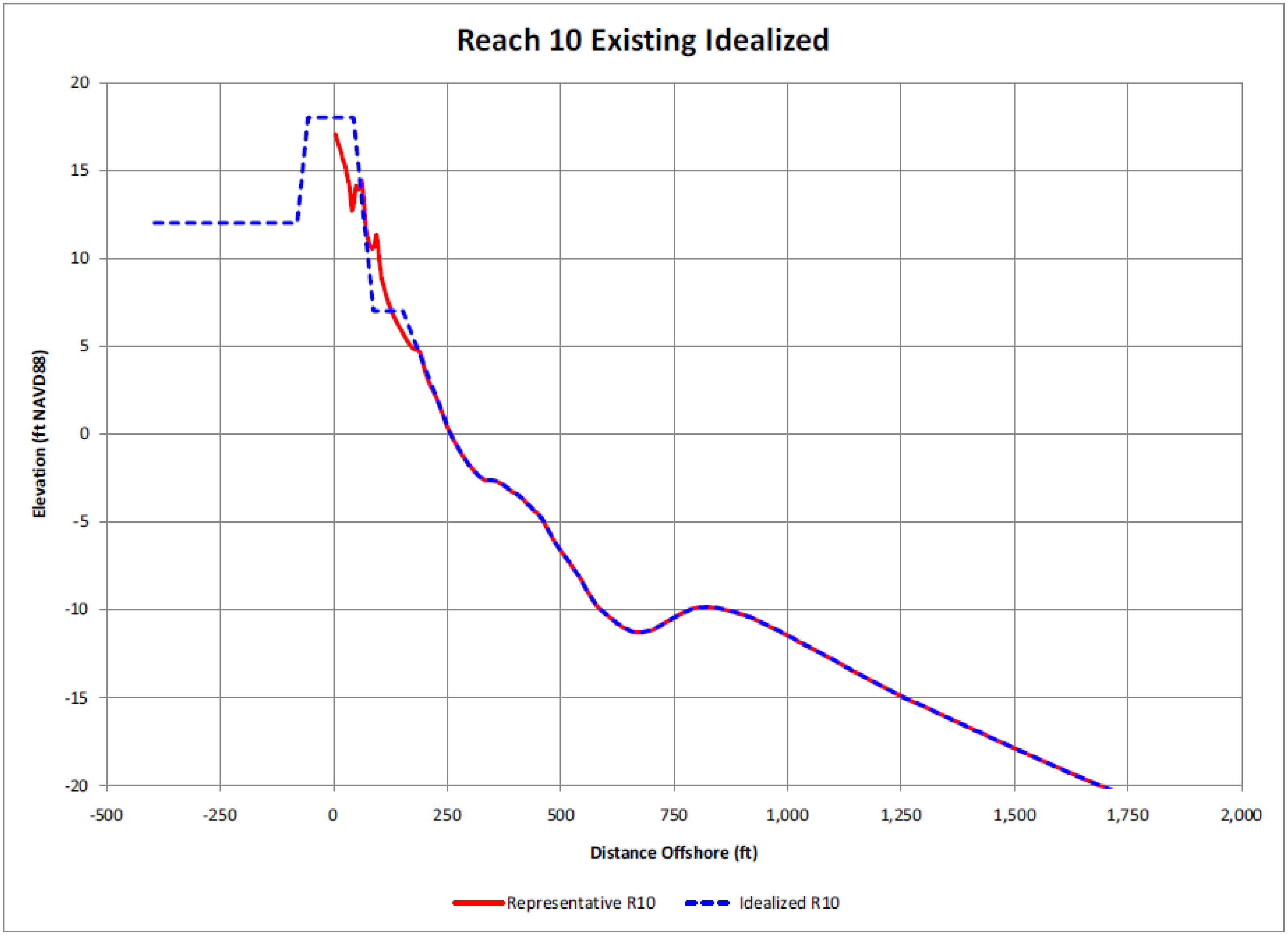


Figure 53 Reach 10 Idealized Existing Condition

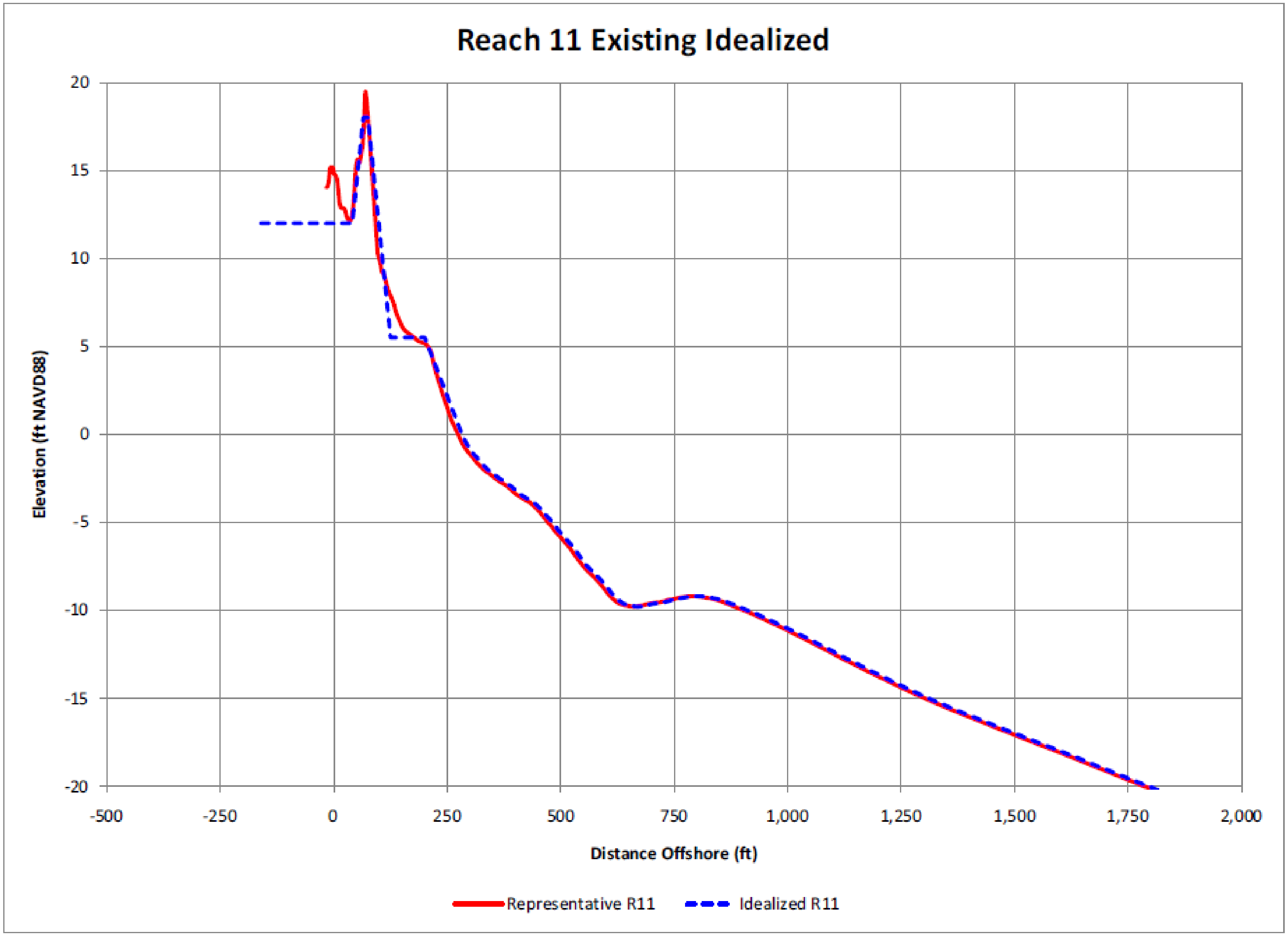


Figure 54 Reach 11 Idealized Existing Condition

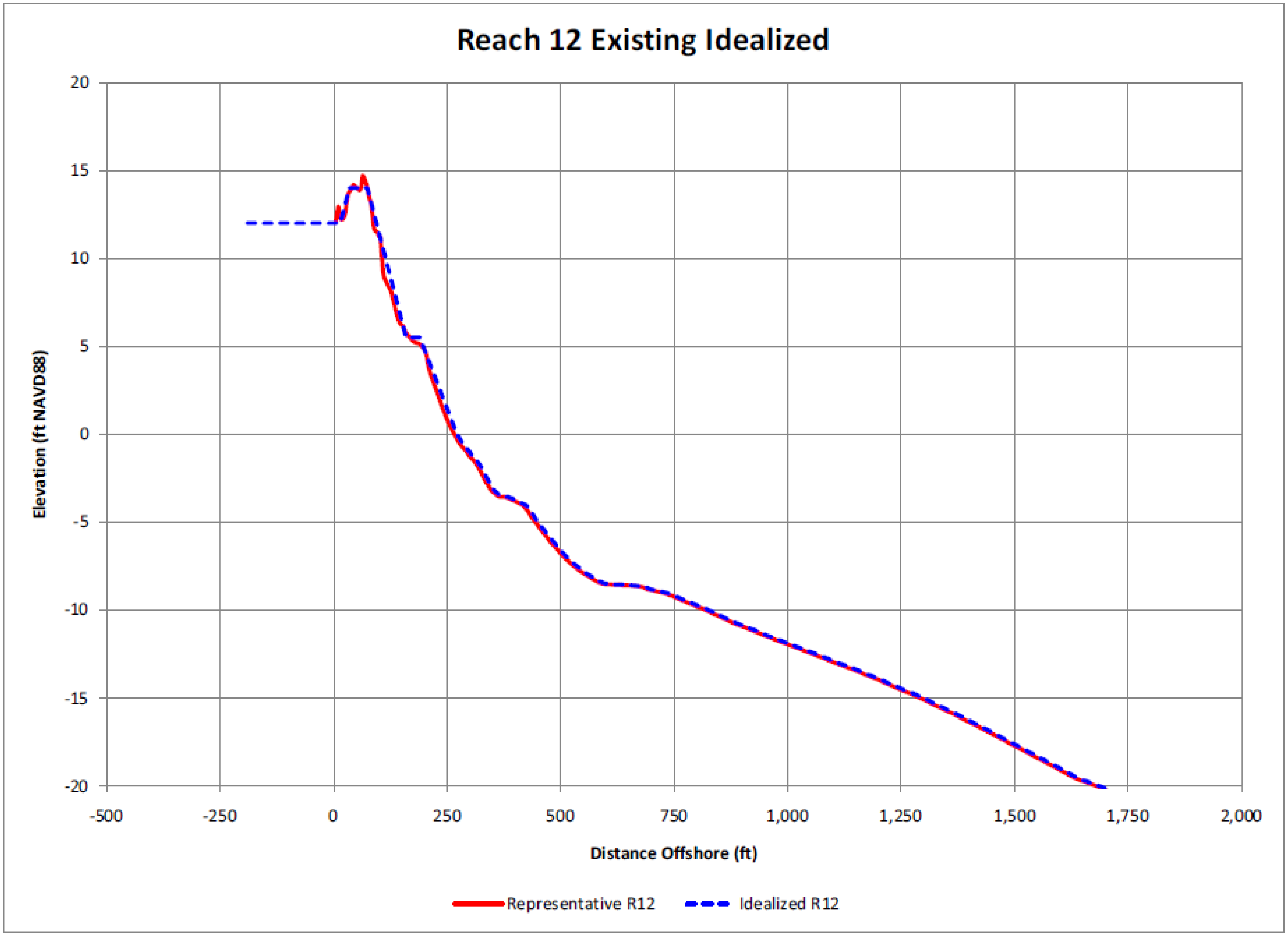


Figure 55 Reach 12 Idealized Existing Condition

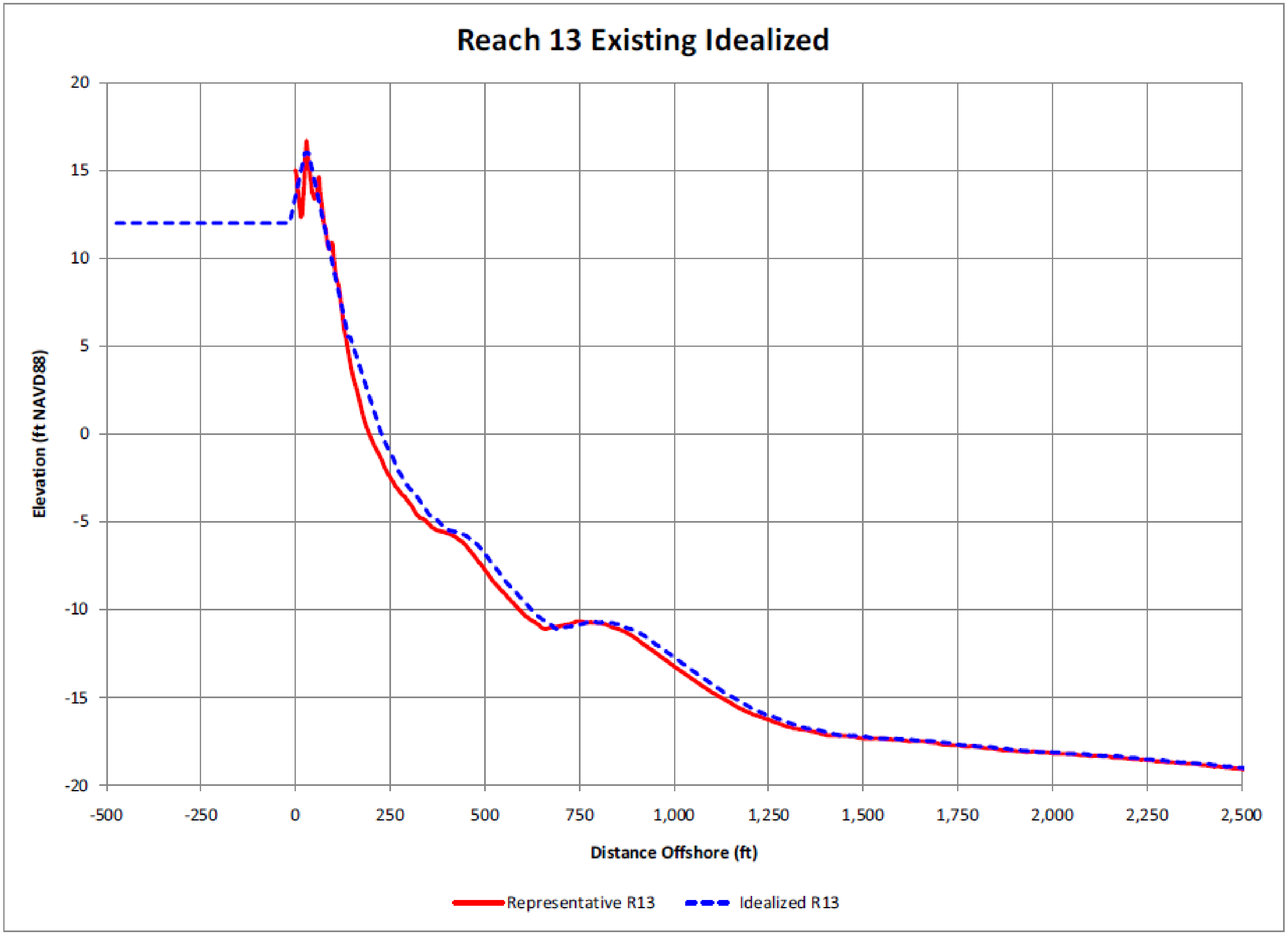


Figure 56 Reach 13 Idealized Existing Condition

3.3.2 SBEACH Project Alternatives

The idealized existing condition profiles were expanded to incorporate a wide array of alternative conditions that could possibly be encountered over a 50 year lifecycle. This expansion included potential project alternatives that could be used in various nourishment projects/templates within SBEACH. To stay within the idealized profile shape framework of Beach-*fx*, and given the fact that much of the shoreline contains structures on top of the existing dunes, it was decided that additions to the front of the existing dune (keeping dune height constant) coupled with a range of berm widths (keeping berm height constant) would be appropriate projects to consider for the island. The one exception to this was in reach 1 where there were no existing structures on the dune. As a result, this reach did include alternatives to increase the dune height. The dune and foreshore slopes were also kept constant from the existing conditions. To develop the matrix of SBEACH runs to be considered for the "with" project conditions, eroded cases of each of the projects were also run. The alternative matrix for Beach-fx is shown in Table 13 and represents 1,764,360 different iterations.

Reach	Upland Elevation	Project Dune Elevation	Project Dune Width	Project Berm Widths
1	8	8	5,15,25,35,50,75	0,25,50,75,100,125,150
		10	5,15,25,35,50,75	0,25,50,75,100,125,150
		11	5,15,25,35,50,75,95,105,115,135	0,25,50,75,100,125,135,150
		13	5,15,25,35,50,75	0,25,50,75,100,125,150
		15	5,15,25,35,50,75	0,25,50,75,100,125,150
2	8	8	5,15,25,35,50,75	0,25,50,75,100,125,150
		9	5,15,25,35,50,75	0,25,50,75,100,125,150
		11	5,15,25,35,50,75	0,25,50,75,100,125,150
		13	5,15,25,35,50,75	0,25,50,75,100,125,150
		15	5,15,25,30,35,40,50,75	0,25,50,75,100,125,150
3	12	12	5,15,25,35,50,75	0,25,50,75,100,125,150
		14	5,15,25,35,50,75	0,25,50,75,100,125,150
		16	5,15,25,35,50,75	0,25,50,75,100,125,150
		18	5,15,25,35,50,75	0,25,50,75,100,125,150
		20	5,10,15,20,25,30,35,50	0,25,50,70,75,100,125,150
4	12	12	5,15,25,35,50,75	0,25,50,75,100,125,150
		14	5,15,25,35,50,75	0,25,50,75,100,125,150
		16	5,15,25,35,50,75	0,25,50,75,100,125,150
		18	5,15,25,35,50,75	0,25,50,75,100,125,150
		20	5,15,25,35,50,75	0,25,50,75,100,125,150
		22	5,15,25,35,50,75	0,25,50,75,100,125,150
		24	5,15,25,35,50,75	0,25,50,75,100,125,150
		26	5,15,25,30,35,40,45,50	0,25,50,75,85,100,125,150
5	12	12	5,15,25,35,50,75	0,25,50,75,100,125,150
		14	5,15,25,35,50,75	0,25,50,75,100,125,150
		16	5,15,25,35,50,75	0,25,50,75,100,125,150
		18	5,15,25,35,50,75	0,25,50,75,100,125,150
		20	5,15,25,30,35,40,45,50,70	0,25,50,70,75,100,125,150
6	20	20	5,15,25,35,50,75	0,25,50,75,100,125,150
		22	5,15,20,25,30,35,40,50	0,25,50,55,75,100,125,150
7	12	26	5,15,25,35,50,75	0,25,50,75,100,125,150
		28	5,15,25,35,50,75,90,95,100,105,110,115	0,25,50,65,75,100,125,150
8	12	12	5,15,25,35,50,75	0,25,50,75,100,125,150
		14	5,15,25,35,50,75	0,25,50,75,100,125,150
		16	5,15,25,35,50,75	0,25,50,75,100,125,150
		18	5,15,25,35,50,75,95,100,105,110,115,120,125	0,25,50,75,80,100,125,150
9	12	12	5,15,25,35,50,75	0,25,50,75,100,125,150
		14	5,15,25,35,50,75	0,25,50,75,100,125,150
		16	5,15,25,35,50,75	0,25,50,75,100,125,150
		18	5,15,25,35,50,75	0,25,50,75,100,125,150
		20	5,15,25,30,35,40,45,50,55	0,25,50,65,75,100,125,150
10	12	12	5,15,25,35,50,75	0,25,50,75,100,125,150
		14	5,15,25,35,50,75	0,25,50,75,100,125,150
		16	5,15,25,35,50,75	0,25,50,75,100,125,150
		18	5,15,25,35,50,75,95,100,105,110,115,120,125	0,25,50,65,75,100,125,150
11	12	12	5,15,25,35,50,75	0,25,50,75,100,125,150
		14	5,15,25,35,50,75	0,25,50,75,100,125,150
		16	5,15,25,35,50,75	0,25,50,75,100,125,150
		18	5,10,15,20,25,30,35	0,25,50,75,100,125,150
12	12	12	5,15,25,35,50,75	0,25,50,75,100,125,150
		14	5,15,25,35,40,50,55,60,65	0,25,30,50,75,100,125,150

Table 13 Sbeach Alternative Matrix

4.1 Selected Plan

4.1.1 Planform Rates and Transition Evaluation

Once the optimum plan has been selected based on the economic output from Beach-fx a refinement to the selected plan must be run to account for the changing erosion rates induced by beach fills. The placement of large quantities of fill material on a beach as part of a beach nourishment program creates a shoreline perturbation on the natural shoreline. This perturbation of the natural shoreline creates changes in the historic sediment flow patterns that displace material from the fill and eventually create equilibrium in the shoreline. Although there are multiple complex models available to model the dispersion of beach fill, including the USACE Genesis model, the dispersion was modeled for the selected plan using the Plan Form Evolution model (PFE) within the Coastal Engineering Design and Analysis System (CEDAS) (Dean, 1989). This model was selected based on balancing project funding and time limitations with the uncertainties known to exist with all shoreline dispersion models near inlet areas.

For the selected plan dimensions, planform erosion rates were calculated for several different nourishment cycles in order to determine the cycle with the highest net benefit. Rates were calculated for 3, 4, and 5 year nourishment intervals based on a 50’ berm width addition. Parameters representing local wave climatology were derived from data collected at station 276 of the Wave Information Studies (WIS) program. From this data the mean wave height was determined to be 3.22’, mean wave period was 4.74 seconds, and wave direction is 165 degrees from north.

For each cycle time period evaluated the initial condition within the Beach Fill Module was set with the berm at 50’ wide. The project includes transitions of 1000’ length on both ends of the project that transition from the 50’ wide placement to 0’ where the project ties into the natural beach. After each simulation the initial condition was adjusted to reflect the ending shoreline position from the previous run. By doing this, each subsequent run included the influence of the material that was dispersed out of the placement areas in the previous run. Six iterations of the beach fill module were conducted in this way for each nourishment interval being considered. The results for the three year nourishment cycle are displayed in Figure 57 which shows how the rates converge by the sixth iteration of the model runs and are typical of the results observed for the 4 and 5 year cycle.

Once the planform erosion rates were calculated for each of the three considered nourishment intervals, the planform erosion rates were input into Beach-fx. The first six planform erosion rates input into Beach-fx corresponded to the six rates calculated within the Beach Fill Module. For planform erosion rates following the sixth nourishment cycle in Beach-fx the sixth cycle was assumed to be unchanged based on the convergence of rates observed in Figure 57. Based on the updated runs with planform erosion rates, a 3 year nourishment cycle was found to have the highest net benefits and is part of the selected plan as discussed in the main project report.

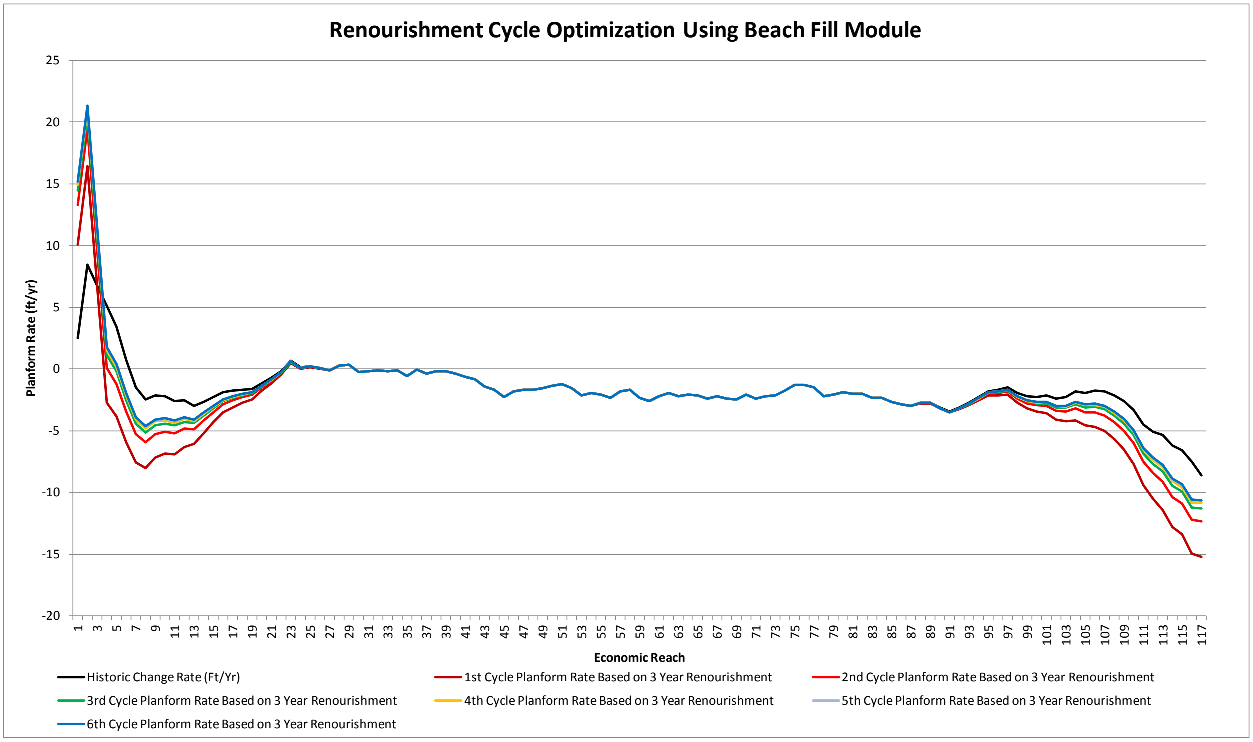


Figure 57 Planform Erosion Rates for the 3 Year Nourishment Interval

4.1.2 Description of Selected Plan

The recommended plan for Bogue Banks varies throughout the island between a combination of a dune/berm plan and a berm only plan. The dimensions representing the existing conditions in Beach-fx and the dimensions for the recommended plan are summarized in Table 14. The dune dimensions shown in this table integrate and are based on the existing idealized dune dimensions for those reaches. These dimensions represent the maximum size of the construction template. The actual final project design (which is done during PED) may involve some variations in the constructed dune width and height from what is shown to account for constructability issues and the avoidance of real estate. However, in no case will the constructed dune exceed the dimensions listed in the TSP project template. While the recommended plan dune conditions vary the recommended berm for the plan is consistent at 50 feet throughout the project area. The typical layouts for a berm and dune plan are shown in Figures 58 and 59. Similar plots are displayed in Figures 60 and 61 for the berm only plan condition. While the conditions will vary through the island depending on existing dune heights and widths and berm widths, these plots give a graphical representation of the general placement locations for the dune and berm. The berm elevations for the recommended plan mirror the existing conditions and are +5.5 feet NAVD for reaches 1, 11, and 12. The remaining project area berm elevation is set at +7 feet NAVD. The project limits for the selected plan are shown in Figure 62.

Projected volumes for the selected plan are summarized in Table 15. These volumes were extracted from the output of the Beach-fx software. The table shows the initial volume required for each reach, as well as the average projected renourishment volume based on a 3 year cycle. The initial volume is the amount of material placed per reach during the initial construction of the project. This measurement was directly extracted from the Beach-fx data as the quantity from the first construction cycle. The average renourishment cycle quantity was not as straight forward to calculate due to the fact that each reach is not renourished during each renourishment cycle. To calculate the average volume placed for the 16 nourishment cycles following initial construction, the total volume placed for these cycles was divided by 16*300, which represents 16 nourishment cycles and 300 iterations of the model for each cycle.

	Representative Existing Conditions			Recommended Plan Dimensions			
Reach	Dune Height	Dune Width	Berm Width	Dune Height	Dune Width	Berm Width	Berm Height
1(1)	11	95	135	16	95	50	5.5
2(2)	15	15	125	15	45	50	7
3(2)	20	5	70	20	10	50	7
4(3)	26	25	85	26	25	50	7
5(3)	20	25	70	20	25	50	7
6(3)	22	15	55	22	15	50	7
7(3)	28	90	65	28	90	50	7
8(3)	18	100	80	18	100	50	7
9(3)	20	30	65	20	30	50	7
10(3)	18	100	65	18	100	50	7
11(2)	18	10	75	18	40	50	5.5
12(3)	14	40	30	14	40	50	5.5
(1) Denotes plans with increased dune height							
(2) Denotes plans with increased dune width							
(3) Denotes reaches where dune dimensions are not federally maintained							

Table 14 Representative Existing and Recommended Plan Dimensions

Figure 58 Typical Dune and Berm Plan View

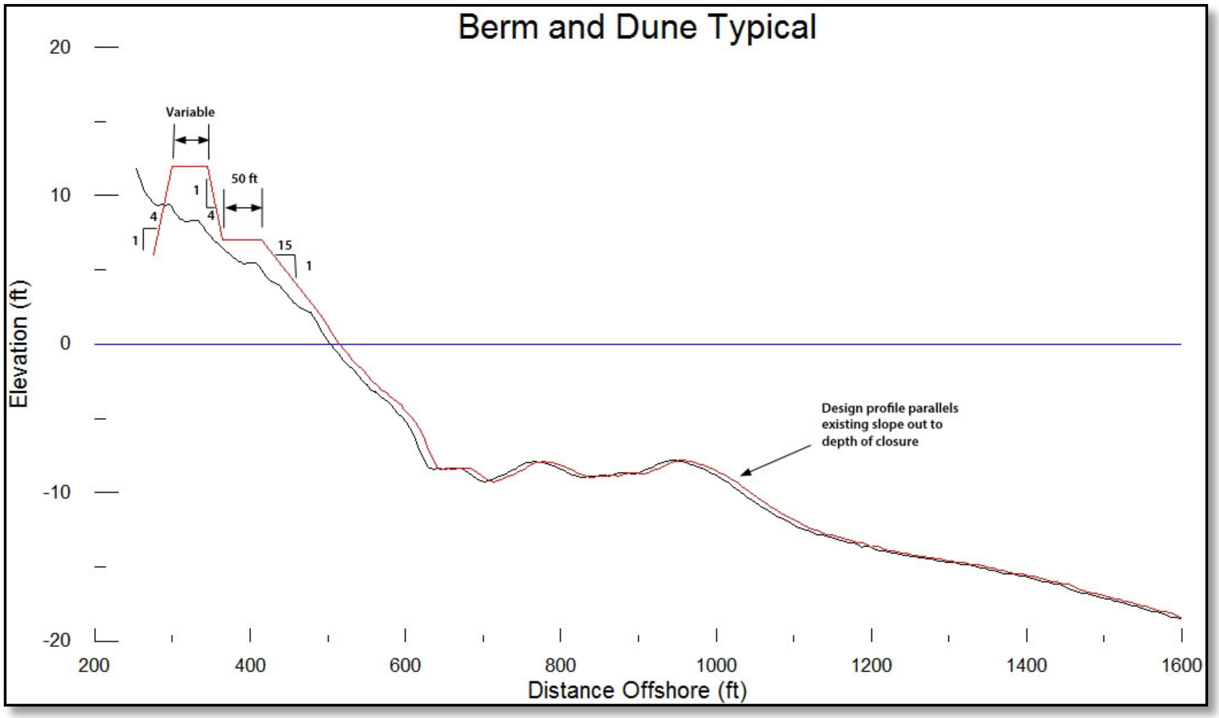


Figure 59 Typical Dune and Berm Cross Section

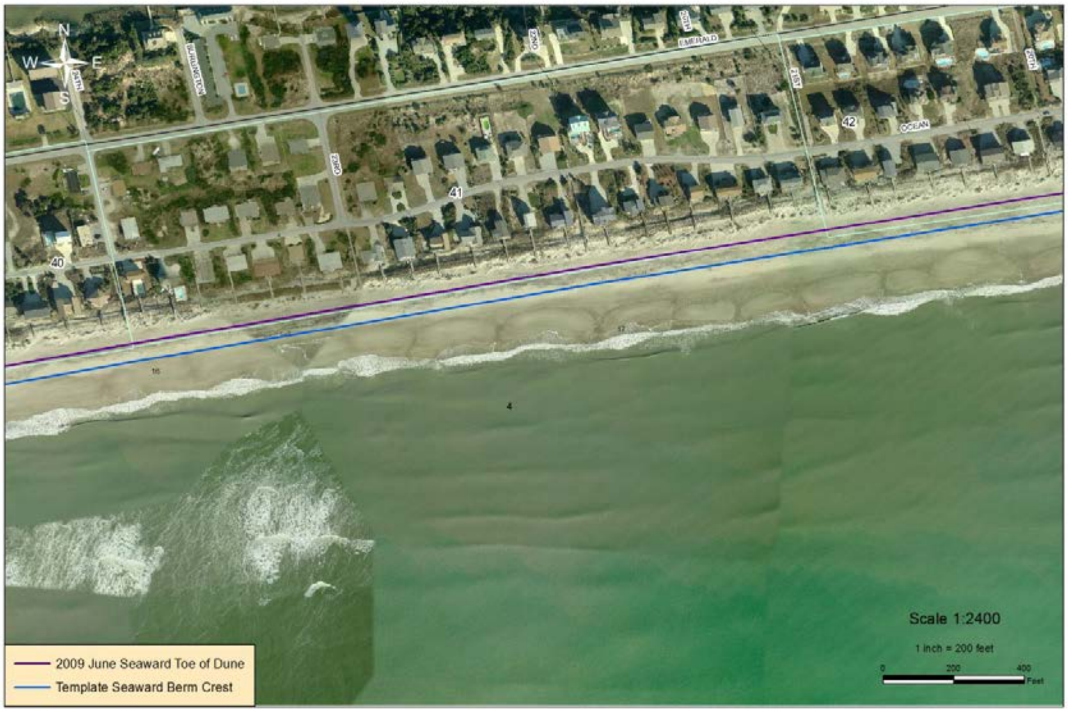


Figure 60 Typical Berm Only Plan View

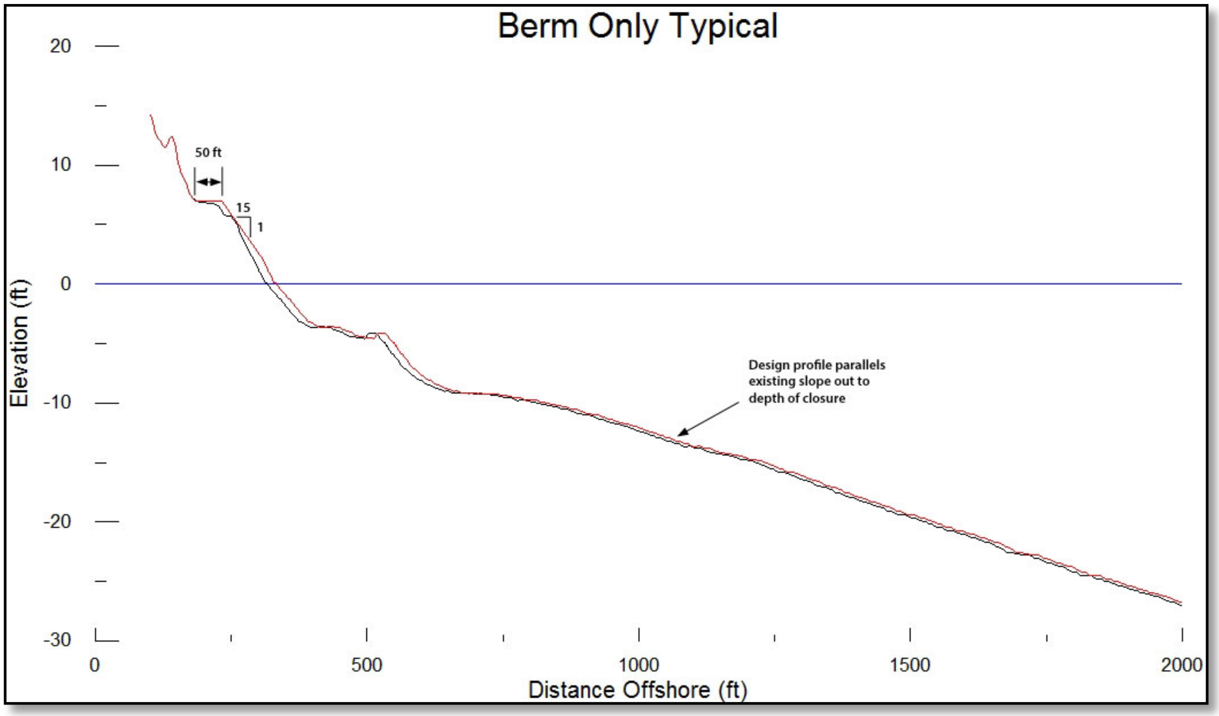


Figure 61 Typical Berm Only Cross Section

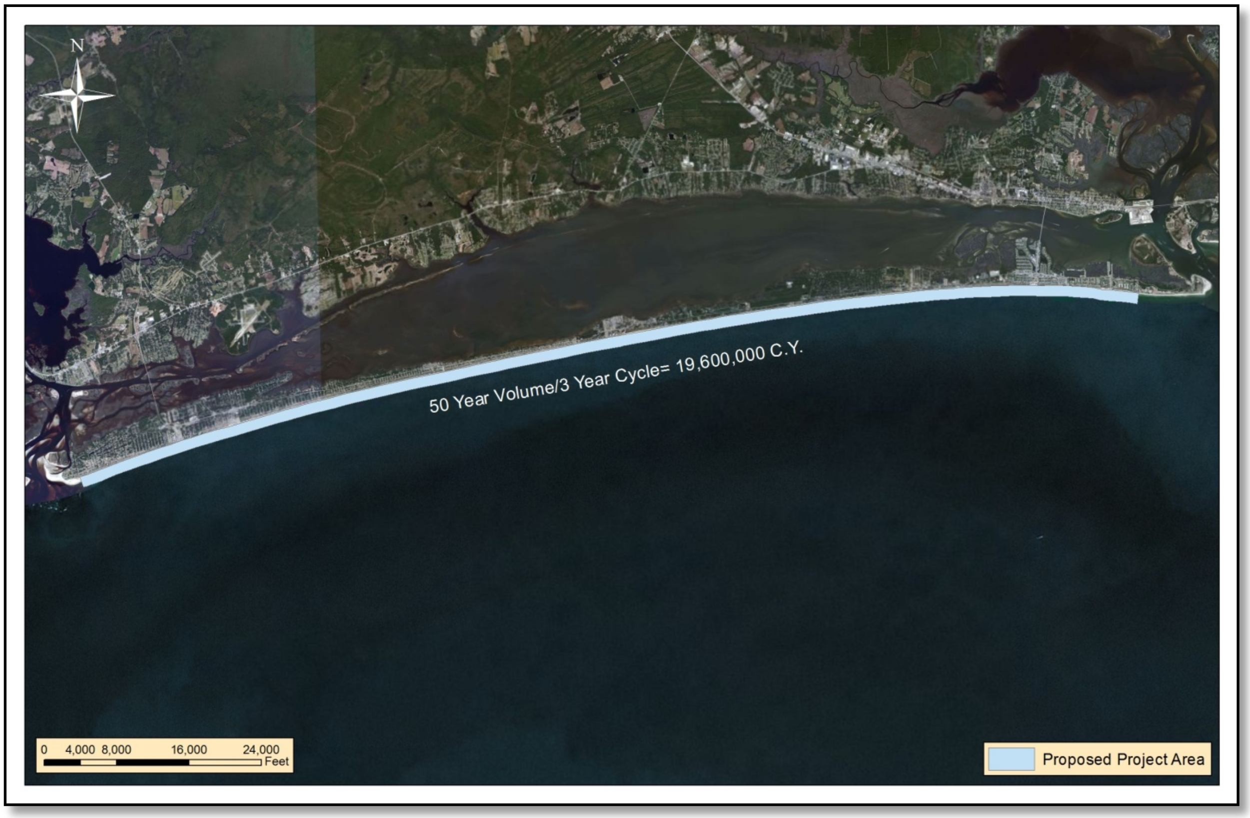


Figure 62 Project Area

Reach	Initial Placement Volume	Total Volume Placed (C.Y.) (300 iterations 16 cycles following initial placement)	Average Renourishment Cycle Placement (C.Y.)
1	28,583	2,884,442	601
2	20,377	2,026,296	422
3	33,555	3,364,436	701
4	26,383	2,748,498	573
5	44,697	6,063,027	1,263
6	44,073	35,296,346	7,353
7	71,044	68,598,638	14,291
8	66,926	6,597,064	1,374
9	63,255	57,581,444	11,996
10	40,203	35,332,759	7,361
11	6,811	56,393,927	11,749
12	11,133	85,918,378	17,900
13	13,024	106,321,672	22,150
14	11,111	76,138,414	15,862
15	14,336	80,467,438	16,764
16	5,250	36,497,311	7,604
17	5,878	47,125,388	9,818
18	5,802	48,995,517	10,207
19	5,109	43,630,524	9,090
20	5,618	43,020,576	8,963
21	200	7,883,461	1,642
22	160	3,333,081	694
23	148	1,281,210	267
24	133	615,272	128
25	164	1,070,930	223
26	129	609,735	127
27	208	2,747,081	572
28	148	1,191,811	248
29	86	728,668	152
30	1,174	8,996,101	1,874
31	1,339	8,600,387	1,792
32	1,200	9,152,144	1,907
33	1,593	8,924,113	1,859
34	922	6,656,653	1,387
35	1,620	15,089,073	3,144
36	1,014	5,664,846	1,180
37	1,518	11,706,672	2,439
38	1,599	9,625,679	2,005
39	1,139	7,320,954	1,525

Table 15 Selected Plan Projected Quantities

40	1,833	13,764,307	2,868
41	1,775	12,928,722	2,693
42	1,180	12,441,527	2,592
43	28,826	63,593,516	13,249
44	25,959	52,485,108	10,934
45	46,603	86,271,107	17,973
46	23,394	46,323,932	9,651
47	21,294	43,125,067	8,984
48	20,498	41,998,251	8,750
49	18,130	38,464,114	8,013
50	11,779	26,402,194	5,500
51	5,888	14,246,600	2,968
52	26,794	56,285,065	11,726
53	30,342	82,471,098	17,181
54	6,825	20,375,363	4,245
55	18,834	51,733,461	10,778
56	20,614	50,405,807	10,501
57	5,129	17,129,361	3,569
58	10,828	44,537,008	9,279
59	3,347	64,352,644	13,407
60	2,526	40,778,215	8,495
61	2,166	41,595,067	8,666
62	2,263	40,494,661	8,436
63	3,561	66,490,828	13,852
64	1,011	18,290,532	3,811
65	444	8,366,283	1,743
66	3,985	76,260,428	15,888
67	1,293	24,754,018	5,157
68	1,512	29,014,779	6,045
69	3,827	72,113,963	15,024
70	2,614	47,305,806	9,855
71	3,096	59,426,649	12,381
72	2,803	53,484,699	11,143
73	1,922	35,939,249	7,487
74	10,663	48,909,643	10,190
75	1,913	27,509,326	5,731
76	644	10,327,249	2,152
77	3,750	32,386,506	6,747
78	14,207	42,116,461	8,774
79	14,473	47,035,153	9,799
80	7,307	26,913,550	5,607

Table 15 Selected Plan Projected Quantities (Cont)

81	14,336	46,826,205	9,755
82	12,563	41,298,739	8,604
83	26,604	74,315,076	15,482
84	25,974	72,504,080	15,105
85	34,749	84,873,300	17,682
86	28,989	95,737,690	19,945
87	40,417	127,065,493	26,472
88	19,403	67,165,301	13,993
89	15,427	53,545,568	11,155
90	21,013	63,332,056	13,194
91	26,657	74,641,301	15,550
92	40,692	123,396,474	25,708
93	71,829	78,247,848	16,302
94	58,062	59,492,187	12,394
95	41,548	38,959,858	8,117
96	35,924	33,240,764	6,925
97	42,151	38,228,116	7,964
98	54,610	56,310,996	11,731
99	32,077	35,285,955	7,351
100	41,339	46,810,905	9,752
101	53,553	61,634,806	12,841
102	38,263	46,458,496	9,679
103	43,045	53,227,659	11,089
104	39,249	48,683,411	10,142
105	33,064	42,823,177	8,921
106	17,092	22,752,880	4,740
107	31,107	43,056,046	8,970
108	34,792	50,613,564	10,544
109	39,430	59,815,614	12,462
110	42,314	66,601,683	13,875
111	43,567	65,667,832	13,681
112	76,615	116,632,270	24,298
113	51,520	80,353,830	16,740
114	54,089	85,513,571	17,815
115	58,320	92,070,876	19,181
116	47,333	75,822,168	15,796
117	56,091	82,553,433	17,199
1000' Transition	53,934		16,536
Total Initial =	2,451,253.72	Average Renourishment=	1,068,745.69

Table 15 Selected Plan Projected Quantities (Cont)

5.1 Borrow Area Impacts

5.1.1 Introduction

Bogue Banks forms a 25.4-mile barrier island off the mainland of Carteret County (Figure 63). The offshore area of Bogue Banks was investigated to identify sites that may be appropriate as borrow material sources for the project. The potential offshore borrow areas that were identified are expected to provide an estimated volume of 42 Mcy of beach placement material.

Changing the bathymetry of the offshore area might affect the wave climate at the shorelines of Carteret County. The Coastal Modeling System CMS-WAVE was used to estimate wave transformation change in the study area and assess any adverse effects along the Bogue Banks and Shackleford Banks shorelines.

The Morehead City area is nationally ranked as number 38 with the amount of years between a Storm or Hurricane coming within 60 miles of the city. Therefore these simulations have been set-up to simulate both normal and extreme weather conditions.

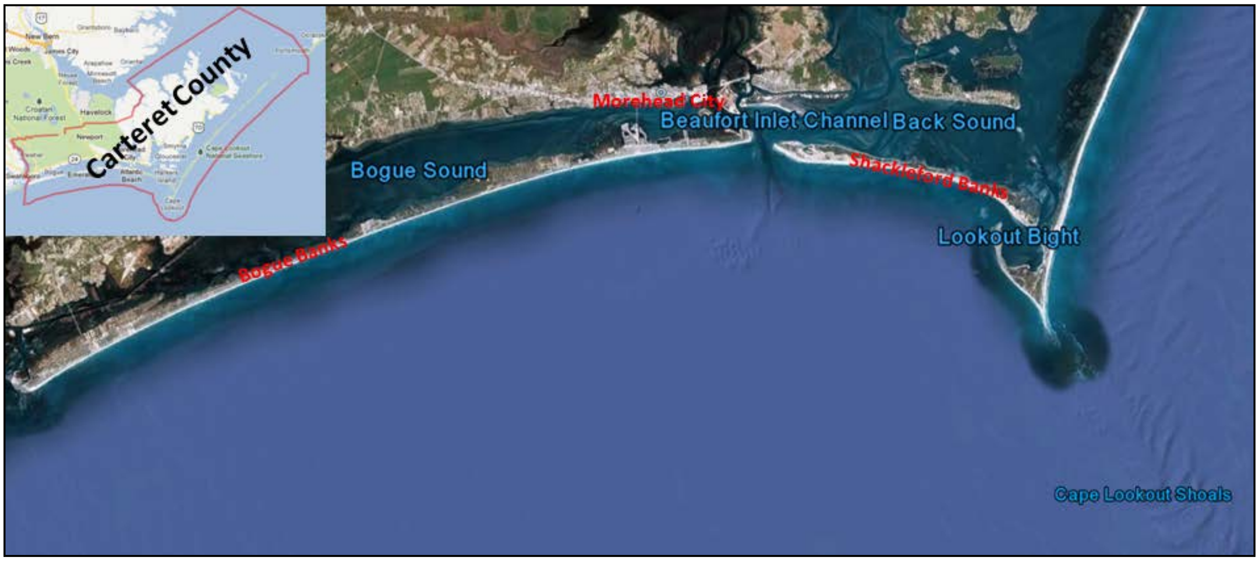


Figure 63- Bogue Banks location map

5.1.2 Grid Development

CMS-WAVE, previously called WABED (Wave-Action Balance Equation Diffraction), is a two dimensional (2D) spectral wave model formulated from a parabolic approximation equation (Mase et al. 2005a) with energy dissipation and diffraction terms. It simulates a steady-state spectral transformation of directional random waves co-existing with ambient currents in the coastal zone. The model operates on a coastal half-plane, implying waves can propagate only from the seaward boundary toward shore. The model includes features such as wave generation, wave reflection, and bottom frictional dissipation (Lin et al., 2008).

CMS-WAVE model requires accurate bathymetry data to construct computational grid over which waves propagate and transform. The bathymetry data for the CMS-WAVE grid was obtained from the existing ADvanced CIRculation model (ADCIRC) mesh of the Western North Atlantic, the Gulf of Mexico and the Caribbean Sea (Brian and Luettich, 2008). The ADCIRC grid has been designed to resolve major bathymetric and topographic features such as inlets, dunes and river courses as identifiable on satellite images, NOAA charts, and various available Digital Elevation Model (DEM) and shoreline datasets (Figure 64). The ADCIRC bathymetry was updated with the following latest available surveys (Figure 64):

- April 2009 bathymetric survey of Beaufort Inlet.
- June 2010 beach profile of Bogue Banks.

The survey data was referenced to the horizontal State Plane Coordinate System (NAD83) in meters and to the vertical Mean Tidal Level (MTL) datum which represents the vertical datum of the model. The NOAA Beaufort, NC station (8656483) was used to reference the data to MTL.

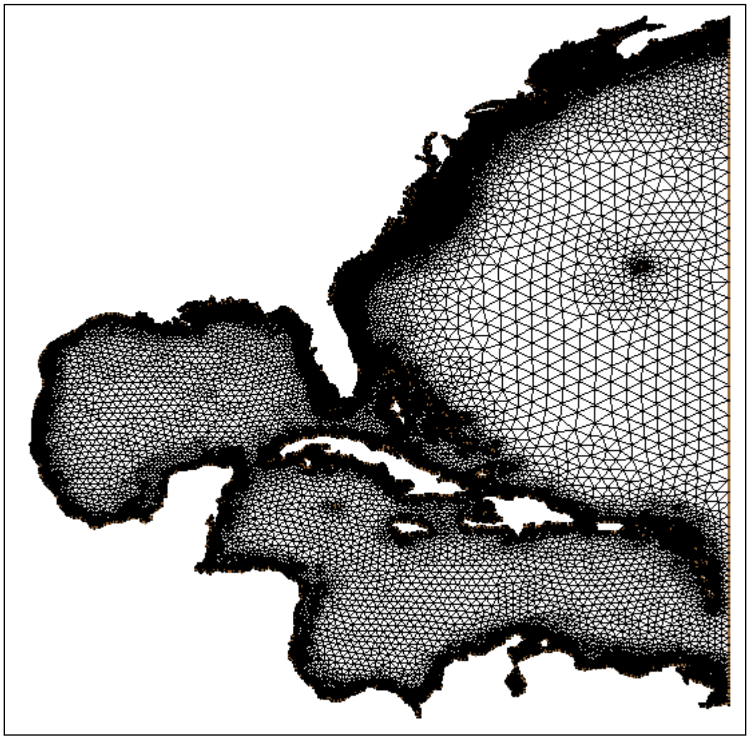


Figure 64- Western North Atlantic, the Gulf of Mexico and the Caribbean Sea ADCIRC grid (Brian and Luettich, 2008)

Figure 65- Survey data coverage

The CMS-WAVE grid was delineated such as to include the anticipated offshore borrow areas and the offshore Wave Information Studies (WIS) 63276 station. The grid orientation is 100 deg counterclockwise from East and extends about 87.7 KM along the shoreline and 23.3 KM offshore (Figure 66). The offshore grid boundary was extended seaward of WIS station 63276 to include more details of the Lookout Cape Shoal. The computational grid was constructed with 457861 cells and with resolution of 75 m in the offshore area. The resolution was increased to about 50 m in the nearshore area and in the offshore proposed borrow sites vicinity to adequately resolve wave energy transportation in the area. The bathymetry of the CMS-WAVE grid was obtained by interpolating the survey scatter data to the grid cells as shown in Figure 67.

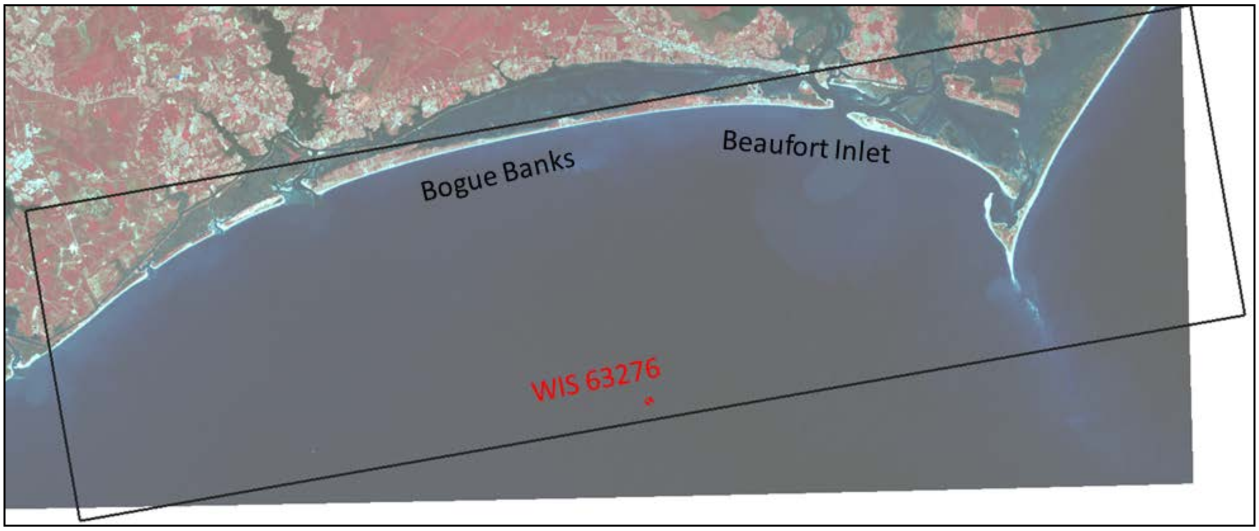


Figure 66- Extent of CMS-WAVE grid

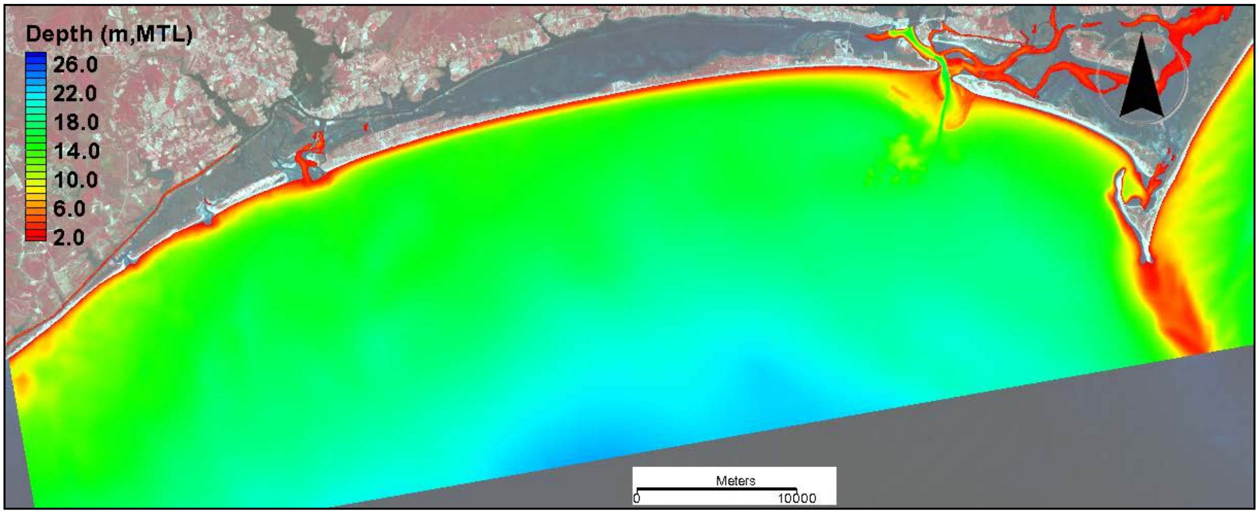


Figure 67- CMS-WAVE grid bathymetry

5.1.3 Model Forcing Conditions

CMS-WAVE was forced with directional wave spectra at the offshore grid boundary. The offshore wave climate provides representative wave boundary conditions. The model was not forced with wind or current fields which are optional.

Wave data used to determine the offshore wave conditions was obtained from the WIS Station 63276 located at Latitude of 34.5° N and Longitude of 76.833° W in 21 m depth. The WIS project produces a high quality online database of hindcast nearshore wave conditions from 1980-1999. The hindcast wave conditions were produced using the latest updated version of the numerical ocean wave generation and propagation model WISWAVE along with wind fields produced by Oceanweather Inc. Figure 68 shows the wave rose diagram of wave height versus wave direction percent occurrence at WIS station 63276 during 1980-1999. The figure shows that waves come mainly from the South East quadrant. Table 15 shows the percent occurrence of heights and periods of all directions at WIS station 63276. It can be seen from the table that wave heights generally range between 0.5-4 m and wave periods range between 5 -16 sec. Also the WIS station mean-maximum summary table (http://wis.usace.army.mil/products.html?staid=63276&lat=34.5&lon=-76.83&dep=21), which states the maximum monthly wave height and period during the 20 years of hindcast, was examined. The maximum wave height and period were 10.0 m and 16.21 s respectively. From these statistics, a set of discrete conditions were selected for simulations. The wave height range was defined at 0.5-m intervals from 0.0 m to 2.0 m and at 2 m interval to 10.0 m. The wave period range was 0 to 18 sec at a 3 sec interval. The wave directions were incremented every 22.5 deg. Significant wave height, peak wave period and vector mean wave direction (degrees clockwise from True north) were adopted in the analysis.

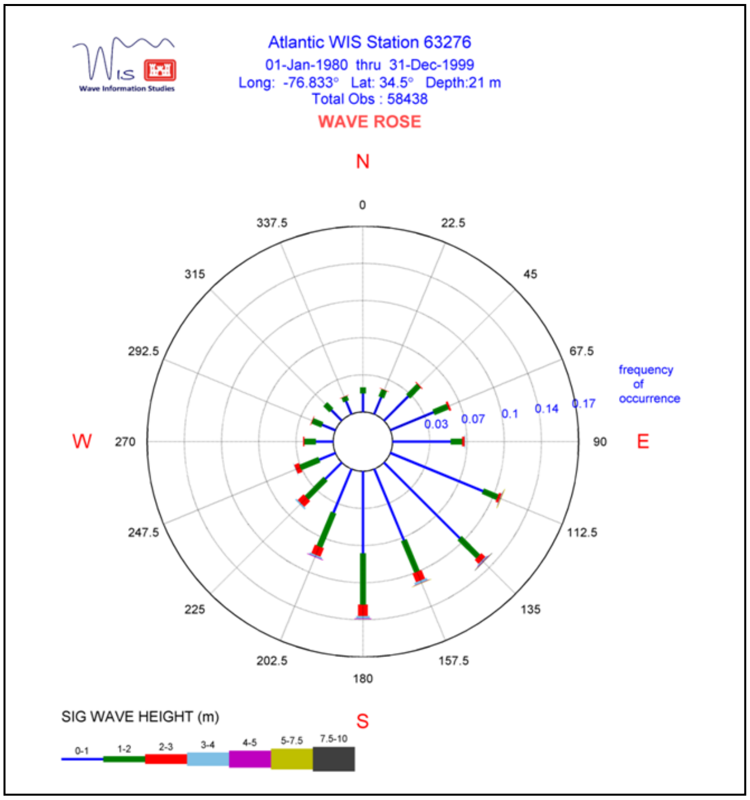
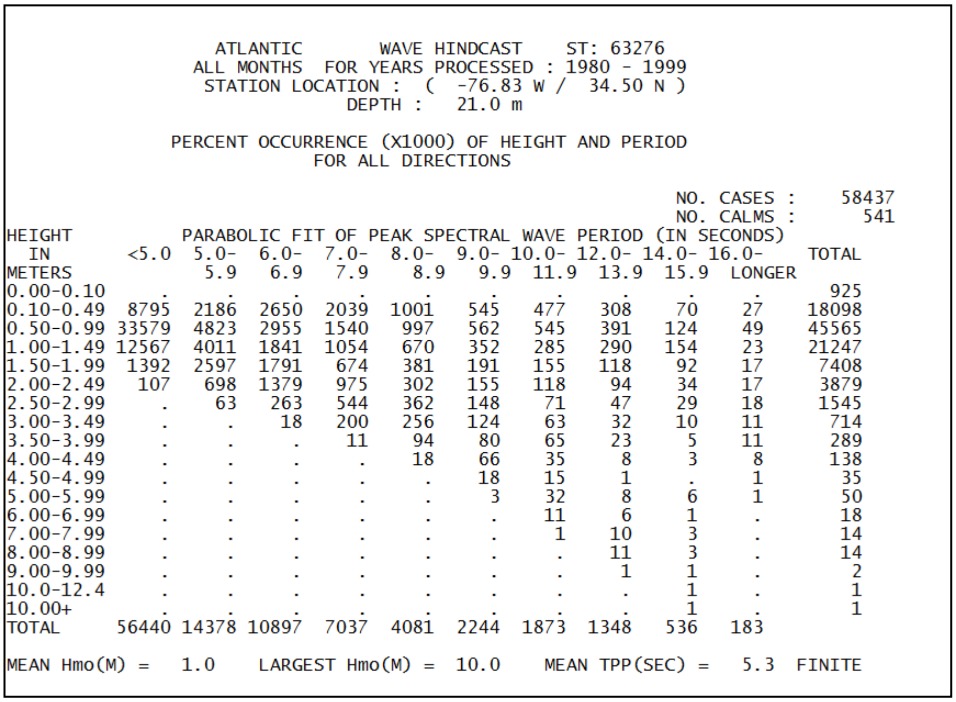


Figure 68- Waverose diagram at WIS station 63276



```
                 ATLANTIC       WAVE HINDCAST     ST: 63276
               ALL MONTHS  FOR YEARS PROCESSED : 1980 - 1999
                STATION LOCATION :  (  -76.83 W /  34.50 N )
                             DEPTH :   21.0 m

              PERCENT OCCURRENCE (X1000) OF HEIGHT AND PERIOD
                          FOR ALL DIRECTIONS

                                                NO. CASES :     58437
                                                NO. CALMS :       541
HEIGHT          PARABOLIC FIT OF PEAK SPECTRAL WAVE PERIOD (IN SECONDS)
  IN        <5.0  5.0-  6.0-  7.0-  8.0-  9.0- 10.0- 12.0- 14.0- 16.0-    TOTAL
METERS             5.9   6.9   7.9   8.9   9.9  11.9  13.9  15.9  LONGER
0.00-0.10      .     .     .     .     .     .     .     .     .     .      925
0.10-0.49   8795  2186  2650  2039  1001   545   477   308    70    27    18098
0.50-0.99  33579  4823  2955  1540   997   562   545   391   124    49    45565
1.00-1.49  12567  4011  1841  1054   670   352   285   290   154    23    21247
1.50-1.99   1392  2597  1791   674   381   191   155   118    92    17     7408
2.00-2.49    107   698  1379   975   302   155   118    94    34    17     3879
2.50-2.99      .    63   263   544   362   148    71    47    29    18     1545
3.00-3.49      .     .    18   200   256   124    63    32    10    11      714
3.50-3.99      .     .     .    11    94    80    65    23     5    11      289
4.00-4.49      .     .     .     .    18    66    35     8     3     8      138
4.50-4.99      .     .     .     .     .    18    15     1     .     1       35
5.00-5.99      .     .     .     .     .     3    32     8     6     1       50
6.00-6.99      .     .     .     .     .     .    11     6     1     .       18
7.00-7.99      .     .     .     .     .     .     1    10     3     .       14
8.00-8.99      .     .     .     .     .     .     .    11     3     .       14
9.00-9.99      .     .     .     .     .     .     .     1     1     .        2
10.0-12.4      .     .     .     .     .     .     .     .     1     .        1
10.00+         .     .     .     .     .     .     .     .     1     .        1
TOTAL      56440 14378 10897  7037  4081  2244  1873  1348   536   183

MEAN Hmo(M) =   1.0    LARGEST Hmo(M) =  10.0    MEAN TPP(SEC) =   5.3  FINITE
```

Table 16- Percent occurrence of wave heights and periods of all directions at WIS station 63276

The regional shore line adopted in the study is approximately oriented at 100 deg (azimuth) as shown in figure 65. Statistics were performed for onshore wave direction bands only (100 deg-290 deg) and other waves were considered as directed offshore and were not considered in the analysis. The wave data was analyzed between 100 deg and 290 deg directions in 22.5-deg bins.

The 20 years hindcast record was used to develop a binned approach based on joint probability of wave direction, period and height. A MATLAB routine was used to calculate the joint probability of wave direction, period and height. Table 16 shows the selected direction-period-height bins used to synthesize the wave climate. The total number of occurrences from the selected bins was 39588 which represent about 68% of the total waves (58438) at WIS station 63276.

Bin	Wave Direction (deg, from North)	Wave Period (sec)	Significant Wave Height (ft)
1	112.5 – 135.0	3.0 - 6.0	0.00 - 0.50
2	135.0 - 157.5	6.0 - 9.0	0.50 - 1.00
3	157.5 - 180.0	9.0 - 12.0	1.00 - 1.50
4	180.0 - 202.5	12.0 - 15.0	1.50 - 2.00
5	202.5 - 225.0	15.0 - 18.0	2.00 - 4.00
6	225.0 - 247.5		4.00 - 6.00
7	247.5 - 270.0		6.00 - 8.00
8	270.0 - 292.5		8.00 - 10.00

Table 17- Selected wave bins

The frequency of occurrence of all possible height-period-direction combinations was estimated. The total number of the combinations listed in table 16 is 188. For each wave direction bin, representative wave conditions with percent of occurrence more than 0.5 were selected to represent the normal or the most commonly occurring conditions in the wave climate for this study. Waves within bin 8 deviate by small angle from the shoreline and were considered as directed offshore and were excluded from the analysis. Accordingly, 36 wave conditions with total percent of occurrence of 54.5 were selected to represent the prevailing wave climate in the study area (Table 17). The Mean-Max summary table for WIS station 63276 was used to extract severe wave conditions. Four wave conditions with extreme wave height and period values were selected to represent storm conditions as shown in Table 17. Wave condition 39 occurred during September 1999 which represents Hurricane Floyd. Wave condition 40 occurred during September 1996 which represents Hurricane Fran. The selected extreme wave conditions had rare occurrences during the hindcast period of 20 years and consequently the percent of occurrence for the four extreme conditions was negligible and was not listed in the table.

Wave Condition	Wave Direction (deg, from North)	Wave Period (sec)	Wave Height (m)	Percent Occurrence
1	123.75	4.5	0.75	4.38
2	123.75	7.5	0.25	2.63
3	123.75	4.5	0.25	2.13
4	123.75	7.5	0.75	1.49
5	123.75	4.5	1.25	0.86
6	146.25	4.5	0.75	4.37
7	146.25	4.5	0.25	1.44
8	146.25	4.5	1.25	1.14
9	146.25	7.5	0.25	1.1
10	146.25	7.5	0.75	0.76
11	146.25	7.5	3	0.61
12	168.75	4.5	0.75	4.95
13	168.75	4.5	1.25	2.04
14	168.75	4.5	0.25	1.2
15	168.75	7.5	3	1.01
16	168.75	7.5	1.75	0.88
17	168.75	7.5	1.25	0.81
18	168.75	7.5	0.75	0.73
19	168.75	4.5	1.75	0.51
20	191.25	4.5	0.75	4.38
21	191.25	4.5	1.25	2.25
22	191.25	4.5	0.25	1.14
23	191.25	7.5	3	0.98
24	191.25	7.5	1.25	0.69
25	191.25	7.5	1.75	0.61
26	191.25	4.5	1.75	0.57
27	191.25	7.5	0.75	0.54
28	213.75	4.5	0.75	2.17
29	213.75	4.5	1.25	1.41
30	213.75	7.5	3	0.74
31	213.75	4.5	1.75	0.62
32	236.25	4.5	0.75	1.24
33	236.25	4.5	1.25	1.17
34	236.25	4.5	1.75	0.67
35	258.75	4.5	0.75	1.48
36	258.75	4.5	1.25	0.81
37	133	16.21	4.3	
38	188	10.81	5.07	
39	146	13.4	8.57	
40	137	14.57	10	

Table 18 Representative wave conditions at WIS station 63276

The Surface-Water Modeling System (SMS) (Zundel, 2005) includes the capability to generate incident spectra using a TMA one dimensional shallow-water spectral shape (named for the three data sets used to develop the spectrum: TEXEL storm, MARSEN, and ARSLOE) (Bouws et al. 1985) and a $\cos^{nn}\alpha$. . To generate a TMA spectrum, the following parameters must be specified: peak wave period (*Tp*), wave height, water depth, and a spectral peakedness parameter (γ). The directional distribution of the spectrum is specified with a mean direction and a directional spreading coefficient (*nn*) . The energy in the frequency spectrum is spread proportional to $\cos^{nn}(\alpha-\alpha_m)$, where α is direction of the spectral component and α_m is the mean wave direction (Smith et al, 2001). For each of the selected 40 wave conditions, TMA wave spectra were implemented by SMS software.

5.1.4 Potential Borrow Areas

There are some limits on the lateral and vertical extent of borrow material sites. Lateral boundaries should be set far from shorelines to avoid adverse impacts on shorelines due to altering the wave energy in the nearshore area. Zones of rock and clay should be considered as undesirable areas when setting the lateral boundaries of the borrow areas. Boreholes were used in identifying the vertical boundaries of the potential borrow sources. The composition and thickness of overburden should be examined and borrow areas should be identified based on depth of suitable material. Buffers must be delineated between suitable and non suitable sediments, which cannot be included in the source's available volume. Buffer areas around sensitive environmental or cultural resources, or around known obstructions, must also be excluded from the source's available volume. Figure 69 shows the locations of boreholes offshore of Bogue Banks and the footprint of four proposed borrow areas. Borrow area Q1 will not be considered for use in the Bogue Banks 50 year nourishment project. If there is a shortage of material in the future it may be reconsidered. Therefore only three borrow areas (U, Y and Q2) will be considered in the wave analysis. The geotechnical analysis describing the details of developing the borrow areas limits are available in Appendix C.

Figure 70 shows an isopach map of the deposit to determine the volume of the borrow materials. An isopach map is a contour map showing the thickness of a deposit between two physical or arbitrary boundaries. In this case, the upper boundary of the deposit is defined by the surface of the sea bottom and can be delineated by bathymetric data. The lower boundary is the borehole depth which is created by interpolating the scatter borehole data to a uniform grid with a resolution of 50 m. The removal depth is to follow the borehole surface created from the borehole scatter data set.

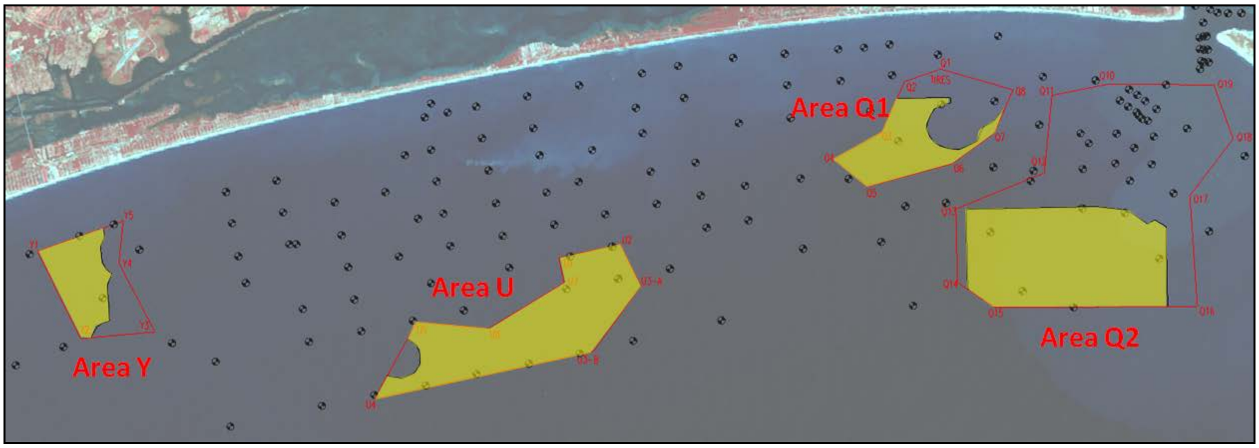


Figure 69- Proposed borrow areas and borehole locations

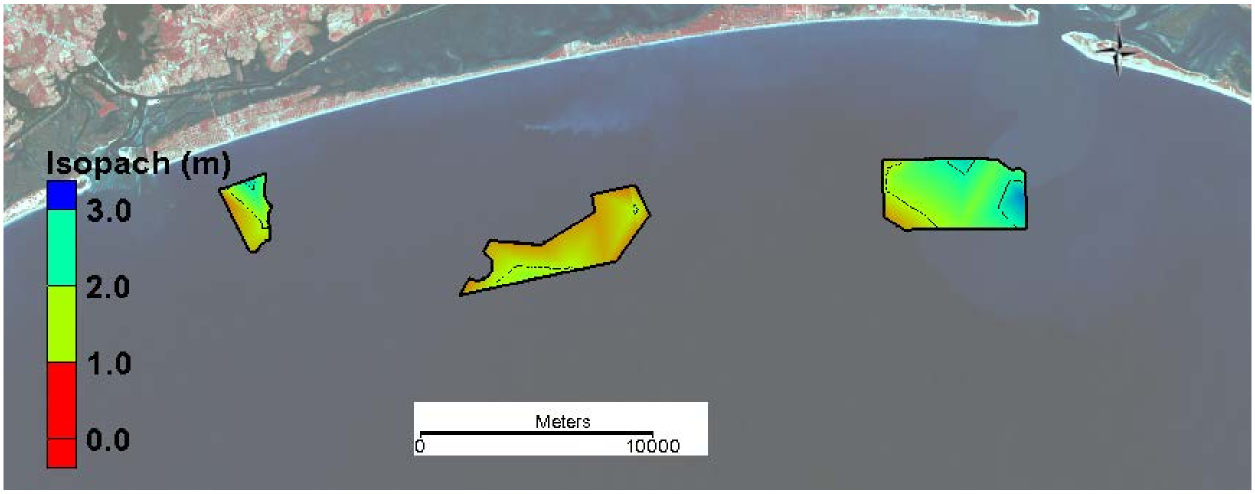


Figure 70- Borrow area isopach

The existing grid bathymetry was modified to incorporate the proposed dredged depths. Figure 71 shows the modified bathymetry of the CMS-WAVE grid at the proposed borrow sites. Therefore the only difference between the before- and the after-dredge CMS-WAVE grids was within the borrow area boxes shown in the figure.

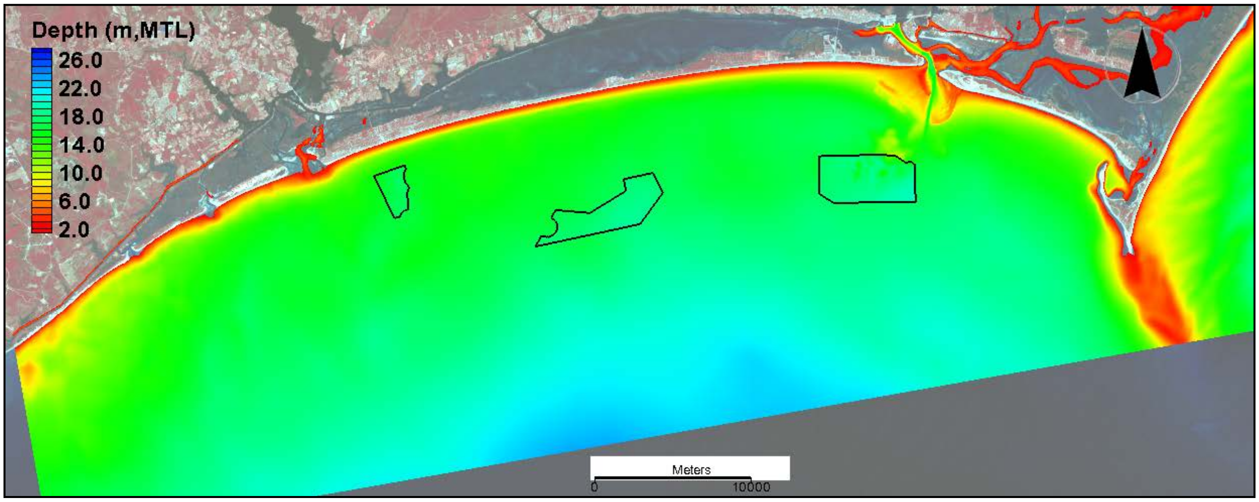


Figure 71- CMS-WAVE grid bathymetry after excavating the proposed borrow area

5.1.5 Wave Model Simulations

CMS-WAVE model simulations were conducted with and without the borrow areas excavation to investigate the adverse effect of mining on the wave climate along Shackleford Banks and Bogue Banks shorelines. CMS-WAVE simulations for the synthesized 40 wave conditions were conducted for the existing and after dredging the borrow areas grids to investigate the impact of dredging on wave climate in the study area.

This analysis was conducted based upon the assumption of fully excavating the entire borrow area. This extreme borrow area removal is an unlikely scenario because there is approximately 59 million cy of material available in these areas, and based on current estimates the project will need only about 22 million cy of material over 50 years. Therefore, the investigated scenario represents a worst case condition.

When wave angles deviate by about 60 deg or more from perpendicular to the seaward boundary, such model-induced energy losses are usually significant (Thompson, et. al., 1999). Wave conditions within Bin 1 deviate by 66.5 deg from perpendicular to the seaward boundary but since only qualitative comparison of wave height is being investigated in this study, the 123.5 deg cases were not rerun with rotated grid.

The four wave transformation processes associated with offshore bathymetric changes due to borrow pits can include wave refraction, diffraction, reflection and dissipation (Tang, 2002). Figure 72 shows the difference in wave height due to excavating the proposed borrow areas for wave case 12 which represents the most prevailing wave climate in the area with percent of occurrence of 4.95. The wave height difference was estimated by subtracting the existing wave height values from the excavated borrow area wave height values. The positive wave height difference (cool colors) indicates wave height increase and the negative wave height difference (warm colors) indicates wave height decrease. The arrows in the figure represent the after dredging wave direction only. The figure shows that dredging the borrow areas has minimal change on the wave climate with maximum wave height change of less than 2 cm. The change in wave height, due to the borrow areas excavation, for the 36 prevailing wave conditions was examined and the maximum increase of wave height was less than 10 cm. Figure 73 shows an example of the wave height change field for wave condition 11 with incident wave height of 3 m and wave period of 7.5 s.

Figure 74 shows the wave height change due to excavating the proposed borrow areas for wave case 40 which represents the most extreme weather condition during the 20 years with very rare occurrence (Hurricane Fran). Inclusion of the water level is important for the extreme wave events because if not included dissipation from depth-induced wave breaking would be overestimated. Therefore, the wave data might be overestimated since surge values were not included in the analysis. Maximum wave heights increase occurred at the eastern and western boundaries of borrow areas Y and Q2, mainly due to wave energy focusing at the borrow areas boundaries. The maximum observed wave height change in the borrow area vicinity was about 0.7 m. Wave transformation was governed by refraction and breaking in the nearshore shallow area in front of the shorelines.

Figures 75 and 76 show the change in wave height, before and after dredging the proposed borrow areas, along transects delineated in front of Shackleford and Bogue Banks shorelines respectively. CMS-WAVE estimated the breaker index at each cell. Grid cells with active breaking are specified with an index of 1 and nonbreaking cells with an index of 0 (Smith et al., 2001). The Transects were delineated just seaward of the breaker index of 1 for each cell. Also, the figures show the cumulative average wave height difference along the Transects (excluding the four extreme wave conditions). Maximum wave height increase of less than 1.5 cm was observed along Shackleford and Bogue Banks shorelines. Even during extreme weather conditions, maximum wave height increase due to the borrow area excavation was less than 1.5 cm along Bogue Banks shoreline. The cumulative average wave height increase was negligible along Shackleford and Bogue Banks shorelines. This is mainly due to wave dissipation at the nearshore shallow bathymetry in front of the shorelines.

Figure 77 shows the wave height change at four points in the vicinity of the borrow areas for the 40 wave conditions. It can be seen from the figure that the maximum increase of wave height, of less than 10 cm, was observed for wave conditions 1 thru 36. The maximum wave height increase, of about 0.7 m, occurred in the borrow area vicinity only during storms. The magnitude of increase in wave height decrease as wave propagate shoreward due to dissipation of wave energy in the nearshore area.

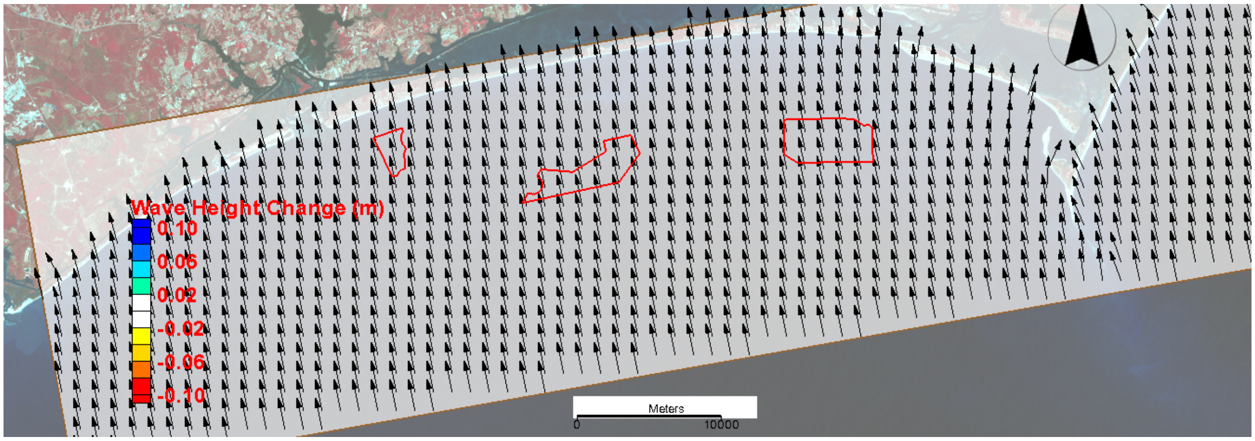


Figure 72- Wave height change for wave condition 12

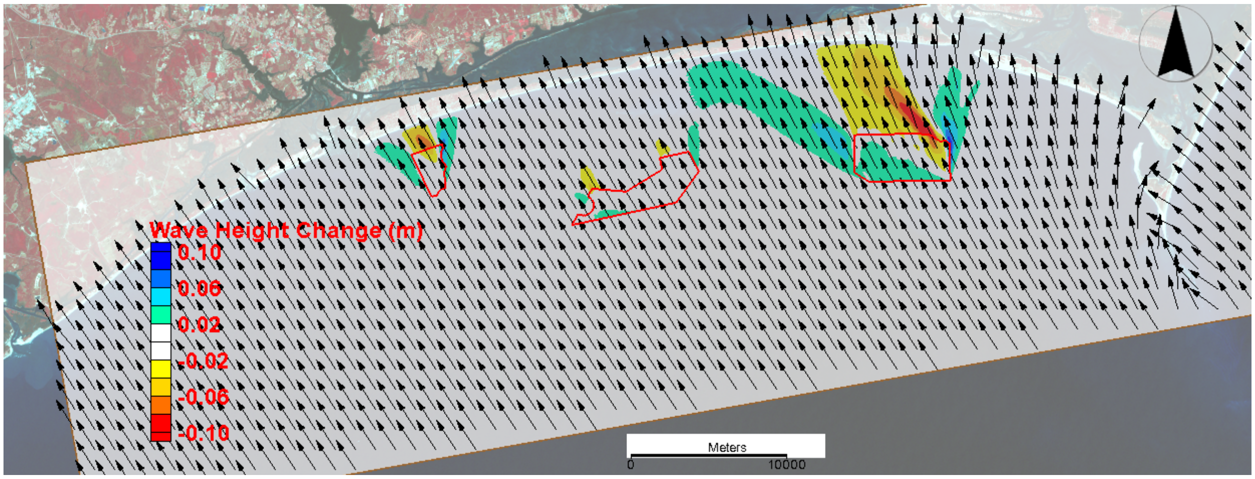


Figure 73- Wave height change for wave condition 11

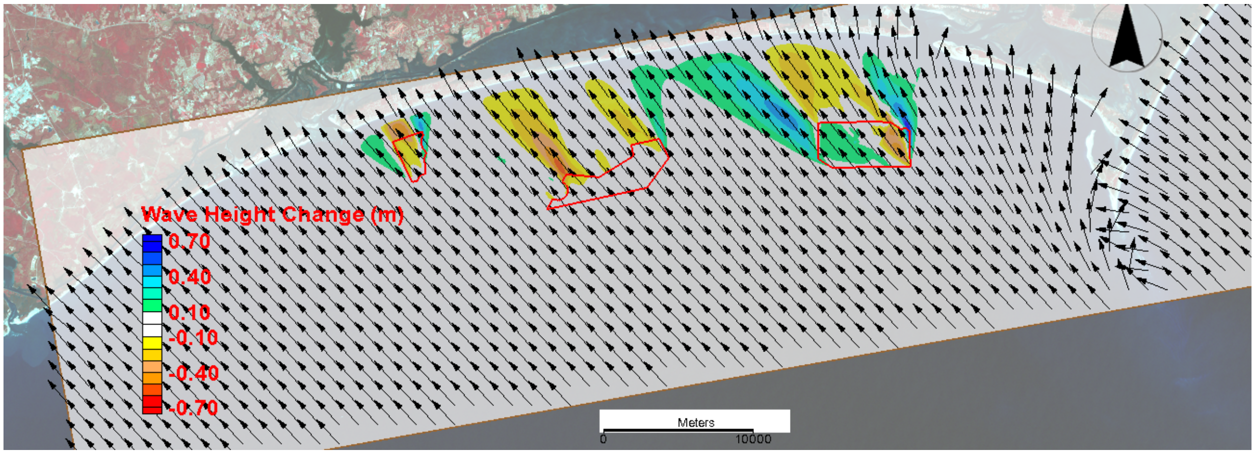


Figure 74- Wave height change for wave condition 40

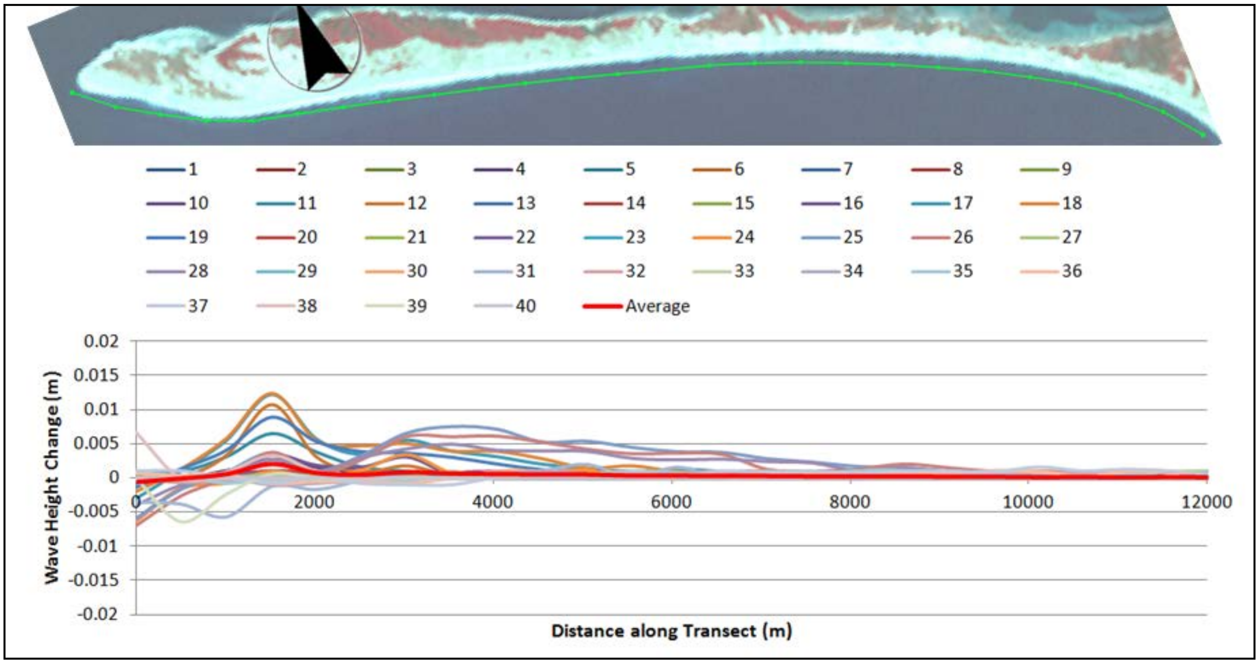


Figure 75-Wave height change along Shackleford Banks Transect

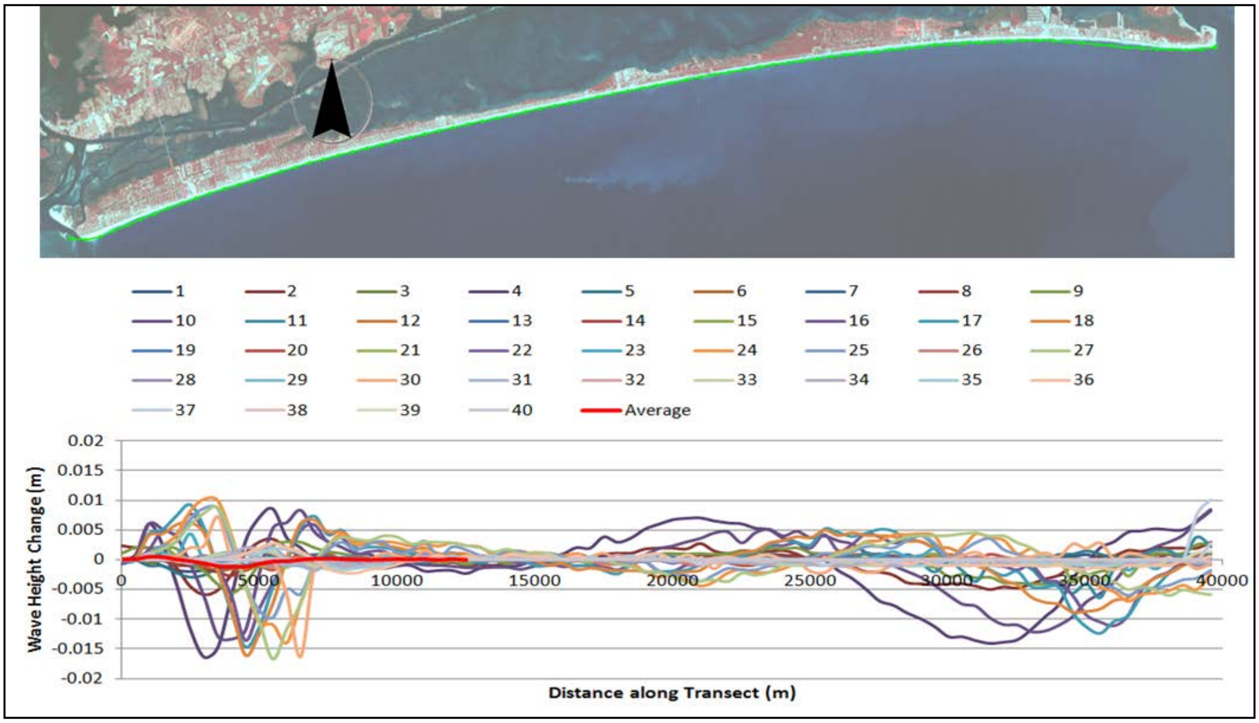


Figure 76-Wave height change along Bogue Banks Transect

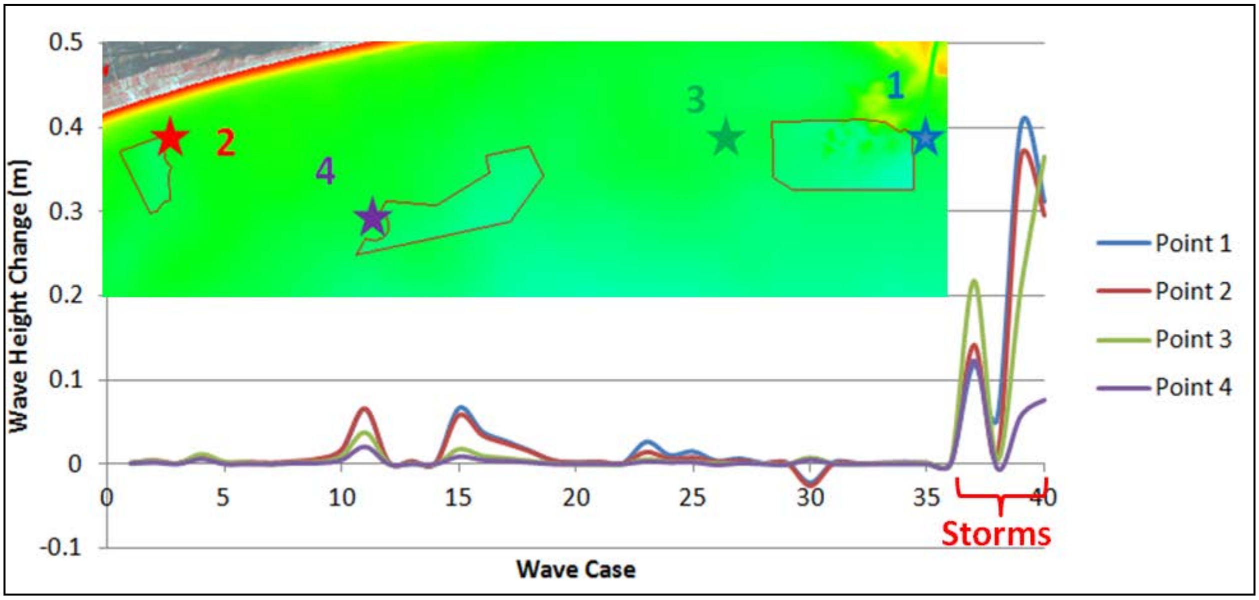


Figure 77-Wave height change at points in the borrow areas vicinity

5.1.6 Borrow Area Impact Analysis Conclusions

CMS-WAVE was used to estimate wave transformation change along Shackleford and Bogue Banks beaches due to the excavation of proposed borrow areas for the Bogue Banks 50 year nourishment project. WIS station 63276 was used to synthesize the offshore wave climate. Forty simulations were conducted to assess the impact of dredging the borrow areas on wave climate in the study area.

Maximum wave height increase of about 1.5 cm was observed along Shackleford and Bogue Banks shorelines for the forty wave conditions. Even during extreme weather conditions, maximum wave height increase due to the borrow area excavation was about 1.5 cm along Bogue Banks shoreline. The cumulative average wave height increase was negligible along Shackleford and Bogue Banks shorelines. This is mainly due to wave dissipation at the nearshore area in front of the shorelines.

Maximum increase of wave height of less than 10 cm was observed, in the offshore borrow areas vicinity, for wave conditions 1 thru 36. Maximum wave height increase, of about 0.7 m, occurred in the borrow area vicinity only during storms.

In general, the change in wave height along Bogue Banks shorelines from full excavation of the proposed borrow areas is negligible even during storms. This is mainly due to dissipating wave energy at the nearshore shallow bathymetry and due to the relatively offshore location of the borrow pits.

References

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