Appendix C

Coastal and Hydraulics Laboratory

ERDC/CHL TR-15-xx

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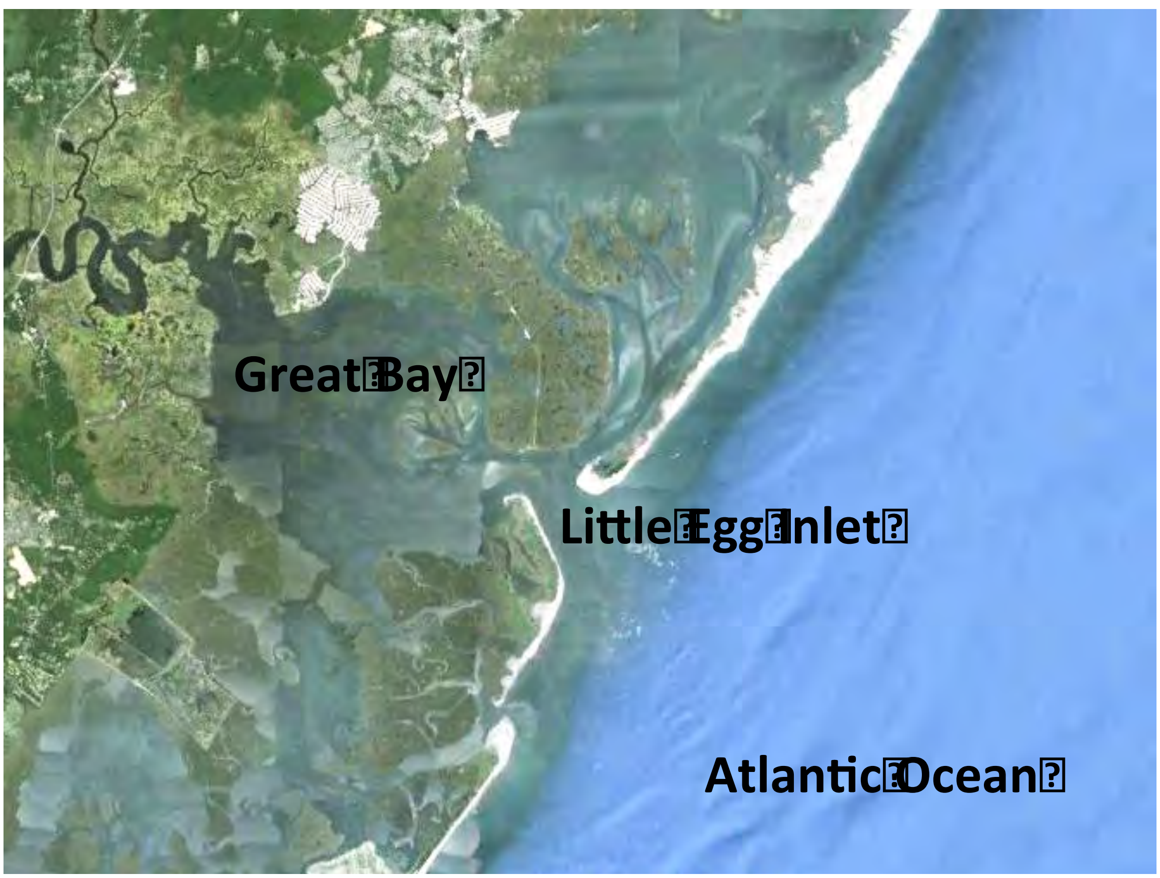
Borrow Area Analysis at Little Egg Inlet, New Jersey

Ashley Frey, Alison Sleath Grzegorzewski, Bradley Johnson

December 2015



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DRAFT report

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Abstract

Numerical modeling studies were conducted in order to assess the impacts of potential borrow area scenarios at Little Egg Inlet, New Jersey. Consequences of the borrow area scenarios were evaluated in terms of normalized wave energy density changes and anticipated shoreline changes. The STWAVE and GenCade modeling efforts did not yield significant impacts for any of the scenarios modeled for this study.

In total, six potential borrow scenarios were evaluated with the nearshore numerical wave model, STWAVE. The potential borrow scenario volumes ranged from 1.2-3 million yd^3. STWAVE numerical modeling results showed that normalized wave energy densities were impacted by a maximum of +/-10 percent along the adjacent shorelines as a result of the Little Egg Inlet potential borrow area scenarios.

Four dredging scenarios, in addition to the No Action scenario, were numerically modeled with GenCade. Scenarios #1-3 involved a one-time-only removal of 1.2-3 million yd^3 of sand from Little Egg Inlet. Scenario #4 involved a periodic removal of 1 million yd^3 of sand every 7 years from Little Egg Inlet. GenCade numerical modeling results showed that as long as large volumes of sand move into Little Egg Inlet area from Long Beach Island to the north, the potential dredging scenarios will not significantly impact the adjacent shorelines.

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Preface

This study for Little Egg Inlet in New Jersey was performed by the Coastal and Hydraulics Laboratory (CHL) of the USACE Engineer Research and Development Center (ERDC) at the request of the U.S. Army Engineer Philadelphia District (NAP).

Ashley Frey of the Coastal Engineering Branch (CEB) of the Coastal Hydraulics Laboratory (CHL) Navigation Division, Alison Sleath Grzegorzewski of the Coastal Processes Branch (CPB) of the Coastal Hydraulics Laboratory (CHL) Flood and Storm Protection Division, and Dr. Bradley Johnson of the Coastal Processes Branch (CPB) of the Coastal Hydraulics Laboratory (CHL) Flood and Storm Protection Division conducted the study and wrote this report. J.B. Smith of the Philadelphia District provided oversight for the study.

At the time of this publication, Ashley Frey was the Acting Chief of the Coastal Processes Branch and Tanya Beck was the Chief of the Coastal Engineering Branch; Dr. Jackie Pettway was Chief of Navigation Division; Dr. Ty Wamsley was Chief of Flood and Storm Protection Division; Dr. Kevin Barry was Associate Director of CHL; and Mr. Jose E. Sanchez was the Director of CHL; LTC John T. Tucker III was Acting Commander of ERDC and Dr. Jeffrey P. Holland was Director of ERDC.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
knots	0.5144444	meters per second
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.609347	kilometers

1 Introduction

1.1 Background

This report describes a numerical modeling study conducted to investigate the impacts of proposed sand borrowing scenarios from the ebb shoal at Little Egg Inlet, located in New Jersey, USA. At the request of the USACE Philadelphia District (NAP), the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics (ERDC-CHL) Laboratory developed a study plan for Little Egg Inlet, using STWAVE and GenCade modeling to evaluate the proposed scenarios.

In response to the devastation experienced by Hurricane Sandy in 2012, USACE Philadelphia District (NAP) conducted analyses towards utilization of the Little Egg Inlet ebb shoal sand bodies as a borrow area for the Barnegat Inlet to Little Egg Inlet Coastal Storm Damage Reduction (CSDR) Project. The general water resource concern to be addressed in this study is whether dredging of the proposed borrow area scenarios at Little Egg Inlet will induce adverse shoreline impacts in the Little Egg Inlet complex or otherwise disrupt the natural sand sharing system in the vicinity of Little Egg Inlet. The principle purpose of the Barnegat Inlet to Little Egg Inlet Coastal Storm Damage Reduction (CSDR) Project is to reduce risk of storm damage from wave attack, storm surge and erosion along the oceanfront of Long Beach Island, as these forces constitute a threat to human life and damage to public and private property and infrastructure. The purpose of this study is to evaluate the proposed borrow area scenarios and adjacent shoreline impacts with the STWAVE and GenCade numerical models so that NAP personnel and other decision-makers can determine an appropriate, implementable solution to the identified water resource concern described above.

Little Egg Inlet connects the Atlantic Ocean and the Great Bay, and is located immediately south of Long Beach Island, a 20-mile barrier island on the central coast of New Jersey. General estimates of net sediment transport along Long Beach Island are approximately 100,000-200,000 yd^3/year towards the south (Cialone and Thompson, 2000). However, estimates range from 50,000-5,000,000 yd^3/year (U.S. Army Engineer District, Philadelphia, 1999). For the present study, it is assumed that a maximum of 3 million yd^3 of sediment will be dredged from the Little Egg Inlet borrow area and will be placed along Long Beach Island to the north of the inlet. Approximately 1 million yd^3 of material is required from Little Egg Inlet for periodic nourishment every 7 years throughout the project life.

1.2 Study Objectives

Potential borrow area scenarios at Little Egg Inlet were identified by Philadelphia District (NAP) for placement along Long Beach Island. The objective of the present study was to perform nearshore wave and shoreline change analyses and to determine the relative impacts of the potential borrow area scenarios on these processes.

1.3 Study Approach

The study described in this report was performed by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). The present study was conducted to assist the Philadelphia District with evaluating the impacts of borrowing sediment from several borrow sites in Little Egg Inlet on the nearshore wave climate and shoreline changes. The approach consisted of the following components:

a. Evaluate offshore wave climate.
b. Numerically model the transformation of offshore waves to nearshore areas for existing and proposed bathymetric configurations.
c. Estimate shoreline changes for existing and proposed bathymetric configurations.
d. Estimate changes in shoal volumes at Little Egg Inlet and the interaction with adjacent beaches for existing and proposed bathymetric configurations.

STWAVE was used to numerically transform the offshore waves to the nearshore zone. The development and application of STWAVE is described in Chapter 2. Numerical modeling of the shoreline response was achieved through the use of GenCade. The development and application of GenCade is described in Chapter 3. A summary of the STWAVE and GenCade model results is presented in Chapter 4 of this report.

1.4 Study Plan

This study was initiated to investigate potential impacts at Little Egg Inlet as a result of proposed borrow scenarios at Little Egg Inlet for the Long Beach Island nourishment project. The four major tasks completed for this study are: (1) initial site investigation and data gathering, 2) nearshore wave transformation analysis, 3) numerical modeling of the shoreline response, and 4) analysis of GenCade results and reporting.

The ERDC-CHL study team defined wave and shoreline modeling tasks and assembled a comprehensive data set of bathymetry, shoreline and boundary characteristics necessary for model grids, boundary conditions, input conditions, and output stations. The NAP project team guided and monitored types of engineering estimates, implementation of the modeling approach, and associated oversight tasks. The ERDC-CHL team prepared weekly progress report documents for NAP. In addition, periodic conference calls were held to discuss the status of the numerical modeling and work progress. Progress reports and conference calls included information about data needs, model setup, assumptions, model limitations, results of tests, and conditions for scenario model runs.

2 Nearshore Wave Modeling

The purpose of applying nearshore wave models is to quantitatively describe the wave parameters (wave height, period, direction, and spectral shape) from the offshore and within the nearshore arena. The nearshore wave model STeady State spectral WAVE (STWAVE) was recently applied for the North Atlantic Coast Comprehensive Study (Cialone et al., 2015). For application consistency, STWAVE was also applied for this study at Little Egg Inlet, New Jersey.

This chapter presents a theoretical description of STWAVE, numerical wave model setup, application methodology, and results obtained for the Little Egg Inlet borrow area scenarios.

2.1 STWAVE

STWAVE is a steady-state, finite-difference, phase-averaged spectral wave model based on the wave action balance equation. STWAVE simulates nearshore wave transformation including depth-induced and current-induced refraction and shoaling, depth- and steepness-induced wave breaking, wind-wave generation and growth, and wave-wave interaction and white-capping.

2.1.1 Model description

The STWAVE model uses the governing equation for steady-state conservation of spectral wave action along a wave ray (Jonsson, 1990):

$$\left(C_g\right)_i \frac{\partial}{\partial x_i} \frac{C C_g \cos(\alpha) E(\omega,\alpha)}{\omega} = \sum \frac{S}{\omega} \qquad (1)$$

where:

C_g = group celerity
C = wave celerity
i = tensor notation for x- and y-coordinates
α = wave orthogonal direction
E = wave energy density divided by the density of water ρ_w and the acceleration of gravity g
ω = angular frequency

S = energy source and sink terms.

Source and sink mechanisms include surf-zone breaking in the form of the Miche criterion (1951), the flux of input energy due to wind (Resio, 1988; Hasselmann, 1973), energy distribution through wave-wave interactions (Resio and Perrie, 1989), white-capping (Resio, 1987; Resio, 1988), and energy losses due to bottom friction (Hasselmann et al., 1973; Padilla-Hernandez, 2001; Holthuijsen, 2007). Radiation stress gradients are calculated based on linear wave theory and provide wave forcing to external circulation models.

The wave orthogonal direction for steady-state conditions is given by the following (Mei, 1989; Jonsson, 1990):

$$C_g \frac{D\alpha}{DR} = -\frac{Ck}{\sinh(2kd)} \frac{Dd}{Dn} \tag{2}$$

where:

R = coordinate in the direction of the wave ray
k = wave number
d = water depth
n = coordinate normal to the wave orthogonal.

The angular frequency is related to the wave number k by the dispersion relation:

$$\omega^2 = gk \tanh(kd) \tag{3}$$

with celerity, C, and group celerity C_g, given by:

$$C = \frac{\omega}{k} \tag{4}$$

$$C_g = 0.5C \left[1 + \frac{2kd}{\sinh(2kd)}\right] \tag{5}$$

Refraction and shoaling are implemented in STWAVE by applying the conservation of wave action along backward traced wave rays. Rays are traced in a piecewise manner. The wave ray is traced back to the previous grid column or row, and the length of the ray segment is calculated. Derivatives of depth normal to the wave orthogonal are estimated (based on the orthogonal direction) and substituted into Equation 2 to calculate the wave orthogonal direction at the previous column. The energy is calculated as a weighted average of energy between the two adjacent grid points in the column and the direction bins. The energy density is corrected by a factor that is the ratio of the angle band width to the width of the back-traced band to account for the different angle increment in the back-traced ray. The shoaled and refracted wave energy is then calculated using Equation 1. The same process is repeated for the next columns.

Readers are referred to STWAVE documentation (Massey et al., 2011; Smith, 2007; Smith et al., 2001; Resio, 1988) for additional model features and technical details.

2.2 STWAVE Model Setup

2.2.1 Grid Development

STWAVE is formulated on a Cartesian grid, with the x-axis oriented in the cross-shore/offshore-onshore direction (I) and the y-axis oriented along-shore (J), parallel with the shoreline. Angles are measured counterclock-wise from the grid x-axis. The bathymetry and topography values were interpolated from the North Atlantic Coast Comprehensive Study (NACCS) ADCIRC mesh (Cialone et al., 2015). The wave grid geometries for both the larger NACCS Central New Jersey STWAVE grid and the refined 20 km x 25 km NAP Little Egg Inlet STWAVE grid are presented in Table 1. Figure 1 shows the relative location of both the larger NACCS Central New Jersey STWAVE grid and the refined 12.4 miles x 15.5 miles (20 km x 25 km) NAP Little Egg Inlet STWAVE grid.

Table 1. STWAVE grid geometry properties.

Grid	Projection	Grid Origin (x,y) (m)	Azimuth (deg CCW from East)	Resolution (m)	Number of Cells	
					I	J
NACCS Central New Jersey (CNJ)	UTM 18	642056.1, 4413284.8	153.1	200.0	468	596

Grid	Projection	Grid Origin (x,y) (m)	Azimuth (deg CCW from East)	Resolution (m)	Number of Cells	
					I	J
Little Egg Inlet (NAP)	UTM 18	1583716.3, 4372707.8	153.1	50.0	401	501

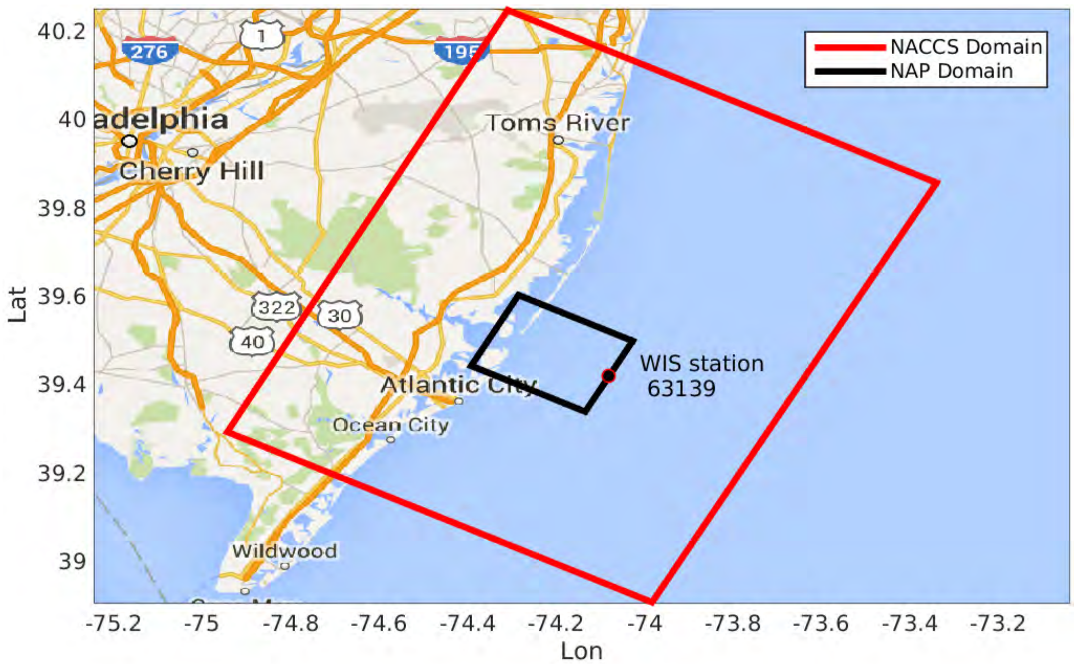

Figure 1. The relative size and placement of both the NAP and NACCS wave domains. Note: The Little Egg Inlet NAP wave domain is 12.4 miles x 15.5 miles (20 km x 25 km).

There are approximately 200k grid cells in total for the NAP Little Egg Inlet wave domain. A finer resolution STWAVE domain with 33 ft x 33 ft (10 m x 10 m) square cell resolution was also tested (with approximately 5 Million grid cells in total), but sensitivity testing indicated the 164 ft x 164 ft (50 m x 50 m) resolution does not impact model fidelity and was selected for computational efficiency.

2.2.2 Offshore Wave Climate

Evaluation of the incident wave climate is a critical first step in nearshore littoral transport studies. Offshore wave information obtained from wave buoys or global- or regional-scale wave hindcasts and forecasts can be transformed through the coastal region using nearshore wave models.

Ideally, a long-term, high-quality hindcast is available with at least a few years of concurrent deepwater directional wave measurements in the same area to validate the hindcast. This study used the 1980-2012 Waves Information Studies (WIS) hindcast at Station #63139, which is located at the offshore boundary of the NAP Little Egg Inlet wave domain (Figure 1) at 74.08 deg W and 39.42 deg N and in a depth of 69 ft (21 m). The ERDC Wave Information Studies (WIS) has developed wave information along U.S. coasts by modeling simulations of past wind and wave conditions. The 1980-2012 WIS parameters are available at 1-hr intervals over the entire 33-year period. At each hourly interval, a number of wave parameters are provided. Parameters typically used to represent waves are significant wave height, peak period, and peak direction. A directional wave rose showing the frequency of significant wave heights at WIS Station #63139 is provided in Figure 2.

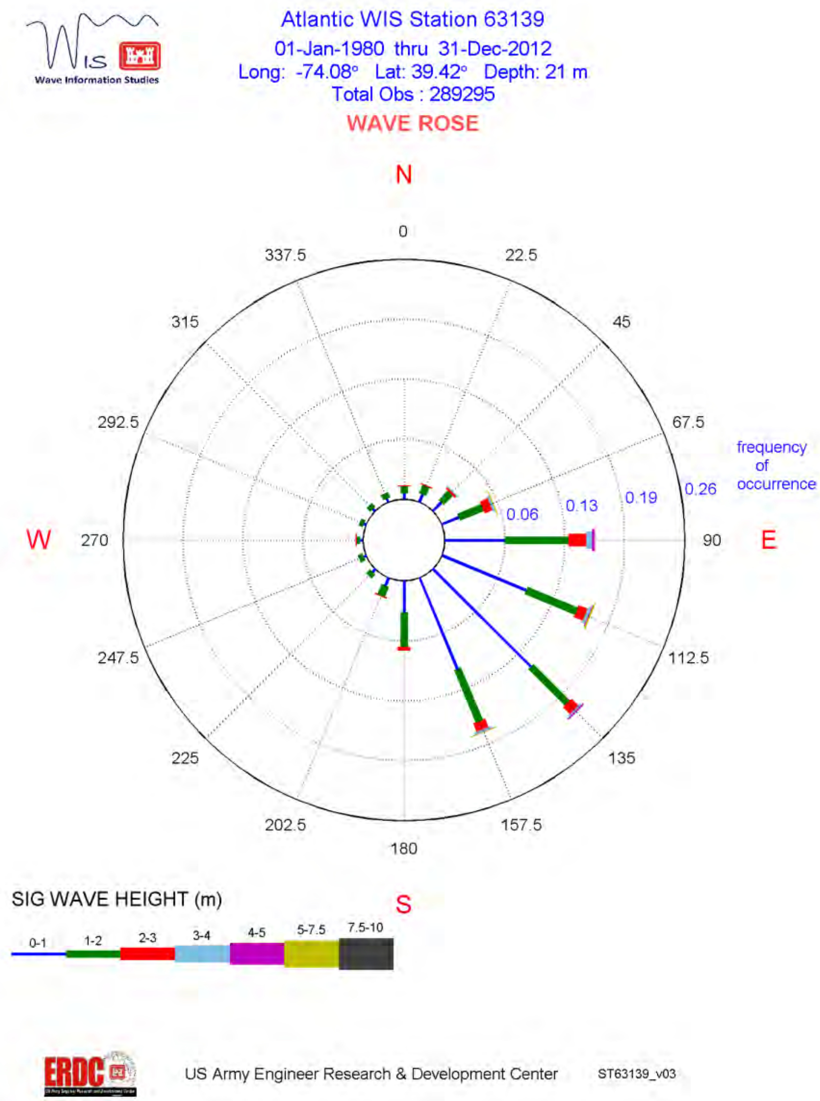

Figure 2. Directional wave rose showing the frequency of significant wave heights at WIS Station #63139.

2.2.3 STWAVE Validation

During the NACCS, STWAVE results were validated and verified using measurements for five tropical storms (Gloria (1985), Josephine (1996), Isabel (2003), Irene (2011), and Sandy (2012)) and two extratropical storms (ET070 (January 1996) and ET073 (December 1996)). The evaluation consisted of time, scatter, Taylor diagrams, and a suite of statistics. Upon completion of each run, the simulations were checked for consistency, and when applicable, the performance of STWAVE was evaluated by comparing existing point source measurements and model results. QA/QC was conducted by plotting the maximum significant wave height envelope in order to identify erroneous estimates or discontinuities in the wave height solution for a given simulation. The interested reader is referred to in Chapter 7 of Cialone et al. (2015) regarding the wave model validation and STWAVE performance metrics.

2.3 Wave Conditions Simulated with STWAVE

STWAVE input requirements include wave conditions defined at the offshore grid boundary. In order to model the nearshore wave transformation, a detailed representation of the offshore wave climate was applied as the model forcing conditions. Although it would be possible to model hourly wave condition snapshots for 33 years, the computational expense would be prohibitive. As an alternative, an efficient method of decomposing the wave field into a smaller number of representative conditions was developed. The first step in generating input wave boundary conditions was to examine the full time-series and percent occurrence tables computed from the parameters at WIS Station #63139. The WIS hourly time-series data have been analyzed and both the probability density function (PDF) and cumulative distribution function (CDF) for wave heights at Station #63139 are shown in Figure 3.

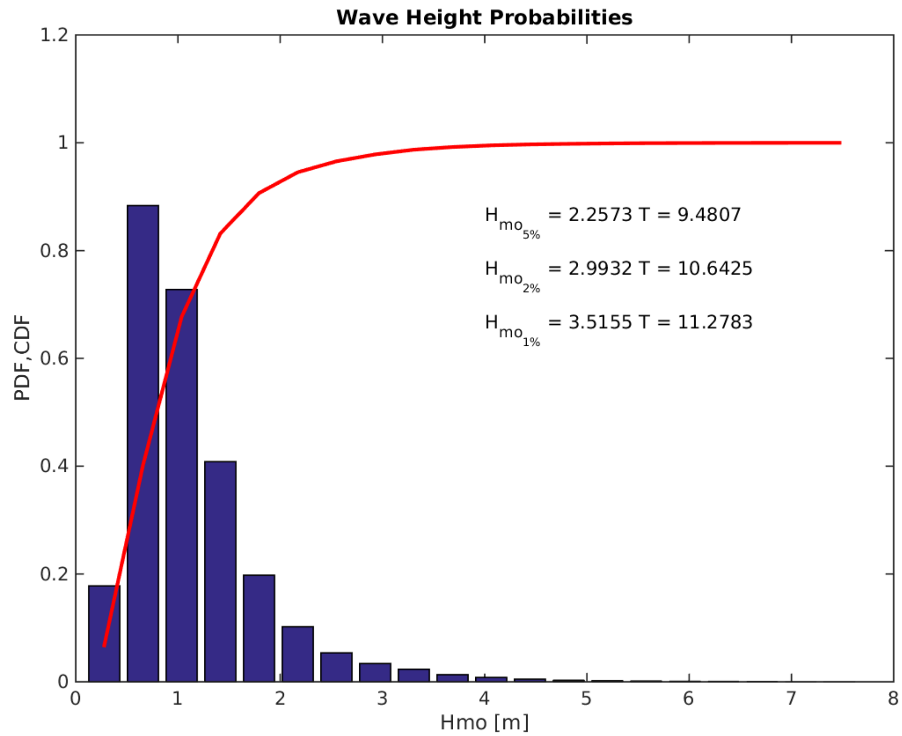

Figure 3. The probability density function (PDF; shown in blue) and cumulative distribution function (CDF; shown as a red line) for wave heights at WIS Station #63139. Note: The 1%, 2%, and 5% wave heights (m) and associated periods (sec) are also indicated in the figure.

Based on the analyses of the 33-years of hourly wave conditions at WIS Station #63139, a subset of 1040 possible wave conditions were identified to be simulated with STWAVE and are and outlined in Table 2. The spanning set consists of 13 possible wave height conditions (ranging from 0.8 ft to 23 ft or 0.25 to 7.0 m), 10 wave periods (ranging from 2.5 to 16 sec), and 8 wave directions (ranging from 45 to 202.5 degrees; defined clockwise from True North). A wave height threshold of 0.7 ft (0.2 m) was used to eliminate waves that would not contribute to total sediment transport. After simulating the set of 1040 identified wave conditions, hourly time-series results for the entire 33-year record were re-constructed from the representative wave conditions.

Table 2. Wave height, period, and direction for subset of possible wave conditions at WIS Station #63139.

Wave Height, m	Wave Period, sec	Wave Direction (degrees CW from True North)
0.25	2.5	45
0.75	5.5	67.5
1.25	6.5	90
1.75	7.5	112.5
2.25	8.5	135
2.75	9.5	157.5
3.25	11	180
3.75	13	202.5
4.25	15	
4.75	16	
5.5		
6.5		
7.0		

For each input height/period/direction combination, a TMA (Kitaigorodskii et al., 1975; Bouws et al., 1985; Hughes, 1984) directional wave spectrum was generated in a water depth corresponding to the seaward boundary of the STWAVE grid (69 ft or 21 m). Spectral frequencies ranged from 0.0167 Hz (T= 59.88 sec) to 0.6 Hz (T= 1.67 sec) at 0.0146 Hz intervals. Spectral directional components covered ±85 degrees from normal incidence to the grid x-axis, in 5-degree increments.

2.4 STWAVE Numerical Modeling Scenarios

The modeling scenarios for the Little Egg Inlet borrow sites are listed in Table 3 below. The depth of potential borrow sites ranged from 18 ft to 25 ft NAVD88 and the volumes ranged from 1.2 million yd^3 to 3.0 million yd^3. Although NAP specified 5 borrow configurations to be modeled, in addition to the existing conditions, a sixth borrow configuration (referred to as Modification #3 in Table 3) was also simulated and is included herein for completeness.

Table 3. Little Egg Inlet Numerical Modeling Scenarios and associated borrow depths and borrow volumes.

Little Egg Inlet Modeling Scenarios	Modification Number	Borrow Depth (ft NAVD88)	Borrow Volume (million yd^3)
Existing Conditions	N/A	N/A	N/A
NJDEP Channel	Mod1	25	1.2
GLDD Channel	Mod2	25	2.2
Expanded NJDEP Channel #1	Mod3	25	3.0
Expanded GLDD Channel	Mod4	25	3.0
Alternative	Mod5	18	3.0
Expanded NJDEP Channel #2	Mod6	25	3.0

The borrow alternatives for each modeling scenario are provided in Figure 4 through Figure 10. Note that the twelve cultural targets are identified with red triangles in each figure and the zero contour is shown with a black outline.

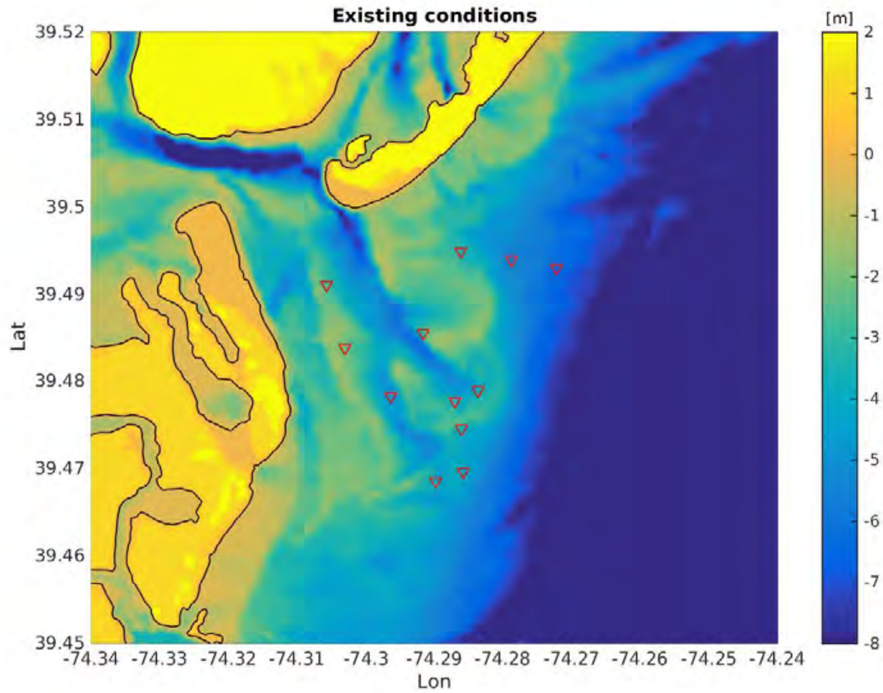

Figure 4. Close-up view of the Existing Conditions scenario. Note: Zero contour is shown as black outline; cultural targets indicated with triangles.

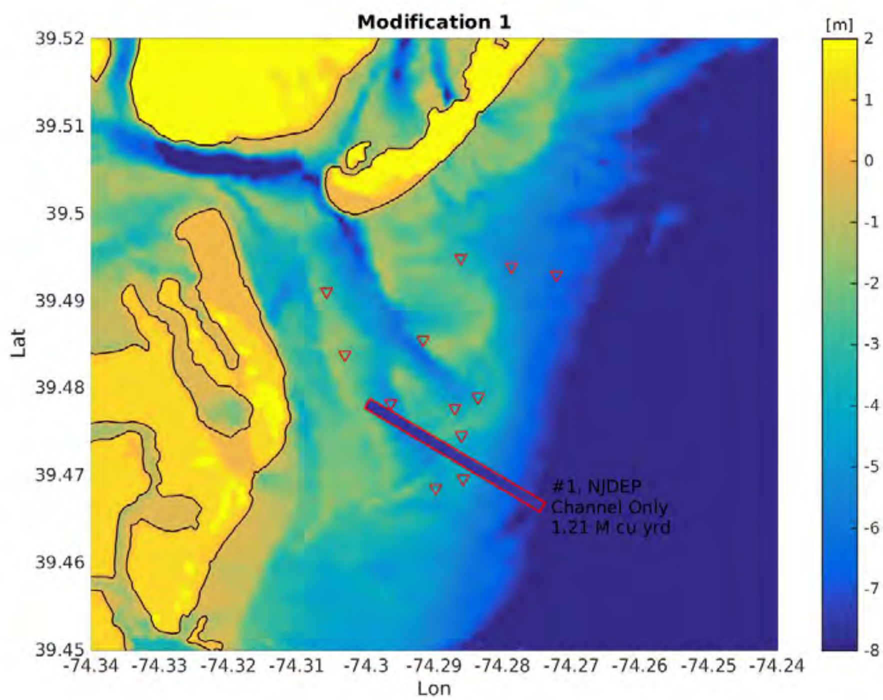

Figure 5. Close-up view of the NJDEP Channel scenario. Note: Zero contour is shown as black outline; cultural targets indicated with triangles.

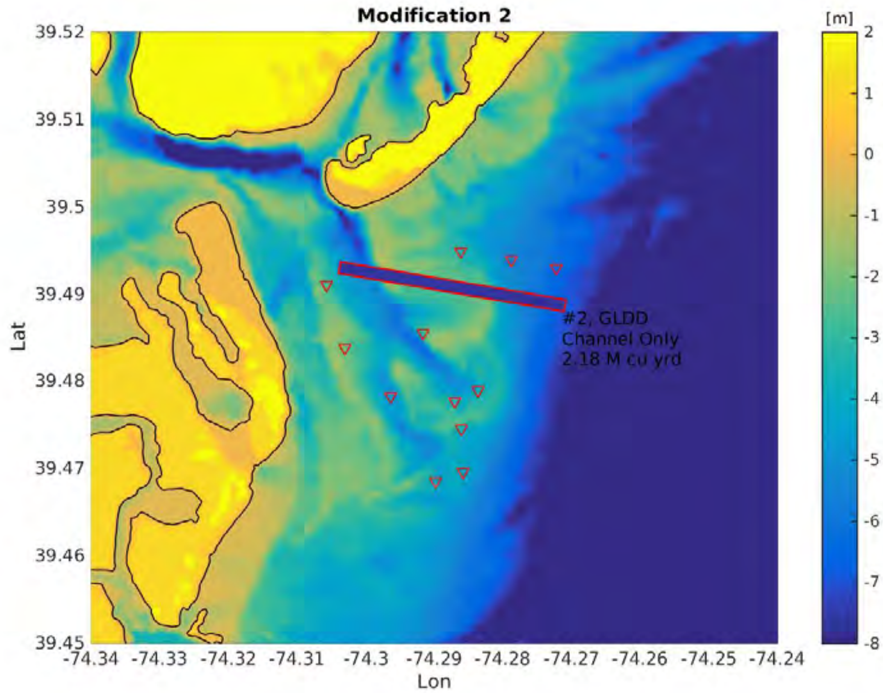

Figure 6. Close-up view of the GLDD Channel scenario. Note: Zero contour is shown as black outline; cultural targets indicated with triangles.

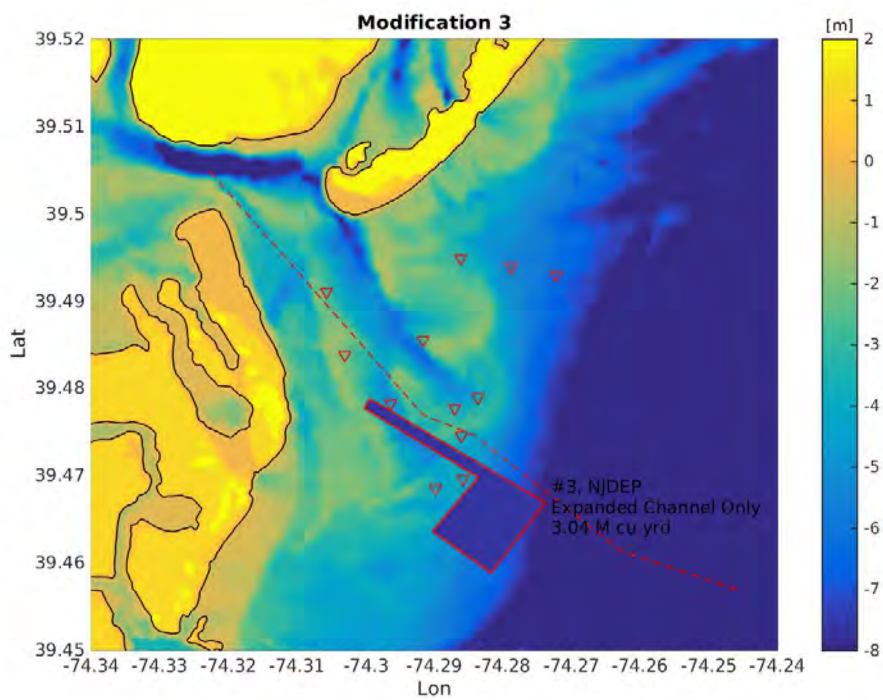

Figure 7. Close-up view of the Expanded NJDEP Channel #1 scenario. Note: Zero contour is

shown as black outline; cultural targets indicated with triangles; cable shown as dashed outline.

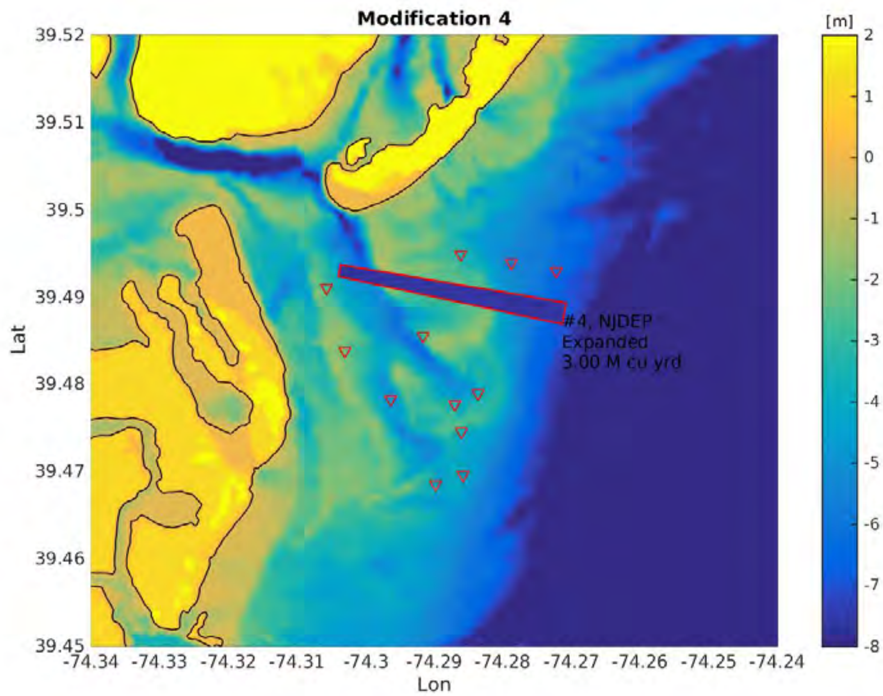

Figure 8. Close-up view of the Expanded GLDD Channel scenario. Note: Zero contour is shown as black outline; cultural targets indicated with triangles.

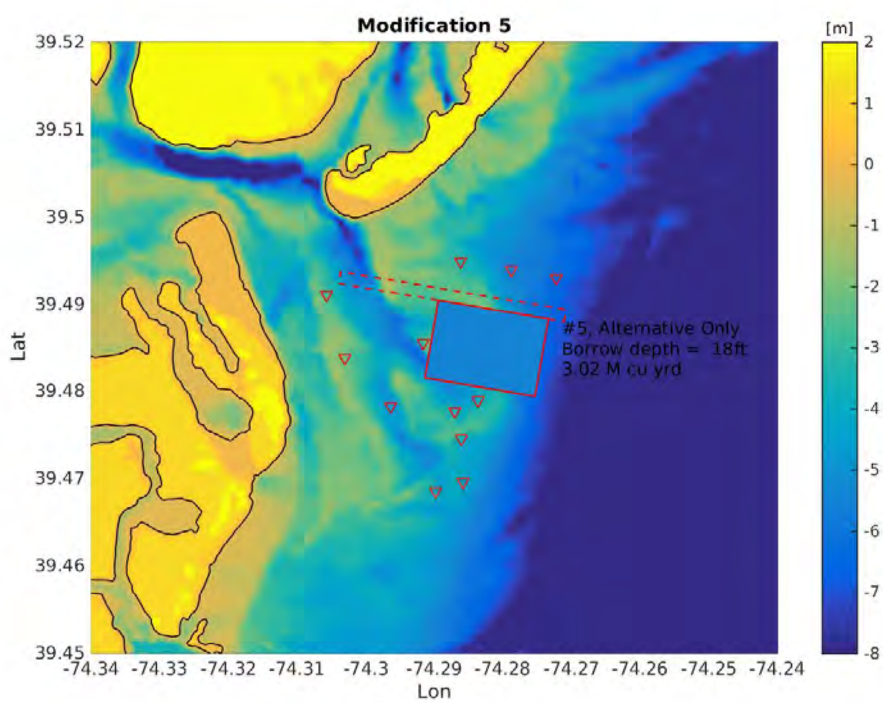

Figure 9. Close-up view of the Alternative scenario. Note: Zero contour is shown as black outline; cultural targets indicated with triangles; GLDD Channel shown as dashed outline.

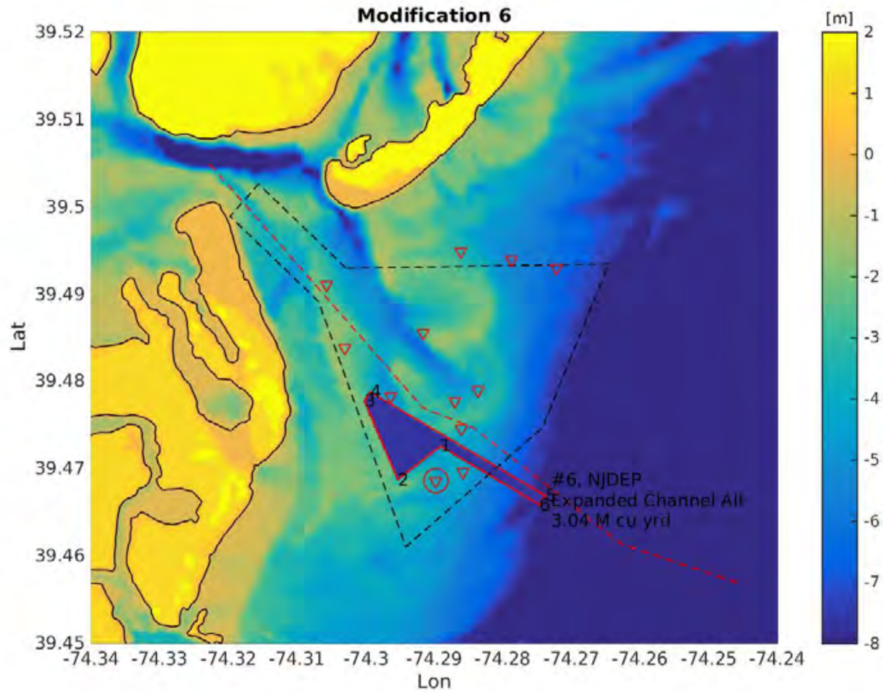

Figure 10. Close-up view of the Expanded NJDEP Channel #2 scenario. Note: Zero contour is shown as black outline; cultural targets indicated with triangles; cable shown as red dashed outline; project outline provided by NAP indicated with black dashed line.

2.5 STWAVE Model Results

The removal of sand through the aforementioned proposed borrow sites will cause changes in the nearshore hydrodynamics through differences in wave refraction and through alterations in the location of breaking dissipation. Sediment transport is primarily of interest for this study, and the relevant wave quantities contributing to sand transport are directly related to the square of the wave height. Figure 11 through Figure 16 show the effect of the borrow sites via the changes in normalized wave energy density, E', where

$$E' = 100 \times \frac{E_{modification} - E_{existing}}{E_{existing}} \quad (6)$$

and

$$E = \frac{1}{T}\int_{0}^{T} \frac{1}{16}\rho g H_{mo}^{2}\ dt \tag{7}$$

where:

E' = normalized wave energy density change
E = mean wave energy density
T = modeled time (T = 33 years)
ρ = mass density of water
g = acceleration due to gravity
H_{mo} = significant wave height

Mean energy density changes are provided as color plots in Figure 11 through Figure 16. Note that contours showing an increase and decrease of 10% are depicted in each figure.

Modifications #1 (NJDEP Channel), #2 (GLDD Channel), and #4 (Expanded GLDD Channel) are similar in layout shape and the effects on the wave energy densities are all similar. The channel borrow regions are characterized by a long narrow cut with an aspect ratio of depth to width ranging from 1:15 to 1:20. With dredging depths of 25 ft, the effect of these modifications is primarily dependent on incident wave angle and refraction. Wave rays of large angles relative to the channel orientation undergo a moderate seaward translation, resulting in a small net seaward shift of energy. Waves rays nearly oriented along the channel, on the other hand, are affected more dramatically by the channel as refraction tends to bend rays away from the depression. The redistribution of energy is apparent in Figure 11, Figure 12, and Figure 13, where the dark blues in the channel footprints indicate smaller energy densities. In the absence of wave breaking, these reductions are balanced by an accumulation of energies on the long sides of the channels as shown in Figure 11, Figure 12, and Figure 13. The majority of the observed changes are due to refraction and are not due to altered wave breaking location.

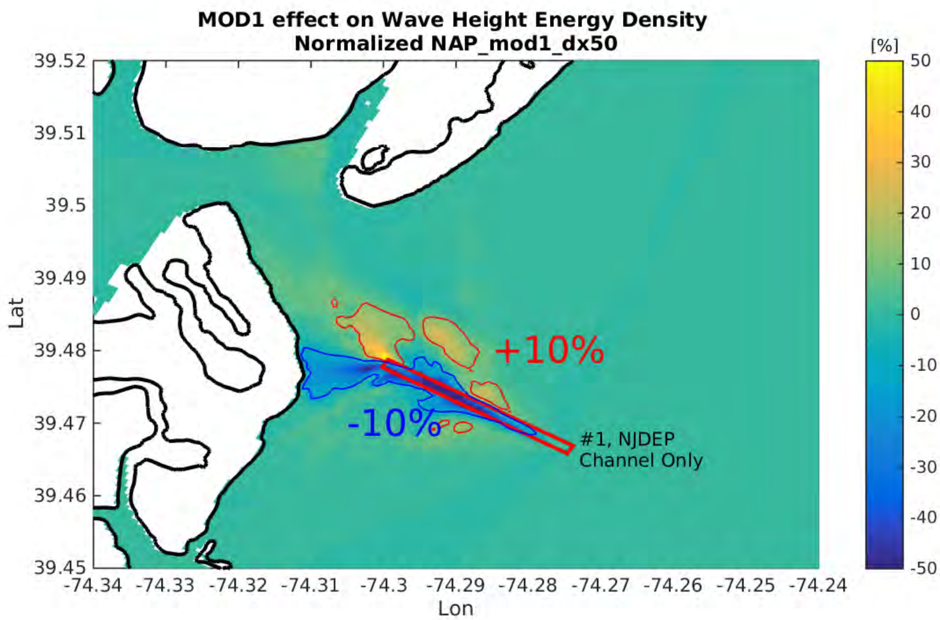

Figure 11. The effect on the normalized wave energy densities for the NJDEP Channel scenario (Modification #1).

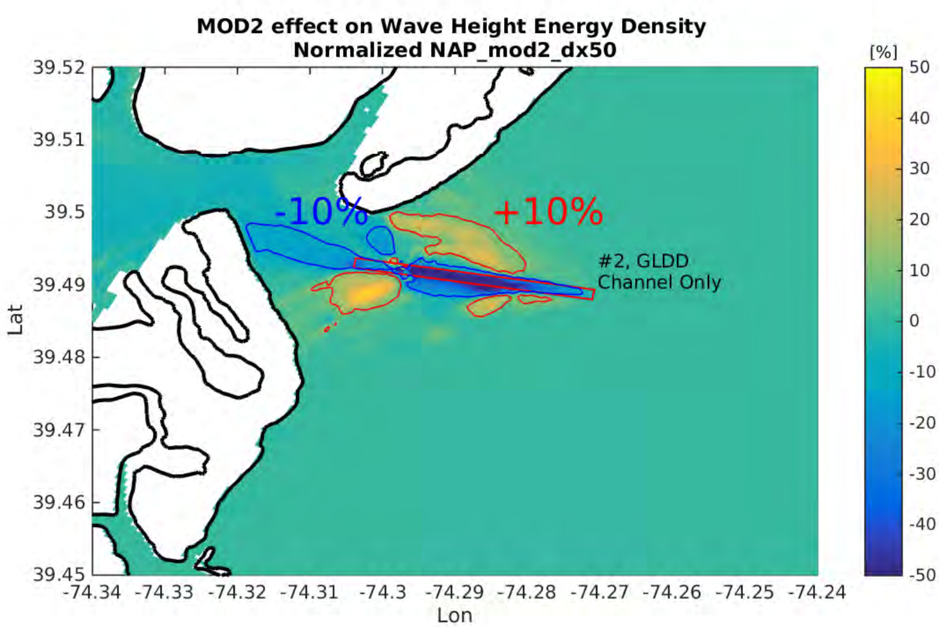

Figure 12. The effect on the normalized wave energy densities for the GLDD Channel scenario (Modification #2).

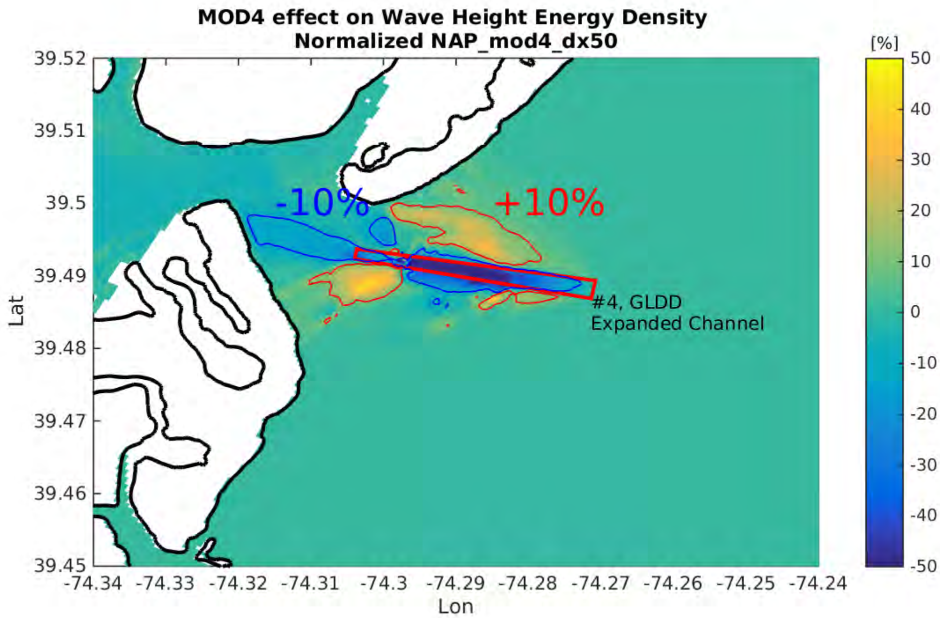

Figure 13. The effect on the normalized wave energy densities for the Expanded GLDD Channel scenario (Modification #4).

Modification #3 (Expanded NJDEP Channel #1) is composed of the Modification #1 (NJDEP Channel) and an expanded rectangular region at the southeast end. Modification #6 (Expanded NJDEP Channel #2) is composed of the Modification #1 (NJDEP Channel) and an expanded triangular region at the northwest end. As previously explained, for waves nearly oriented along the feature axis, the depression acts to bend energy away from the channel. The rectangular and triangular areas with 25 ft dredged depth act as regions of defocusing by refraction and a reduction in energy to the west is seen in Figure 14 and Figure 15.

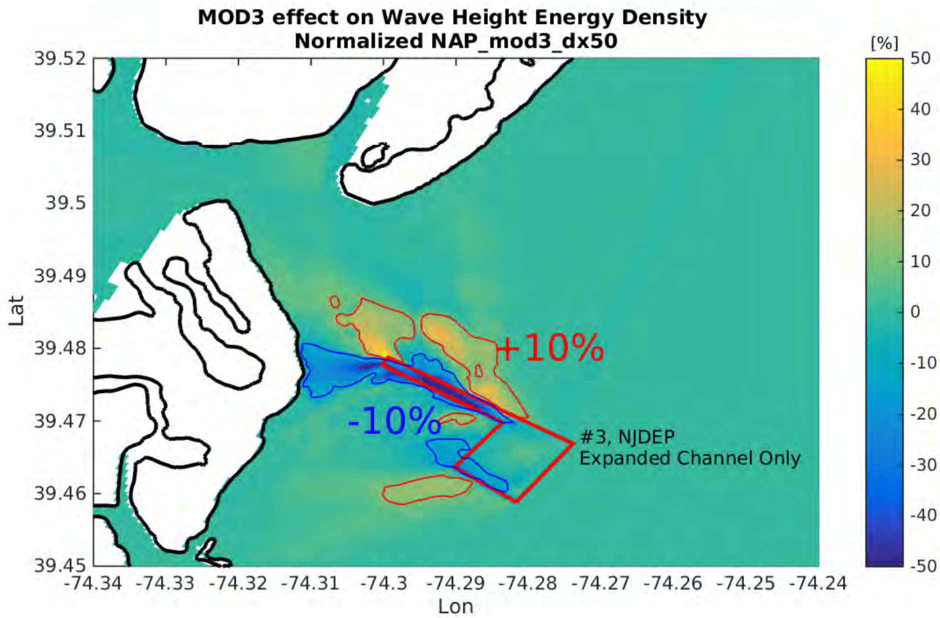

Figure 14. The effect on the normalized wave energy densities for the Expanded NJDEP Channel #1 scenario (Modification #3).

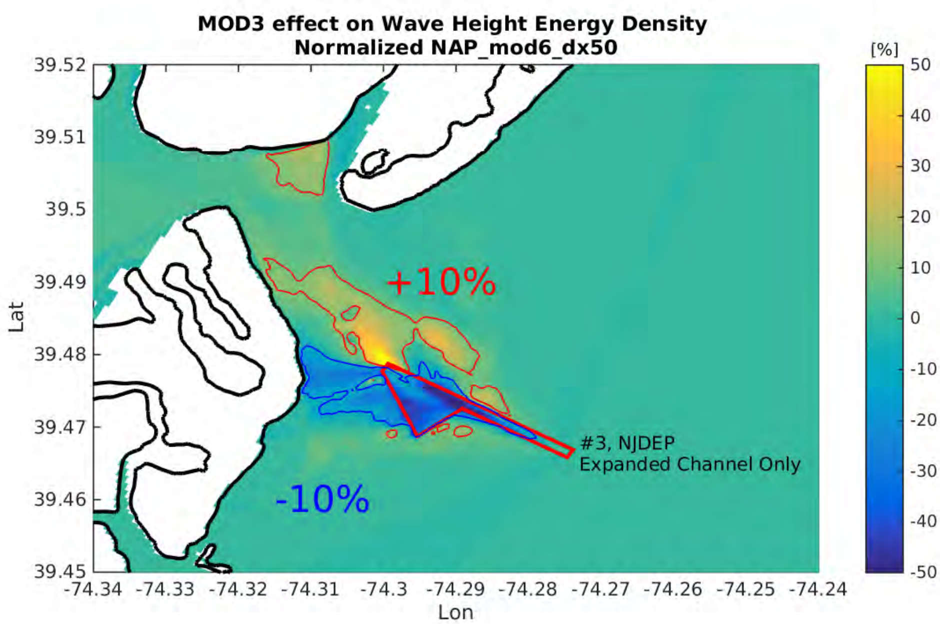

Figure 15. The effect on the normalized wave energy densities for the Expanded NJDEP Channel #2 scenario (Modification #6).

Modification #5 (Alternative) is a significant design departure from the other borrow scenarios, with a rectangular borrow site and a relatively shallow dredge depth of 18 ft. The effects of refraction for this alternative are less dramatic, but can be seen as local energy reductions along the north and south feature boundaries. The primary result of the modification is a large increase in wave energy to the west of the borrow site. This region of larger waves is due to changes in wave breaking. The existing conditions are characterized by a shallow ebb shoal within the borrow boundaries that results in breaking and energy dissipation for the largest wave conditions. When the depth of the region is increased for Modification #5, the average energy flux over the dredged region is increased and results in a more energetic nearshore region to the west, as seen in Figure 16.

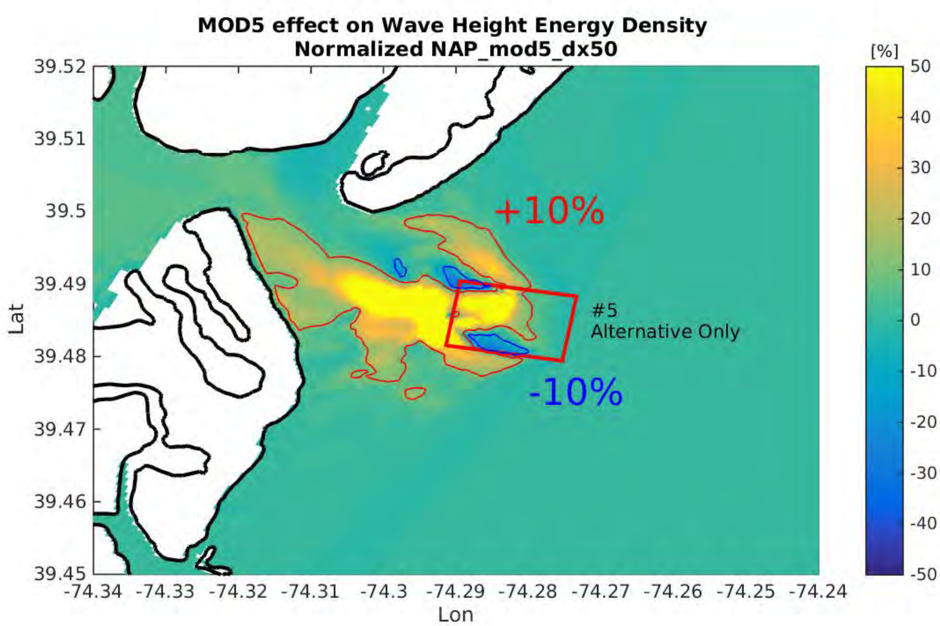

Figure 16. The effect on the normalized wave energy densities for the Alternative scenario (Modification #5).

2.6 GenCade Input from STWAVE Model Output

Breaking wave height and direction are used to calculate longshore sediment transport. The main output from STWAVE simulations consists of arrays of significant wave height, peak period, and peak direction over the entire grid for each incident wave condition. These data are useful for visualizing wave transformation over the entire grid. Station output as specific locations in the grid can be generated during the STWAVE simulations or specific location output can be extracted from the main output arrays as part of post-processing. For GenCade input, STWAVE output was extracted at stations that are seaward of the nearshore surf zone, so that STWAVE had not yet invoked breaking limits on the wave height. With this criteria on the STWAVE results selected for output, the breaking wave height and angle required for littoral transport computations could be accurately estimated within GenCade (Chapter 3).

3 GenCade

This chapter describes the set up and calibration of the GenCade model (Frey et al., 2012; Frey et al., 2014) as well as the evaluation of model alternatives at Little Egg Inlet. GenCade was applied to the study area to model adjacent shoreline change.

3.1 Numerical Modeling Approaches and Conventions

3.1.1 Description

GenCade is a one-line shoreline change, sand transport, and inlet sand-sharing model. GenCade is based on GENESIS, a project-scale, engineering design-level model (Hanson and Kraus, 1989) and Cascade, a regional-scale, planning level model (Larson et al., 2003), two previous models developed by the ERDC. Due to the synthesis of these two models, GenCade may be applied to regional or local project scales incorporating inlet channels and shoals as well as long-term trends in regional geomorphology. GenCade simulates shoreline response to beach nourishment; inlet dredging; construction of groins, jetties, and breakwaters; and bypassing at inlets. GenCade was first released in 2012, and new versions have been released over the past three years. The latest version, GenCade_v1r6, was released in July 2015, and was applied for this study.

There are a number of standard assumptions that constrain GenCade, because it is a one-line model. First, the beach profile shape remains constant. Second, the landward and seaward depth limits of active sand transport within the profile are constant. Third, sand is transported alongshore by the action of breaking waves and longshore currents. Fourth, the detailed structure of the nearshore circulation is ignored. Finally, there is a long-term trend in shoreline evolution. Further details about these constraints can be found in Frey et al. (2012; 2014).

3.1.1 Units, Coordinate System, Datum

The United States Customary System was applied in all model runs. The horizontal coordinate system is State Plane, New Jersey, Federal Information Processing Standards (FIPS) 2900. The horizontal datum is NAD83 and the vertical datum is NAVD88.

3.1.2 Direction Convention

The GenCade grid is aligned so that the water (ocean) is to the left of the grid when facing the positive x-direction. In this study, the grid x-axis is oriented from northeast to southwest. If oriented on the beach and looking towards the water, transport is negative to the left (north) and positive to the right (south). Waves may be imported in any sign convention (meteorological, oceanographic, or Cartesian); the model automatically converts wave direction to positive or negative values relative to shore normal.

3.2 Model Setup

3.2.1 Model Domain

The GenCade model domain (Figure 17) extends from the southernmost groin on Long Beach Island southward to Brigantine Inlet. The grid extends 3 mi along Long Beach Island. The total length of the grid is approximately 6.53 mi. The GenCade grid consists of 345 cells spaced 100 ft apart. The grid x-axis is oriented at 234 degrees from the north (model grid origin is at the northeast and extends to the southwest).

The setup of the GenCade model is shown in Figure 17. The green line represents the initial shoreline (2002 shoreline) and the thin red line is the regional contour. There are two dark blue lines along the initial shoreline near the inlet; these lines represent the extent of the inlet. The light blue line extending from the model origin to the shoreline is the groin for the gated boundary condition, defined as a boundary where a groin, jetty, or other feature interrupts, partially or completely, the movement of sand alongshore. The red circles represent the wave gauges. The lower resolution aerial photography was provided from the Import From Web feature within the Surface-Water Modeling System (SMS) (Aquaveo 2015). The high resolution aerial photographs were downloaded from the New Jersey Department of Environmental Protection from March 2002.

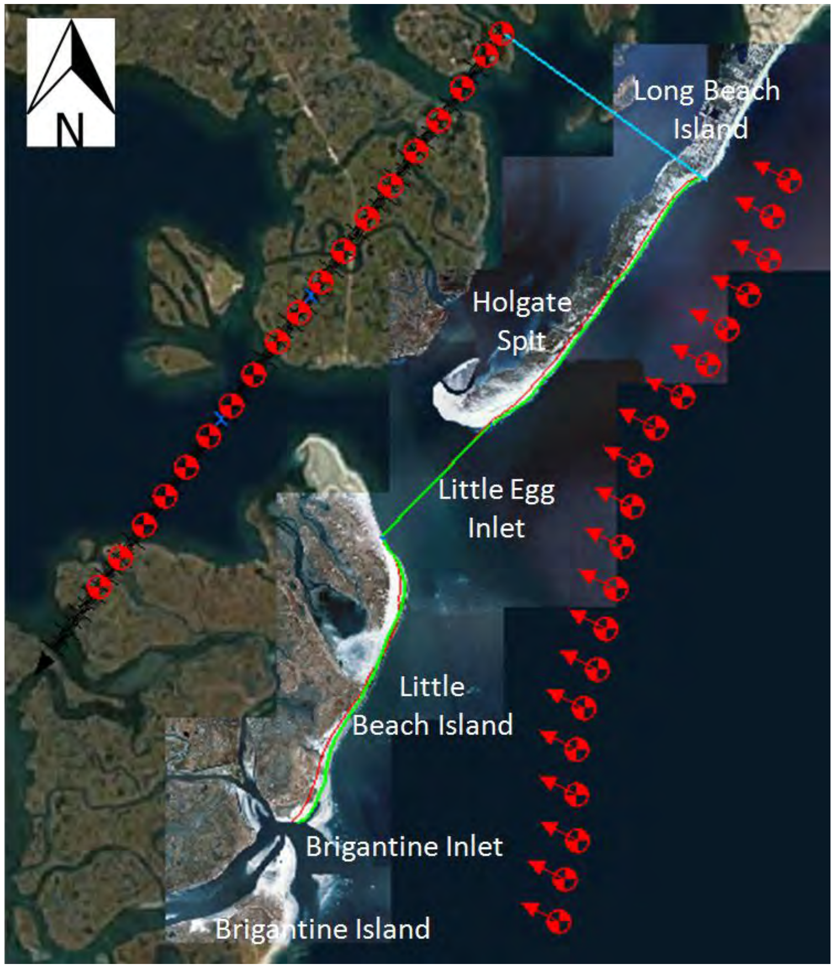

Figure 17. GenCade model setup.

3.2.2 Initial Shoreline Position

The U.S. Geological Survey (USGS) developed two shapefiles with all of the available New Jersey historical shorelines between 1836 and 2000 (USGS 2015). However, the 2000 shoreline was incomplete and the most recent complete shoreline in the vicinity of Little Egg Inlet was the 1977 shoreline. The 1977 shoreline is not representative of the present shorelines, so this shoreline was not used in the analysis. No digitized shoreline positions exist after 2000. Instead, aerial photography from 1995, 2002, 2007, and 2012 were downloaded from New Jersey Department of Environmental Protection. Shorelines were manually drawn and extracted from the georeferenced aerial photography. The 1995 shoreline is an outlier compared to the 2002, 2007, and 2012 shorelines; therefore, it was excluded from the calibration procedure. The 2002 shoreline was smoothed and applied as the initial shoreline position for calibration. The shoreline must be a continuous arc across the entire GenCade domain. A straight arc was added to connect the shorelines northeast and southwest of Little Egg Inlet and create a single, continuous arc. Because GenCade calculates shoreline change and there is no shoreline within an inlet, the position of the initial “shoreline” at the inlet is inconsequential and simply a model requirement.

3.2.3 Regional Contour

The regional contour maintains the desired overall shoreline curvature without the presence of structures, even when GenCade is run for a very long time period. On an open coast, the shoreline will gradually evolve to the shape of the regional contour instead of a straight line.

Due to the curved shape of the shorelines adjacent to Little Egg Inlet, a regional contour is necessary to prevent the calculated shoreline from evolving to a straight line. A regional contour might be a single smoothed shoreline, an average of multiple shorelines, or a bathymetric contour. In this case, the regional contour was developed from three of the shorelines derived from aerial photographs: 2002, 2007, and 2012. These shoreline positions were averaged to develop a single curved line representing the regional contour. Finally, the regional contour line was smoothed through the smoothing function in the SMS to remove some of the local effects while the large-scale shapes that are the results of processes acting over a long time scale remained.

3.2.4 Inlet Shoal Volumes

GenCade employs the Inlet Reservoir Model (IRM) (Kraus, 2000) to calculate the change in shoal volumes at inlets and interaction with adjacent beaches. The model requires an initial volume and an equilibrium volume for each shoal (ebb, flood, left bypass, left attachment bar, right bypass, and right attachment bar; Figure 18). It also allows the user to specify reduction of shoal volumes in time through dredging. Each shoal traps sediment based on the calculated volume at each time step and the equilibrium volume. Unless the inlet shoal system is completely at equilibrium, only a portion of the sand entering the system will leave the system and be transported further along the beach.

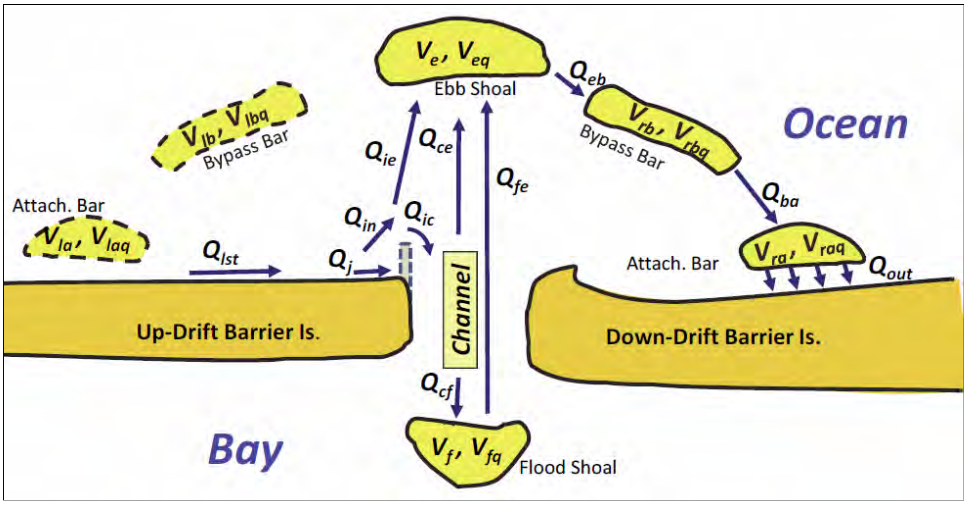

Figure 18. Schematic of the interaction between morphological elements in an inlet (from Frey et al. 2012).

Initial and equilibrium volumes for the inlet shoals were approximated based on aerial photographs and a 2015 inlet and shoal survey. The boundaries of each of the shoals were chosen from the inlet and shoal survey. Contours based on the 2015 survey were created in ArcGIS to better determine the extent of the shoals. After the area of each shoal was estimated, an average thickness of 6 ft was assumed. The survey did not extend to the flood shoal, right attachment bar, or right bypass bar, so these areas were estimated solely from aerial photography. To compare, using the relationships in Walton and Adams (1976), the estimated ebb-shoal volume at Little Egg Inlet would be 50,000,000 yd^3. At the start of the calibration process, shoals were assumed to be in near-equilibrium; in other words, the initial volumes and equilibrium volumes of each shoal were equal. Volumes were iteratively adjusted to achieve model calibration. Because initial and equilibrium shoal volumes are difficult to calculate, these volumes contribute to model uncertainty. Table 4 lists inlet shoal volumes applied.

Table 4. Inlet shoal volumes, yd^3.

Shoal	Initial	Equilibrium
Ebb	9,170,000	13,100,000
Flood	1,750,000	2,500,000
Left Bypass	1,875,000	3,750,000
Left Attachment	1,250,000	2,500,000
Right Bypass	1,750,000	1,750,000
Right Attachment	1,000,000	1,000,000

3.2.5 Model Forcing

One of the submodels in GenCade is a wave model that calculates breaking wave height and angle alongshore based on the wave information given at a referenced depth offshore. However, this is a simplified approach and is only applicable to a sea bottom with approximately straight and parallel contours. Due to the offshore bathymetry in the vicinity of Little Egg Inlet, proceeding with the internal wave model only is not the best approach. Instead, STWAVE was used to calculate the wave transformation over the actual bathymetry from the offshore reference depth to the location immediately offshore of wave breaking. A representative time series was created at 20 save stations in STWAVE, and this wave information was used as input for the GenCade modeling. One exception was that the STWAVE save station located the furthest northeast was mapped to cell 1 within GenCade, meaning the save station was beyond the alongshore domain of GenCade. Therefore, this save station was removed from the calibration setup. The nearshore references points are shown as red, partially-filled circles with arrows located at various distances offshore (and these circles are also located along the grid to show which cell is associated with which wave station) in Figure 17. The time period from 2002 to 2007 was used to represent typical conditions to compare calculated shoreline change to the calibration data available. No shoreline positions later than 2012 are available, but through GoogleEarth and other aerial photography, the same long-term trends are noted (the shoreline recedes over a long period of time, for example). Based on the historical trends, it is reasonable to use the 2002 and 2007 shorelines to calibrate the model.

3.2.6 Boundary Conditions

The boundaries of the GenCade model are at the southernmost groin along Long Beach Island and at north side of Brigantine Inlet. A gated boundary condition was specified at the left (north) boundary (on Long Beach Island) to facilitate sand transport into and out of the grid. The transport of sand at the left boundary is based on the length and porosity of the groin. The groin length was 325 ft, and the groin's porosity was set to 0. Because it is difficult to measure the porosity of a groin, the porosity was modified during the calibration process to best match the final shoreline position. The measured shoreline change at the right (south) boundary at Brigantine Inlet was used to apply a moving boundary condition of -80 ft over the five year simulation. When a moving boundary condition is selected, the boundary will move a specific distance (specified by the user) over a certain time period.

3.2.7 Summary of Model Parameters

In addition to the previously discussed parameters, there are a few other parameters that must be specified before running GenCade. The average berm height and depth of closure were specified based on the typical beach profiles provided by NAP. Berm height is the elevation of the berm for a typical beach profile, and depth of closure refers to the elevation of the seaward limit of sediment transport for the time period of consideration. The berm height was specified as 5 ft relative to mean sea level (MSL) and the depth of closure was 20 ft MSL. The median grain size was specified based on size analysis of vibracore samples in Little Egg Inlet and along Long Beach Island and Brigantine Island. The D_{50} of the samples ranged from 0.22 mm along Brigantine Island to 0.31 mm in Little Egg Inlet. D_{50} cannot be varied alongshore within the model, so a D_{50} of 0.25 mm was used as input for the model to represent the range.

The starting date for the calibration period was 23 March 2002 and the ending date was 31 March 2007. The time step was 0.1 hr and the recording time step was 168 hr (1 week).

3.3 Model Calibration

In order to properly estimate shoreline change and sand transport, GenCade must be calibrated with measured data. The calibration process is iterative, beginning by varying parameters which impact the entire domain and ending with more local parameters. Because shorelines are easier to collect or derive than longshore sand transport, GenCade is usually calibrated with the measured shoreline data. K1 and K2, the sand transport calibration coefficients, are the primary parameters used for calibration. A variation in K1 will impact the entire modeling domain while a variation in K2 will affect the evolution in the areas influenced by wave diffraction near structures. The only structure present in this GenCade modeling domain is at the left (north) boundary (gated boundary condition), so varying K2 does not have a large impact on the calculated shoreline change and longshore transport. GenCade allows the user to amplify the wave heights or wave angles or specify an angle offset. None of these parameters were adjusted during the calibration. Finally, ISMOOTH, the number of cells in the offshore contour smoothing window, was modified through an iterative approach. A larger value of ISMOOTH results in a regional contour with less curvature. When ISMOOTH = 1, the offshore contour would be parallel to the initial shoreline. If ISMOOTH is equal to the number of GenCade cells in the domain, the offshore contour would be a straight line parallel to the x-axis. Because ISMOOTH has the greatest impact when there is an abrupt change in shoreline position (near a structure) and the only structure included in this calibration is the gated boundary, varying ISMOOTH had little impact on the results. Therefore, the default ISMOOTH value of 11 was used in this calibration. Table 5 summarizes the parameters used in the calibration and also states the default values in GenCade.

Table 5. GenCade parameters and values used in calibration.

Parameter	Value	Default Values
K1	0.2	0.5
K2	0.1	0.2
Height Amplification Factor	1	1
Angle Amplification Factor	1	1
Angle Offset	0	0
Number of cells in offshore contour smoothing window (ISMOOTH)	11	11

Figure 19 shows the initial shoreline and the cross-shore distance from the grid. Little Egg Inlet is labeled. The grid origin is on Long Beach Island; therefore, the left side of the figure corresponds with Long Beach Island and Holgate Spit (the locations to the north of the inlet). The right side of the figure represents the end of the grid and is associated with Brigantine Inlet (south of Little Egg Inlet). The format of showing shoreline position compared to the grid x-axis is typical when using GENESIS, but it is more difficult to analyze the results than showing shoreline change. Therefore, the measured and calibrated shorelines will be displayed in shoreline change from initial in ft/yr.

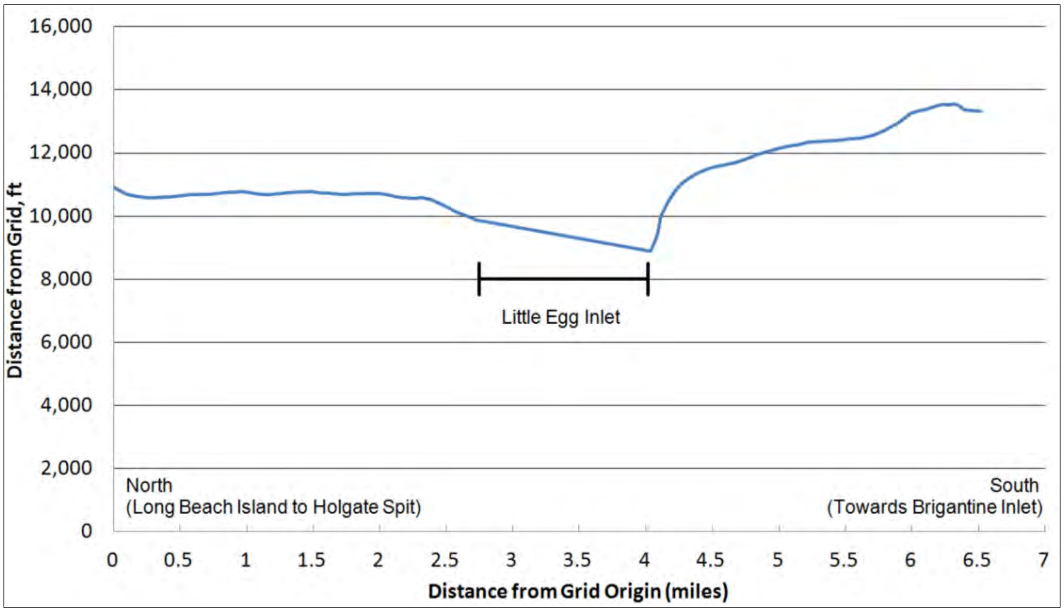

Figure 19. Initial GenCade shoreline position showing Little Egg Inlet.

Figure 20 compares the calibrated and observed shoreline change rates per year from 2002 to 2007. While previous sediment budgets were reviewed, these sediment budgets consisted of larger, regional-scales. Most of the sediment budget cells spanned many miles and represented the full distance along the adjacent barrier islands. The 1986-2003 (USACE 2006) sediment budget provided transport rates at Little Egg Inlet; however, because hydrographic survey data did not cover the entire inlet, the volume of shoal growth within the inlet was solved iteratively to balance the control volume. Additionally, the origin of the GenCade grid is located in the middle of a sediment budget cell, so there are no transport rates at that site listed in the literature. Therefore, transport magnitude and direction were compared with those in the literature, but shoreline change was used as the primary criteria for calibration. Shoreline change is calculated reasonably well along the entire domain. The model calculates erosion in all of the areas where erosion occurs, and advance is calculated in places where advance is observed. In Figure 20, accretion is towards the top of the figure and erosion is towards the bottom. For example, at about 4.75 mi from the orgin (to the south [right] of Little Egg Inlet), the shoreline accrete about 60 ft/yr. The model-calculated shoreline change produces results most similar to the observed values within about 0.5 mi of the inlet. In nearly all locations, the measured shoreline erosion is greater than the calculated shoreline erosion. This indicates that there is more volume loss along the domain than calculated. Cross-shore sediment transport (on-shore/offshore transport) is not included in GenCade calculations, so it is likely that cross-shore losses account for some of the shoreline recession along Long Beach Island and North Brigantine Island/Little Beach Island. If an offshore sink term, a parameter which removes sand associated with user-specified GenCade cells, was added to the model to represent these losses, GenCade might have produced a calculated shoreline more similar to the measured shoreline. However, an offshore sink term was not included, because it is difficult to verify the erosion due to cross-shore losses.

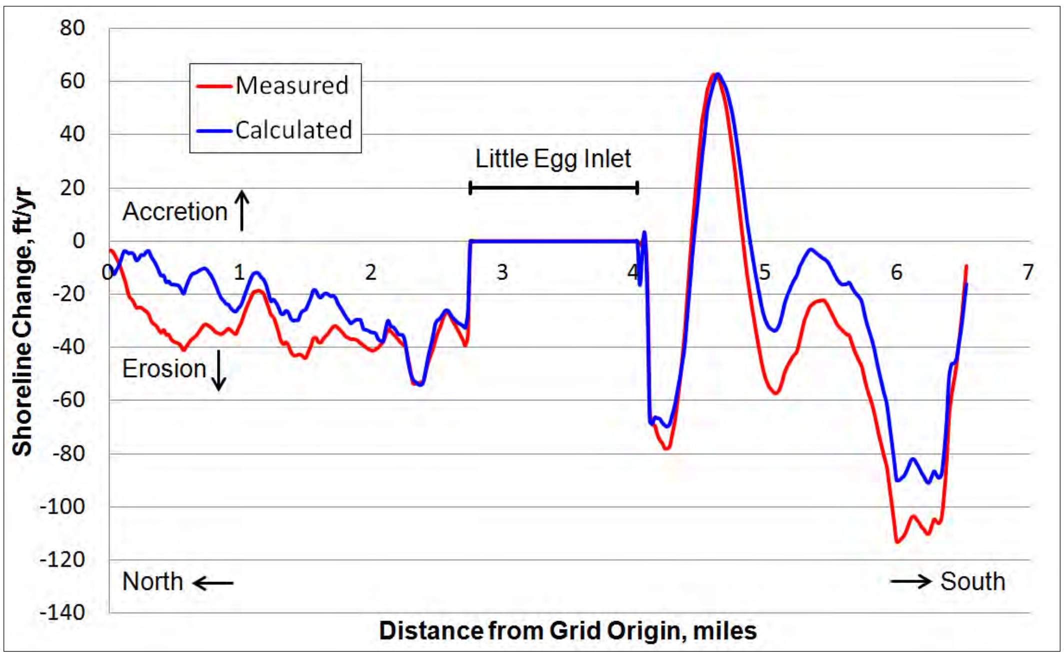

Figure 20. Measured and calculated shoreline change results.

3.4 Model Alternatives

Initially, it was intended to use the wave time-series from the save stations of each STWAVE alternative as input for each GenCade alternative. However, the differences in bathymetry for the alternatives were located landward of wave breaking and the STWAVE save stations, so each STWAVE alternative would produce an almost identical time-series. Therefore, to illustrate differences between dredging alternatives, it was determined that each dredging volume would be entered in the Inlet Reservoir Model (IRM) within GenCade. The IRM describes shoal volume evolution at inlets and their interaction with adjacent beaches. NAP requested that four different dredging alternatives be modeled: 1) initial volume of 1,200,000 yd^3, 2) initial volume of 2,200,000 yd^3, 3) initial volume of 3,000,000 yd^3, and finally 4) 1,000,000 yd^3 dredged every 7 years. The duration of each simulation was 33 years to represent the full length of the time-series from STWAVE. In addition to dredging alternatives, NAP indicated that a beach nourishment project is under construction along 15 mi of Long Beach Island from just south of Barnegat Light to the terminal groin at Holgate. The dominant direction of transport is to the south, and it is expected that sand from the beach nourishment will move towards Little Egg Inlet, as has predominantly occurred over the long-term. After the initial construction is completed (10,000,000 yd^3), about 1,000,000 to 2,000,000 yd^3 will be placed along Long Beach Island every seven years, assuming no major storm events require emergency fills. In order to account for the sand transported south and moving into the model domain, several source terms were added to the simulations. Because it is not known how much of the sand will be transported to the Little Egg Inlet vicinity, a range of source terms were used, ranging from 100,000 yd^3/yr to 500,000 yd^3/yr. It is expected that the volume of sand moving into the GenCade domain will be within that range. The first source alternative adds 250,000 yd^3/yr along the first 1.9 mi of the domain. An additional alternative add sources of 500,000 yd^3/yr to the same alongshore distance. Another source alternative varies the locations in which sediment is added to the shore. For the first 10 years of the simulation, sand is added to the first 1.9 mi of the domain. For the second 10 years, sand is added to the first 2.7 mi of the domain (to Little Egg Inlet). Finally, for the last 13 years, sand is added to 5.7 mi of the domain, excluding Little Egg Inlet. It is possible that this approach might be more representative of real conditions, because the sand will continue moving to the south through time and it is unknown how quickly the sand will move alongshore. It is also possible that it takes a number of years before the Little Egg Inlet area sees the impacts of the beach nourishment placed on Long Beach Island. The last source alternative adds a source term to the first 1.9 mi of the domain, but the source is specified beginning at the start of the sixth year. No source is included within the model for the first five years. To better represent the movement of sand along the domain, smaller source terms of 100,000 yd^3/yr and 250,000 yd^3/yr were modeled and the source term locations were modified each year. In these cases, it was assumed that the sand moved one mile every year. For example, a source term was added to cells along the first mile of the domain during year one. Then during the second year of the simulation, the source term was applied to cells along the first two miles. After 7 years, because the GenCade domain is 6.53 mi long, a sand source is applied to the entire domain. Table 6 is shown below to summarize the dredging alternatives modeled. Table 7 shows the various source term alternatives simulated. Each of the source term alternatives was run with each of the dredging alternatives for a total of 24 alternatives plus no action.

Table 6. GenCade dredging alternatives.

Dredging Alternatives	Description
No Action	No Dredging
Dredging Alternative #1	1,200,000 yd^3 at beginning
Dredging Alternative #2	2,200,000 yd^3 at beginning
Dredging Alternative #3	3,000,000 yd^3 at beginning
Dredging Alternative #4	1,000,000 yd^3 every 7 years

Table 7. GenCade source term alternatives.

Source Term Alternatives
250,000 yd^3/yr Along First 1.9 Mi
500,000 yd^3/yr Along First 1.9 Mi
500,000 yd^3/yr Along First 1.9 Mi, 2.7 Mi, and 5.7 Mi
500,000 yd^3/yr Along First 1.9 Mi (After 5 Years)
100,000 yd^3/yr Along Entire Domain
250,000 yd^3/yr Along Entire Domain

3.4.1 No Action

All alternatives, including the No Action alternative, were run for 33 years (to represent the sand management options considered and utilize the full wave time-series). The purpose of the No Action case was to determine what would happen to the shoreline if dredging was not pursued and the beach nourishment on Long Beach Island was not constructed. It is also important to mention that the model does not know that previous beach placement has occurred on Long Beach Island. It assumes the same berm height and depth of closure as within the model domain, and transport rates and shoreline position are driven by the waves. In order to have a better understanding of the effects of dredging and the movement of sand from the beach nourishment project, shoreline change per year for each alternative was shown after 10 years and after 33 years. Two other variations of the No Action case were also simulated. Construction of the beach fill on Long Beach Island has already begun, and the sand will eventually move towards Little Egg Inlet. In order to model future shoreline change with the beach fill and without dredging, source terms of 100,000 yd^3/yr and 250,000 yd^3/yr were applied across the domain to represent the movement of the sand. Figure 21 illustrates the No Action alternative after 10 years and Figure 22 shows the No Action alternative after 33 years. Similar to the calibration case, the shoreline recedes northeast (left side of the figure) of the inlet. There is a small location to the southwest of the inlet (right of the inlet) which experiences advance (most likely the attachment bar), and the shorelines adjacent to this point (north and south) erode. After 10 years, about 30 ft/yr of erosion is calculated less than a mile to the northeast of the inlet. More than 40 ft/yr of erosion is expected about 2 miles south of the inlet. To represent the movement of sand along Long Beach Island from the beach fill, two source terms were applied to the model domain. Because the volume of sand that moves towards Little Egg Inlet is unknown, two different rates are used as source terms. However, even with a 250,000 yd^3/yr source term, the difference in shoreline change per year compared to the No Action case is minimal. Although shoreline retreat is predicted in all cases along Long Beach Island (mile 0 to mile 2.75 in the figure), the largest difference in shoreline change between the No Action and the 250,000 yd^3/yr source term is about 10 ft/yr. For example, about 1 mi from the origin, the calculated shoreline change for the No Action case is -18 ft/yr and the calculated shoreline change for the 250,000 yd^3/yr source term case is about -8 ft/yr. After 33 years, the shoreline recession just to the northeast of the inlet is about 20 ft/yr for the No Action case. The same attachment bar feature is also present to the south of the inlet while about 2 mi south of the inlet, about 15 ft/yr of advance is calculated. After 33 years, the difference in shoreline change along Long Beach Island between the No Action case and the cases with source terms but without dredging is smaller than after 10 years. The differences in shoreline change to the southwest of Little Egg Inlet between the No Action and source term cases are larger than after 10 years, which is to be expected because the sand (when a source term is applied) is slowly moving to the southwest.

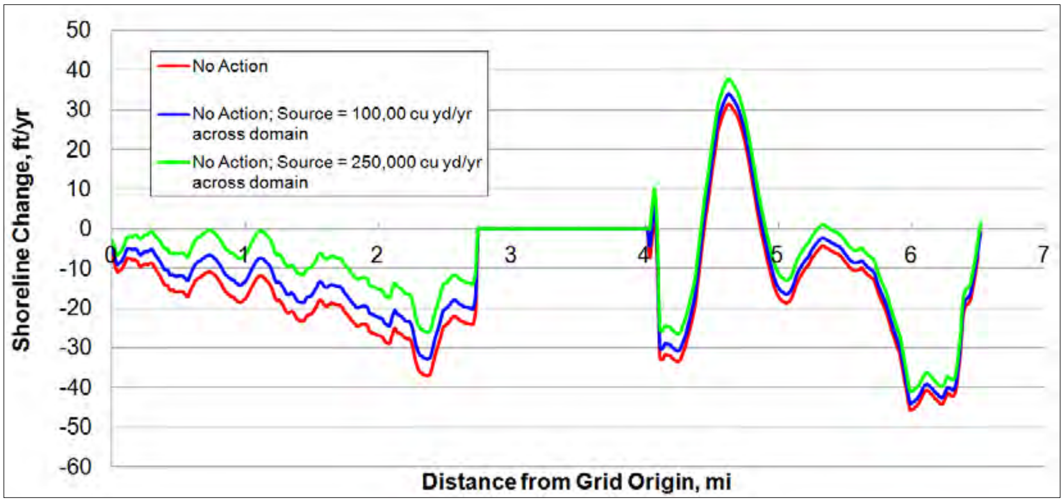

Figure 21. Shoreline change per year for no dredging action after 10 years.

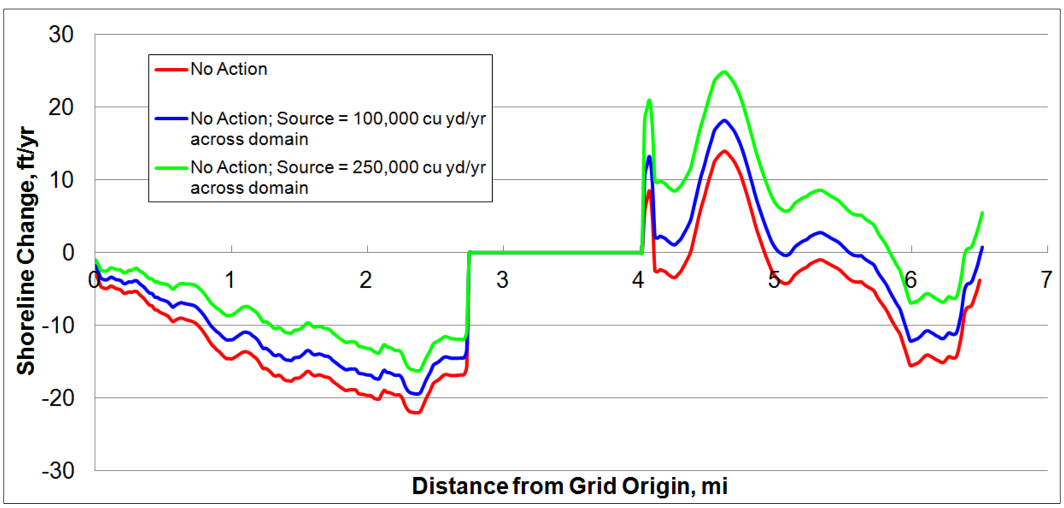

Figure 22. Shoreline change per year for no dredging action after 33 years.

One limitation of GenCade is all inlets are fixed and cannot migrate along-shore. Throughout a simulation, the same cells will be defined as the inlet and the bypass bar. Even though inlets widen, narrow, close, or migrate in nature, this is not a capability in GenCade. For these simulations, a large volume of sand settles in the inlet system and is not bypassed to the downdrift beach. It is also possible that instead of replenishing the morphological units (ebb shoal, bypassing bars, and attachment bars), sand from the beach nourishment may form a large spit at the end of Long

Beach Island. A spit could cause the inlet to migrate or narrow; however, spit formation cannot be modeled with GenCade.

3.4.2 Dredging Alternative 1: 1,200,000 yd^3 at beginning of simulation

The first dredging case consists of removing 1,200,000 yd^3 from the inlet (ebb shoal) at the beginning of the simulation. The sand is removed over the course of a single month. There are no other differences between this case and the No Action case. In order to determine whether or not dredging will adversely affect the adjacent shorelines, it is necessary to account for the sand moving into the system from Long Beach Island. Therefore, difference variations of dredging alternative 1 were modeled. The different source alternatives are listed above in Table 7. Figure 23 shows shoreline change per year after 10 years for all alternatives (except using a source term of 100,000 and 250,000 yd^3/yr across the entire domain) where 1,200,000 yd^3 was dredged at the beginning of the simulation. The alternatives are compared to the No Action case. After 10 years, the majority of the differences in shoreline change are noticed to the northeast (left in the figure) of the inlet. In all cases, enough sand has been added to advance the shoreline beyond the position of the initial shoreline for the first 1.5 mi of the domain. Because the transport direction is to the southwest, dredging does not have much of an impact on the northern adjacent beaches. Therefore, the No Action and the 1,200,000 yd^3 dredging without a source case are identical from the grid origin to the Little Egg Inlet (between 2.75 and 4 mi from the origin). As expected, when the source term is smallest (250,000 yd^3/yr), the shoreline advances the least to the northeast of the inlet. Because the source term of 500,000 yd^3/yr is delayed five years (dark pink line), the shoreline does not advance as much as the cases where the sand is added for the entire simulation. Directly downdrift of the inlet (to the right in the figure), the No Action case experiences the least amount of erosion and the greatest advance at about 4.75 mi along the domain. Without a source term and initially dredging 1,200,000 yd^3, the shoreline recedes about 10 ft/yr more than the No Action case. Therefore, 10 years after dredging 1,200,000 yd^3, slight erosion compared to the No Action case is predicted, but this impact is minor and could be within the bounds of error in GenCade.

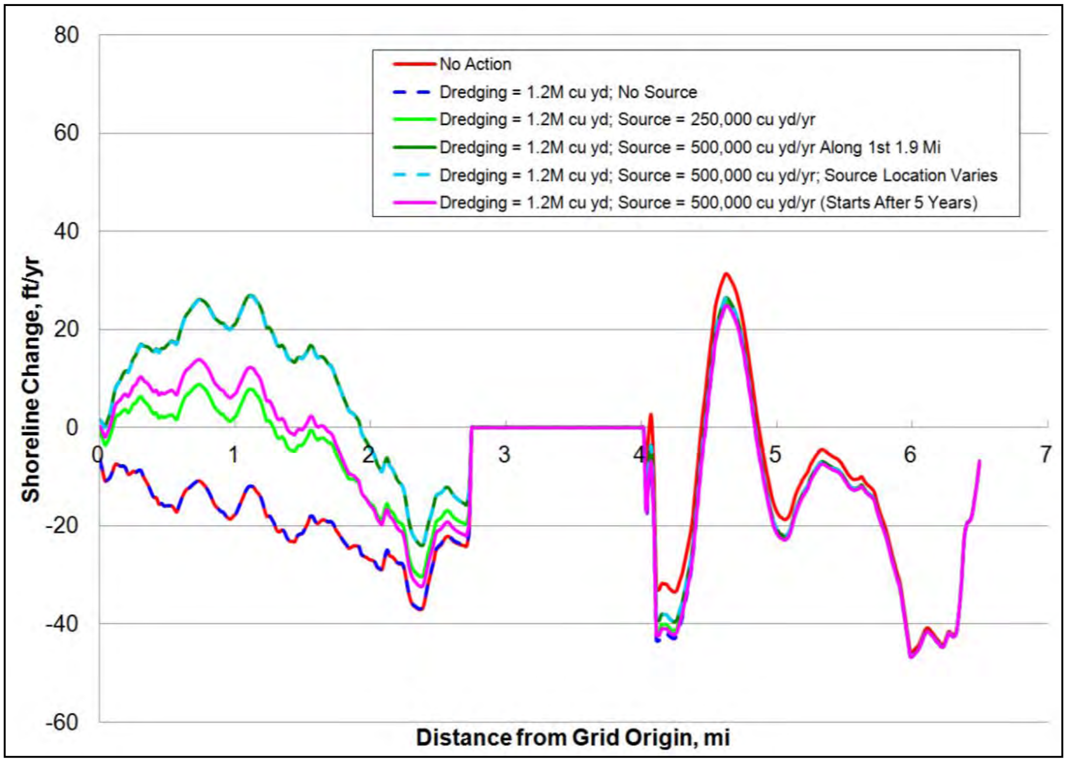

Figure 23. Shoreline change per year after dredging 1,200,000 yd^3 after 10 years.

The results of shoreline change after 33 years are shown in Figure 24. As expected, after 33 years of a continuous source of sand, shoreline position of all alternatives is seaward of the No Action case (less erosion than the No Action case is predicted). The only case that experiences more erosion adjacent to the inlet than the No Action case is the case where there is no source term. When 500,000 yd^3 is added to the model each year, the shoreline advances about 10 ft/yr more than the No Action case. While this could be considered significant, it is not an adverse impact.

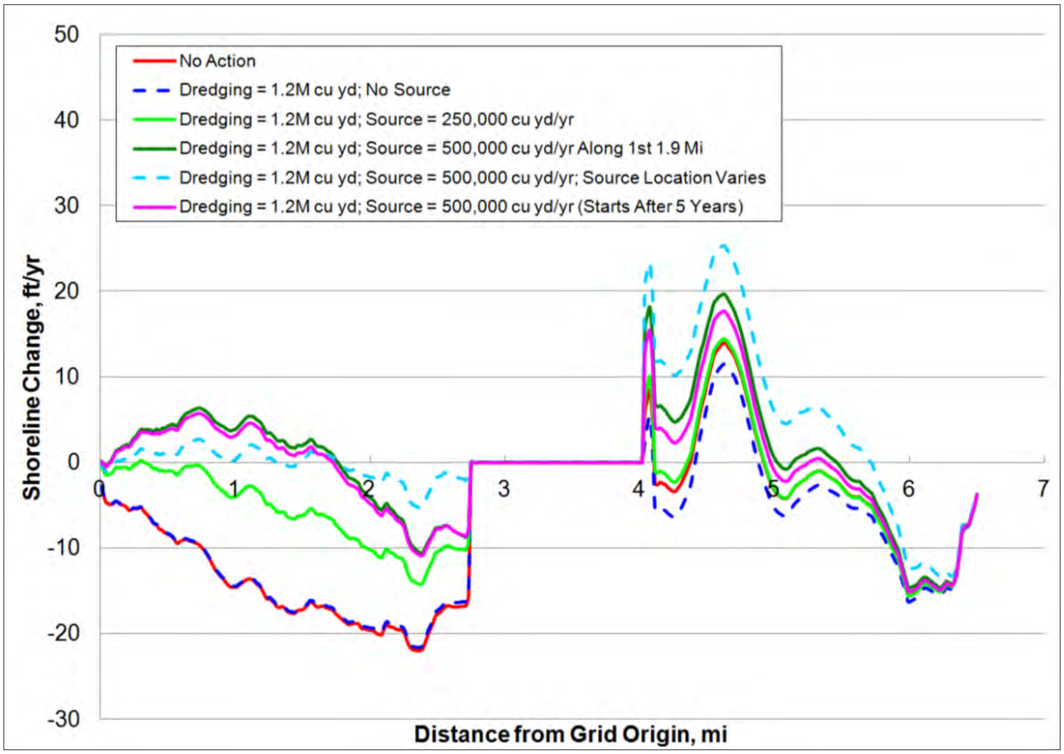

Figure 24. Shoreline change (ft/yr) after dredging 1,200,000 yd^3 after 33 years.

In addition, to represent more realistic conditions of sand moving along the beach, two other alternatives were modeled which adjusted cells associated with the source term. For the first year, the source term was applied to the first mile of the simulation. During the fifth year, the source term was applied over the first five miles. Once the source term reached the end of the GenCade grid, the source term was applied over the entire domain for the remaining years in the simulation. These two alternatives (100,000 and 250,000 yd^3/yr) are compared to the No Action case and the dredging alternatives without a source term after 10 and 33 years (Figure 25 and Figure 26). After 10 years, the shoreline advances (grows) up to 120 ft (12 ft/yr) beyond the No Action case to the north of the inlet. South of the inlet, all cases experience slightly more erosion than the No Action case directly adjacent to the inlet, but further from the inlet, the shoreline position of the alternatives becomes more landward. After 33 years, all locations along the shoreline experience an advance compared to the No Action case except directly south of the inlet when sand is dredged and no source term is added (beach nourishment from Long Beach Island is not considered). When 250,000 yd^3/yr is added to the shoreline, the shoreline position directly downdrift of the inlet is landward of the initial shoreline.

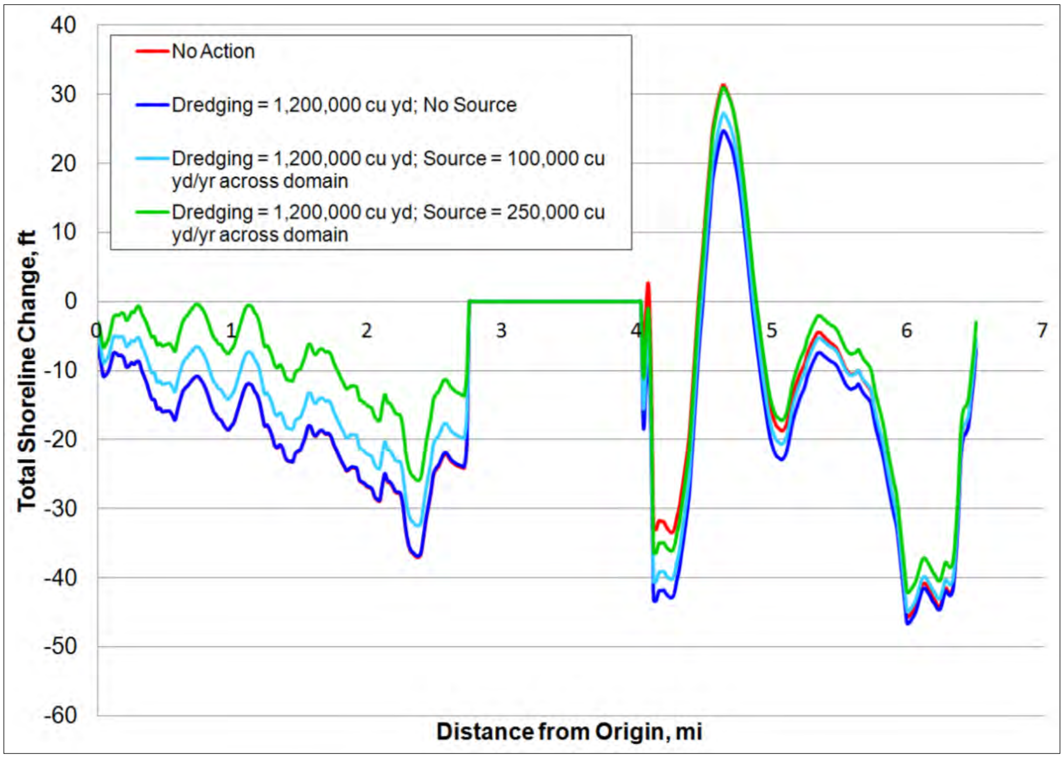

Figure 25. Shoreline change (ft/yr) after dredging 1,200,000 yd^3 after 10 years.

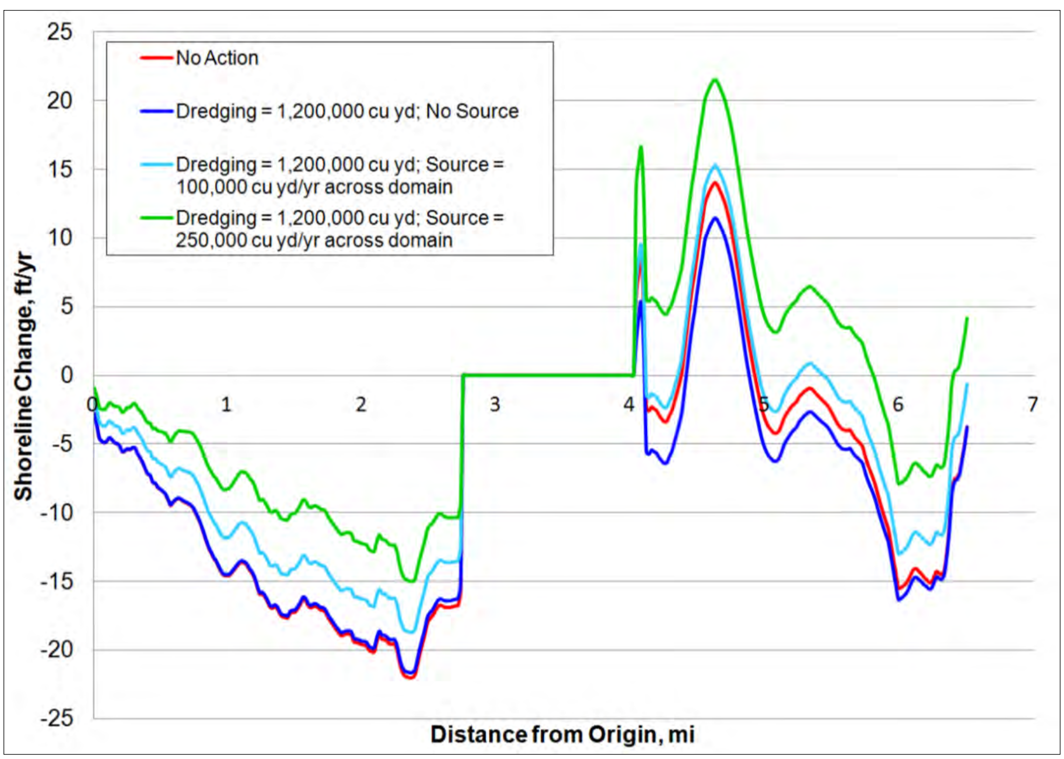

Figure 26. Shoreline change (ft/yr) after dredging 1,200,000 yd^3 after 33 years.

3.4.3 Dredging Alternative 2: 2,200,000 yd^3 at beginning of simulation

Shoreline change results (in ft/yr) after initially dredging 2,200,000 yd^3 are shown in Figure 27 (after 10 years for most modeled scenarios), Figure 28 (after 33 years for most modeled scenarios), Figure 29 (after 10 years for the smaller source term scenarios across the entire domain), and Figure 30 (after 33 years for the smaller source term scenarios across the entire domain). The results when smaller source terms are placed along the entire GenCade domain are separated from the larger source terms, because they might be more realistic and it is easier to view the results without all of the other alternatives in the same figures. The same trends as the 1,200,000 yd^3 dredging are observed. After 10 years, the alternatives experience shoreline advance compared to the No Action case updrift of the inlet. However, downdrift of the inlet, after 10 years, the dredging cases predict more erosion than the No Action alternative. While it is expected that a large volume of sand will move towards Little Egg Inlet after construction of the beach fill, it is not known how quickly and how much sand will move into the vicinity of Little Egg Inlet. In the modeling alternatives, sand is added to specific cells and then is transported based on the waves and the longshore transport calibration coefficients (K1 and K2). If sand moves along the shoreline more quickly than in the simulations, the shoreline directly downdrift of the inlet will receive sand earlier. For this reason, in the second set of simulations, the source term is adjusted to include all cells after 7 years. After 33 years, all of the cases with source terms calculate shoreline advance (compared to the No Action case) to the northeast of the inlet. The only alternatives that erode more than the No Action case to the south of the inlet are the dredging case without a source or when introducing a source of 250,000 yd^3/yr. Most of the alternatives show a large shoreline advance for the first two miles along the domain and then the shoreline recedes near Little Egg Inlet. This indicates that sand is staying within these cells and only a small percentage is moving alongshore. In the case of the light blue dashed line, a source term is added to the first 1.9 mi of the domain. After 10 years, this source term is expanded to include the first 2.7 mi. For the last 13 years, the source term is applied to the first 5.7 mi of the domain (excluding the inlet). Sand will continue moving along the shoreline instead of settling updrift of the inlet. It is possible that the sand might move more quickly and fill most of the ebb shoal and move south of the inlet faster than the simulations predict.

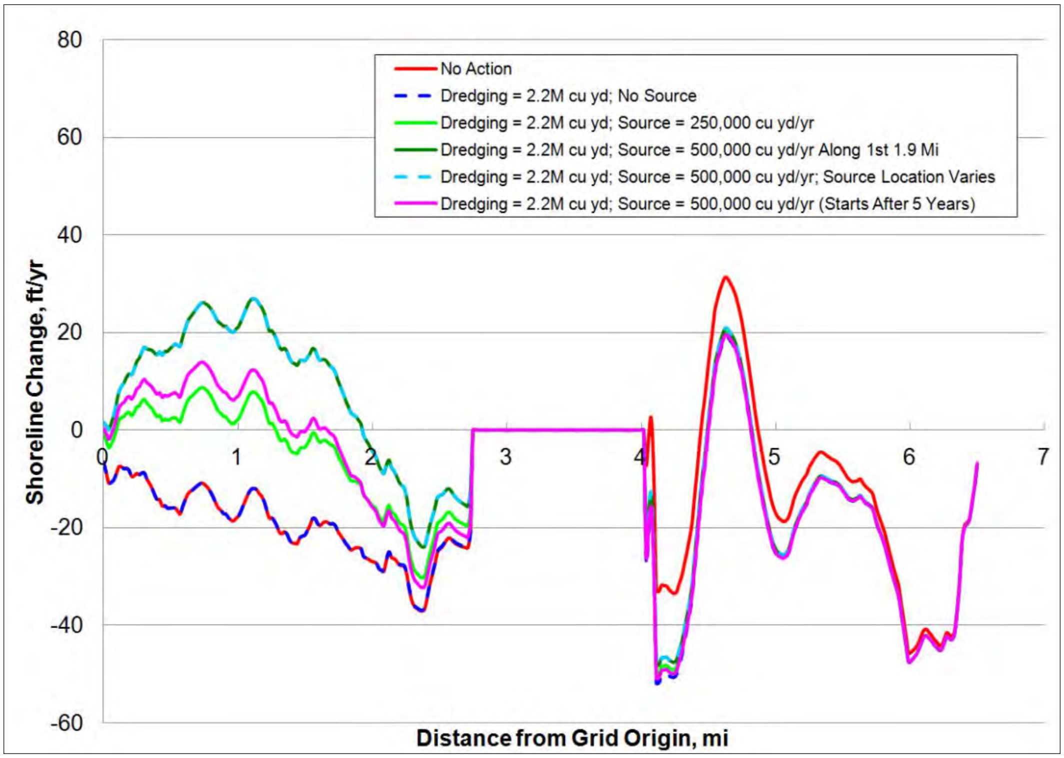

Figure 27. Shoreline change (ft/yr) after dredging 2,200,000 yd³ after 10 years.

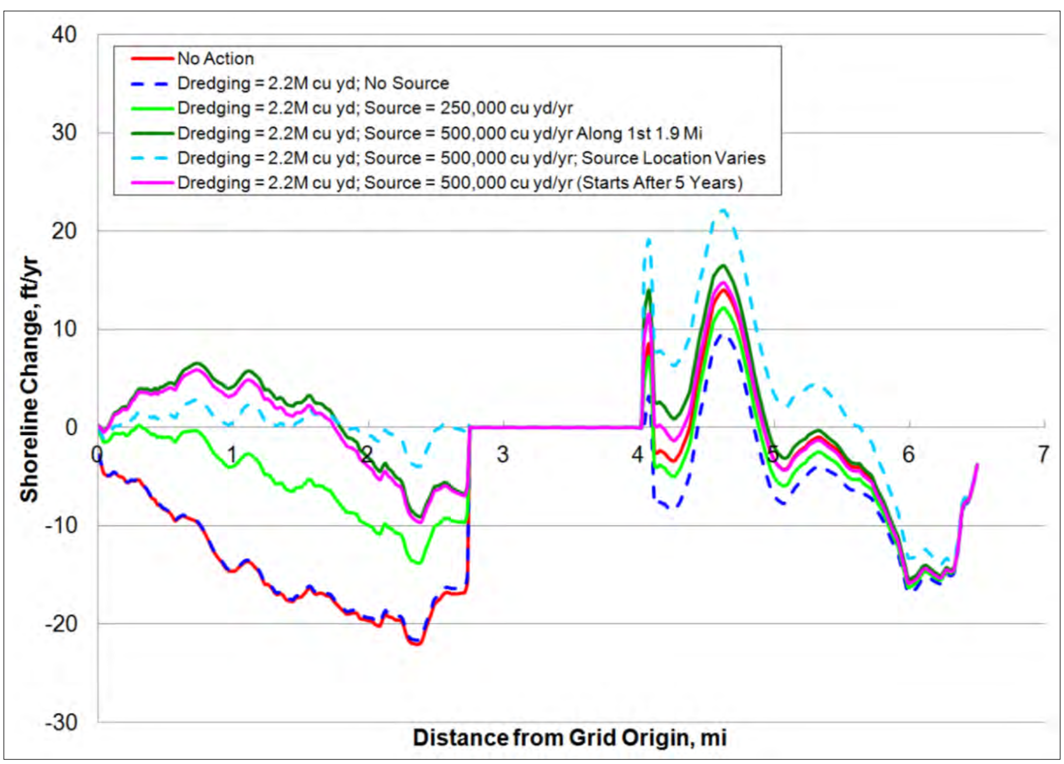

Figure 28. Shoreline change (ft/yr) after dredging 2,200,000 yd^3 after 33 years.

In order to provide more details about the source terms across the entire domain, these alternatives have been separated in next set of figures. Figure 29 shows the total shoreline change (ft/yr) after 10 years. The shoreline positions north of the inlet are almost identical to those in which 1,200,000 yd^3 were dredged. Directly south of the inlet, the alternatives predict more erosion than the No Action case. This is because 2,200,000 yd^3 was removed from the inlet, and the ebb shoal is attempting to recover and capture more of the sand moved by longshore transport. As the ebb shoal recovers, the shoreline downdrift of the inlet recedes less with a source term of 250,000 yd^3/yr compared to the No Action case. It is also important to note that the initial and equilibrium volumes specified in the model are based on rough estimates from the inlet bathymetry. If the initial volumes are greater or the equilibrium volumes are lower, the shoreline downdrift of the inlet will not recede as much as is shown in the figures.

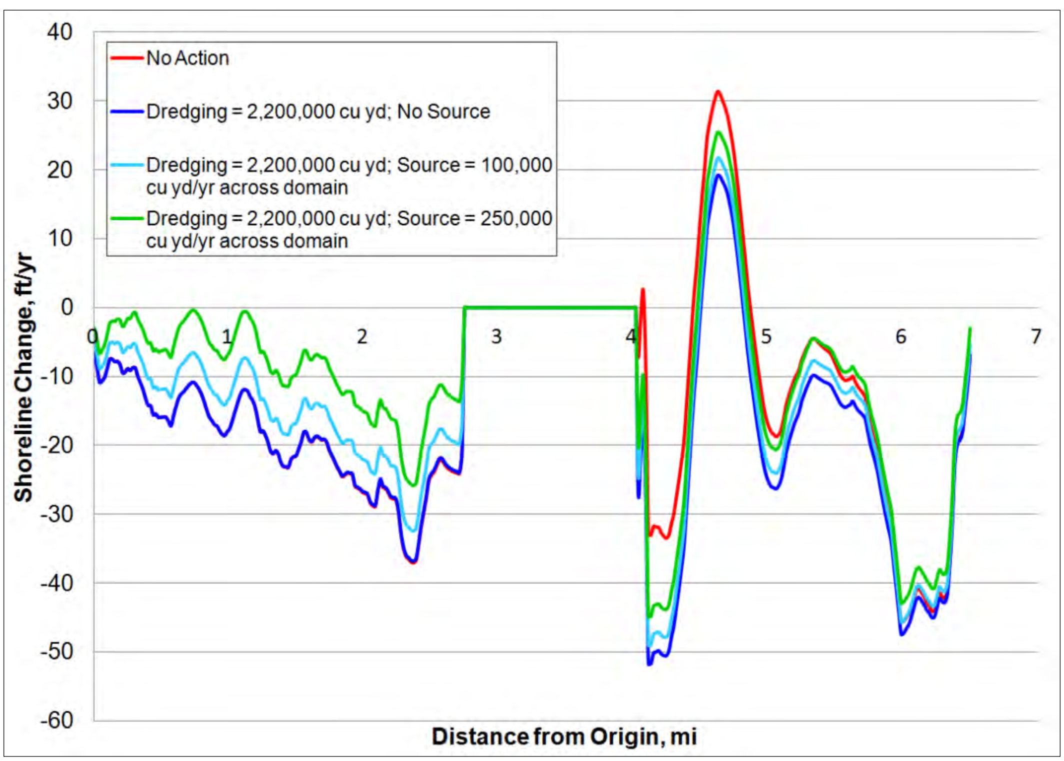

Figure 29. Shoreline change (ft/yr) after dredging 2,200,000 yd^3 after 10 years.

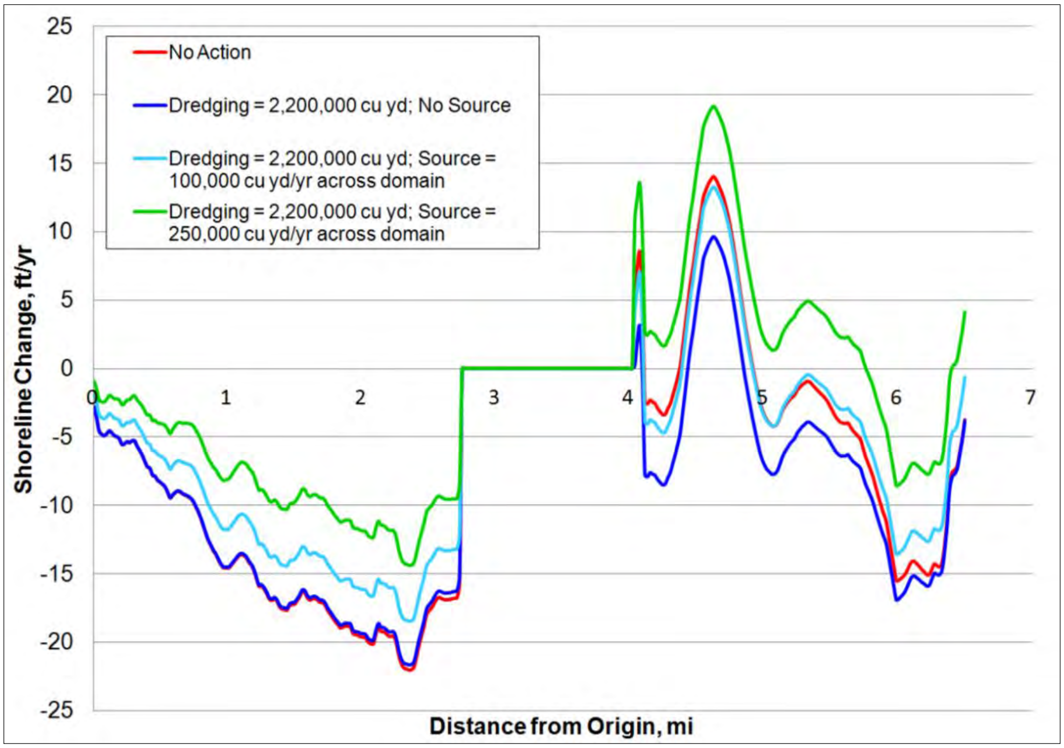

Figure 30. Shoreline change (ft/yr) after dredging 2,200,000 yd^3 after 33 years.

3.4.4 Dredging Alternative 3: 3,000,000 yd^3 at beginning of simulation

The third set of alternatives involves initially dredging 3,000,000 yd^3 from the inlet at the onset of the each simulation. Figure 31 and Figure 32 show the model results in ft/yr after 10 and 33 years, respectively. Similar to the previous cases, the majority of the sand remains on Long Beach Island after 10 years and the alternatives show erosion to the south of Little Egg Inlet. After 33 years, almost every case shows advance compared to the No Action case along the entire domain. The blue dashed line shows the most advance in the vicinity of the inlet, because the source term is varied along the shore over the simulation period.

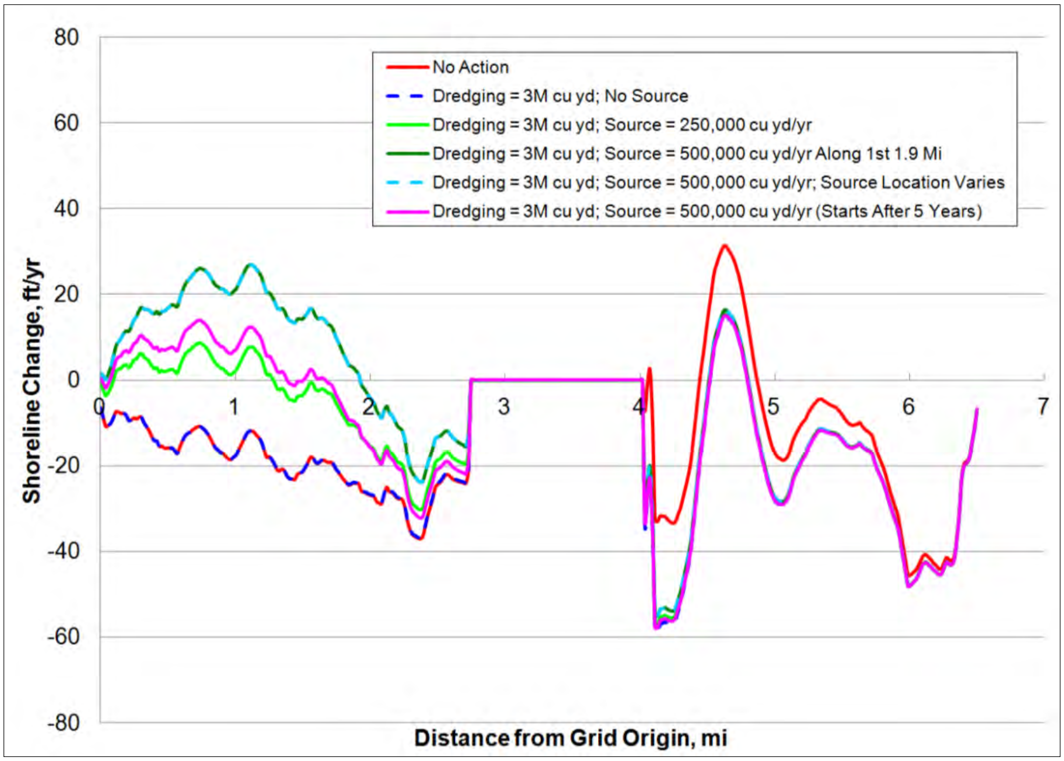

Figure 31. Shoreline change (ft/yr) after dredging 3,000,000 yd³ after 10 years.

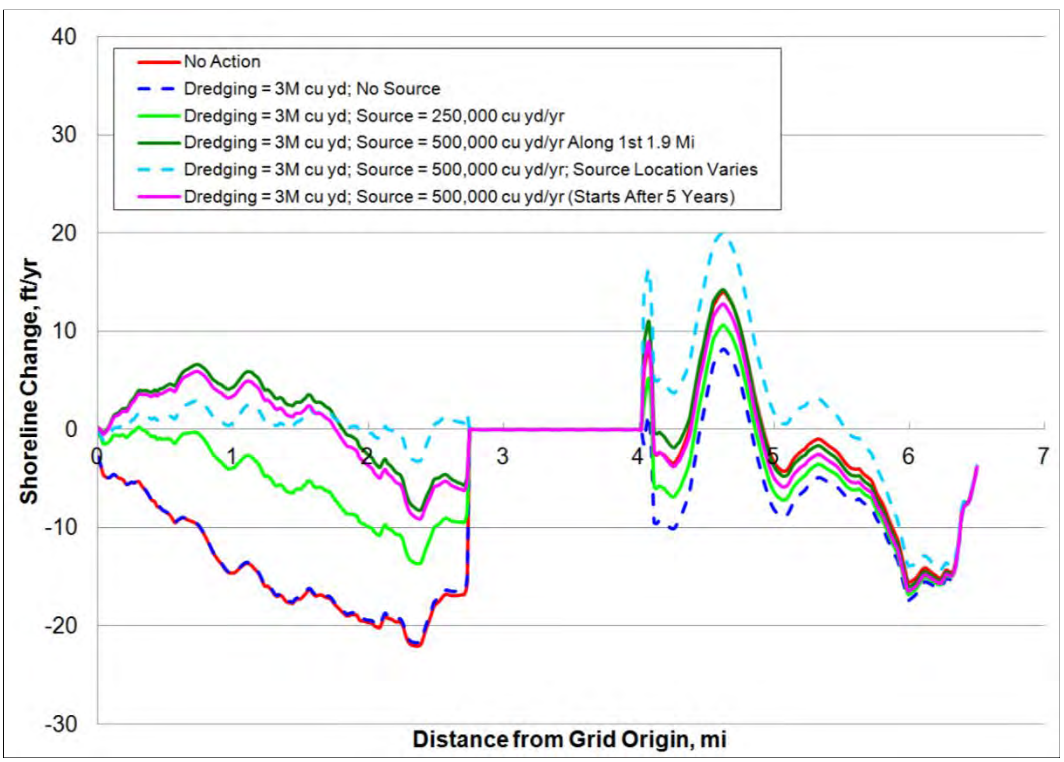

Figure 32. Shoreline change (ft/yr) after dredging 3,000,000 yd^3 after 33 years.

Similar to the previous dredging alternatives, the alternatives with the source term applied across the domain are shown separately from the other alternatives (Figure 33 and Figure 34). After 10 years, all of the dredging alternatives show a significant amount of erosion compared to the No Action case. This is to be expected when dredging 3,000,000 yd^3 during a single event. However, Figure 34 shows that the ebb shoal has begun to recover, because the shoreline when using a source term of 250,000 yd^3/yr is further seaward than the No Action case along the entire domain. Also, the volume of the ebb shoal is greater at the end of the simulation than the initial ebb shoal volume. When applying a source term of 100,000 yd^3/yr, the shoreline is similar to the No Action case along most of the domain.

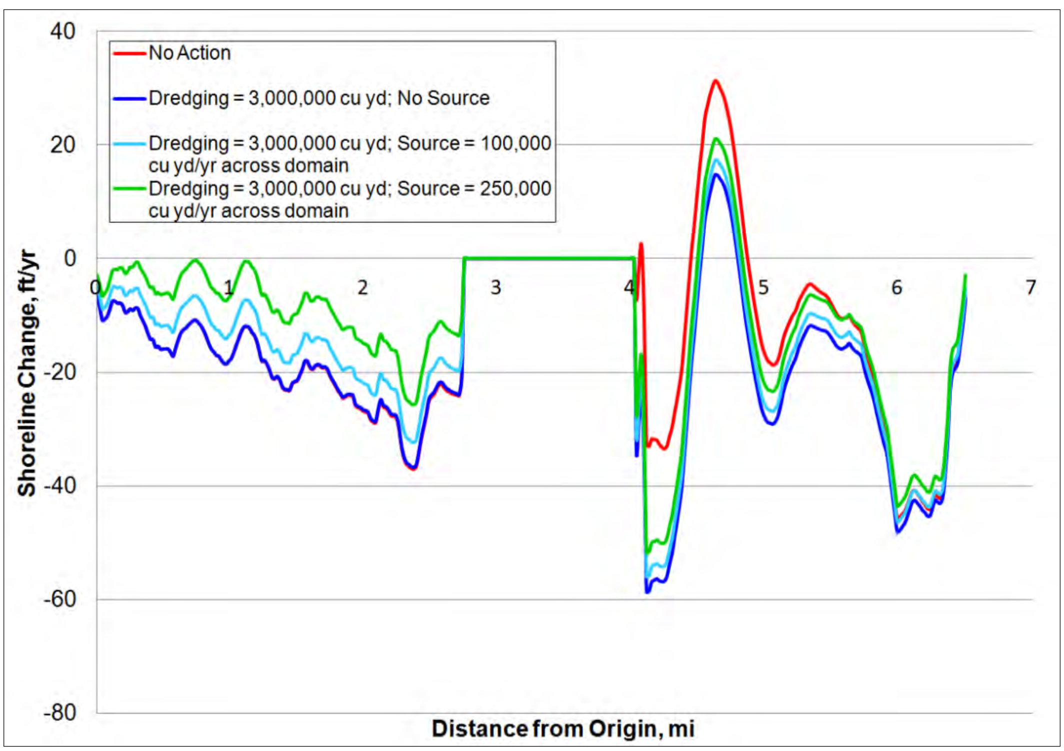

Figure 33. Shoreline change (ft/yr) after dredging 3,000,000 yd^3 after 10 years.

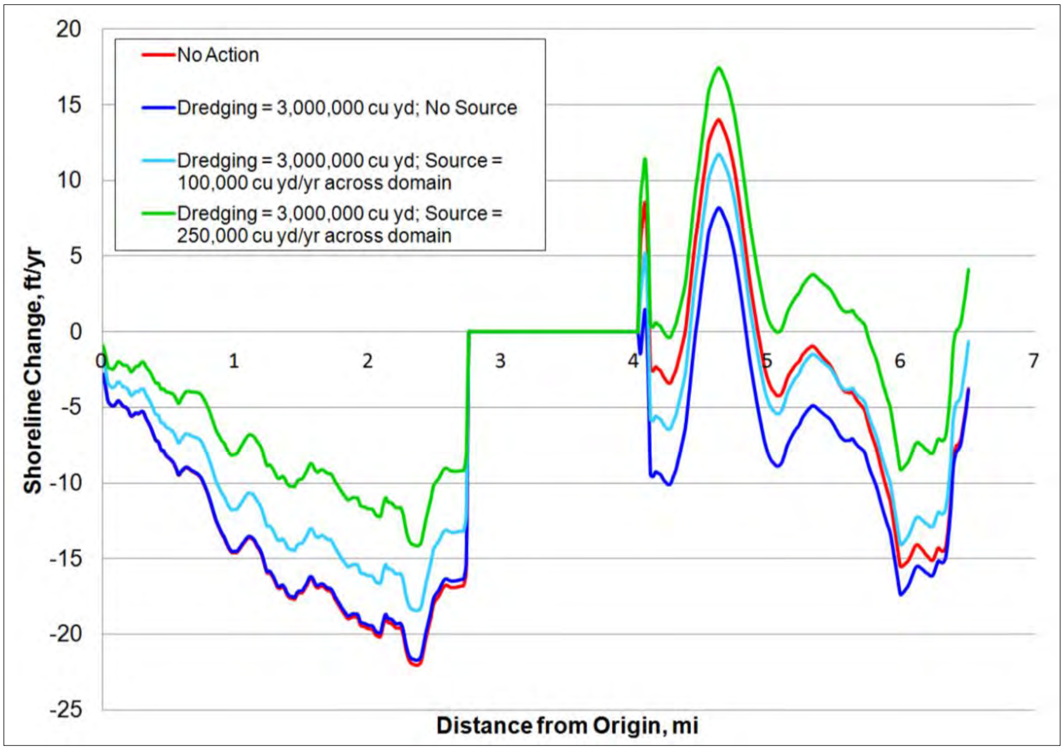

Figure 34. Shoreline change (ft/yr) after dredging 3,000,000 yd^3 after 33 years.

3.4.5 Dredging Alternative 4: 1,000,000 yd^3 every 7 years

The last alternatives remove 1,000,000 yd^3 from the inlet every 7 years. Seven years is the authorized project's interval, so these alternatives are more realistic than the first three sets. Shoreline change results (ft/yr) after 10 and 33 years are shown in Figure 35 and Figure 36. After 10 years, there is a slight amount of erosion for all cases compared to the No Action case. However, as the sand continues to move along the shore, it is less likely the adjacent beaches will retreat compared to the No Action alternative. For example, after 33 years, when a source term is added further along the shore every 10 years, advance is predicted along the entire domain.

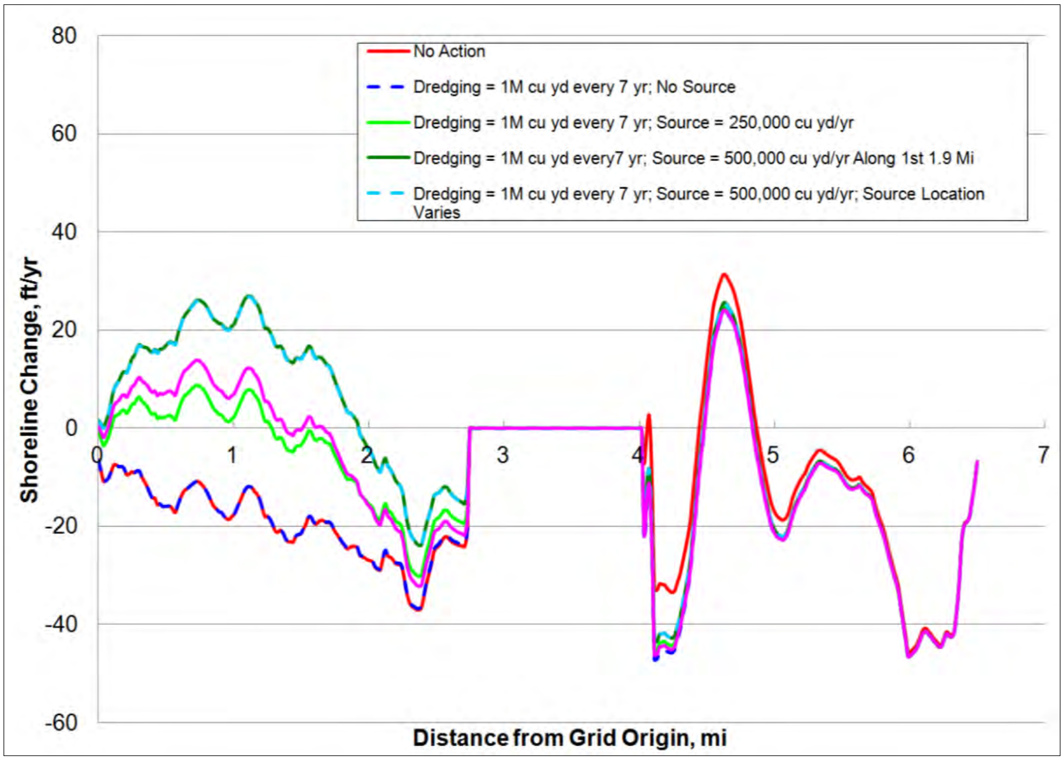

Figure 35. Shoreline change (ft/yr) after dredging 1,000,000 yd^3 every 7 years after 10 years.

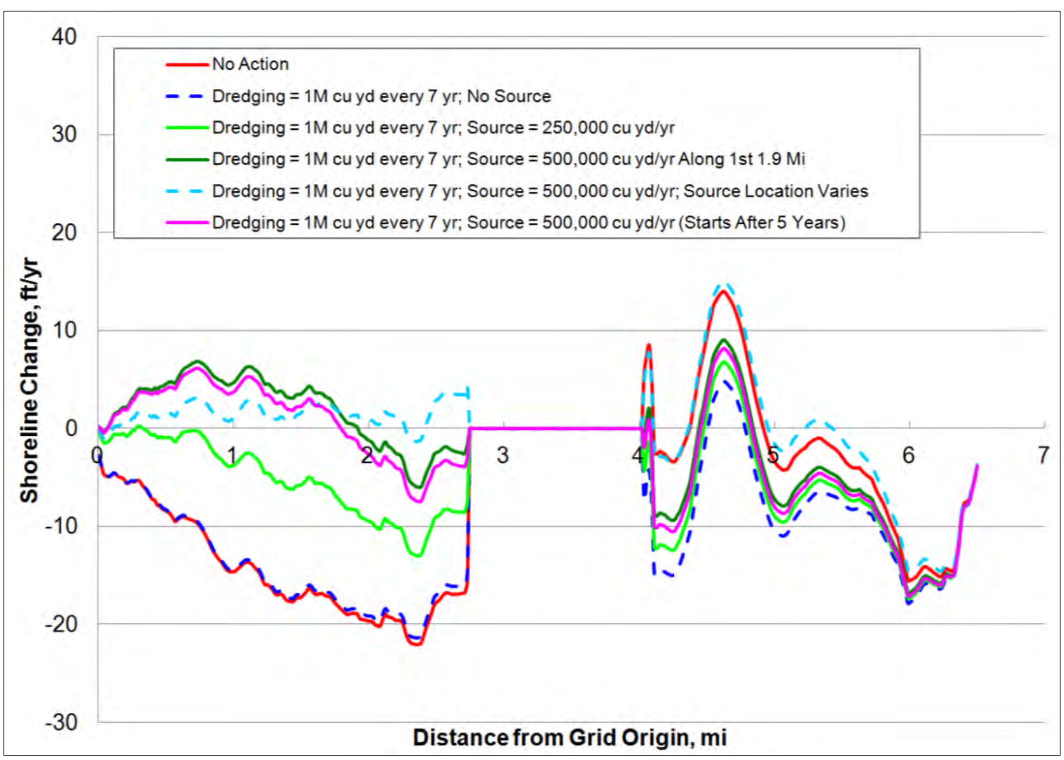

Figure 36. Shoreline change (ft/yr) after dredging 1,000,000 yd[3] every 7 years after 33 years.

Figure 37 and Figure 38 provide results for alternatives that are most similar to future dredging and beach fill construction. It is more likely that Little Egg Inlet will be dredged many times on a dredging interval at a lower quantity rather than dredging it one time. Also, applying the source term to only the first mile after the first year and adjusting it to include the entire domain after 7 years is probably similar to how sand from the Long Beach Island will move into the Little Egg Inlet area. After 10 years, the shoreline directly downdrift of the inlet for the No Action case will recede the least compared to the other alternatives. However, this only occurs for a very short stretch of the shoreline. It is possible that the inlet might migrate over time, and the GenCade results directly adjacent to the inlet might not be relevant if that happens. After 33 years, a total of 5,000,000 yd^3 of sand has been removed (five dredging events) from the inlet through dredging. In order for the ebb shoal to recover, it must capture a percentage of the transported sand. Some of the sand is trapped in the inlet system; therefore, there is a slight retreat of the shoreline adjacent to the inlet. Finally, when 250,000 yd^3/yr is used as a source term, after 33 years, the shoreline is equal to or landward of the No Action case except for a small section of the coast immediately to the south of the inlet.

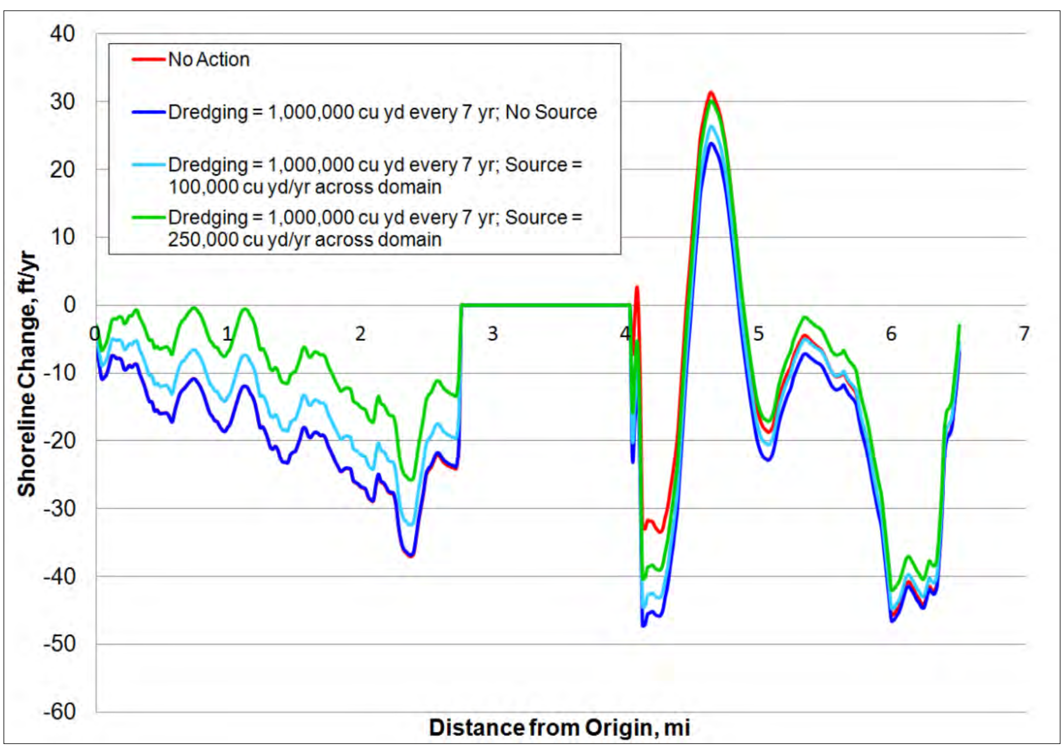

Figure 37. Shoreline change (ft/yr) after dredging 1,000,000 yd^3 every 7 years after 10 years.

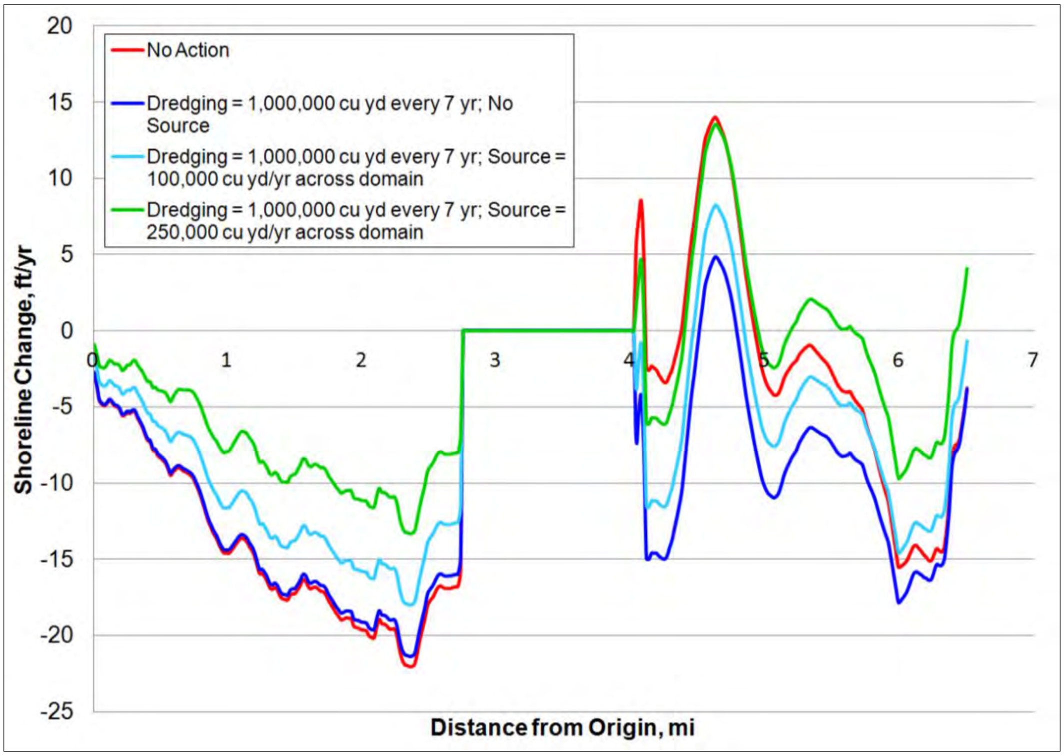

Figure 38. Shoreline change (ft/yr) after dredging 1,000,000 yd^3 every 7 years after 33 years.

3.4.6 Little Egg Inlet shoal evolution

One of the most important factors of whether or not the shorelines adjacent to Little Egg Inlet are impacted is the shoal evolution of the inlet. After dredging, if the inlet captures most of the sediment removed during dredging, the adjacent shorelines will erode. While the shorelines adjacent to Little Egg Inlet may erode slightly initially, once the sand from the Long Beach Island project moves to the south, the shorelines should no longer experience adverse effects.

The ebb shoal evolution for selected alternatives is shown in Figure 39. The ebb shoal in the No Action case continues to grow through the entire simulation, and the final ebb shoal volume increases to 12.275 million yd^3 after 33 years. Because the ebb shoal was not in equilibrium (the initial volume was not equal to equilibrium), the ebb shoal will continue to grow until it reaches equilibrium. Therefore, over the 33 year period, more than 3,000,000 yd^3 were captured in the ebb shoal and removed based on the longshore transport from the updrift beach. When 1,000,000 yd^3 is dredged from the inlet at the beginning of the simulation, the ebb shoal volume almost immediately decreases to 8.17 million yd^3. After 33 years, the shoal volume grows to 12,000,000 yd^3, so the ebb shoal increased by almost 2,900,000 yd^3 after dredging. Therefore, when including the volume removed from the inlet that was replenished, the ebb shoal gained almost 3,900,000 yd^3 and removed this volume from the rest of the system. Using a source term that varied along the domain over time caused the least impact near the inlet. After dredging was completed, the ebb shoal in this alternative gained close to 4,000,000 yd^3. However, because the sand has already moved down the beach and the increase of sand is experienced around the inlet, the greater volume being captured by the inlet does not cause an adverse impact to the adjacent beaches. As expected, when 3,000,000 yd^3 was removed from the inlet at the beginning of the simulation, the ebb shoal needed to capture a greater volume of sand to recover. It takes more than 10 years for the calculated shoal volume to equal the initial shoal volume. It takes between four and seven years for the shoal to recover (where the calculate shoal volume is equal or greater than the initial shoal volume) when 1,200,000 or 2,200,000 yd^3 are dredged. After an initial dredging of 3,000,000 yd^3, the ebb shoal gains nearly 6,000,000 yd^3 of sand. However, after 33 years, in both cases where 3,000,000 yd^3 were dredged, the ebb shoal was slightly smaller than the other ebb shoals in the other cases. Finally, dredging 1,000,000 yd^3 every 7 years is the most realistic option, because it represents the expected dredging interval. During the 33 year simulation, there are five dredging events (total of 5,000,000 yd^3 removed). Immediately before each dredging event, the ebb shoal recovers so that the volume is slightly more than the initial volume in that cycle. For example, after 7 years, the ebb shoal increases to 9.5 million yd^3, meaning that the ebb shoal captured a total of 1,300,000 yd^3 after the first dredging. The ebb shoal volume at the end of the 33 year simulation is about 10.35 million yd^3. Considering the 5,000,000 yd^3 removed over the course of the simulation, a total of 6.18 million yd^3 was transport from the adjacent shorelines and deposited in the ebb shoal. Although the 7 year interval alternative captured the most sand, the dredging was done incrementally and gave the ebb shoal time to recover. Because of the likely ebb shoal recovery and the additional sand within the system, dredging 1,000,000 yd^3 within the inlet's ebb shoal every 7 years should not adversely affect the adjacent shorelines.

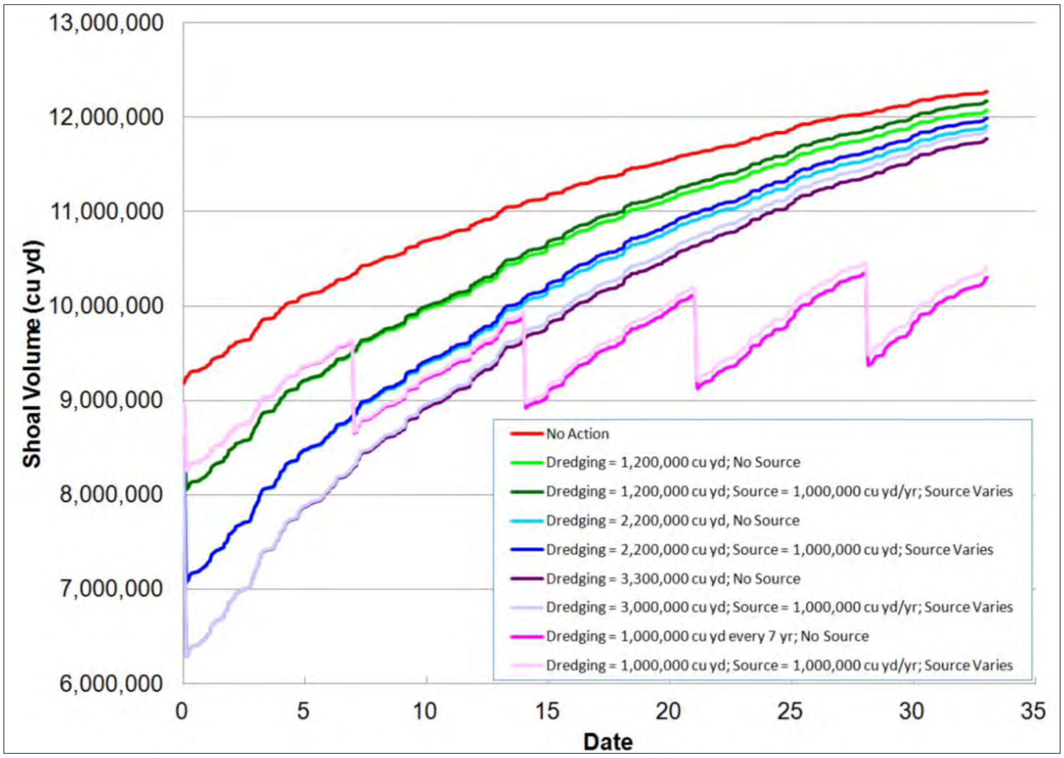

Figure 39. Ebb shoal evolution over 33 years.

3.5 GenCade Model Results

Based on the GenCade numerical modeling results, it is not expected that a small dredging event (~1,000,000 yd^3) every 7 years will adversely affect beaches adjacent to Little Egg Inlet as long as beach nourishment is placed along Long Beach Island to the north and the sand moves to the south, as expected. There are a number of variables that cannot be quantified in GenCade, so the purpose of this exercise is to produce an analysis of several alternatives compared to No Action. While the model was calibrated for this study, it is possible that the future conditions for long-term shoreline trends could change (even though it is an assumption of the model). Additionally, there are two unknowns at this time: the actual shoal volumes of the inlet at present compared to equilibrium volumes and the rate and volume of the sand that moves into the domain from the Long Beach Island beach nourishment project. Shoal volumes were estimated from incomplete inlet surveys. If comprehensive recent and historical bathymetry of the inlet and morphological units were available, a better estimate of initial and equilibrium volumes could be made. If the equilibrium volumes were less and/or the initial volumes were greater, less sand would be trapped in the inlet shoals. Finally, it is expected that a large volume of sand will move into the Little Egg Inlet area. It is not known how long it will take for this to occur or what volume will be added. The best way GenCade can take into account additional sand moving into a GenCade domain is through a source term. The source term adds volume to each cell specified by the user. However, one difficulty in the GenCade modeling was determining which cells should receive the source term. It appears that when the source term is constant (by cells and volume) throughout the simulation and concentrated in specific cells rather than the entire domain, a large percentage of the sand stays in those cells and does not move further down the coast. Therefore, it is reasonable to expand the source term to a greater number of cells further along the shoreline while keeping the total volume the same as the other examples. This ensures that sand is continuing to move along the domain. Although there are limitations within this model, the results do show that as long as sand moves into the Little Egg Inlet area from the Long Beach Island beach nourishment project, dredging Little Egg Inlet should not dramatically impact the adjacent shorelines. If the beach fill occurs and a large amount of sand moves into the vicinity, modeling shows that no adverse impacts to the shoreline are expected.

4 Summary

Numerical modeling studies were conducted in order to assess the impacts of potential borrow area scenarios at Little Egg Inlet, New Jersey. Consequences of the borrow area scenarios were evaluated in terms of normalized wave energy density changes and anticipated shoreline changes. The STWAVE and GenCade modeling efforts did not yield significant impacts for any of the scenarios modeled for this study.

In total, six potential borrow scenarios were evaluated with the nearshore numerical wave model, STWAVE. The potential borrow scenario volumes ranged from 1.2-3 million yd^3. STWAVE numerical modeling results showed that normalized wave energy densities were impacted by a maximum of +/-10 percent along the adjacent shorelines as a result of the Little Egg Inlet potential borrow area scenarios.

Four dredging scenarios, in addition to the No Action scenario, were numerically modeled with GenCade. Scenarios #1-3 involved a one-time-only removal of 1.2-3 million yd^3 of sand from Little Egg Inlet. Scenario #4 involved a periodic removal of 1 million yd^3 of sand every 7 years from Little Egg Inlet. GenCade numerical modeling results showed that as long as large volumes of sand move into Little Egg Inlet area from Long Beach Island to the north, the potential dredging scenarios will not significantly impact the adjacent shorelines.

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March 4, 2016

Virginia Rettig, Refuge Manager
U.S. Fish and Wildlife Service
Edwin B. Forsythe National Wildlife Refuge
Oceanville, NJ 08231

Dear Ms. Rettig,

Thank you for providing the U.S. Geological Survey (USGS) with the opportunity to comment on the Army Corps of Engineers report entitled "Borrow Area Analysis at Little Egg Inlet, New Jersey". A team of geoscientists from the USGS conducted a thorough review of the document, and found that while the methods appear internally consistent, the validity of many of the model assumptions are not tested. There also appeared to be limited testing of model sensitivity to these assumptions, which would likely change the outcome of the results. In this review, we include an overview of our major findings, deficiencies, observations, and recommendations.

Thank you again for the opportunity to provide input on this important document. We look forward to further collaboration between our agencies.

Sincerely,

Walter Barnhardt, Director
USGS Woods Hole Coastal and Marine Science Center
Woods Hole, MA 02543

USGS evaluation of Frey et al., "Borrow Area Analysis at Little Egg Inlet, New Jersey"

N.K. Ganju[1], P.S. Dalyander[2], J.H. List[1], and N.G. Plant[2]
[1]Woods Hole Coastal and Marine Science Center
[2]St. Petersburg Coastal and Marine Science Center

Summary

We have reviewed the methods, results, and conclusions of the USACE report entitled "Borrow Area Analysis at Little Egg Inlet, New Jersey". The report presents the results of two modeling components used to quantify the likely impacts of dredging scenarios: (1) STWAVE to estimate the changes in wave energy distribution, and (2) GenCade to estimate likely impacts of the dredging on shoreline change. Because wave model output are provided to GenCade seaward of the proposed dredging sites, the longshore transport rates in GenCade do not change in the model in response to alterations to the bathymetry as they would in the real system, and the impacts to waves and shoreline change are therefore considered independently in the report. The report's abstract summarizes the study approach and presents three major statements based on the study. These statements are (1) a primary **result** that dredging would cause less than a 10% change to the average wave energy in the inlet region; (2) an **assumption** that large volumes of sand move into the inlet; and (3) a primary **conclusion** that dredging would not significantly impact the shoreline in the inlet vicinity.

In response to the final FWS comment ("Response to Planning Aid Report Comments", pg. 3) concerning impacts to the wilderness area: the most likely impact of removing significant volumes of sand from the Little Egg Inlet ebb-tidal delta will be erosion of the down-drift beach, which is part of the wilderness area. There is evidence, in the form of inlet bypassing bars which are welding onto the south beach, that the volume of sediment in the ebb-tidal delta complex is in equilibrium with the tidal prism, and when averaged over the long-term, the amount of sediment bypassing the inlet to nourish the down-drift beach is likely to be similar to what is entering via alongshore transport from the north. If part of the ebb-tidal delta is removed, the inlet bypassing will be reduced until the ebb-tidal delta volume is again at an equilibrium volume, with the sediment delivered by the long-term net alongshore transport towards the south. It cannot be assumed that there will be an accelerated rate of sediment delivery to the inlet because the beach 2.5 miles (and farther) updrift of the inlet has been renourished (having to do with the "source term" – see below).

The abstract states that the modeling efforts did not yield significant impacts for any of the scenarios modeled for this study. It is unclear what criteria are used to determine whether an impact is significant or insignificant. If a 10% change in wave energy, a key result, is considered insignificant, there needs to be some quantification of what this change means for alongshore transport gradients and/or shoreline change. It is possible that a small but persistent impact on the wave field over the shoal could lead to a significant impact to the inlet and shoreline over the longer time intervals considered by this study. This effect could have been evaluated, if the study had explicitly considered the influence of wave transformation over the modified shoal on alongshore sediment flux or shoreline change. However, STWAVE model output was extracted from points seaward of the ebb shoal, so wave transformation over the shoal and borrow pit are not considered in the modeling.

GenCade numerical modeling results showed that as long as large volumes of sand move into Little Egg Inlet area from Long Beach Island to the north, the potential dredging scenarios will not significantly impact the adjacent shorelines. This result is dependent on the assumption of a “source term,” an additional sand source that is added to specific segments of the shoreline, or to the entire modeling domain (Table 7), following the renourishment of Long Beach Island. The justification for adding this source term appears to be that the renourishment will accelerate the delivery of sand to the south. However, the GENESIS model part of GenCade should already predict the alongshore transport rate and delivery of sand to Little Egg Inlet, both before and after the beach renourishment. The processes by which this transport would be accelerated following renourishment, and why GENESIS is unable to model this increase, are not explained. Without the addition of a source term, the GenCade results do predict downdrift beach erosion, which is consistent with the inlet equilibrium concept, as described above (Fig. 38, no source case).

Finally, the study concludes that neither the wave energy impacts nor the sediment redistributions associated with any of the dredging alternatives would have a significant impact. The model framework relies on the previously mentioned simplification of considering wave impacts and shoreline change independently; an assumption regarding sand transport from another nourishment projects; and calibration factors (such as shoal volumes) that had to be tuned rather than independently calculated. There should be clear metrics for determining significance that encompasses the simultaneous response of the waves to a borrow sites, the interaction of this wave response on sediment transport near the shoreline, and the shoreline response. The impact of key assumptions and calibration factors on these metrics should also be explicitly considered. Additional model evaluation, requiring observations of actual sediment source behavior, is required to assess the validity of the sediment source assumptions. Additional model sensitivity studies could also evaluate the likelihood of finding a significant impact (once significance is defined) given uncertainty in the GenCade calibration parameters.

Additional specific issues

Nearshore wave modeling

The Little Egg Inlet (LEI) NAP grid appears to be forced on the offshore boundary. It should probably be nested within the NACCS grid. If not nested, swell from directions that are not normal to the offshore boundary will likely underestimated due to shadowing and this will decrease the sensitivity of the domain to modifications.

The wave model validation section refers to the NACCS validation from a separate study. Because of the point mentioned above, that validation may not be applicable to the LEI simulations. Then, because the LEI simulations focus on impacts over the shoal and in the inlet, new data are probably required to evaluate the performance where it matters for this study.

Vegetated shorelines

A 10% increase in wave energy density along vegetated estuarine shorelines (such as that near the Tuckerton Field Station 39.51 N, -74.31 W) will likely lead to a linear increase in erosion (Leonardi et al., 2016). In fact, this is one of the most rapidly eroding shorelines in Barnegat Bay, and this modeling indicates that at least a few of the scenarios lead to increased wave energy density at that location (e.g. Fig. 11, 15, 16).

Shoreline-change modeling

The wave input is taken from stations offshore of the borrow area, so the modeling study did not account for the changes in the shoal due to dredging that were modeled with STWAVE. That is, there was no explicit wave transformation over shoal to feed in to shoreline change modeling.

The “regional shoreline contour” seems to predispose the model to recreate the historic shoreline change. We believe that this approach is intended to represent very long-term sediment transport processes that affect large-scale shoreline curvature that may not be resolved by GenCade. The “regional contour” was taken as the average of three shorelines, 2002, 2007, and 2012 and this regional shoreline will be approximately equal to the 2007 shoreline and on any section of coast with a long-term trend in shoreline position from 2002 to 2012. A simulation from 2002 to 2007 that requires a return to the regional contour, as appears to be the case with GenCade, will necessarily resemble the 2007 shoreline. GenCade may be overtuned to predict the 2007 shoreline and the similarity between observed and modeled shoreline change in Fig. 20 may reflect overtuning rather than providing evidence of model skill.

Inlet flow dynamics

The analysis does not consider changes to inlet cross-sectional area and friction, and how that will affect flows in/out of Great Bay. For instance, changes in tidal dynamics due to dredging could affect salinity in the Great Bay/Mullica River system. This effect can be quantified with one-dimensional classical estuarine models.

References

Leonardi, N., Ganju, N.K. and Fagherazzi, S., 2016. A linear relationship between wave power and erosion determines salt-marsh resilience to violent storms and hurricanes. Proceedings of the National Academy of Sciences, 113(1), pp.64-68.