ERDC/CHL TR-10-4

Coastal and Hydraulics Laboratory

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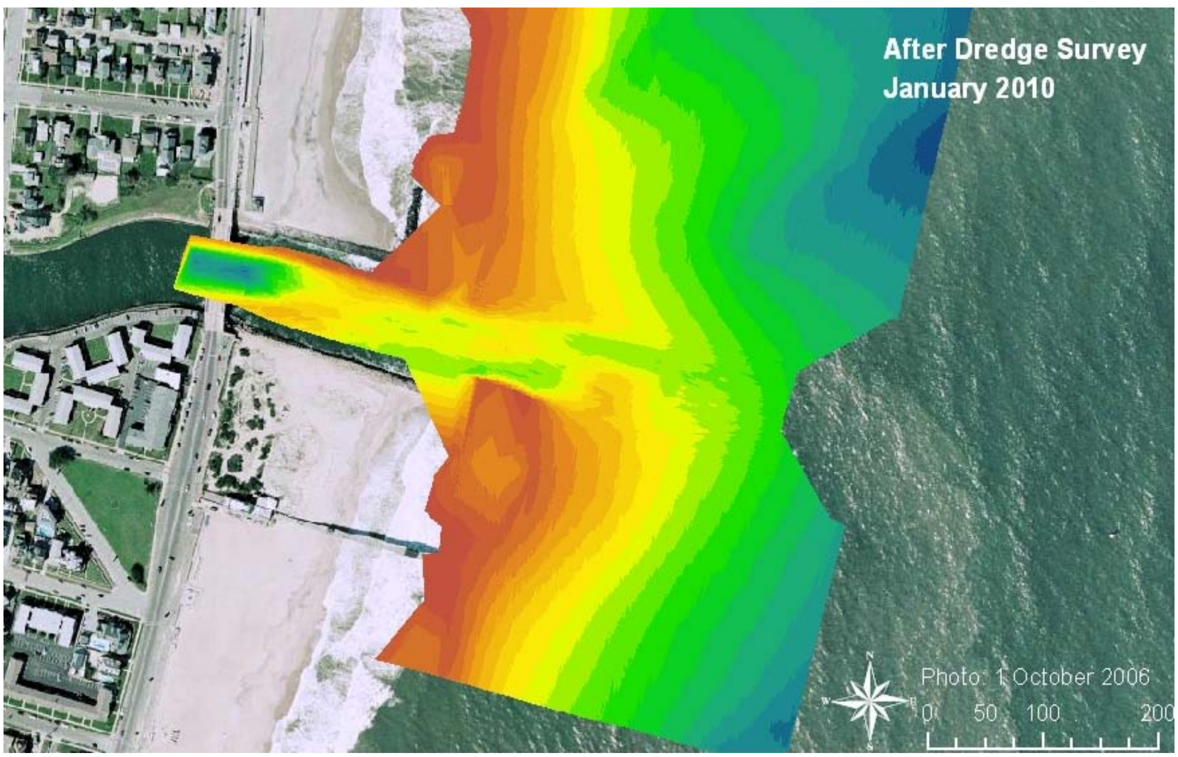
Coastal Inlets Research Program

Shark River Inlet, New Jersey, Entrance Shoaling: Report 2, Analysis with Coastal Modeling System

Tanya M. Beck and Nicholas C. Kraus

July 2010



Shark River Inlet entrance, NJ, New York District after-dredge survey, January 2010

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Final report

Prepared for U.S. Army Engineer District, New York
26 Federal Plaza,
New York, NY 10278-0090

Under Coastal Inlets Research Program

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Abstract: This report, the second in a series, documents a numerical modeling study performed with the Coastal Modeling System (CMS), supported by field data collection, to quantify alternative plans to reduce navigation channel maintenance cost, at Shark River Inlet, NJ. Since about year 2000, channel maintenance dredging requirements at the inlet have increased. Although Shark River Inlet possesses a small back bay, the current through the inlet is strong because of the small width between jetties. In the past century, this coast was sand deficient. With recent beach nourishment projects placed as part of a federal erosion-control program, the longshore sand transport potential along the coast is being met, allowing an ebb-tidal delta to form at the entrance. This delta is expected to increase in volume over the next two decades to reach about 0.92×10^6 m^3. Therefore, the dredging maintenance strategy must transition to one similar to those at other small tidal inlets along the Atlantic Ocean coasts of New Jersey and New York. This study concluded that 30-m channel wideners, a type of advance maintenance, will increase the time required between scheduled maintenance dredging. Other alternatives evaluated were extension of the north jetty to reach the same effective length as the south jetty, and a channel oriented to the northeast, which appears to be the direction of the natural channel under the present jetty configuration. The CMS proved to be a powerful tool for evaluating alternatives for maintaining the navigation channel in the short term and long term.

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Preface

This report documents a quantitative analysis of the sediment shoaling processes at Shark River Inlet, NJ, performed at the request of the U.S. Army Engineer District, New York (hereafter, the New York District). This study follows Report 1 in this series , Technical Report ERDC/CHL-TR-09-7, to determine the cause of the accelerated entrance-channel shoaling and to answer other questions posed by the New York District that include developing alternative operation and maintenance plans for the inlet federal navigation channel.

The study effort was conducted during fiscal year 2010 by staff of the Coastal Inlets Research Program (CIRP), a navigation research and development program of Headquarters, U.S. Army Corps of Engineers. Based on recommendations made in Report 1, the CIRP's Coastal Modeling System (CMS) was applied to gain quantitative understanding of the hydrodynamics and sediment transport processes at the inlet and to evaluate alternatives for increasing the time period between scheduled dredging. The CMS, driven by tide and hindcast waves, was capable of reproducing observed trends in ebb-tidal delta development and changes in volume of notable morphologic features. The modeling system was verified by reproducing observed water levels in the Shark River estuary and current velocity in the inlet. The CMS was then applied to evaluate selected alternatives for reducing dredging frequency in maintaining the inlet navigation channel.

This study was performed by Tanya M. Beck, Coastal Engineering Branch (CEB), Navigation Division (ND), Coastal and Hydraulics Laboratory (CHL), and Dr. Nicholas C. Kraus, Senior Scientist Group, CHL. Dr. Julie Dean Rosati, Flood and Coastal Division, Coastal Processes Branch, CHL, and CIRP Program Manager reviewed a preliminary draft of this document. Information and coordination in support of this study, as well as study review, were provided by New York District personnel Edward Wrocenski, Lynn M. Bocamazo, Adam B. Devenyi, Gerlyn T. Perlas, Jessica Fischer, Joseph Olha, Christina Rasmussen, and John F. Tavolaro. Cooperation of the New York District is acknowledged for willingness to extend the spatial extent of the 9 June 2008 post-dredging survey as an aid in support of to this study. This work was conducted

under the general administrative supervision Dr. Jeffrey P. Waters, Chief, CEB, and Dr. Rose M. Kress, Chief, ND.

At the time of publication of this report, COL Gary E. Johnston, EN, was Commander and Executive Director. Dr. Jeffery P. Holland was Director.

1 Introduction

This study on navigation channel shoaling processes at Shark River Inlet, NJ, was performed at the request of the U.S. Army Engineer District, New York (hereafter, the New York District). The objective was to develop alternatives to reduce the cost of channel maintenance dredging. The study involved gaining understanding of the causes of increased channel shoaling within Shark River Inlet, formation of an ebb-tidal delta where none had existed in the project lifetime, and functionality of the inlet as a sink within a framework of regional sediment management. Channel survey data and bathymetry records were analyzed in a GIS approach, extending work in a previous report (Kraus and Allison 2009) , and the Coastal Modeling System (CMS) was established at the site to interactively calculate the waves, wave-induced current, tidal flow, sand transport, channel shoaling, and geomorphology change including channel shoaling. Short-term field measurements were also made for verification of the tidal current calculation in the CMS.

Until about the year 2000, the ocean entrance to Shark River Inlet required minor, infrequent maintenance dredging (every 7 to 10 years). Subsequent to year 2000, the surveys by the New York District documented increasing shoaling at the inlet entrance, first from the south and then from the north, necessitating unplanned dredging to maintain the navigation channel. Surveys indicate that prior to nourishment of the adjacent beaches starting in the late 1990s, Shark River Inlet lacked an ebb-tidal delta. It was anticipated that channel shoaling would increase slightly after nourishment of the adjacent beaches, but re-establishment of an ebb-tidal delta was not considered. Thus, Shark River Inlet has a large and clear signal with which to examine interacting beach and inlet processes and to test numerical simulation models for predicting morphology change at inlets.

Specific questions posed by the New York District were:

a. What is the cause of the accelerated and rapid shoaling at Shark River Inlet?

b. What short-term strategies can be employed to alleviate excessive channel shoaling and keep the channel clear for as long a period of time as possible?

c. What long-term possible solutions will optimally help to keep the channel clear?

These questions were addressed through operation of the CMS, driven by tide and hindcast waves, which reproduced observed trends in ebb-tidal delta development and changes in volume of notable morphologic features. The modeling system was verified by comparison to the observed water level in the Shark River estuary and current velocity in the inlet. The CMS was then applied to evaluate four alternatives for reducing dredging frequency in maintaining the inlet navigation channel. The alternatives were developed in collaboration with the New York District to answer their questions.

Study area

The regional study area for the northern New Jersey coast extends from Sandy Hook, a 10-km long spit located approximately 30 km to the north of Shark River Inlet, to Manasquan Inlet located 10 km to the south (Figure 1). The coastline is oriented north-south with a few small estuaries or lakes located between the Atlantic Highland bluffs. Sediment, primarily consisting of sand along the nearshore and beach face originates from reworked glacial material and has an average grain size ranging between 0.2 and 0.35 mm. Kraus et al. (1988) found that the average nearshore profile for the Shark River area had a median grain size diameter of 0.26 mm. Tide in the area is predominantly semi-diurnal with a spring range of 2 m and neap range of 1 m. Waves arrive out of the north in the winter and from the south in summer, producing a net longshore sand transport to the north (US Army Corps of Engineers (USACE) 1954; Caldwell 1966).

The northern Atlantic coast of New Jersey has experienced a severe sediment (sand) deficiency for the past century, resulting in loss of beaches, placement of dense numbers of sand-retention structures such as groins, bulkheads, and seawalls, and overall winnowing of finer sand to leave a coarser lag (Kraus et al. 1988). The beach profile has tended to steepen in approach to equilibrium with the coarser sand. The regional, long-term trend of net longshore sand transport on this coast is directed from south to north (USACE 1954; Angas 1960; Caldwell 1966), feeding the northern Sandy Hook spit (Psuty and Pace 2009) and further depleting the sand supply in the nearshore, because little sand can return from the north.

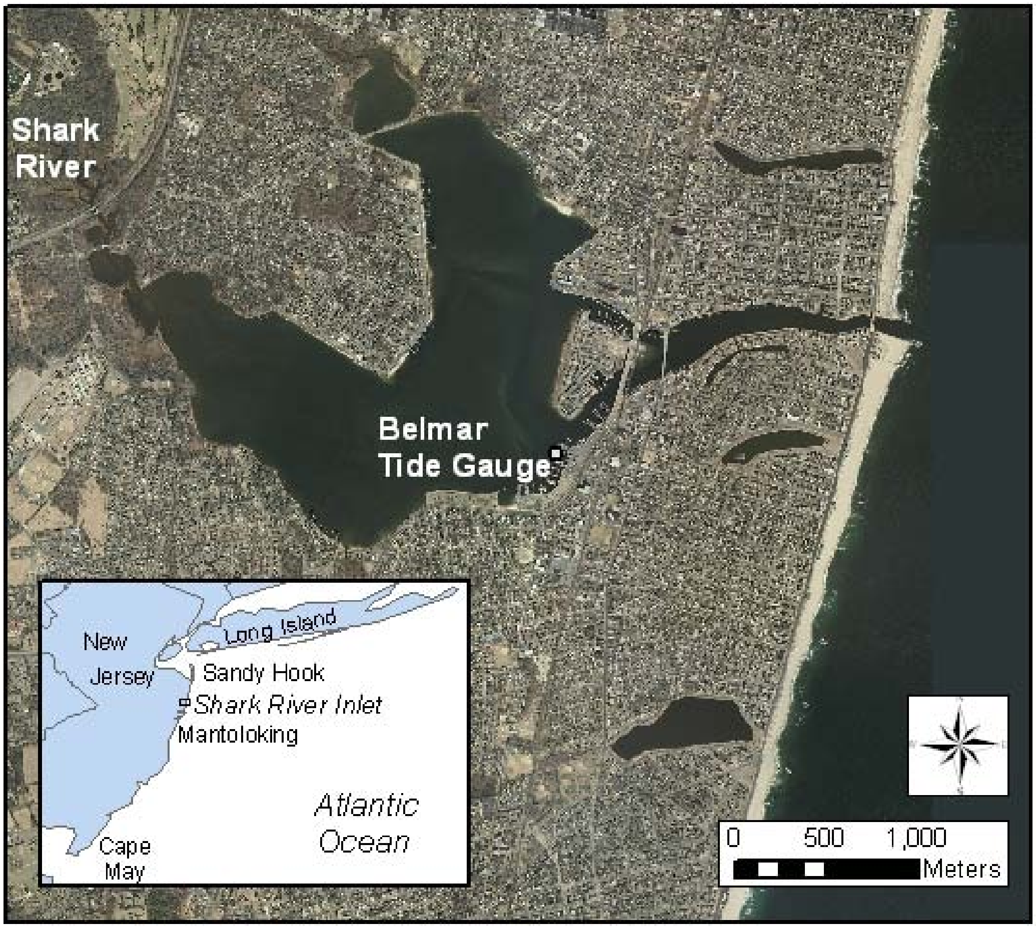

Figure 1. Location map for Shark River Inlet, NJ.

Shark River Inlet is located in Monmouth County along the Atlantic Highlands region of the New Jersey shore and is the northernmost inlet on this coast (Figure 1). The inlet is served by a federally maintained navigation channel connecting the small estuary of Shark River with the Atlantic Ocean. There is no significant river flow to the estuary, which is fed by several small streams. The shallow estuary is situated between upland ridges and has a developed shoreline.

Shark River Inlet navigation project

Shark River Inlet is stabilized by two parallel rubble stone jetties owned and maintained by the State of New Jersey. Two curved jetties were constructed in 1915, and between 1948 and 1951 the State rebuilt and realigned the jetties to extend straight to the ocean (Angas 1960). Aerial photographs from 1920 and 1933 illustrate the original curved jetties and the impoundment along the south jetty (Figure 2). Although these jetties have experienced maintenance since 1951, the parallel configuration has continued with the north and south jetties 160 m and 290 m long, respectively, and 91 m apart. A 152 m-long shore-parallel external spur extends northward from the north jetty (Figure 3) and was built to protect its landward end during winter storms.

Figure 2. A) Shark River Inlet, February-March 1920, post early construction (1915). Photograph taken during rehabilitation of the original State built, curved jetties; B) Shark River Inlet, 23 January 1933, post construction of curved jetties and land reclamation of the flood tidal delta and northern portion of the estuary. Note that impoundment along the south jetty, post construction, created a wide beach extending to the jetty tip. Also, following jetty construction, an asymmetric shoal developed offshore of the inlet, as illustrated by wave breaking in the lower figure.

Figure 3. North jetty with shore-parallel external spur extending to the north (3 Aug 2009).

The federal navigation project consists of the entrance channel, which is 5.5 m deep and 45 m wide from the Atlantic Ocean to a point 152 m landward of the inlet, connecting to a channel 3.7 m deep and 30 m wide extending 2 km into the estuary (Figure 4). The navigation vertical datum is mean low water (MLW), referenced to a long-term project benchmark on land.

The inlet, connecting the estuary of Shark River to the ocean, is 60 m wide at the narrowest section near the Highway 1 Bridge and increases to 200-m width at State Road 35. Highway 1 crosses the entrance channel (70 m wide) with two bridge piers located near the center of the inlet. The inlet then divides into two channels landward of the entrance, the north and south feeder channels (40 and 100 m wide, respectively), which are the original flood channels situated around the now well-developed flood tidal delta known as Shark River Island. Two bridges span this section, Highway 35 and 71, as well as railroad tracks, each with five to ten small piers spanning the channels. Bridge piers will increase flow resistance. Channel cross-sectional area is further decreased due to several shallow and intertidal, oyster-encrusted shoals. Landward of these channels, the estuary opens up to a shallow and relatively small embayment.

Material dredged from the inlet entrance, consisting of beach-suitable sand, is bypassed to an open-water disposal site located offshore between the second and third groins located 0.6 and 1.0 km to the north of the inlet. The upper right-hand corner of Figure 4 depicts the placement locations from a December 2007 dredging and disposal.

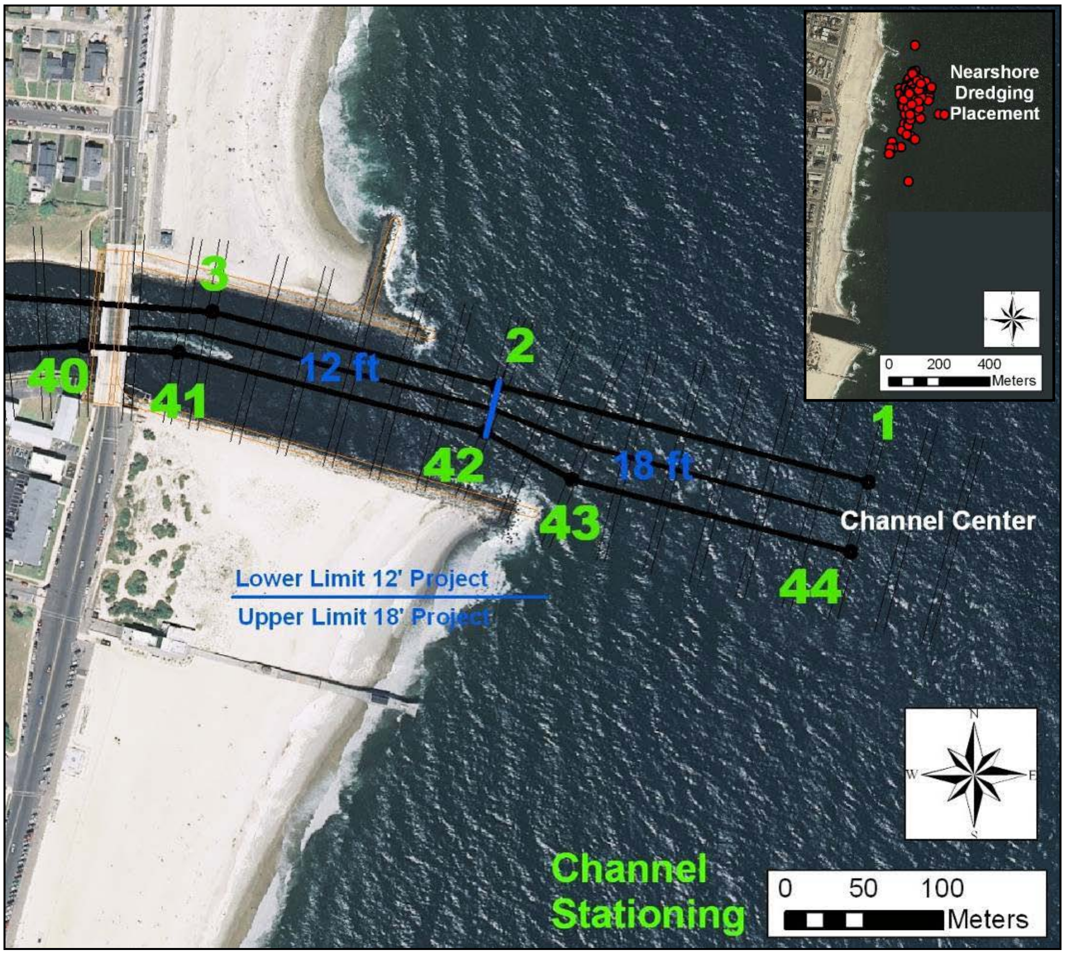

Figure 4. Federal navigation project at Shark River Inlet; Nearshore dredging placement location (from 2007) located in the upper right-hand corner.

Littoral processes and sand budget

Based on a regional sand budget, the long-term net potential longshore sand transport rate has most recently been estimated at 153,000 m^3/year to the north, with the gross transport rate at 696,000 m^3/year (USACE 2006), in accord with previously reported trends (USACE 1954; Johnson 1956; Angas 1960; Caldwell 1966). Shark River Inlet is located 17 km north of a nodal zone in longshore sand transport (in the town of at Mantoloking) that is produced by sheltering of the north New Jersey coast by Long Island, NY, and continental landmass from waves out of the north (USACE 1954;

Caldwell 1966). The gross transport rate at the site is the sum of the north- and south-directed rates. The gross transport rate contributes to shoaling of littoral material into the navigation channel, apart from impoundment and bypassing. Long-term net and gross sand transport rates correspond to potential longshore transport and can be realized only if sand is fully available to be transported in the littoral zone. Littoral material will bypass the channel as well as deposit in it, because shallow channels are not complete traps to littoral transport, especially during storms.

Angas (1960) documents that the south (up-drift) jetty impounded considerable sand volume along the adjacent beach, in contrast to the beach to the north, which was severely eroded. Therefore, in 1958 and 1959, a sand bypassing project was conducted at Shark River Inlet by excavation with a crane and transport by truck. At the time of writing the Angas (1960) paper, a target volume of 172,000 m^3 was expected to be bypassed. More than half of this amount, about 105,000 m^3, had been bypassed in the first winter season. This mechanical bypassing action is in accord with present estimates of both the direction and volume of net longshore sand transport. Angas (1960) also notes that a bar tended to form around the south jetty, directed to the north. However, Angas (1960) states that any material bypassed was believed to arrive to the shore much farther north of the area directly down drift that was deprived of sand, and therefore did not benefit the beach adjacent to the north jetty. Sorensen (1990) concluded that the net and gross longshore transport rates were smaller by an order of magnitude than the values stated, but we believe the sediment deficiency along this coast at that time was not considered in his analysis.

As part of the Sea Bright to Manasquan Inlet Beach Erosion Control Project, in 1997 the New York District placed approximately 4.1 million m^3 of fine to medium sand to the south of Shark River Inlet. During 1999-2000, another 2.4 million m^3 of sand was placed to the north of the inlet. The sand was taken from offshore sources. 13 long groins in Belmar and the Borough of Spring Lake, located south of the inlet, were notched (lowered in elevation) in 1997 and 1998 near the shore to promote sand movement into a local erosion hot spot and straighten the local shoreline. In the autumn of 2002, one additional groin was notched in Spring Lake, at the same time as the placement of about 172,000 m^3 of sand in Spring Lake (Bocamazo et al. 2003; Donohue et al. 2004). Construction of the Erosion Control Project and notching of the groins provided sand that will partially, if not completely, re-establish natural longshore sand transport potential in the region of placement. The General Design Memoranda for the Erosion Control Project (USACE 1989, 1994) anticipated increased shoaling and shorter time interval between dredging at the Shark River Inlet entrance to approximately every 2 to 3 years owing to increased availability of sand.

Inlet processes

Shark River Inlet is not classified as a river mouth because it does not experience notable freshwater flow that would contribute to maintaining inlet stability. The entrance serves a relatively small estuary complex estimated at 324 ha. Jarrett (1976) found a tidal prism of 4.19×10^6 m^3, channel cross-sectional area of 2.79×10^3 m^2, and inlet entrance width to depth (hydraulic radius) ratio of 17. The ebb current in this inlet is known to be strong, making navigation and surveying sometimes difficult, but the marinas in the estuary are well protected and experience calm water. The unusually strong current is attributed to hydraulic efficiency imposed by the small entrance width to depth ratio, one of smallest of 108 U.S. inlets and the smallest among 35 Atlantic coast inlets tabulated by Jarrett (1976). A deeper channel exerts less bottom friction on the current.

A harmonic analysis was performed for the month of August 2009 at the nearby ocean tide gauge at Sandy Hook, NJ, operated by National Oceanographic and Atmospheric Administration (NOAA) tide station (No. 8531680) and a tide gauge Belmar, maintained in the Shark River Estuary by the U.S. Geological Survey. These data are plotted in Figure 5, and computed harmonics for the measurements and for CMS calculations to be discussed are listed in Table 1. The semi-diurnal components of the analysis show little variation in phase and only a slight reduction in amplitude, indicating little tidal attenuation through the inlet. Smaller, high-frequency harmonics have nearly equal amplitudes and are close in phase. Lack of tidal attenuation and phase difference indicates the efficiency of the narrow inlet channel to flush the small estuary. This hydraulic efficiency owes both to a small width to depth ratio and to negligible impedance from bottom features such as sand waves in the channel entrance.

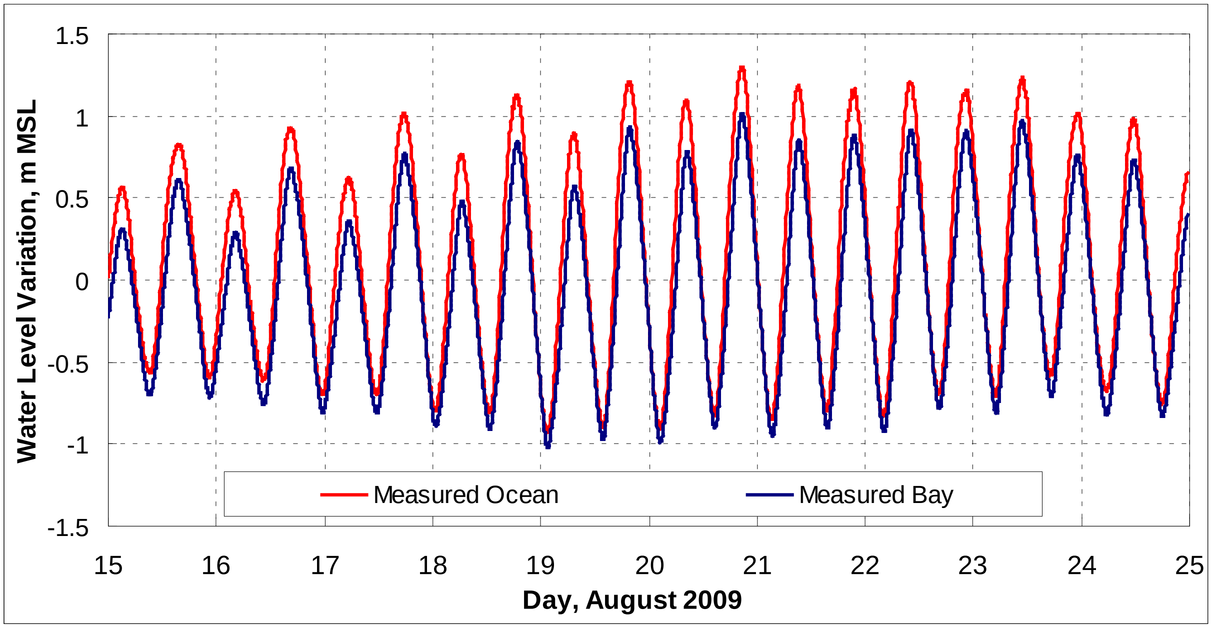

Figure 5. Observed time series of water level at Sandy Hook (ocean gauge) and Belmar (located in the bay).

Table 1. Tidal Constituents for Sandy Hook and Belmar (units of amplitude A in m, and units of phase P in deg)

Station	Q1		O1		K1		N2		M2		S2		M4		M6	
	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P
Sandy Hook	0.014	303.3	0.06	63.78	0.105	120.2	0.17	87.21	0.687	193.5	0.145	283.1	0.022	295.2	0.014	296.9
Belmar	0.014	307.5	0.062	67.58	0.109	126.3	0.15	95.56	0.599	201.2	0.123	297.0	0.021	322.4	0.02	236.2

According to a commonly applied empirical relation (Walton and Adams 1976), the tidal prism at Shark River Inlet can support an ebb-tidal delta of 0.92×10^6 m^3 at dynamic equilibrium, if sand is available to form and maintain this feature. Because there is no significant input of river sediment, the ebb-tidal delta will be composed of sand that would otherwise reside on the beach and should be accounted for in the sand budget. Inlets on the coasts of northern New Jersey and Long Island tend to be wave dominated, as opposed to tide dominated. Hayes (1979) and Davis and Hayes (1984) characterized inlet ebb-delta planform morphology according to tidal range and average incident wave height. Wave-dominated inlets have an ebb delta that is roughly horseshoe shaped around the entrance. Formation of ebb- and flood-tidal deltas is normally calculated as part of the sand budget developed in planning of new inlets to be opened, and the need for accounting for such a new sand volume at an existing inlet is unusual. Approaching maturity or equilibrium volume, an ebb delta will naturally bypass most of the sand arriving to it unless it is intercepted by a maintained navigation channel, which would trap some portion. That portion can be bypassed mechanically or hydraulically during channel maintenance.

Wave climate

Two distinct meteorological patterns of persistent south-westerly trade winds and the passages of winter storms from the northwest control the wave climate along the New Jersey coast. With the exception of the infrequent arrival of tropical storms, these two patterns produce a bimodal distribution of wave energy. Figure 6 illustrates the frequency occurrence of wind speed and direction at Sandy Hook, measured for the years 1997-99. As winter storms, or cold fronts, pass from west to east, there is a switch in wind direction from the northwest to the northeast. However, due to the sheltering of the New Jersey Coast located south of Long Island, NY, waves generated from strong northwesterly winds are negligible as the storms pass. It is only after a winter storm has moved east over the open Atlantic Ocean that the area can receive large swell-type waves associated with the frontal passage. Figure 7 illustrates the yearly distribution of wave height and period in separate rose diagrams developed from the Wave Information Study (WIS) hindcast of the USACE (http://chl.erdc.usace.army.mil/wis) for Station 129 on the Atlantic coast. For much of the year, southwesterly winds generate fair-weather waves out of the south, whereas frontal passages generate larger swell-type waves that can only approach the northern New Jersey coast from the east.

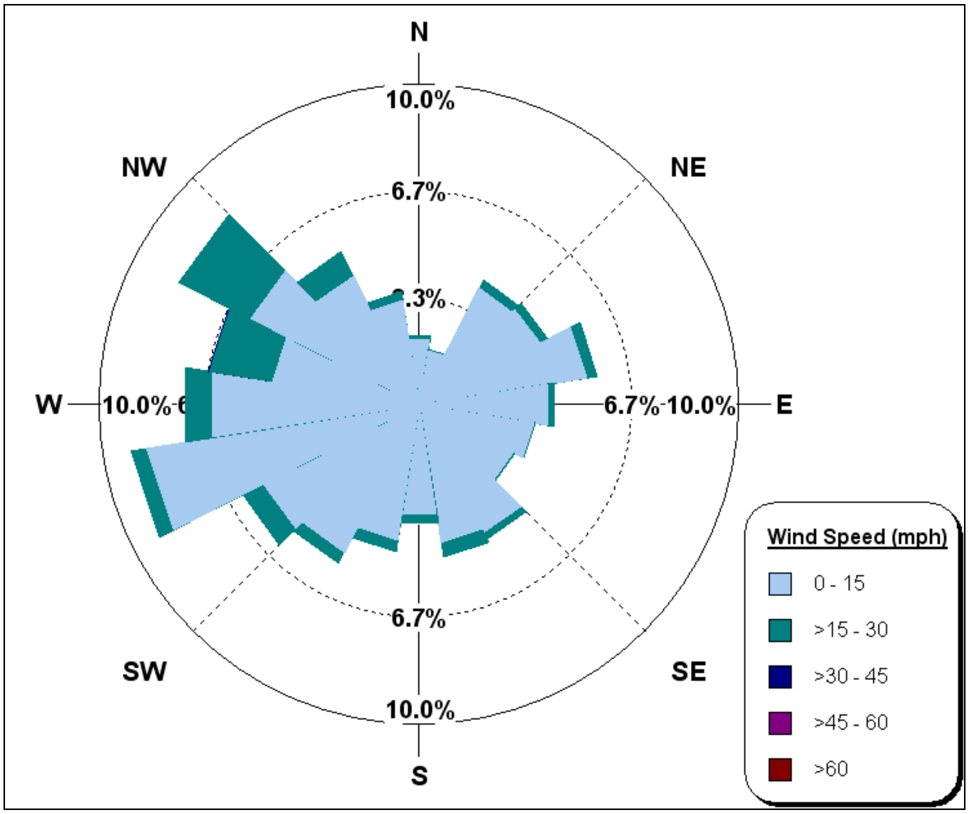

Figure 6. Rose plot of measured wind speed at Sandy Hook for the years 1997-1999.

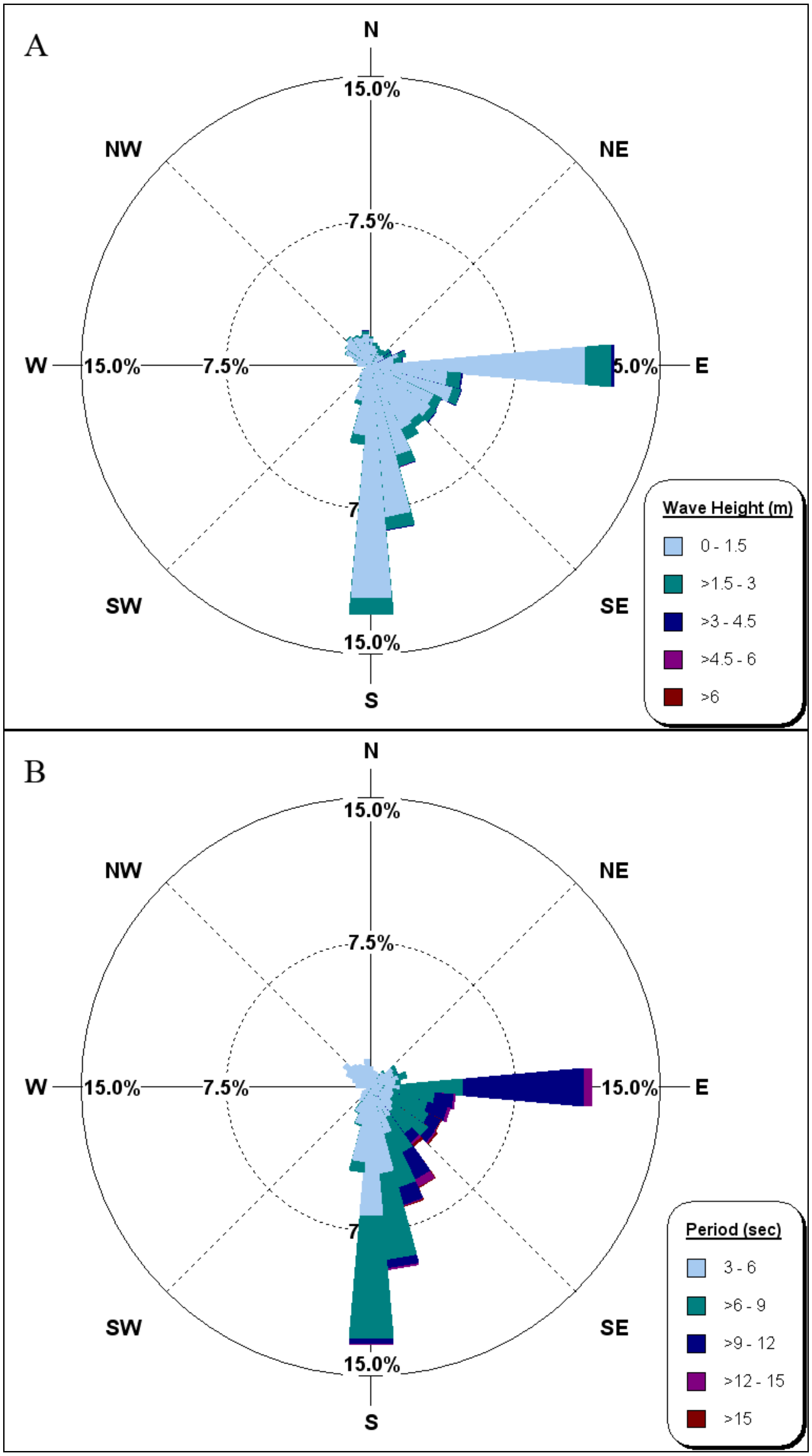

Figure 7. Rose plot of WIS hindcast (a) wave height, and (b) wave period for Station 129, Asbury Park, for the 1980-1999 dataset.

2 Study Procedure

Wave-driven potential sand transport

In addition to literature cited on sand budget studies, the potential sand transport rate was calculated for assessment prior to intensive numerical modeling with the CMS. The CERC formula (USACE 2002) was applied to estimate the potential longshore sand transport within the study area. The longshore wave energy flux, P_{ls} at breaking was calculated with wave parameters from the USACE WIS hindcast dataset for Station 129. The transport rate Q is calculated as:

$$Q = \frac{K}{(\rho_s - \rho) g (1 - n)} P_{ls} \quad (1)$$

where K is an empirical coefficient taken here as 0.77, ρ_s is density of (quartz) sediment, ρ is density of fresh water, g is the acceleration due to gravity, and n is the sediment porosity (taken to be 0.4).

Total volume of sand transported was calculated from WIS directional spectra available at hourly intervals from 1980 to 1991. Waves were refracted and shoaled to breaking under assumed plane and parallel contours. The resultant calculations are summarized in Figure 8, a bar graph of the north- and south-directed, net, and gross sediment transport. The calculations show the dominating influence of the southerly directed waves as compared to waves from winter storms. These calculated annual estimates indicate a net longshore sand transport rate directed to the north except for years 1987 and 1992, when there is a small reversal to the south, probably related to the sites proximal location near the regional nodal point in longshore transport. The net was almost zero in 1998, an El Niño year. Existence of the nodal point owes to sheltering of winter waves by Long Island, New York, and New England (USACE 1954; Caldwell 1966).

The calculated net longshore sand transport typically varies between 100,000 and 200,000 m^3/year, directed to the north, with an average net transport of 170,000 m^3/year. For the 20-year interval, the gross rate averaged 800,000 m^3/year. The direction of net to the north and the values of net and gross rates are in agreement with trends determined in a recently compiled long-term sand budget (USACE 2006).

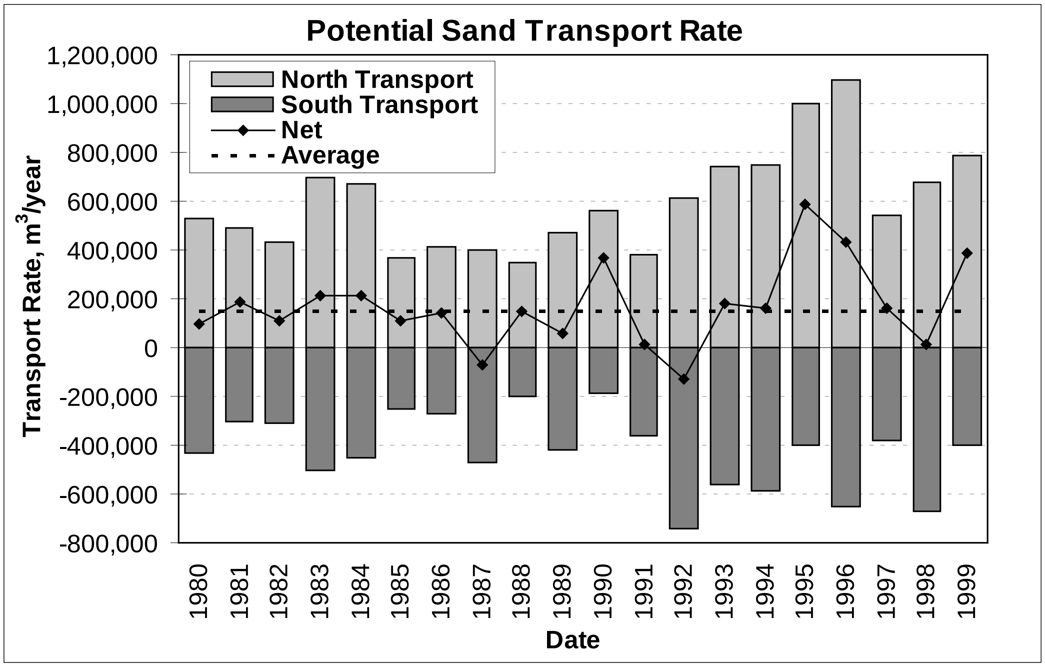

Figure 8. Calculated potential longshore sand transport rates based on WIS station 129 directional spectra.

Short-term field measurements

The current was measured on 20 August 2009 for validation of the CMS. Down-looking acoustic Doppler current profiler (ADCP) data were collected for 13 hours on three cross sections within the inlet (Figure 9). One cross section (CS1) was located in the main channel. The other two cross sections were located on the ocean side of the landward-most bridge (SR-35), covering both the north (CS2) and south channels (CS3). Bay bathymetry was also surveyed with a multi-beam echo sounder. These roving ADCP and bathymetric data were performed with RTK GPS equipment referenced to a local NOAA tidal benchmark at Belmar.

Dredging data

The digital dataset provided by the New York District consists of 27 bathymetric surveys of Shark River Inlet from 1995 to January 2010. Survey coverage depended on purpose. Surveys conducted for dredging-need assessment may include both a before- and after-dredging surveys; and channel-condition surveys are made on an as-need basis. Since realignment of the jetties to their present location in the late 1940s, dredging of Shark River Inlet was relatively infrequent, occurring every 7-10 years. The first set of surveys from 1995, 1998, 1999, and 2000 were channel condition surveys, increasing in frequency following the 1997 beach nourishment. After the condition survey of May 2000, before- and after-dredging surveys increased significantly in regularity to twice a year because the channel began to shoal more frequently. Table 2 lists the surveys conducted by the New York District that were analyzed in this study.

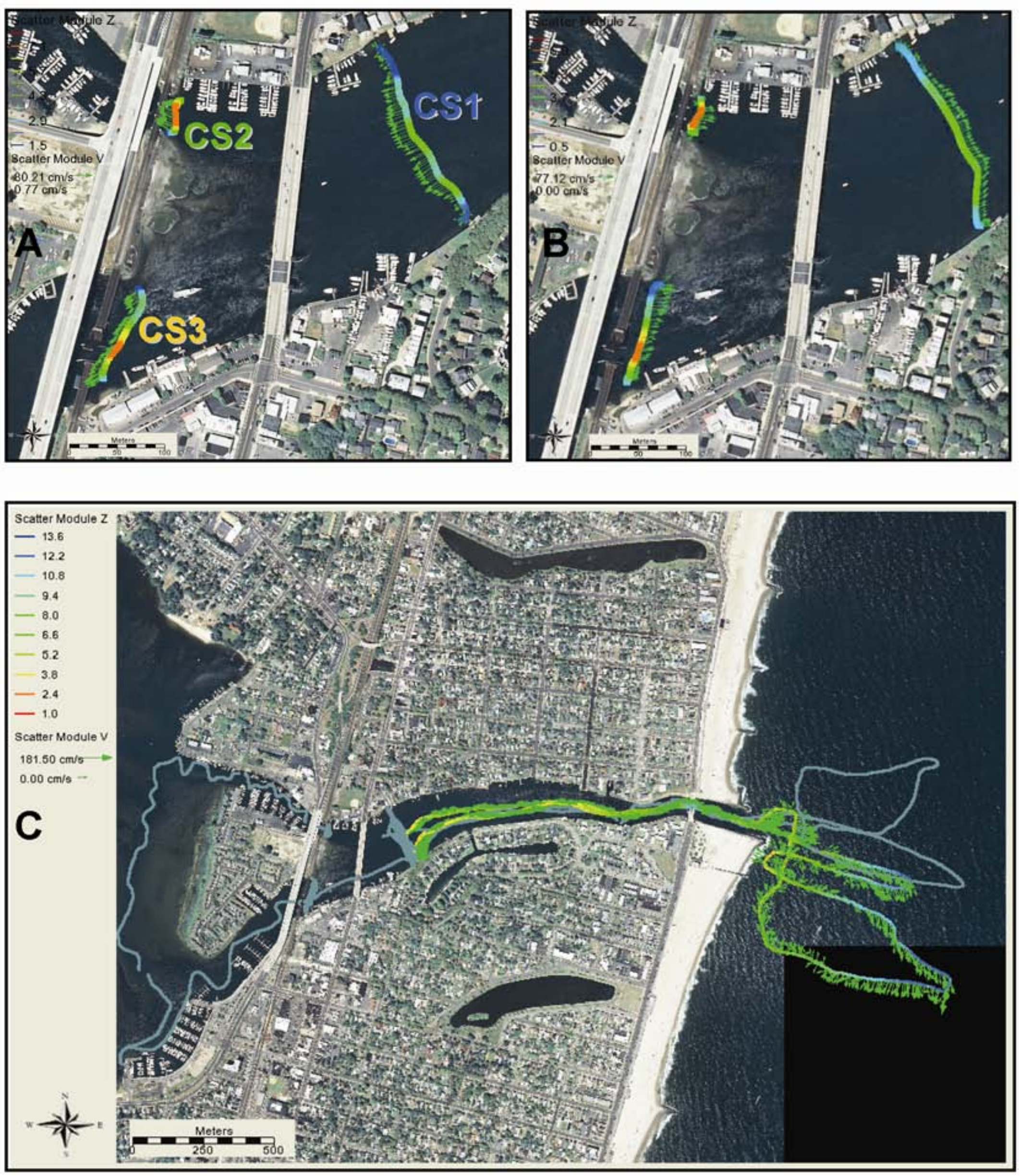

Figure 9. Depth-averaged, measured current velocity across three cross sections. A) Depth-averaged measured flooding current; B) Depth-averaged measured ebbing current; C) Additional measured profiles covering the area of the ebb jet during ebbing tide.

Table 2. New York District Survey Data Analyzed in This Study

Date	Survey Type	Date	Survey Type
1 Jan 1995	Condition	28 Mar 2006	Condition
6 Jan 1998	Condition	30 Aug 2007	Before dredging
6 May 1999	Condition	4 Jan 2008	After dredging
11 Apr 2000	Condition	25 Mar 2008	Condition
16 Apr 2002	Condition	9 Jun 2008	After dredging
6 Dec 2002	Before dredging	31 Oct 2008	After dredging
18 Jan 2003	After dredging	8 Dec 2008	Before dredging
7 Jul 2003	Condition	6 Jan 2009	After dredging
7 Aug 2003	After dredging	15 Apr 2009	Before dredging
28 Apr 2004	Condition	1 May 2009	After dredging
10 Jun 2005	Condition	20 Aug 2009	Before dredging
23 Dec 2005	After dredging	10 Dec 2009	After dredging
23 May 2006	Condition	6 Jan 2010	After dredging
27 Nov 2006	Condition		

CMS model preparation

The CMS, a physics-based model of waves, flow, sediment transport, and morphology change, was applied in this study. The CMS is a product of the Coastal Inlets Research Program (CIRP) at the US Army Engineer Research and Development Center and is composed of two coupled models, CMS-Flow (Buttolph et al. 2006; Wu et al. 2010) and CMS-Wave (Lin et al. 2008). CMS-Flow is a finite-volume, depth-averaged model that calculates water surface elevation and flow velocity. CMS-Flow is coupled with CMS-Wave that calculates spectral wave propagation including refraction, diffraction, reflection, shoaling, and breaking, and it also provides wave information for the sediment transport formulas. CMS-Flow can be driven by an ocean tide, as done here, and by wind forcing. The Non-equilibrium Sediment Transport (NET) method, based on a total load advection-diffusion approach (Sanchez and Wu 2010), was selected to calculate sand transport rates in CMS-Flow based on the Lund-CIRP transport formulae (Camenen and Larson 2007) from within CMS-Flow for combined waves (breaking and non-breaking) and current. Bed change is then calculated periodically and updated in both the wave and flow models.

The model domain for the CMS covered a local scale of approximately 11 km centrally located around Shark River Inlet (Figure 10). Two separate grids, one for the waves and the other for flow and sand transport, cover the same alongshore distance with the ocean extending seaward 8.5 km for the wave model and 3.5 km for the circulation model. Bathymetry needed to develop the backbay, entrance channel, and ocean was assembled from several datasets and converted to mean sea level (MSL) as given by the local tidal datum for Long Branch, NJ (NOAA). Bay bathymetry consisted of USACE and New Jersey State collected channel bathymetry and data collected during the August 2009 field measurements. The nearshore and ocean bathymetric datasets were a combination of 2005 LIDAR (NOAA) and the National Geodetic Data Center's Coastal Relief Model (NOAA). The temporal coverage of the channel surveys collected by the New York District provided the main modification for each developed grid.

CMS-Flow was driven with measured open ocean tide from the Sandy Hook gauge. The calculated water level variation and current velocity were verified through comparison with the bay tide gauge and field measurements for the month of August 2009. Wave data from WIS station 129 provided input parameters for generating spectral waves for driving CMS-Wave. The wave grid boundary overlies the location of the hindcast station, located at 26-m water depth.

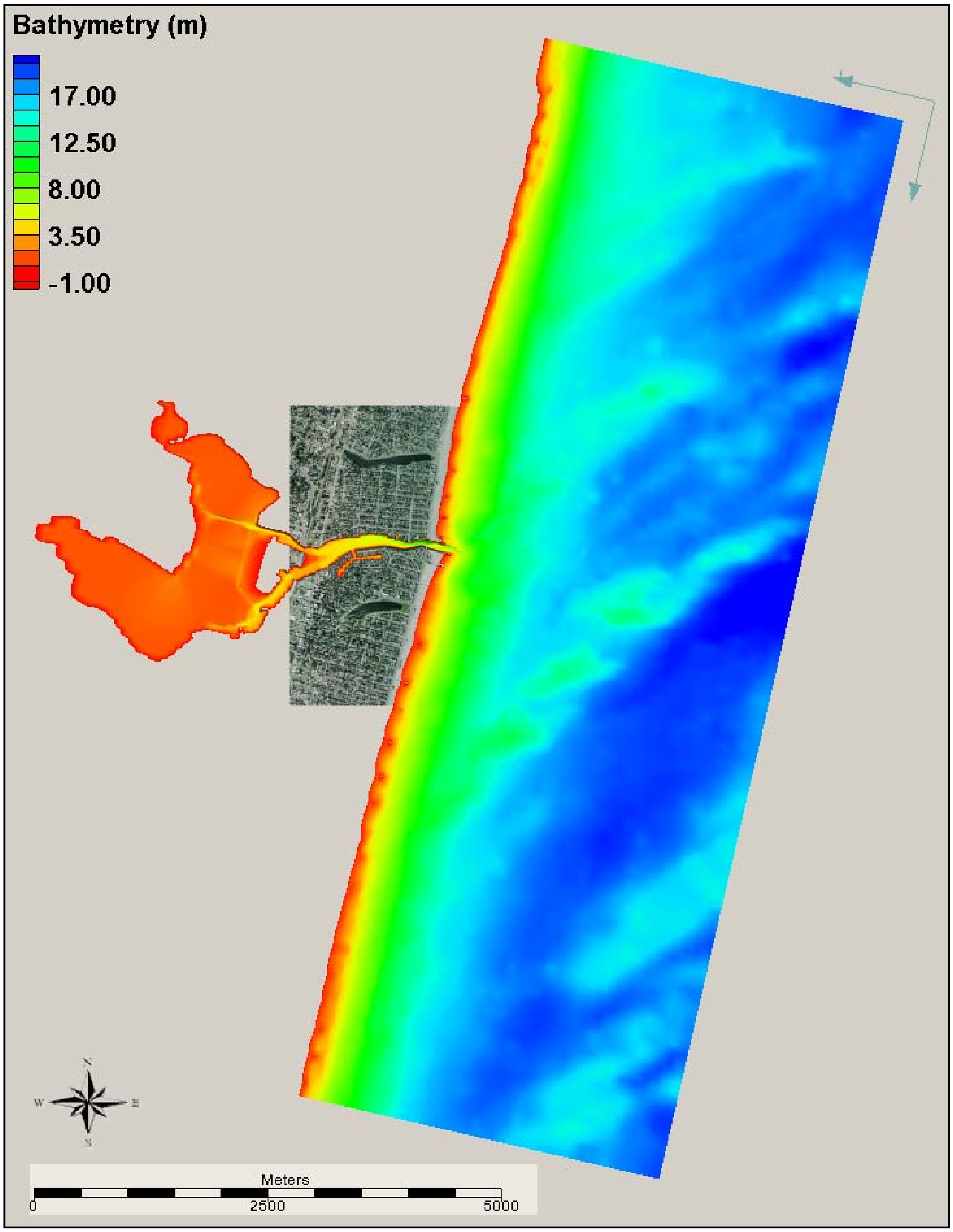

Figure 10. CMS domain for Shark River Inlet, NJ, CMS simulation.

3 Geomorphology

Observed geomorphology: 1995-2002

The bathymetric dataset analyzed, tabulated in Table 2, covers 27 surveys available from January 1995 to January 2010 and describes the geomorphologic change occurring at the inlet. Figures 11 through 15 are examples from the dataset, illustrating depth contour maps set to MLW and with the same horizontal scale. The 1995 and 1998 surveys indicate that the entrance channel was devoid of notable shoals and that the maintained navigation channel extended to deep water without encountering an ebb-tidal delta (1995 survey in Figure 11). All surveys indicate that the beach profile south of the inlet is more advanced seaward as compared to the north side. The south jetty-tip shoal is attributed to the fillet (sand impoundment) on the up-drift side of the inlet, extending the nearshore profile beyond the south jetty, a pervasive feature as apparent in photographs from the 1920s and 1930s (Figure 2).

The April 2000 survey (Figure 11), made after nourishment of both the south beach (1997) and the north beach (1999-2000), indicates shoals approaching the channel from both north and south, with considerable sand entering the entrance margin on the north. Figure 12 shows before- and after-dredging surveys conducted in December 2002 and January 2003, and indicate the extent to which the channel is now dredged. A substantial influx of sand, from both the north and south, is observed in the December 2002 before-dredging survey and marks the initial formation of a growing ebb-tidal delta. Surveys subsequent to the 2000 survey indicate a large shoal on either the north or south jetty tip. Such morphologic variation is attributable to seasonal changes in wave direction, where high waves incident from either the north or south, and their associated current, would transport sand along these shoals and into the channel, as seen in the July 2003 Condition Survey. Similarly, Williams and Kraus (2010) document seasonal morphologic change at Packery Channel, an inlet in Corpus Christi, TX, where longshore bars approaching the inlet on both sides shift location and volume between summer and winter.

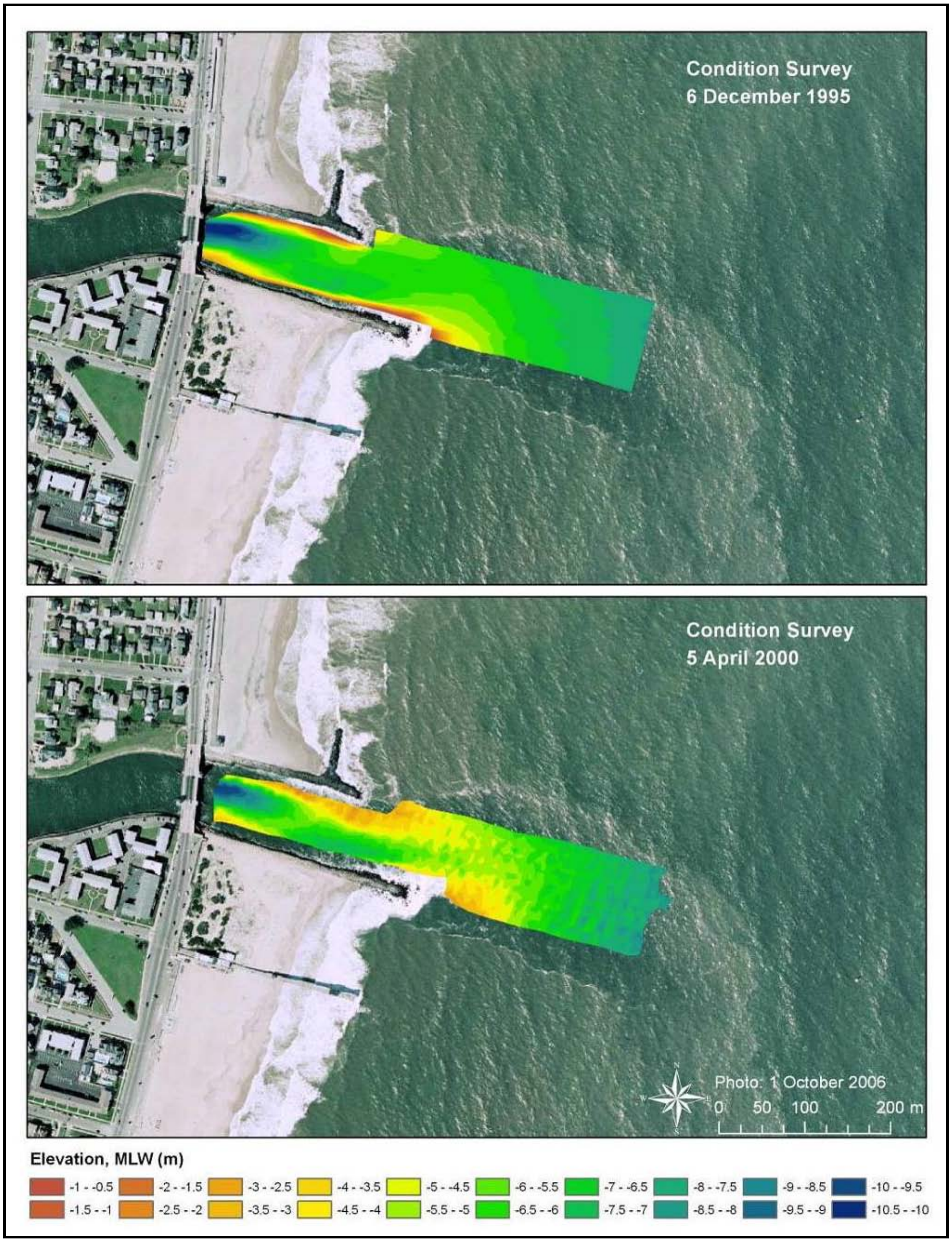

Figure 11. Shark River Inlet entrance, NJ, surveys of December 1995 and April 2000.

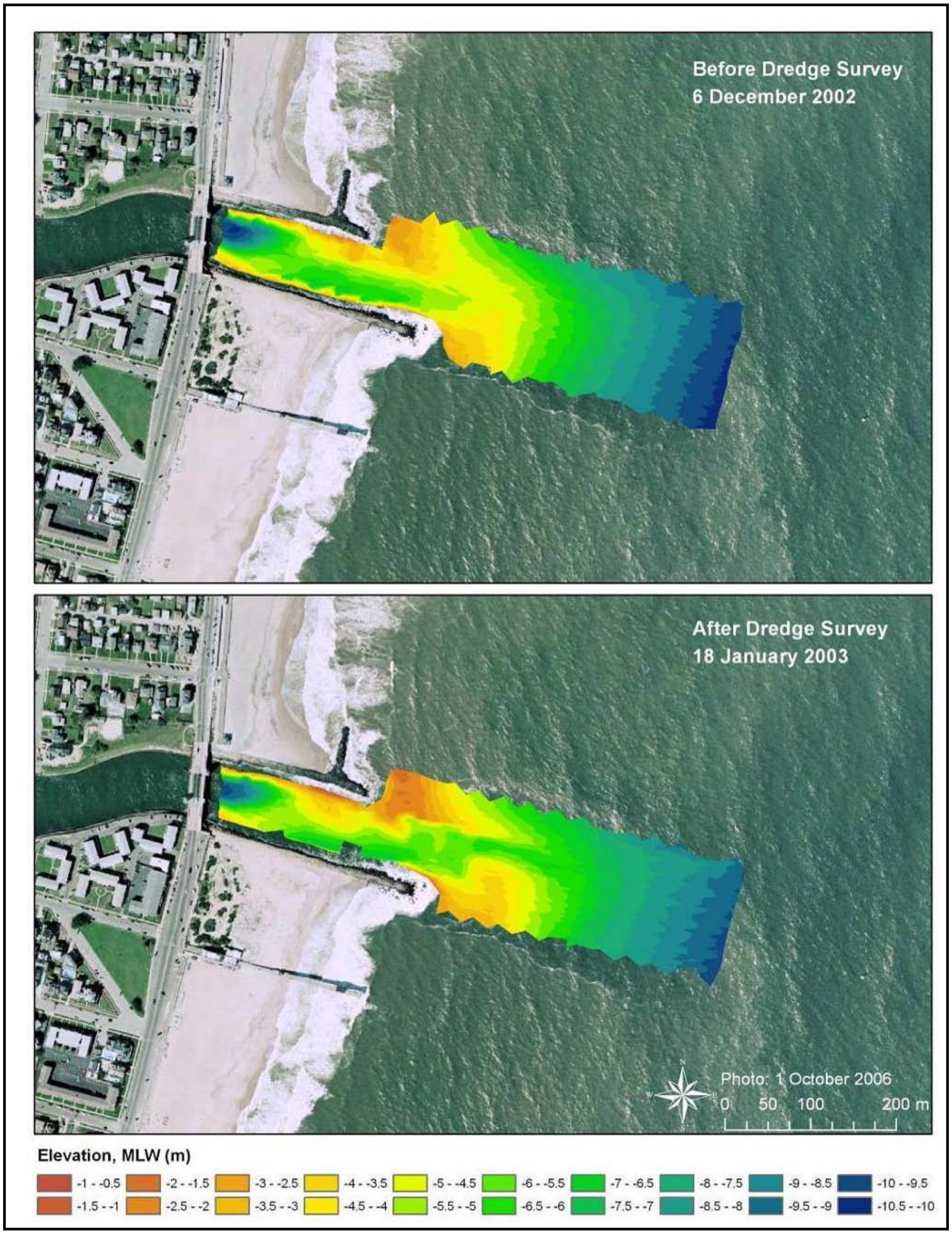

Figure 12. Shark River Inlet entrance, NJ, surveys of December 2002 and January 2003.

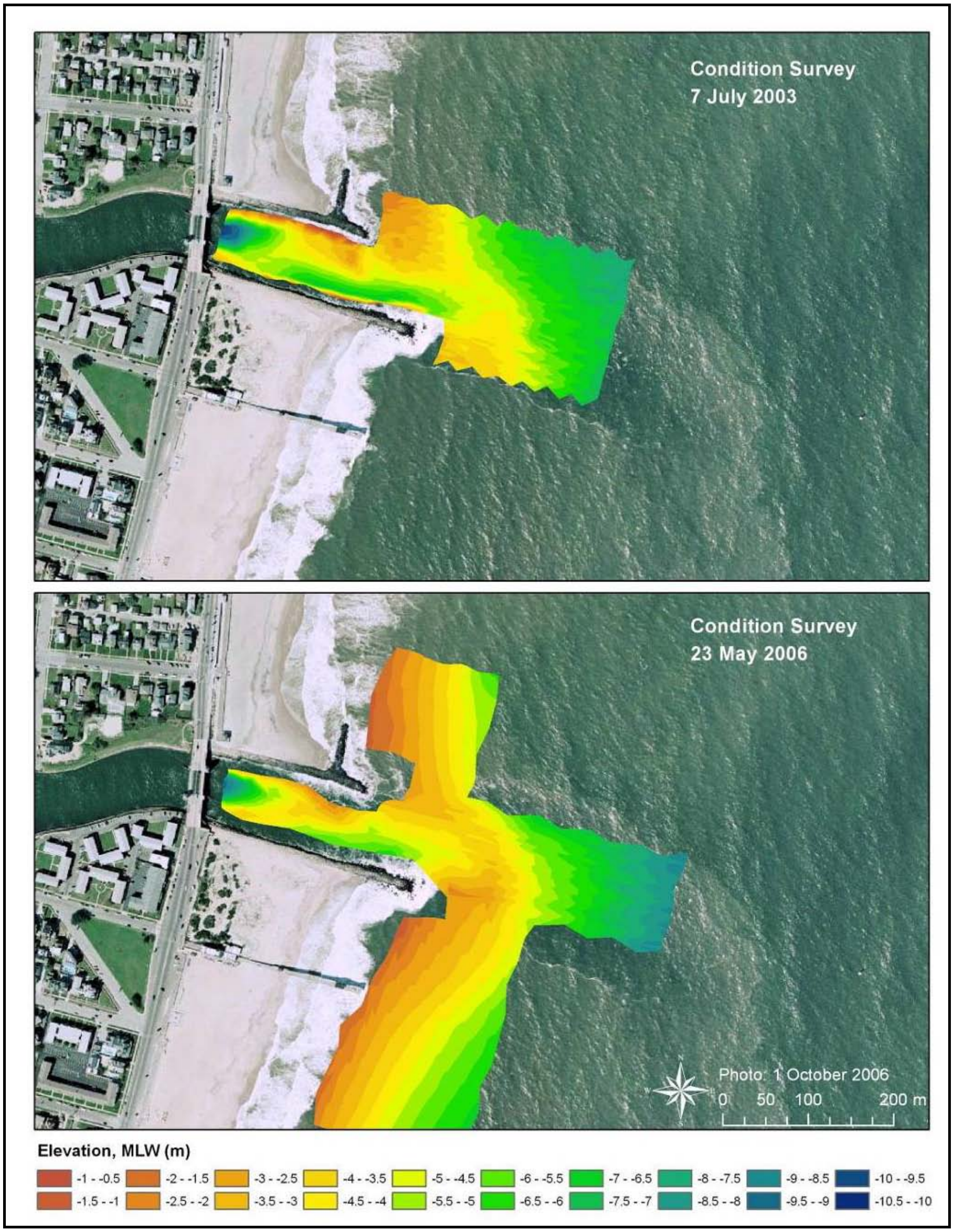

Figure 13. Shark River Inlet entrance, NJ, surveys of July 2003 and May 2006.

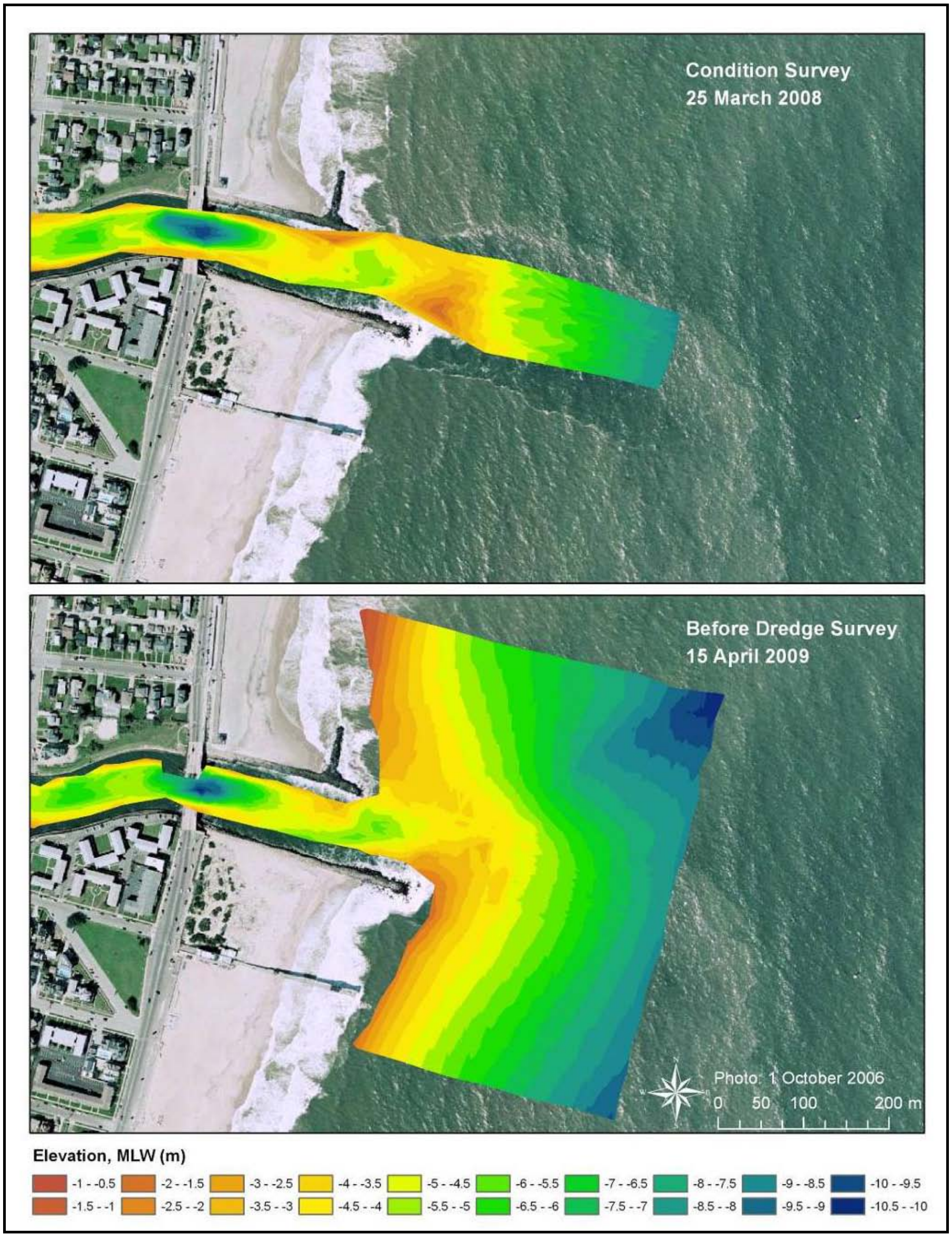

Figure 14. Shark River Inlet entrance, NJ, surveys of March 2008 and April 2009.

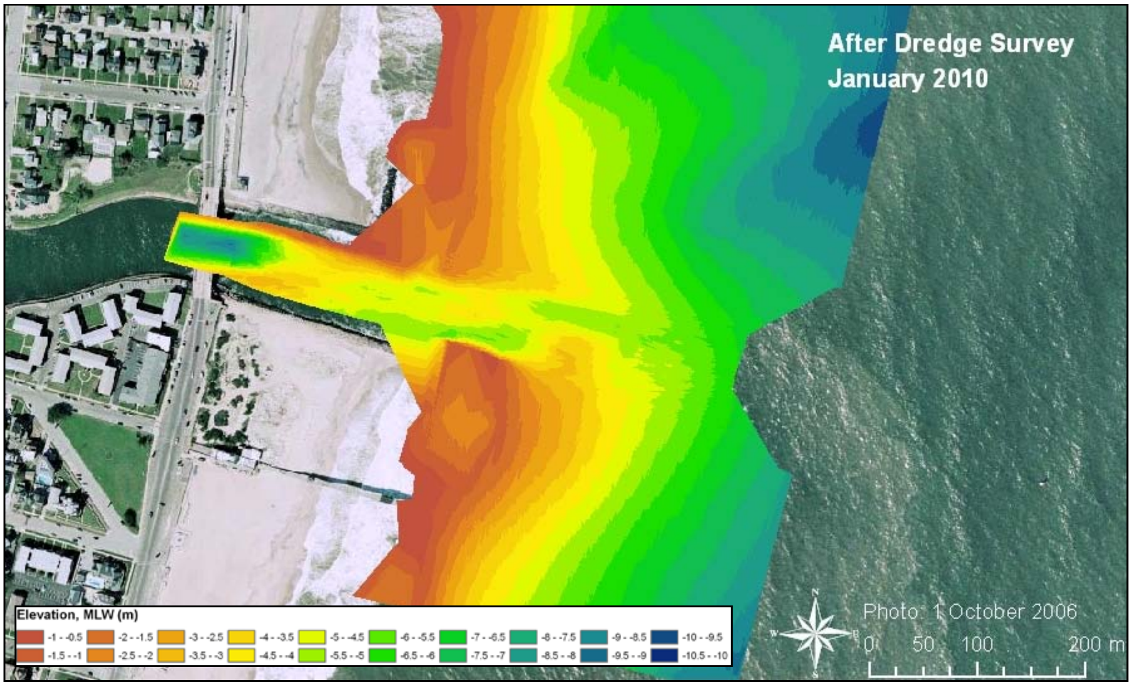

Figure 15. Shark River Inlet entrance, NJ, survey of January 2010.

Observed geomorphology: 2002-2006

After the December 2002 dredging, the entrance channel experienced rapid shoal encroachment that required increased dredging frequency (Table 2). Following the December 2002 dredging, the inlet was surveyed at least twice a year and sometimes more frequently to monitor channel conditions. The 7 July 2003 survey indicates formation of an entrance bar, part of the horseshoe-shaped ebb delta morphology characteristic of wave-dominated inlets (Figure 13). The surveys following in 2004 and 2005 indicate continued impoundment along the north jetty and continued ebb-tidal delta growth. As the sand influx rebuilt both the up-drift (south) and down-drift (north) nearshore profiles alongside the inlet, the horseshoe-shaped ebb-delta morphology becomes more symmetric as seen in the May 2006 survey (Figure 13). The May 2006 survey reveals sand waves over the ebb delta. Such sand waves form perpendicular to the dominant current and are indirect evidence of strong longshore current transporting sand across the ebb delta and inlet entrance.

Observed geomorphology: 2006-2010

Surveys of March and August 2007 (not shown) are consistent with the 2005-2006 survey trends in ebb delta development. Also, a transverse or diagonal bar, a persistent morphologic feature, is observed to have formed across the inlet channel (first seen in the April-May 2002 surveys), running from the tip of the north jetty to the landward end of the south jetty and intersection with the bridge. The transverse bar is in part caused by the tendency of the ebb current exiting from under the north side of the bridge to clear sand in its area of influence, which then deposits where the current velocity decreases. However, the source of sand in the channel is expected to be littoral (marine) in origin and not fluvial or bay derived because of the recent appearance of the bar.

Recent entrance channel surveys from 2006 and later had greater coverage, particularly the April 2009 survey (Figure 14), to capture the growth of the ebb delta. Asymmetric ebb delta formation, starting about the year 2007, is driven by the net longshore transport and forcing the channel toward the northeast. However, after each dredging to a straight and perpendicular channel alignment, the sediment rapidly fills the 5.5 m deep dredged pit to an average of 3 m depth MLW and the entrance bar develops. The shoals along each jetty tip increase in volume seasonally, dependent on the direction of the dominant waves. This shoaling pattern is most evident from the post-dredging survey of January 2010 (Figure 15), illustrating two large shoals in the form of recurved, offshore bars on either side of the dredged channel.

Shoal volume, plotted in Figure 16, increased over the last 10 years as compared to the May 1999 survey. The shoal volume was calculated over the channel stationing area between the jetties (Figure 4), from the Highway 1 bridge seaward to the 5.5 m contour depth. Because of limited coverage of most channel surveys, complete ebb-tidal delta volumes could not be calculated for each survey. However, the total volume increase for the last decade, from May 1999 to April 2009, is calculated to be approximately 90,000 m^3 with 40,000 m^3 within the entrance channel and greater than 50,000 m^3 outside of the jetties.

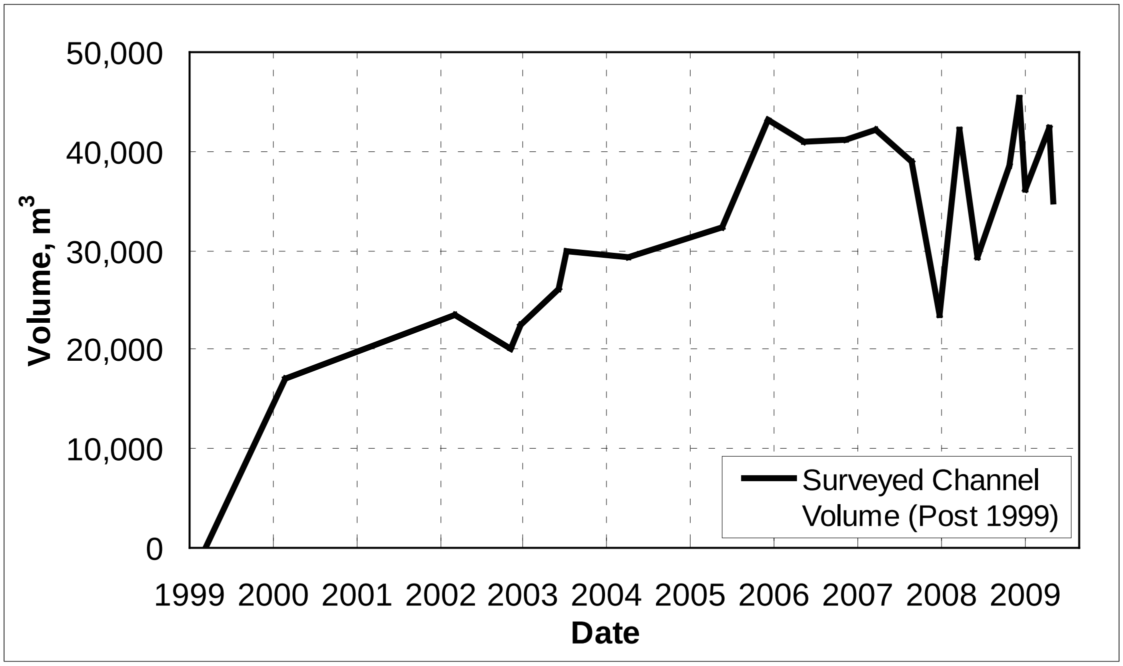

Figure 16. Volumetric change of the entrance channel to Shark River Inlet. Calculations based on the volume change after 1999 and cover the width of the channel from the bridge out to the -5.5 m (mlw) elevation contour.

4 Hydrodynamic Data and Circulation Modeling

Water level

CMS-calculated water level variation is compared with water levels from the Belmar gauge (location shown in Figure 1) in Figure 17. Because the Sandy Hook gauge is located 30 km north of Shark River, the calculations have a slight phase advance in comparison to the measurements because the tidal wave propagates from north to south on this coast. The ocean gauge typically leads the bay gauge by 20-30 min. Tidal constituents of water level calculated by the CMS show good correspondence with the gauge in the estuary at Belmar, including reproduction of the overtides M4 and M6, which originate from non-linearities in tidal wave shoaling in the nearshore and through the inlet (Table 3).

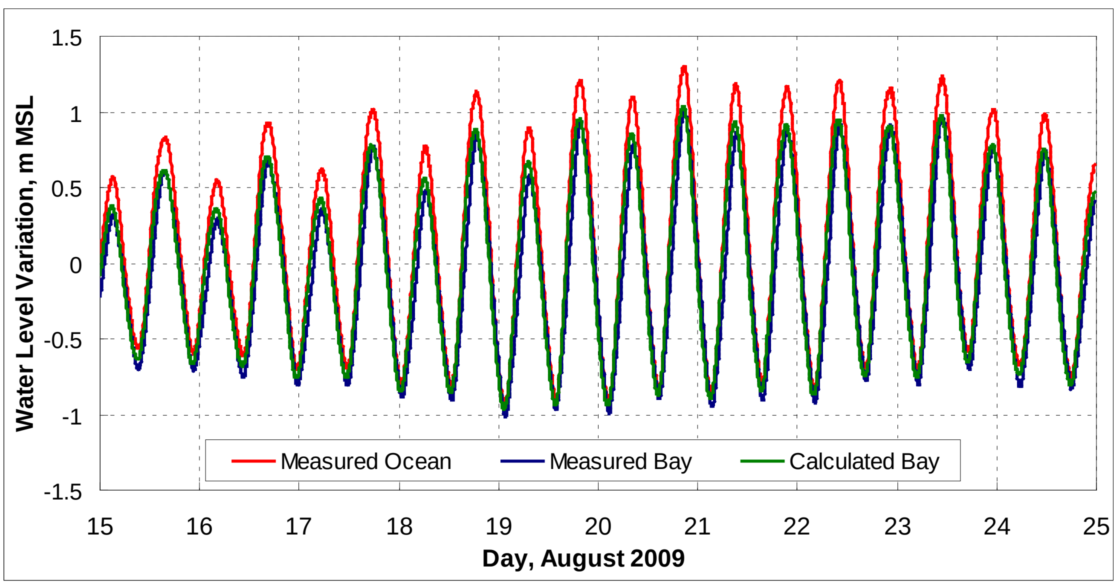

Figure 17. Observed time series of water level at Sandy Hook and Belmar ("Bay") and calculated water level at Belmar.

Table 3. Tidal Constituents for Sandy Hook, Belmar, and Calculated with the CMS (units of amplitude A in m, and units of phase P in deg)

Station	Q1		O1		K1		N2		M2		S2		M4		M6	
	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P
Sandy Hook	0.014	303.3	0.06	63.78	0.105	120.2	0.17	87.21	0.687	193.5	0.145	283.1	0.022	295.2	0.014	296.9
Belmar	0.014	307.5	0.062	67.58	0.109	126.3	0.15	95.56	0.599	201.2	0.123	297.0	0.021	322.4	0.02	236.2
Calc. Belmar	0.011	310.3	0.054	74.54	0.09	133.6	0.13	109.99	0.561	213.3	0.115	311.2	0.026	3.0	0.016	281.7

Current

Figure 18 is a rendering of the overall circulation calculated at an ebb tide. The wave-generated longshore current on both sides of the inlet is seen as well as the concentrated ebbing flow within the bay on the north and south channels. Current velocity measured on 20 August 2009 at the locations, shown in Figure 19, is plotted in Figure 20 versus the calculated, centrally-located peak velocity in the three main channels. Measurements and calculations show close correspondence for the main channel (CS 1) and south channel (CS 3) within 5% measured values, with calculated velocity for the north channel (CS2) being greater with a maximum over-prediction of about 10%. The magnitude and general shape, current asymmetry, of the measured current velocity are well reproduced by the CMS, with an average peak velocity of 1.0 m/s in measurements and calculations. The CMS calculation also exhibits nonlinearity around 9 AM, in agreement with the measurements. Predicted currents for the bay were small, 0.01 to 0.05 m/s, relative to the entrance channel and nearshore.

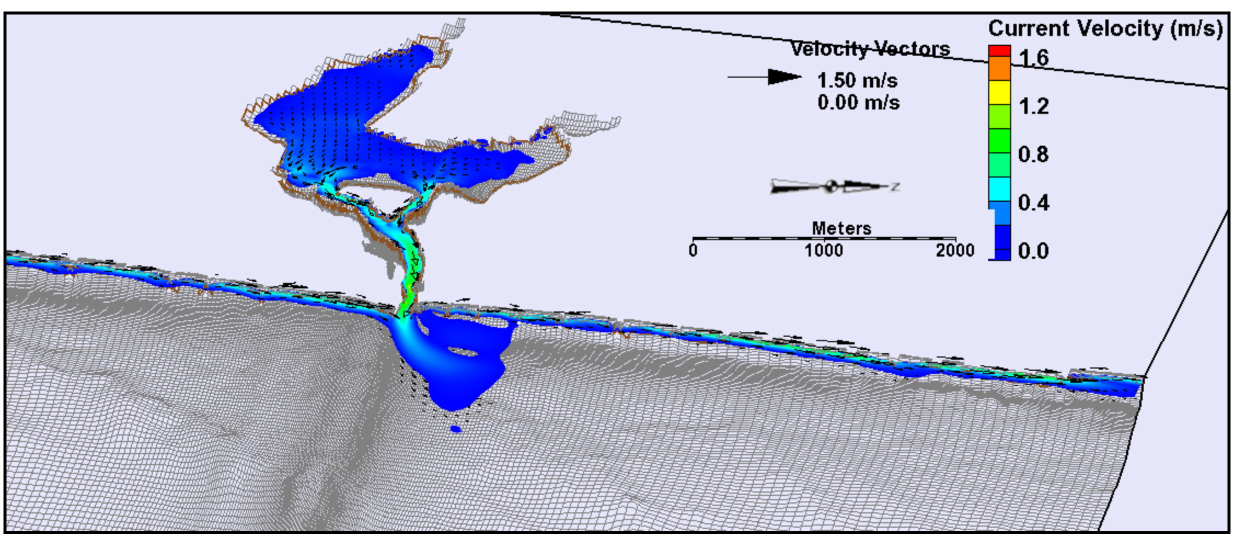

Figure 18. Numerically simulated current; 2-D averaged velocity vectors displayed in 3-D view.

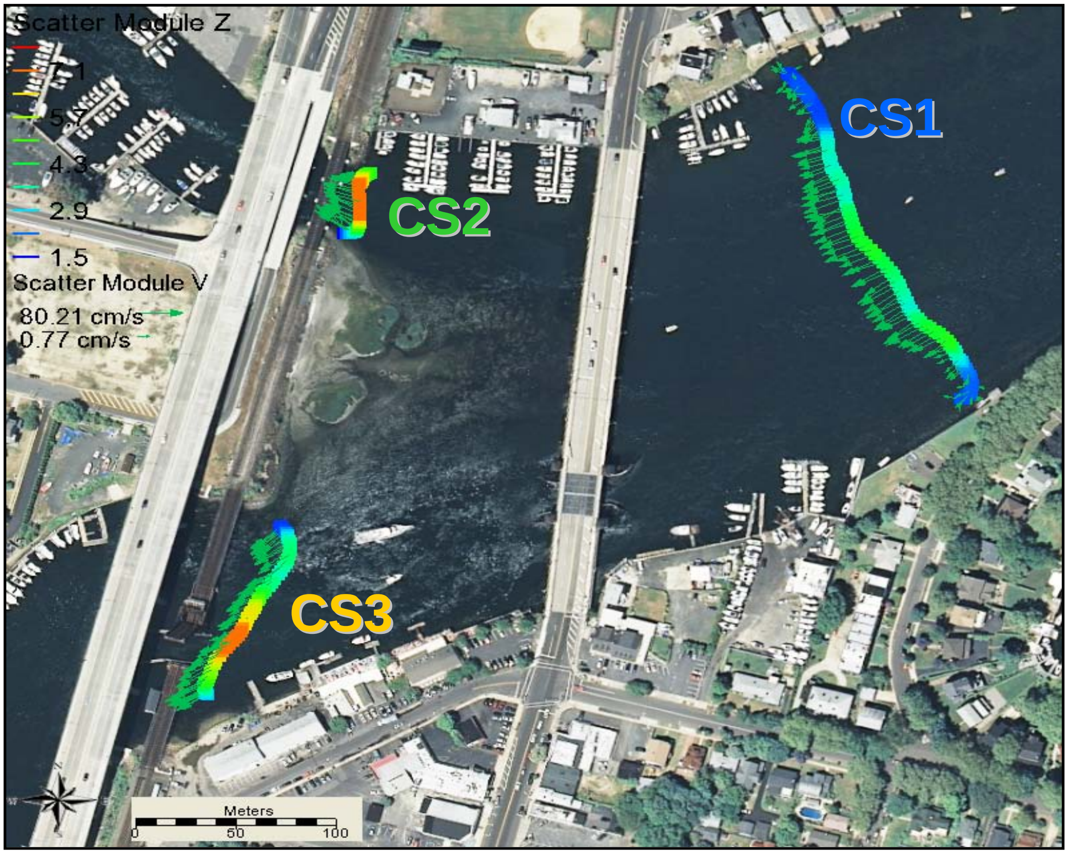

Figure 19. Measured depth-averaged current velocities along surveyed cross sections (CS).

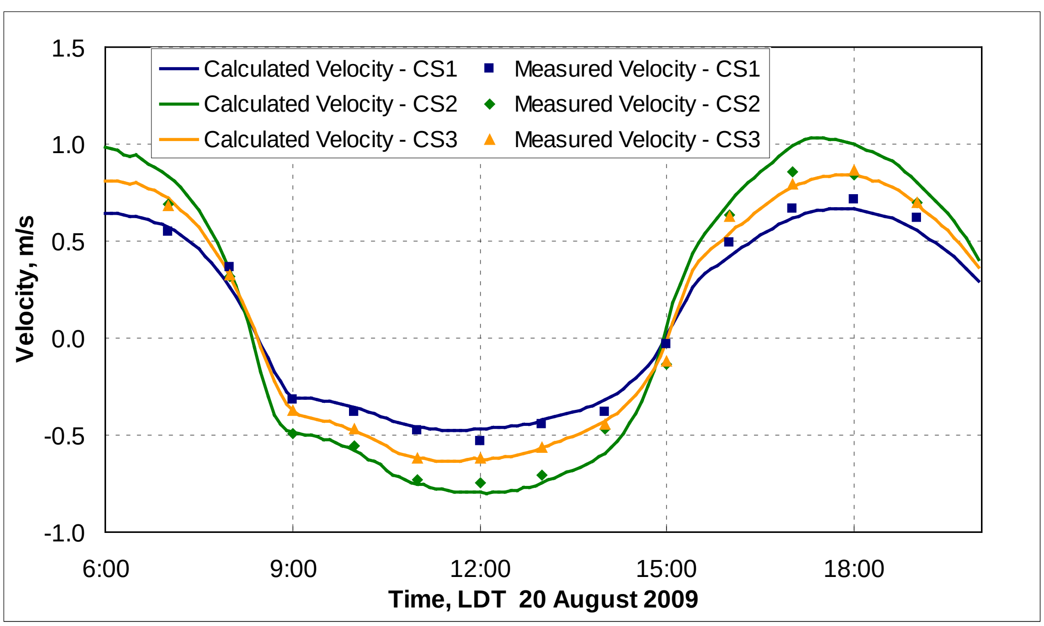

Figure 20. Measured and calculated current velocities at point locations along surveyed cross sections (CS) shown in Figure 18.

Calculated currents in the nearshore, primarily induced by breaking waves, are illustrated in Figures 21-24. During the winter, cold fronts drive much of the southward-directed longshore sediment transport. Examples of the southward-directed longshore current interacting with the ebbing and flooding current for Shark River Inlet are shown in Figures 21 and 22, respectively. Note the development of circulation cells within the groins along the north side, and the stronger longshore current velocities entering the channel from the north. Much of the developed ebb delta shelters the adjacent southern shoreline from developing currents; however, the delta is not large enough to initiate the typical refraction patterns associated with tidal inlets.

Figures 23 and 24 show the calculated current under southerly approaching waves. This type of current is generated by typical wave heights and directions for much of the year, especially during the summer. Longshore current velocities are more developed under both ebbing and flooding cases along the southern shorelines because the shoreline is unstructured and therefore has uninterrupted flow. During flooding, the strong longshore current velocity feeds into the inlet and must be responsible for much of the sedimentation in the vicinity. However, the interaction of the longshore current, notably the northerly directed currents, and the ebb jet reverses direction of some current, where flood-directed currents occur along the southern jetty during the ebbing current, and ultimately deflects the jet toward the northwest. This deflection tends to channelize the flow, and ultimately drives the maintained navigation channel toward a northwesterly orientation. Figures 21 and 23 show that the ebb current tends to exit the entrance with a northeast orientation because of the unequal lengths of the jetties, the south jetty being longer.

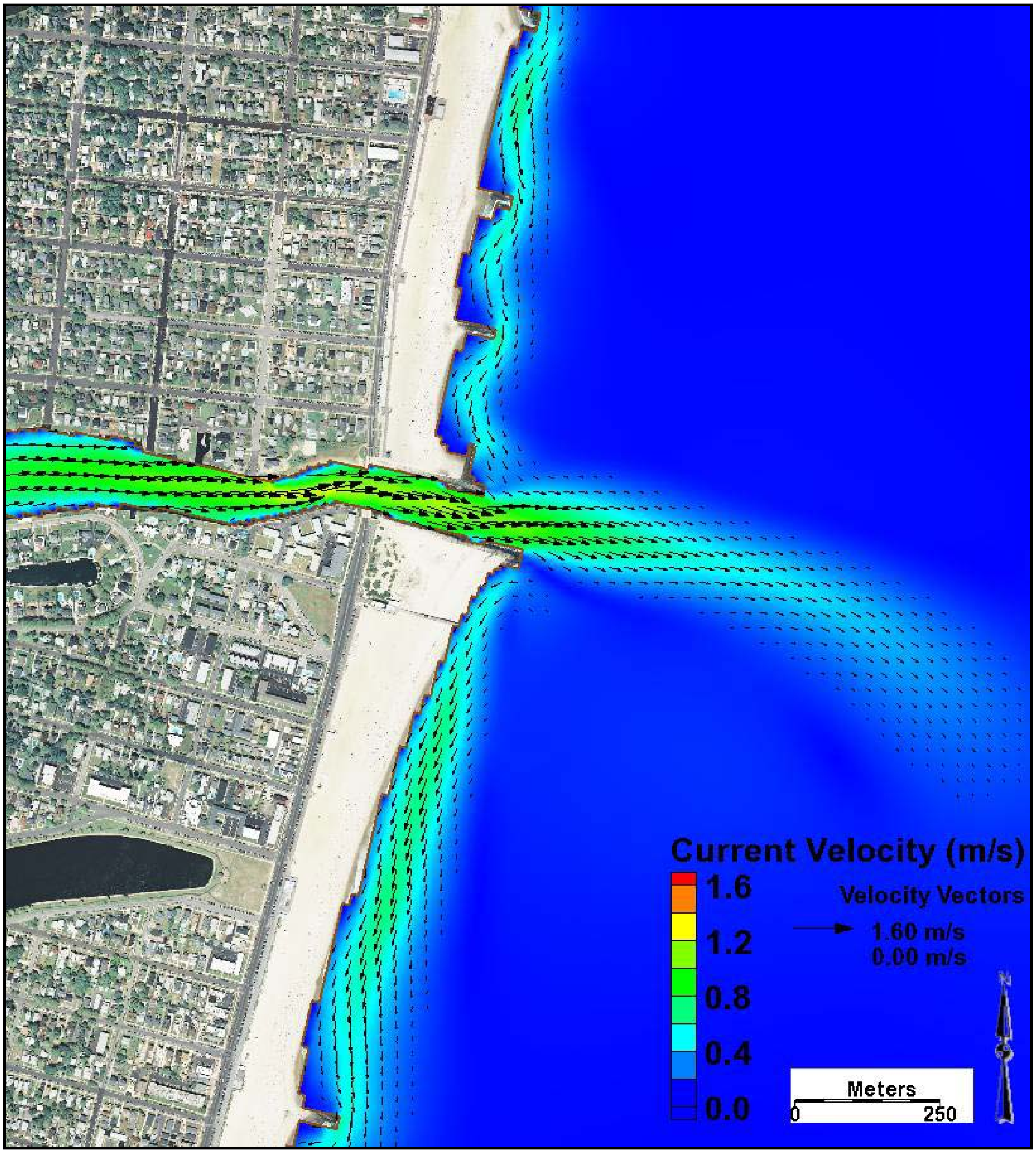

Figure 21. Calculated current at Shark River Inlet during ebb under northerly approaching, oblique waves.

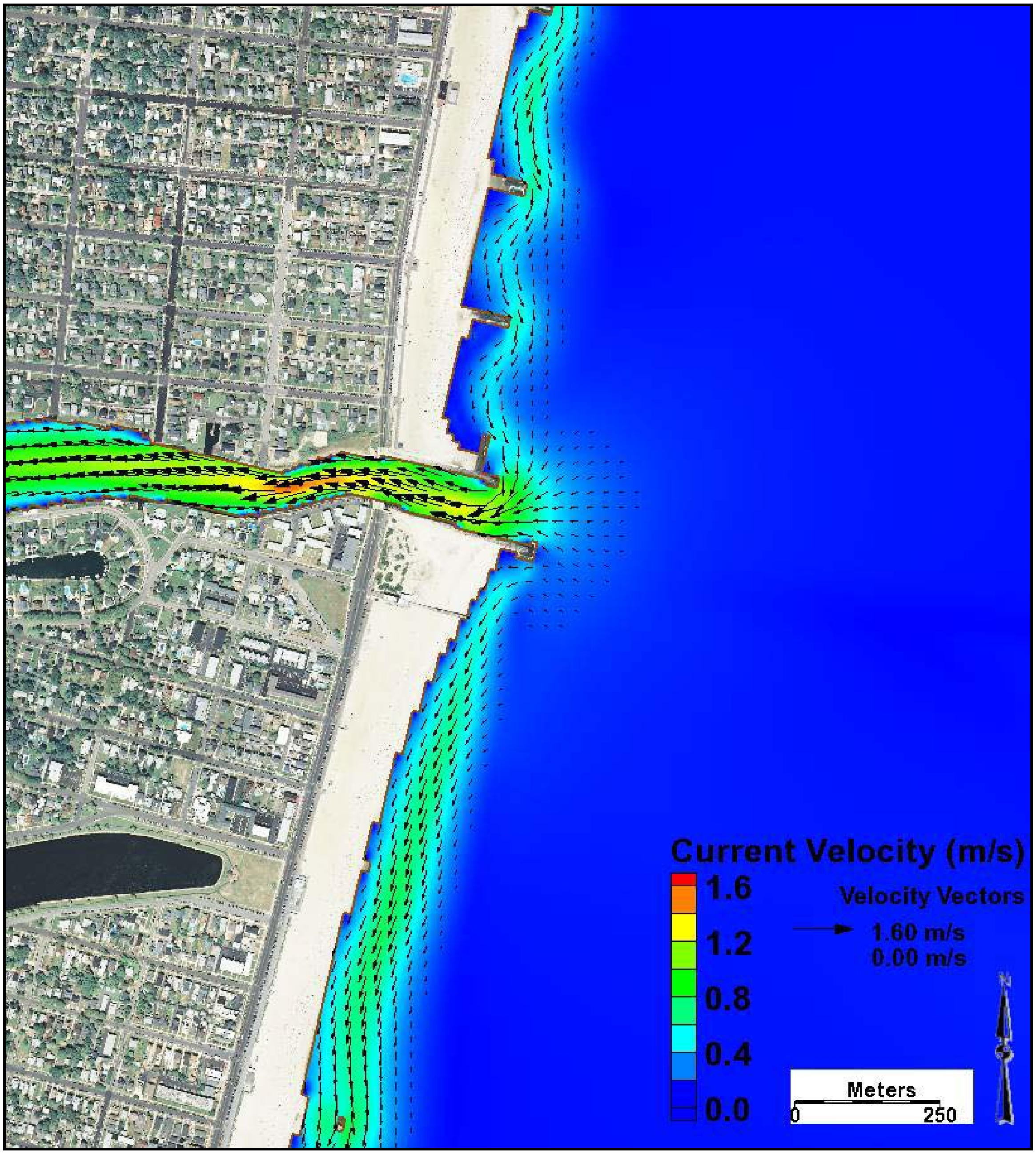

Figure 22. Calculated current at Shark River Inlet during flood under northerly approaching, oblique waves.

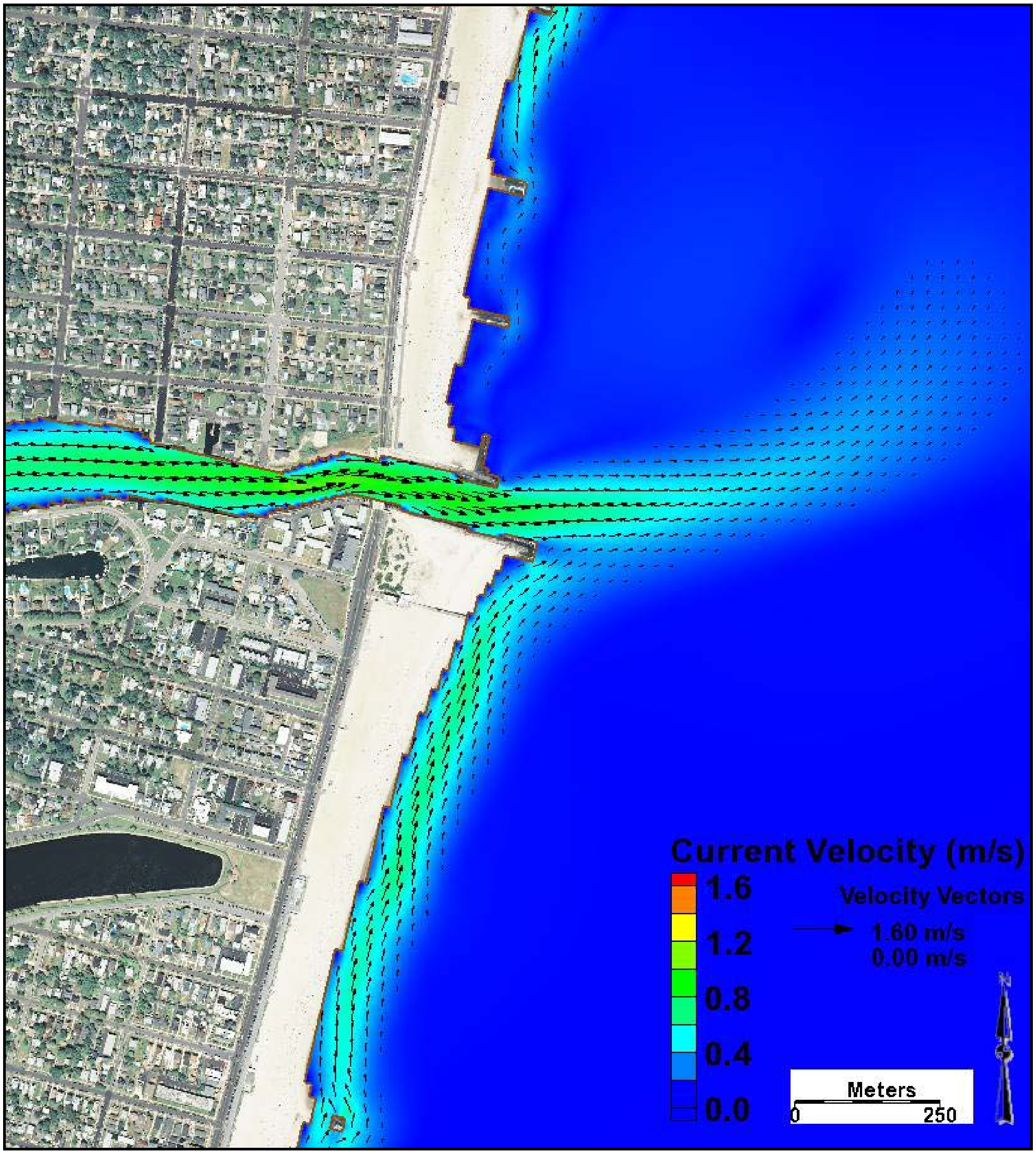

Figure 23. Calculated wave-current interaction at Shark River Inlet during ebb under southerly approaching, oblique waves.

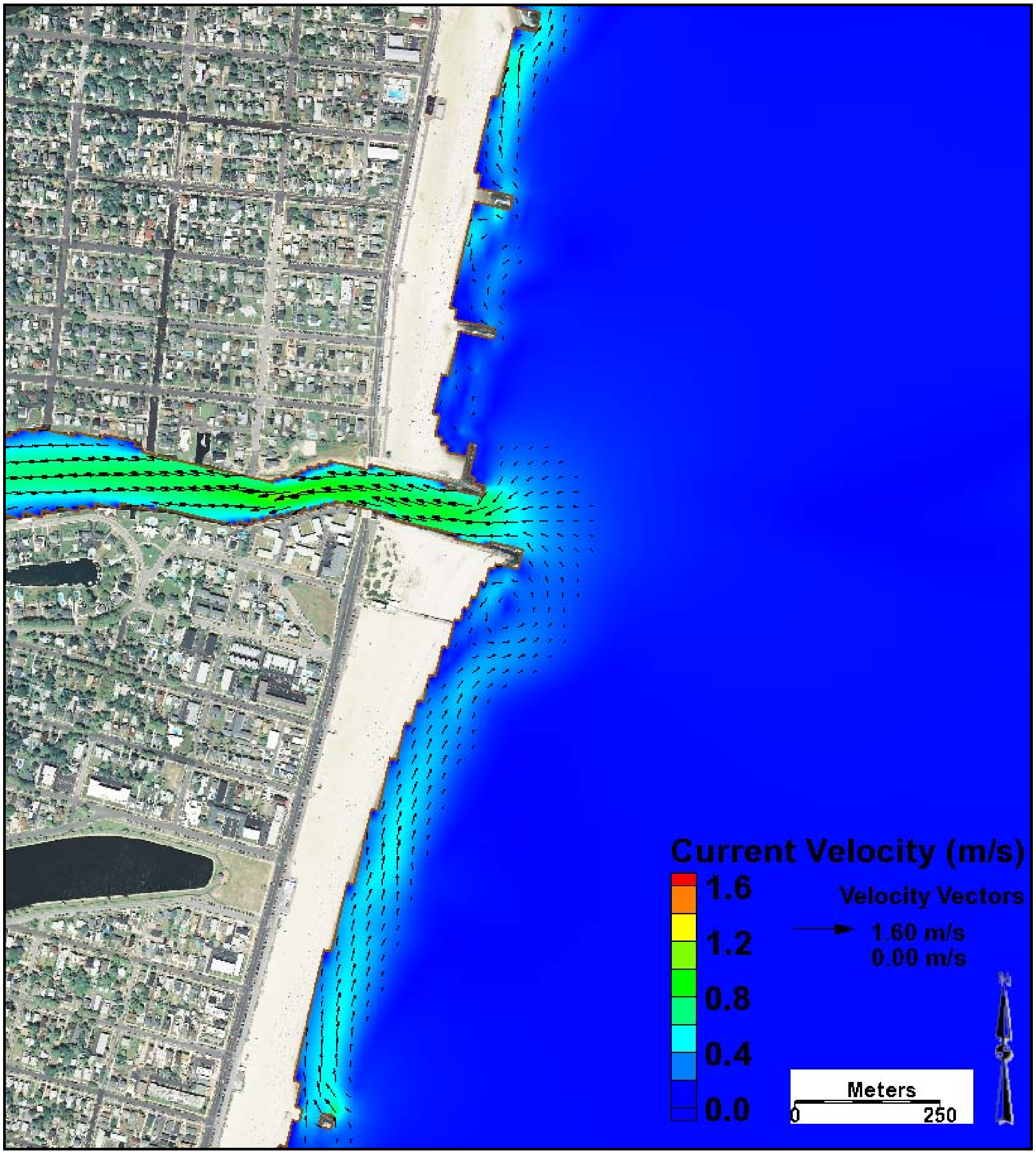

Figure 24. Calculated wave-current interaction at Shark River Inlet during flood under southerly approaching, oblique waves.

5 Channel Infilling and Morphology-Change Modeling

Morphology change was numerically simulated with an inlet bathymetry from 1999, prior to shoaling in the inlet, and it produced a qualitative representation of ebb-tidal delta generation for a 3-year simulation. The CMS was then applied to evaluate morphologic outcomes of five alternatives for reducing dredging frequency in channel maintenance (Figures 25-26). The alternatives are summarized in Table 4. The ebb-delta growth alternative is defined by an initial bathymetry with a recent shoreline position from 2005, after nourishment of the adjacent beaches, and an inlet bathymetry from 1999. An existing condition from a recent January 2009 bathymetry formed the basis to generate a grid for a contemporary representation of the inlet after dredging (Figure 25). This grid was used for model validation of morphology change (Alt 1, a non-response alternative) and for the base bathymetry for Alts 2, 3, and 4.

Alt 2 defined a widened dredged channel ("channel widener," a type of advance dredging) 15 m on each side as recommended by Kraus and Allison (2009), and Alt 3 defines a widened dredged channel 30 m wide. Alts 2, 3, 4 and 5 are shown in Figure 26. Alt 4 examined a 75-m extension of the north jetty, making it parallel and equal in length to the south jetty. Alt 5 was based on the December 2008, before-dredging bathymetry, which has a naturally NE-SW trending channel orientation, and was modified to a depth of 5.5 m below MLW.

The growth of the ebb-tidal delta, beginning about year 2000, follows the first large-scale injection of sand to the littoral system. Based on the assumption that onset of shoaling was initiated by an increase in sand supply from the adjacent nourished beaches, the CMS was run to predict growth of the ebb delta at the entrance channel as Alt 1. Sand calculated to be deposited in the channel for a simulation time of 3 years, totaled approximately 30,000 m^3 (Figure 27). This volume is consistent with measured rates of accumulation in the entrance channel, compiled in Figure 16, where shoaled volume peaked at around 40,000 m^3 after 7 years. The entire calculated ebb delta after 3 years had a volume of 90,000 m^3. Also, the CMS produced an asymmetric ebb-tidal delta and migration of the entrance channel to the northeast, similar to observations (Figure 14).

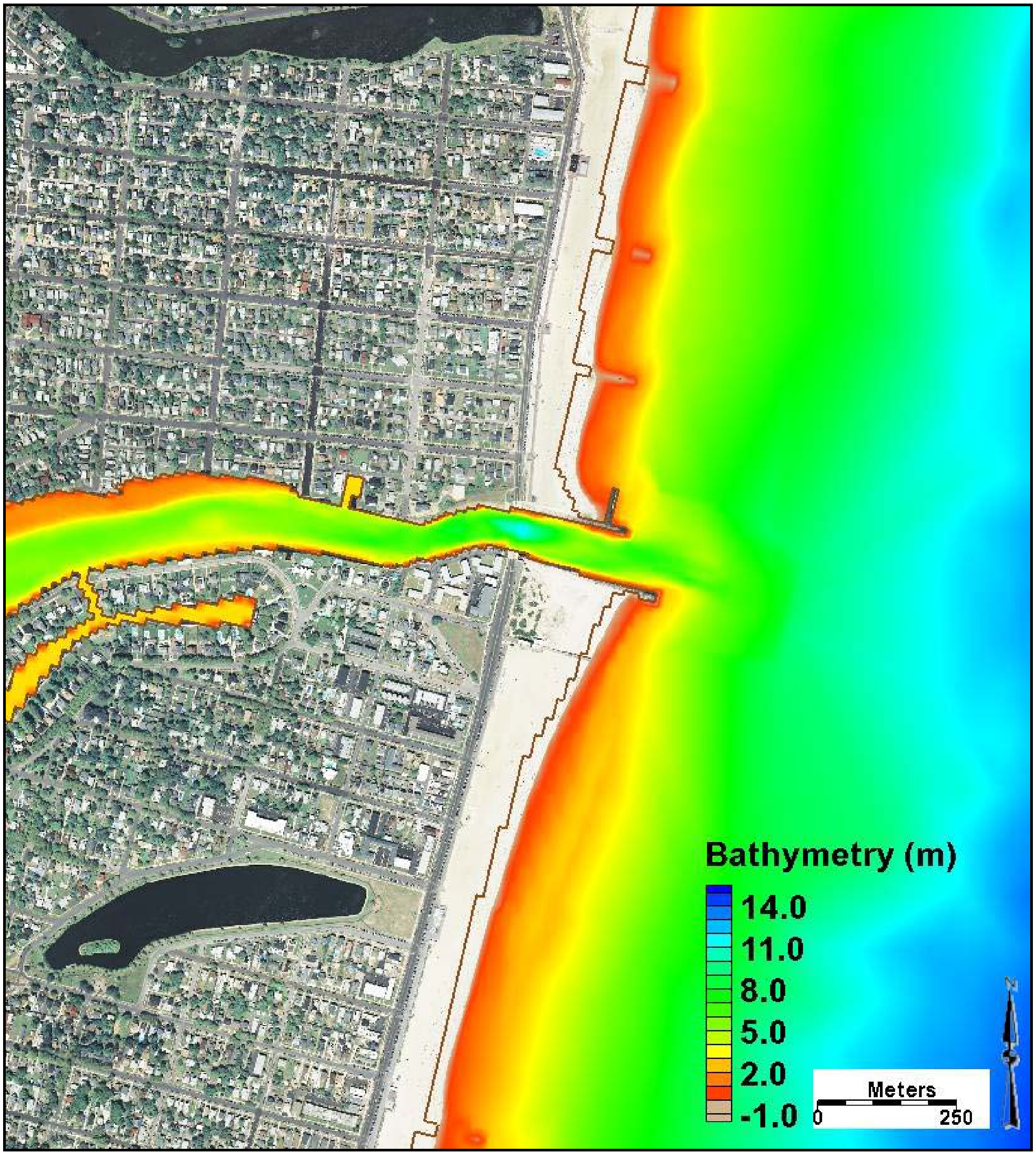

Figure 25. Shark River Inlet CMS grid, Alt 1.

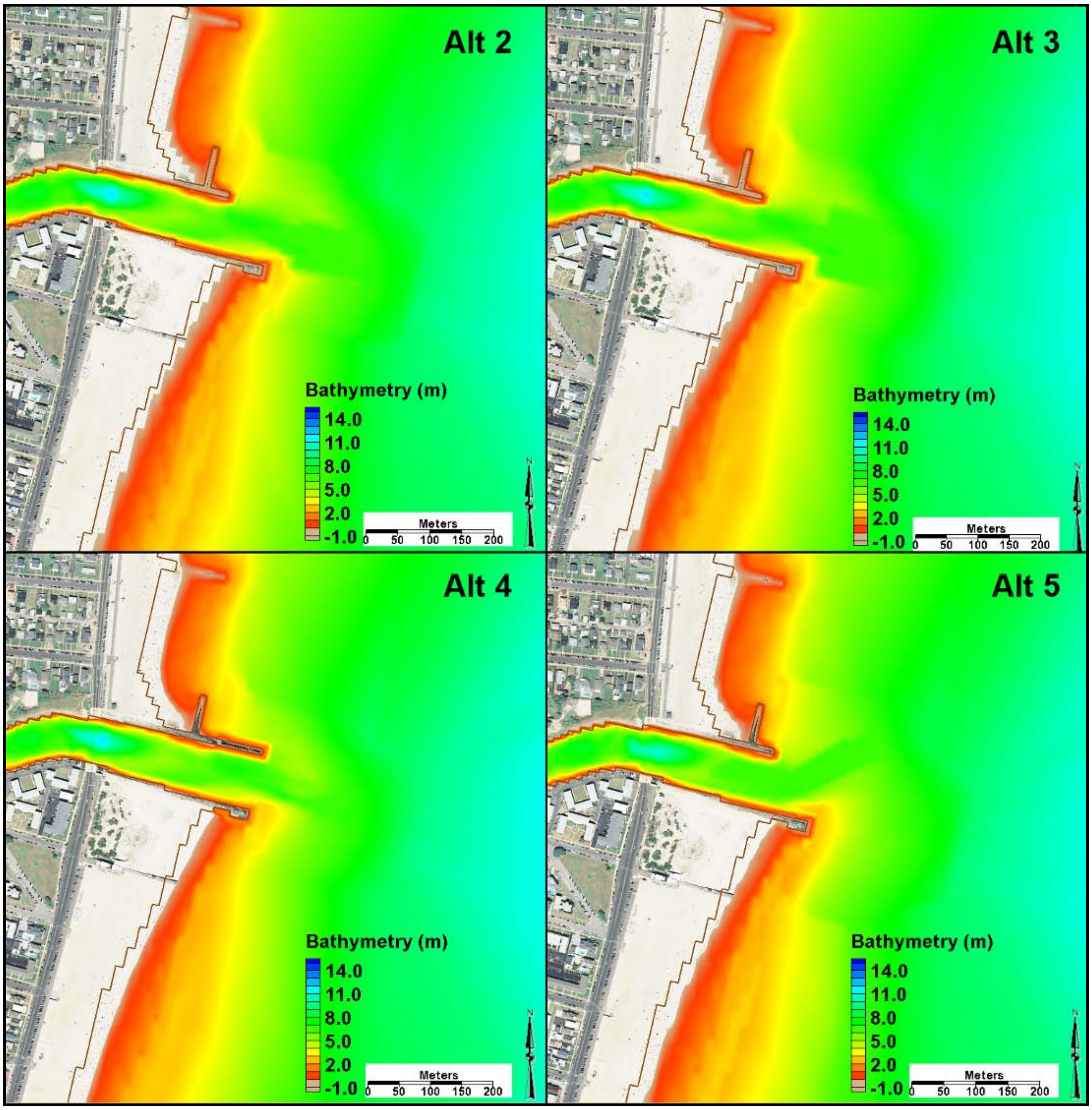

Figure 26. Shark River Inlet CMS grid, Alts 2-5.

Table 4. Definition of Alternatives

Alternative	Definition	Description
Alt 1	After-dredging January 2009	Initial Condition of a post-dredged channel from January 2009
Alt 2	15-m wideners	Advance dredging increasing channel width 15 m to the north and south
Alt 3	30-m wideners	Advance dredging increasing channel width 30-mto the north and south
Alt 4	75-m north jetty extension	Extend north jetty parallel to at seaward limit of the south jetty
Alt 5	NE-SW channel maintenance	Align the authorized channel with the channel that naturally forms with a NE-SW orientation to exit past the north jetty

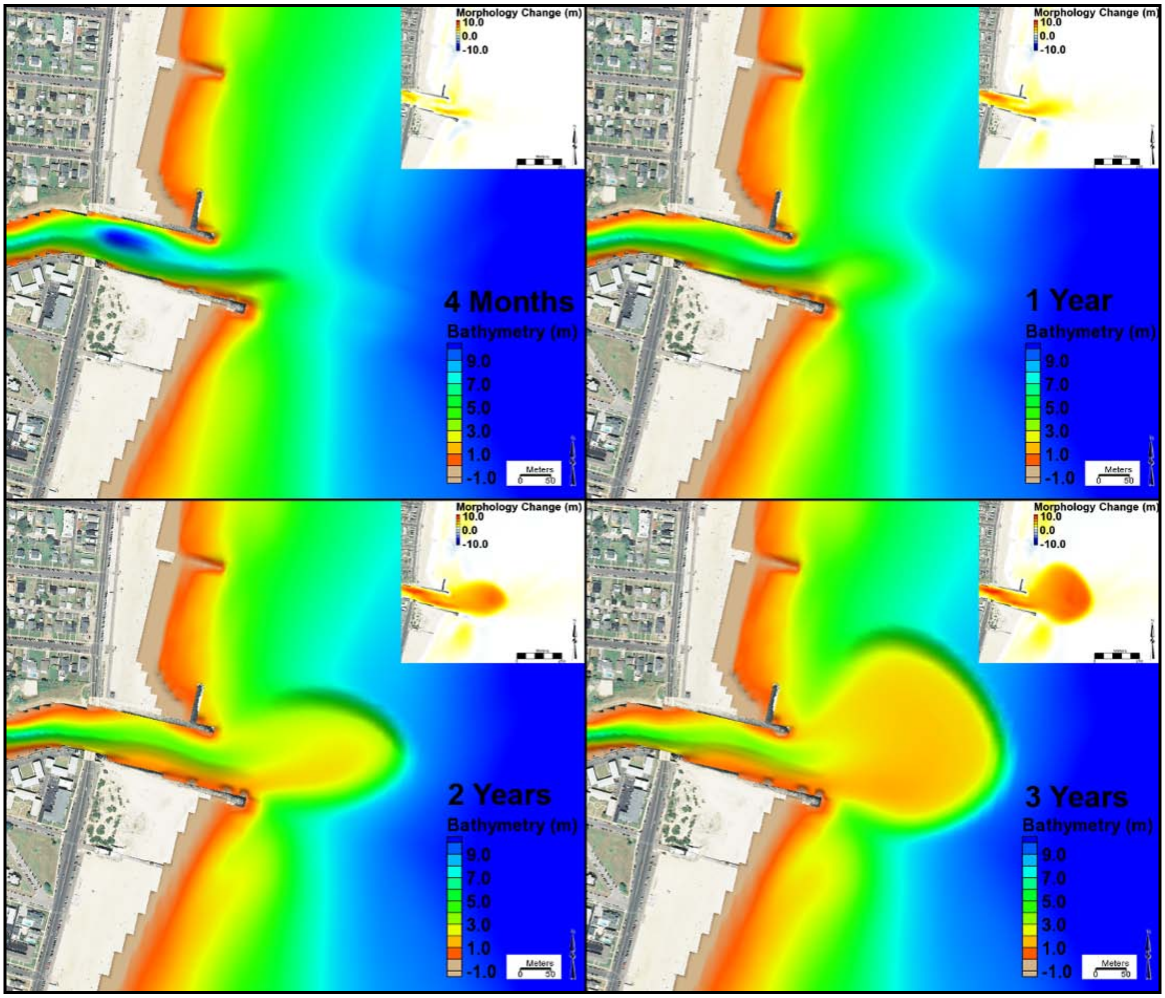

Figure 27. Calculated morphology change for the 1999 existing condition.

Existing condition verification

Alternative 1, the non-response alternative, was tested first to verify the existing condition for the hydrodynamic model as well as verify channel infilling rates and potential sand transport. The simulation was run for four months, a typical recent dredging interval, to compare channel infilling rates and patterns, and then set to complete a full year of model morphology change. Results from the measured January 2009 bathymetry served to verify channel infilling rates (Figure 28). Based on the surveys, channel infilling volume expected for the 4-month simulation is about 10,000 m^3 for the entrance channel alone.

The CMS mean water level is specified as MSL, and it is convenient to refer to this datum in the following (as shown in Figures 25 to 40). The New York District datum MLW is approximately 0.8 m below MSL at the Long

Branch gauge. The measured seaward section of the infilled channel had approximately 1-2 m of deposition between the limiting depth of 4.2 to 5.0 m over the entrance bar and the dredged depth of 6.3 m (MSL). This deposition represents the initial build up of the entrance bar immediately following dredging, illustrated in April 2009 survey in Figure 14. Calculated limiting depths over the channel were approximately 4.5 m (MSL). The calculated deposition compares well in both volume and morphology with much of the deposition occurring along the south side filling in towards the north and development of an entrance bar at the same location relative to the jetty tips (Figure 29). The scales of A and B in Figure 29 appear different, but are the same because the measured bathymetry shown in A only covers a portion of the ebb delta.

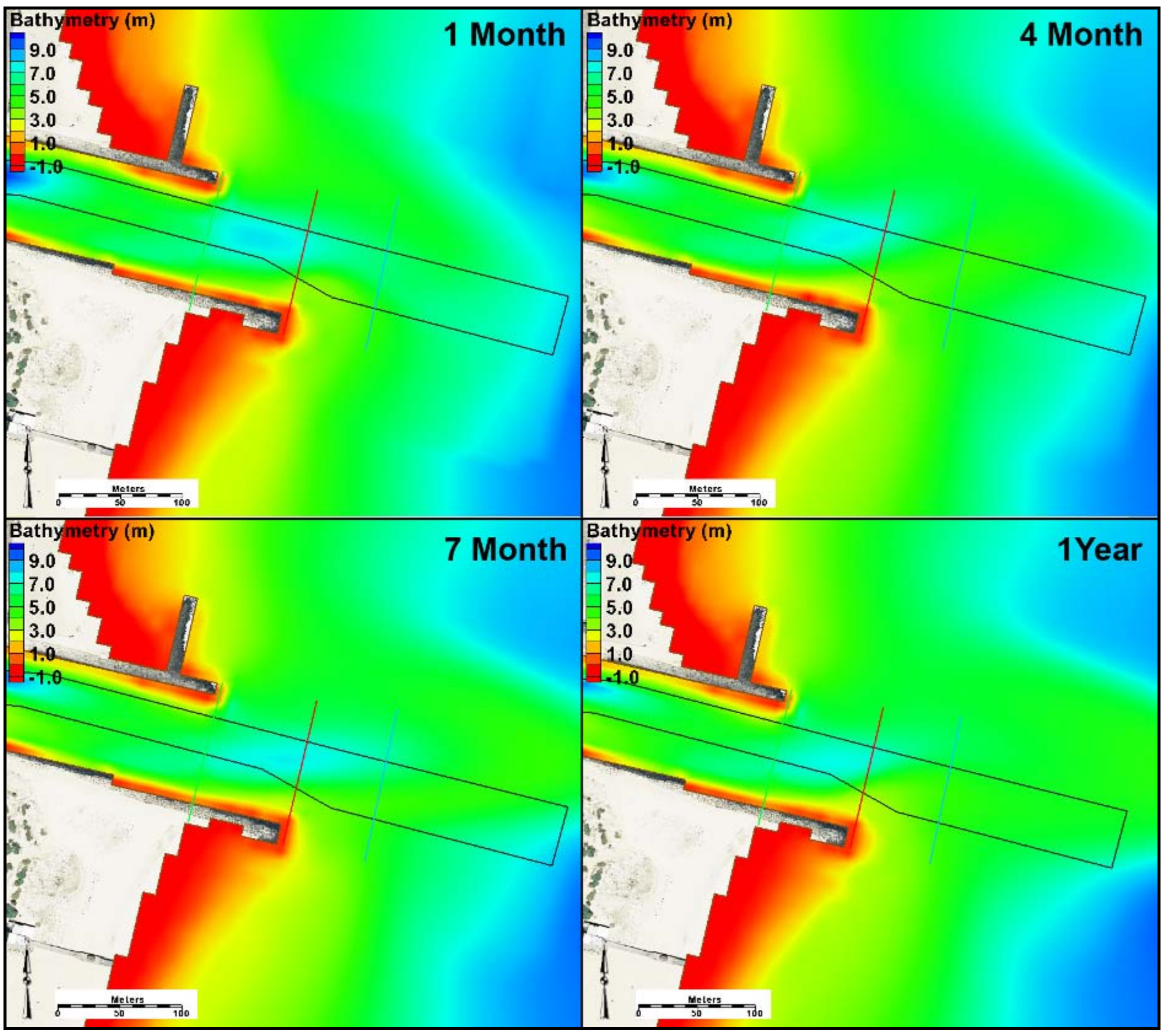

Figure 28. Calculated morphology change, Alt 1; Note: CS1 – green (inside channel), CS2 is in red (south jetty-tip), and CS3 is in blue (offshore).

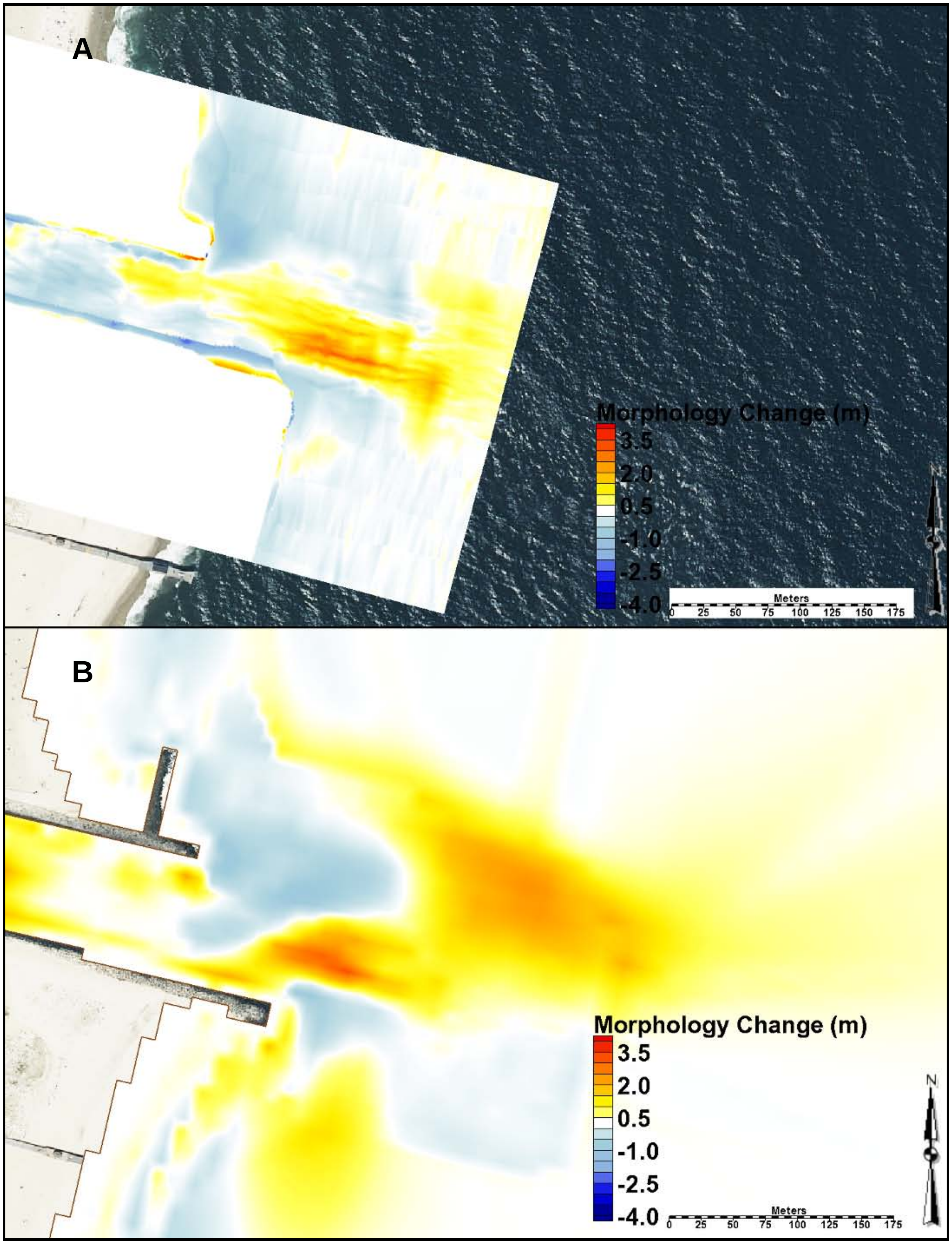

Figure 29. Measured (A), and calculated (B) morphology change, January to April 2009 , Alt 1.

Alternatives

Under the two channel widening alternatives, Alts 2 and 3, there is a significant change in morphologic response by extending the dredging north and south of the authorized channel. Channel infilling volume for the 4-month simulation of Alt 2 and Alt 3 is greater by 5,000 m^3 (Figure 30); however, the limiting depth of the shoal in Alt 2 is only 5.3 m as opposed to 5.0 m. The proximal side of the channel is scoured greater (-7.0 to -9.0 m MSL) than the authorized depth. There is a large offset of channel orientation toward the north as a result of the greater volume of shoaling around the south jetty tip. In conjunction with the south shoaling, currents are no longer directed parallel through the channel, but meander under the influence of both morphology and jetty configuration. A decrease in shoaling response for Alt 3 as opposed to Alt 2 was found after four to six months (Figure 31); however morphologic response essentially converged in both modeled alternatives.

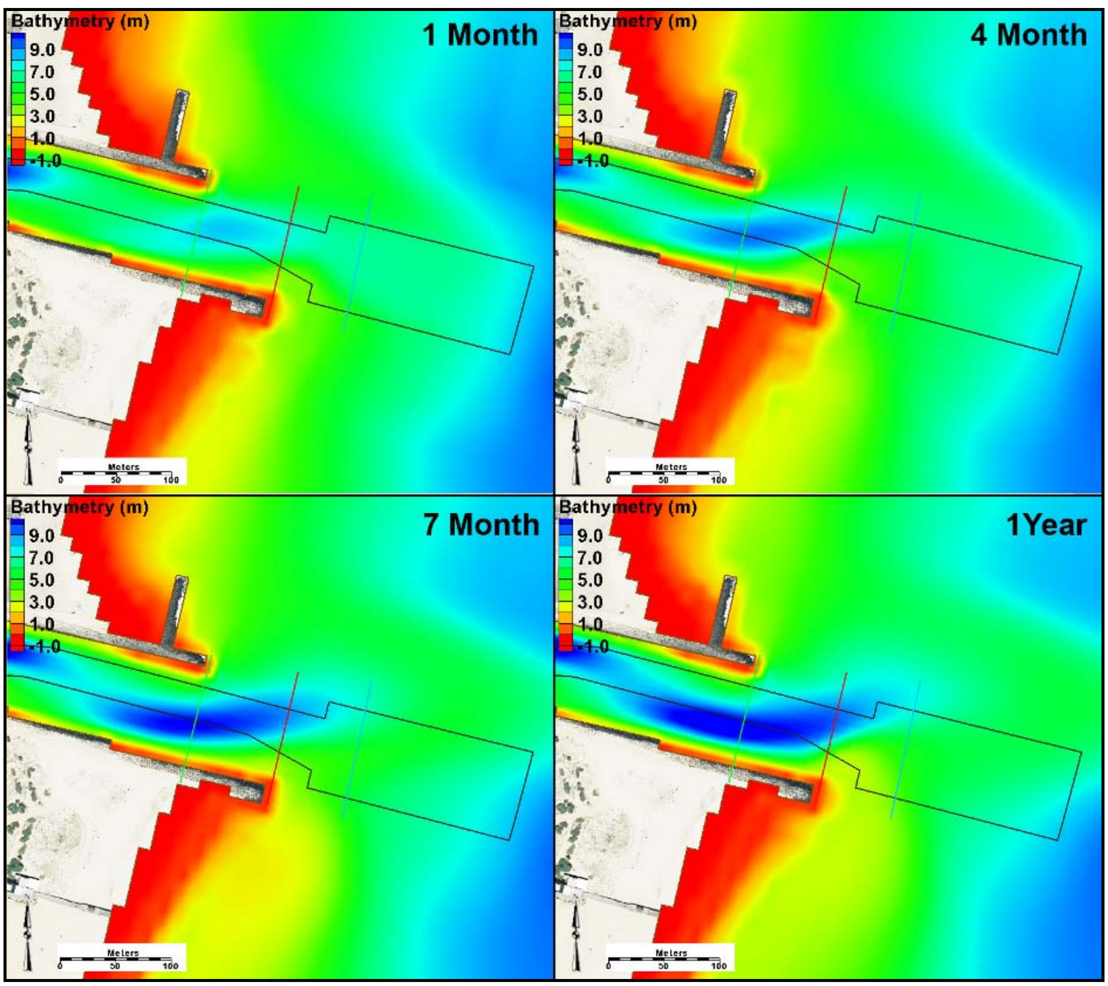

Figure 30. Calculated morphology change, Alt 2.

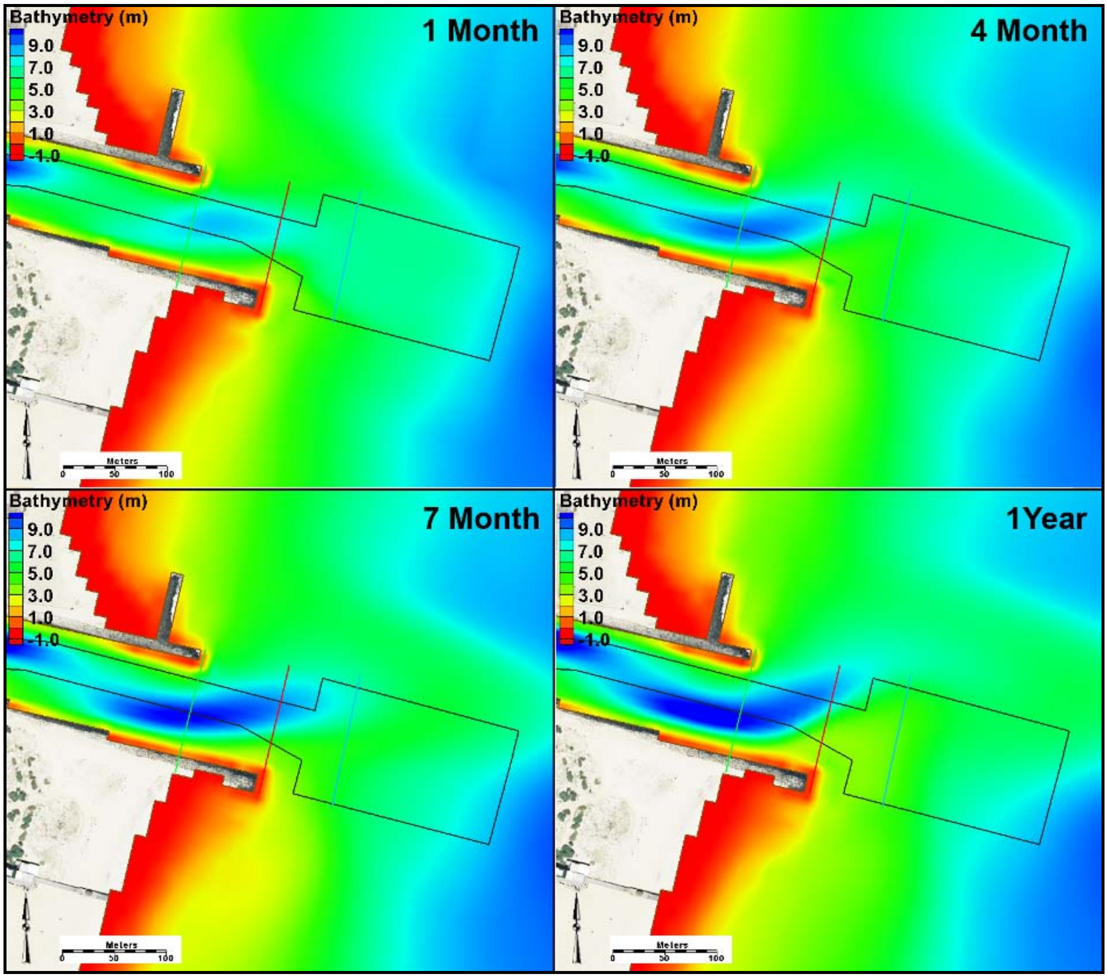

Figure 31. Calculated morphology change, Alt 3.

Morphology change calculated for Alt 4 indicates a stronger along-channel current in the inlet, resulting in a clear and perpendicular channel (Figure 32) scouring beyond the direct influence of the adjacent, shallow nearshore. The most dominant process controlling this morphology is the current pattern resulting from the confluence of ebbing and flooding currents over a longer extent of channel with parallel or straight boundaries. The extended straight boundaries decrease the potential for a meandering pattern, which was exacerbated in Alts 2 and 3, and produces stronger along-inlet current velocity, which maintains a deep and symmetric channel morphology. Finally, the channel slopes approach equilibrium under the new centrally-located stable and deeper channel and, as a result, a large volume of sediment is deposited along the sides of the channel.

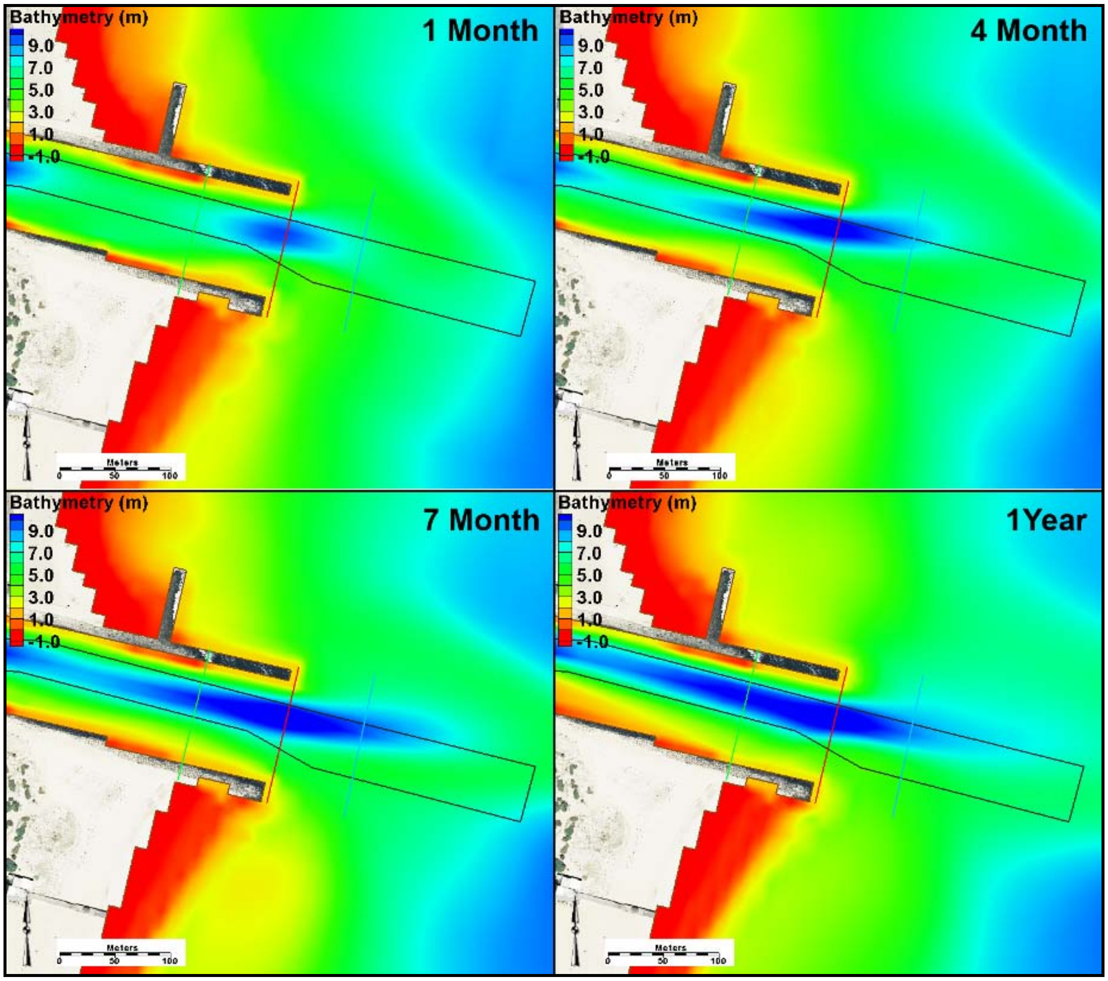

Figure 32. Calculated morphology change, Alt 4.

Alternative 5 was the least effective at maintaining navigable channel depths for a longer period of time as opposed to the present dredging practice (Figure 33). Although the initial channel morphology directed NE-SW for this alternative represents the present condition, volume of sand removed (under the dredging) is relatively small and, therefore, there is little accommodation space for the sand transported around the distal part of the ebb-tidal delta. The calculated result of this alternative is most similar to Alt 1, where no changes were made to the post-dredged bathymetry from January 2009.

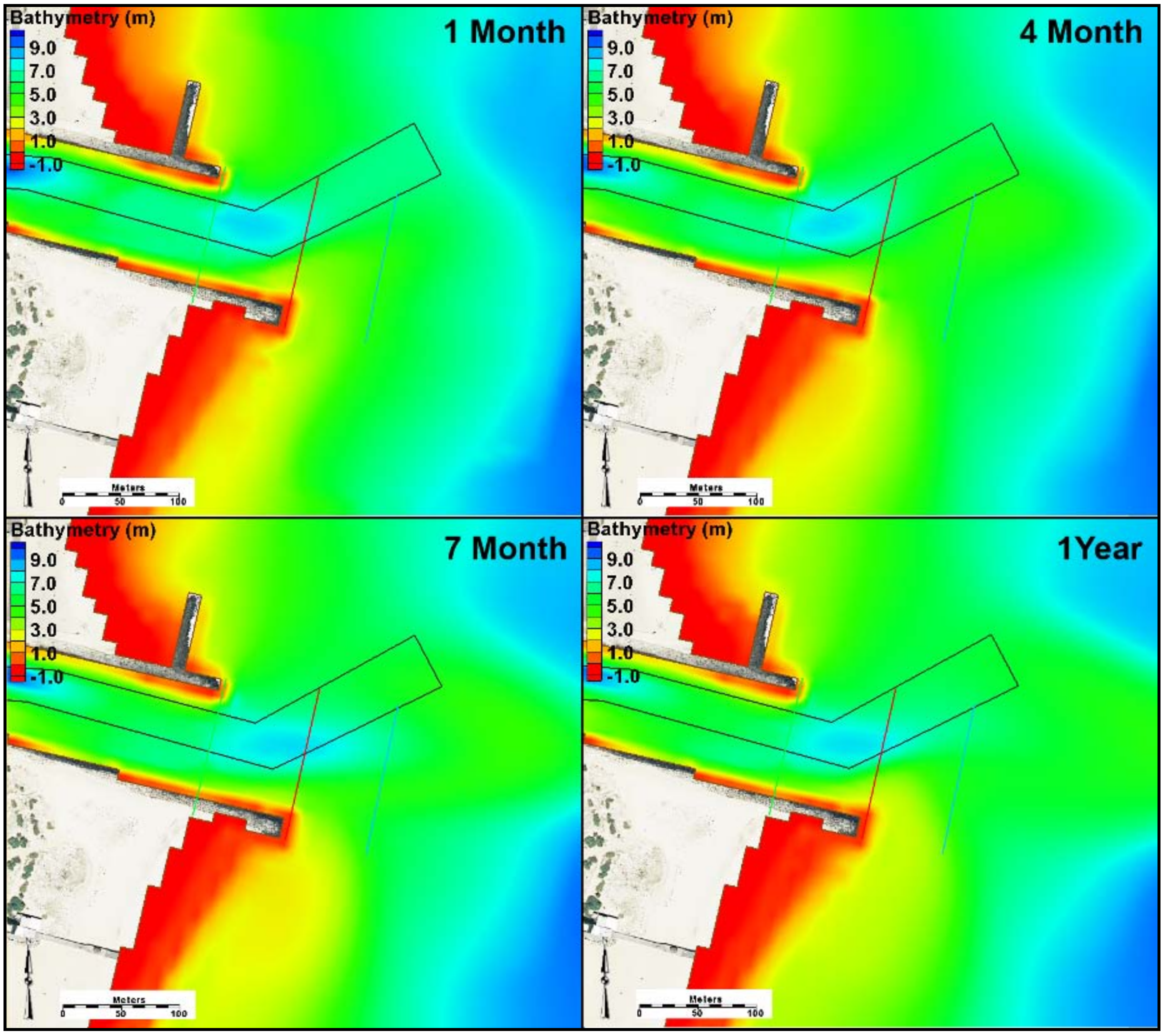

Figure 33. Calculated morphology change, Alt 5.

Three cross sections across the entrance channel to Shark River Inlet were selected to compare measured and calculated shoaling rates and patterns. Measured bathymetry change for each cross section from January to April 2009 is plotted in Figure 34. The first cross-section, CS1 (denoted in green in Figure 28), shows good correlation between measured and calculated changes. This part of the channel typically experiences seasonal shoaling, which did not occur during the four months between the January and April 2009 survey. During the late summer to winter months, some shoaling occurs along the northern side of the channel (Figure 35).

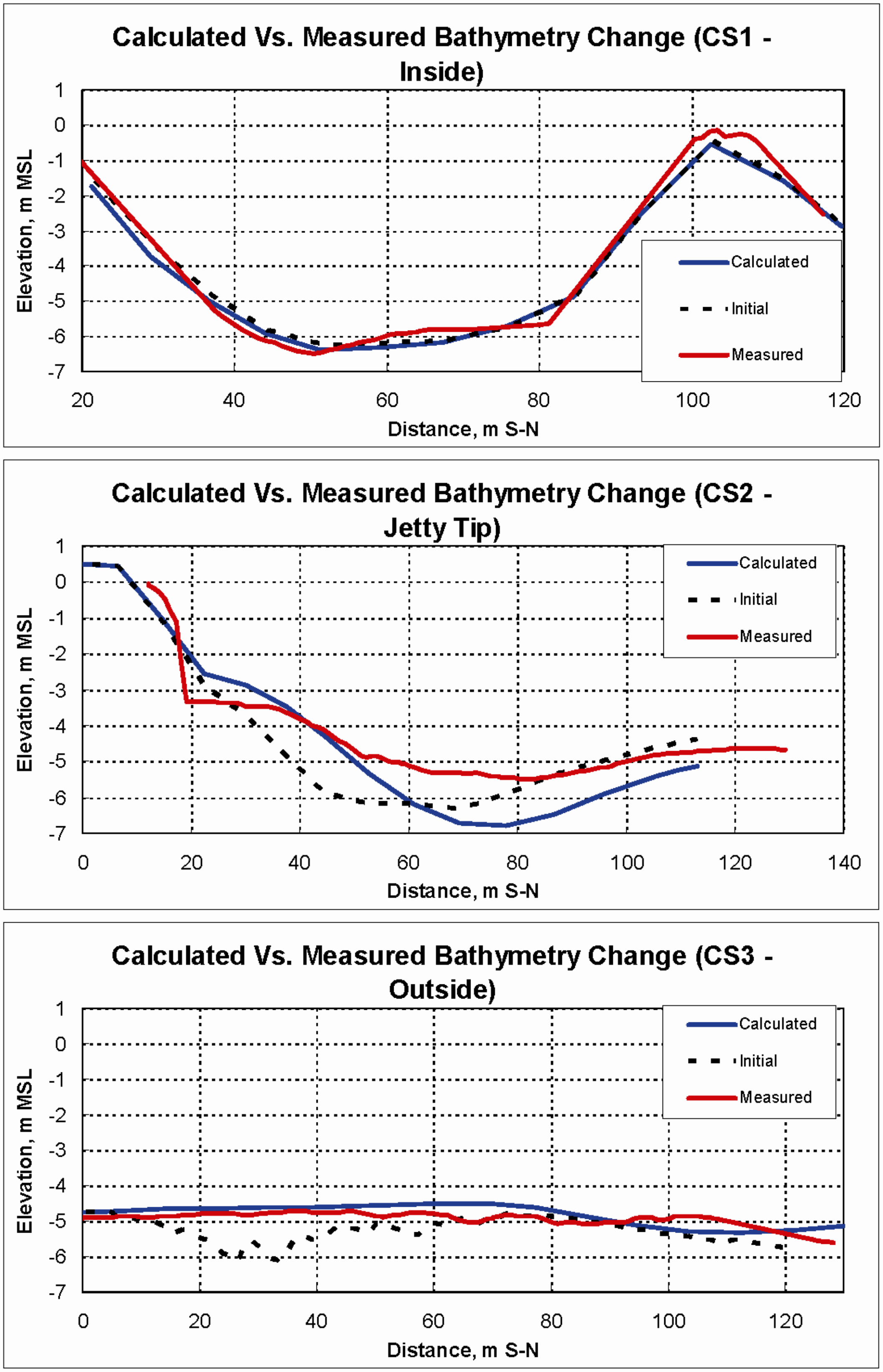

Figure 34. Measured and calculated channel depth, January to April 2009, Alt 1, at three locations across the inlet channel.

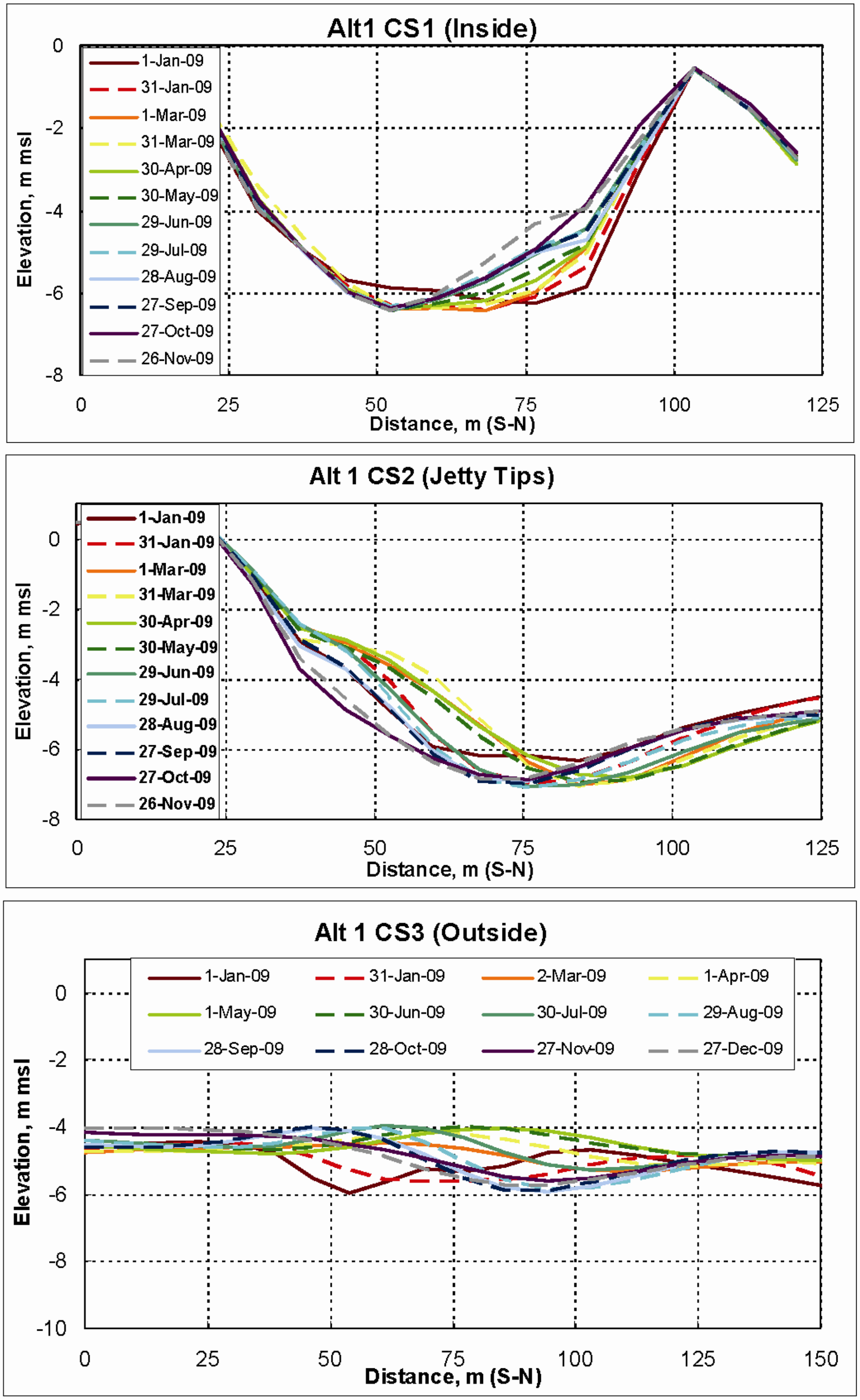

Figure 35. Calculated channel infilling, Alt 1, at three locations across the inlet channel.

Channel infilling patterns were well represented in both CS2 and CS3 (red and blue cross sections, respectively) with CS3 matching the measured change. CS2 covers the most dynamic area in the channel, which experiences the highest volumetric changes over time as shoaling occurs. As a result, the calculated depth change along the cross section does not match the measured shoal elevations. However, the pattern of deposition is concurrent with observed patterns, and the total volume of sediment that enters this portion of the navigation channel is consistent with measurements. Seasonal shoaling is apparent in the fluctuations of CS2, where channel infilling by April is apparent; however, it is eroded over the remainder of the year simulation as the shoaling pattern changes (Figure 35). CS3 covers the distal portion of the ebb-tidal delta and largely the limiting depth of the entrance bar. During the first six months, a small volume of sand moved over the entrance bar, and was eroded over the remainder of the simulation to previous depths.

Erosion and deposition patterns represented in cross section for Alts 2 and 3, plotted in Figures 36 and 37, have similar magnitudes and rates. There is little difference in performance between these alternatives in morphologic response for the first four to six months. Both exhibit scouring within the confines of the jetties (CS 1 and CS2), which continues beyond the first six months. This scouring is the result of an enhancement of sinuosity of the channel. A notable initial difference between each alternative is the increase in depth along the northern portion of CS2 and CS3 for Alt 3 with the 30-m channel wideners. For both alternatives, CS2 shows steady migration of the channel toward the north as the sinuous channel is initially deflected toward the northeast. CS3 for both alternatives illustrates the rapid shoaling for the first few months, resulting in more sand filling in the 30-m channel for Alt 3, but stopping at nearly the same depth and timeframe as for Alt 2. This infilling response corresponds to the larger volume of sand initially infilling the channels for Alts 2 and 3 (with Alt 3 experiencing more sedimentation due to available accommodation space), and is the result of the ebb-delta platform reaching an equilibrium level (Figure 36 and 37). Following this, the response of both alternatives is similar in magnitude, with greater scouring and southward migration of the confined portion of the channel illustrated in CS2 and CS3.

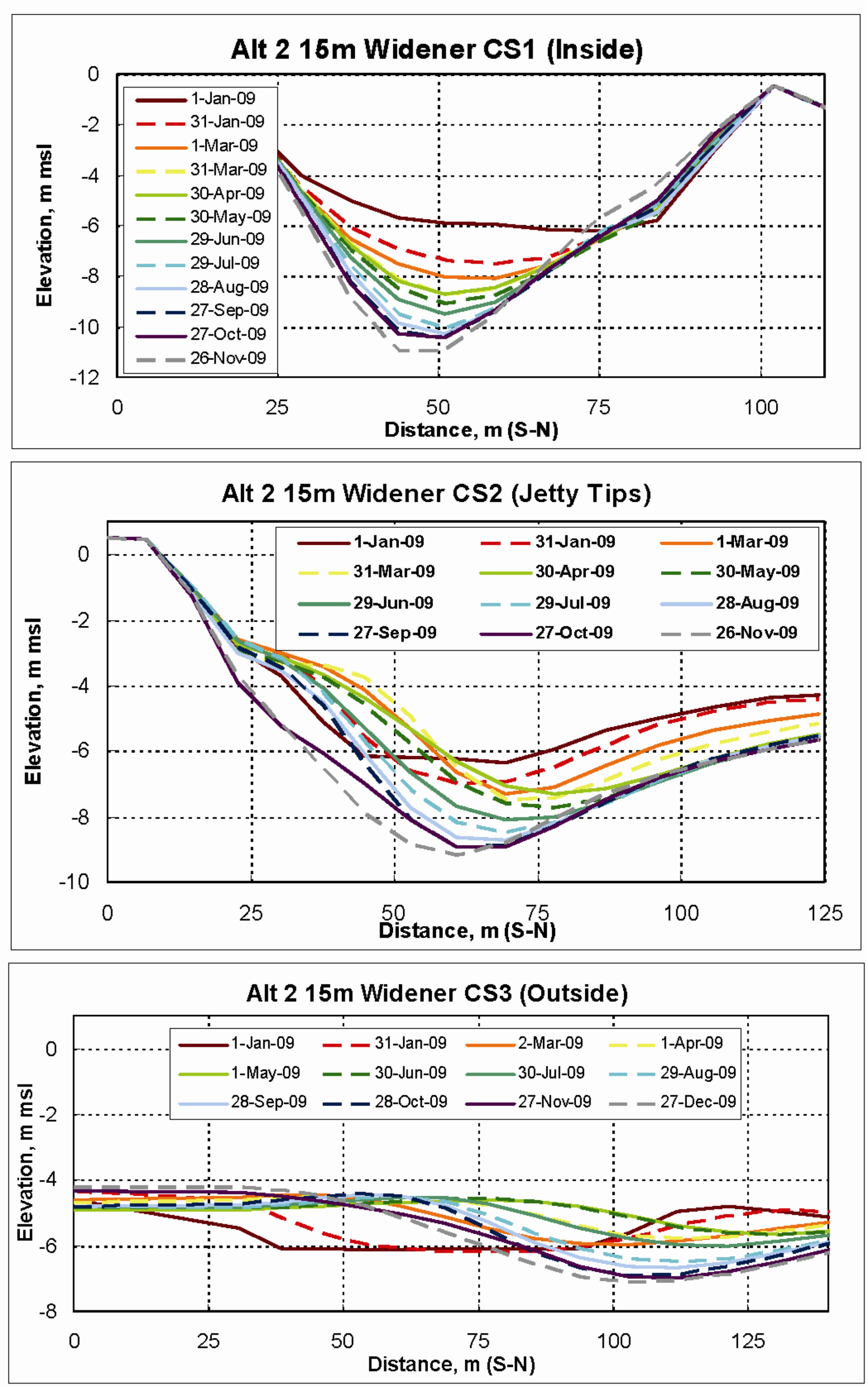

Figure 36. Calculated channel infilling, Alt 2, at three locations across the inlet channel.

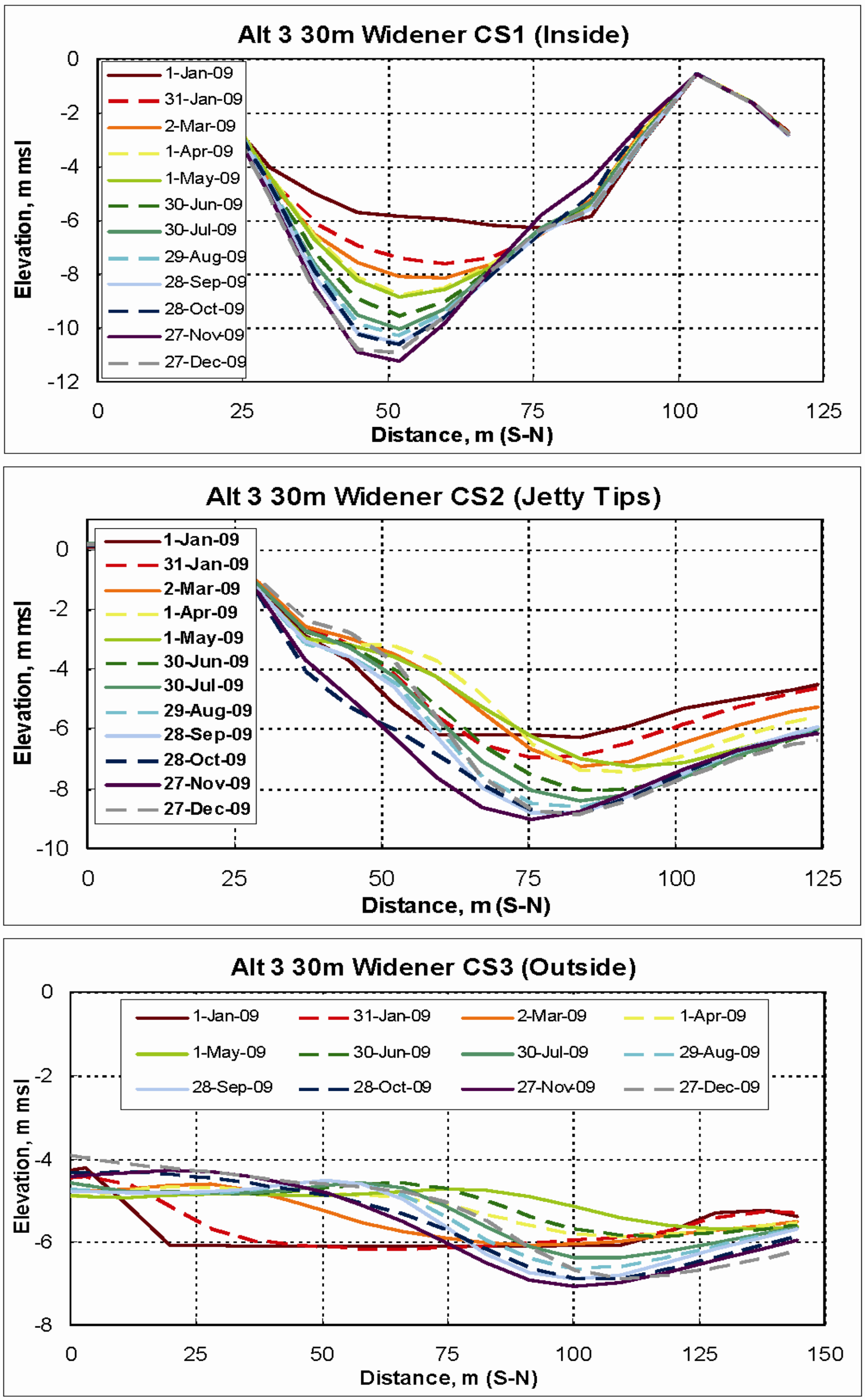

Figure 37. Calculated channel infilling , Alt 3, at three locations across the inlet channel.

An immediate response to modified tidal currents is apparent in the cross sections for Alt 4, shown in Figure 38. For CS1, which is now a cross section located within the confines of the jettied channel, is slowly scoured month by month to a depth similar to the present depths located around the Ocean Ave. Bridge pilings. However, CS2, located at the tips of the north and south jetties, responds rapidly with several meters of erosion in the first month. The newly scoured channel develops with the deepest portion nearest to the north jetty during the first six months, and then slowly migrates (15 – 20 m to the south) toward the center of the channel, to a stable depth of approximately 11 m (MSL). Seaward of the jetties, but still within reach of the ebb jet, the channel develops and scours perpendicular to the coast at a steady rate of 0.5 to 1.0 m/month. Similarly, the channel migrates 20 to 30 m to the south to a more central location in relation to the jetties.

Alt 5 (Figure 39) is similar to Alt 1 in calculated erosional and depositional patterns; however, the channel had less sedimentation over the full year long simulation. CS1 had minimal change in depth with only 1-2 m of sedimentation along the north side of the channel. The jetty-tip cross section (CS2) had the initial volume of sedimentation for the first three to four months of the simulation, which was followed by erosion as the channel scoured alongside the south jetty. Sedimentation patterns over CS3 were similar to other alternatives, where some initial sedimentation occurred downdrift of the maintained channel; this deposit subsequently eroded to 6 m (MSL) over the year simulation.

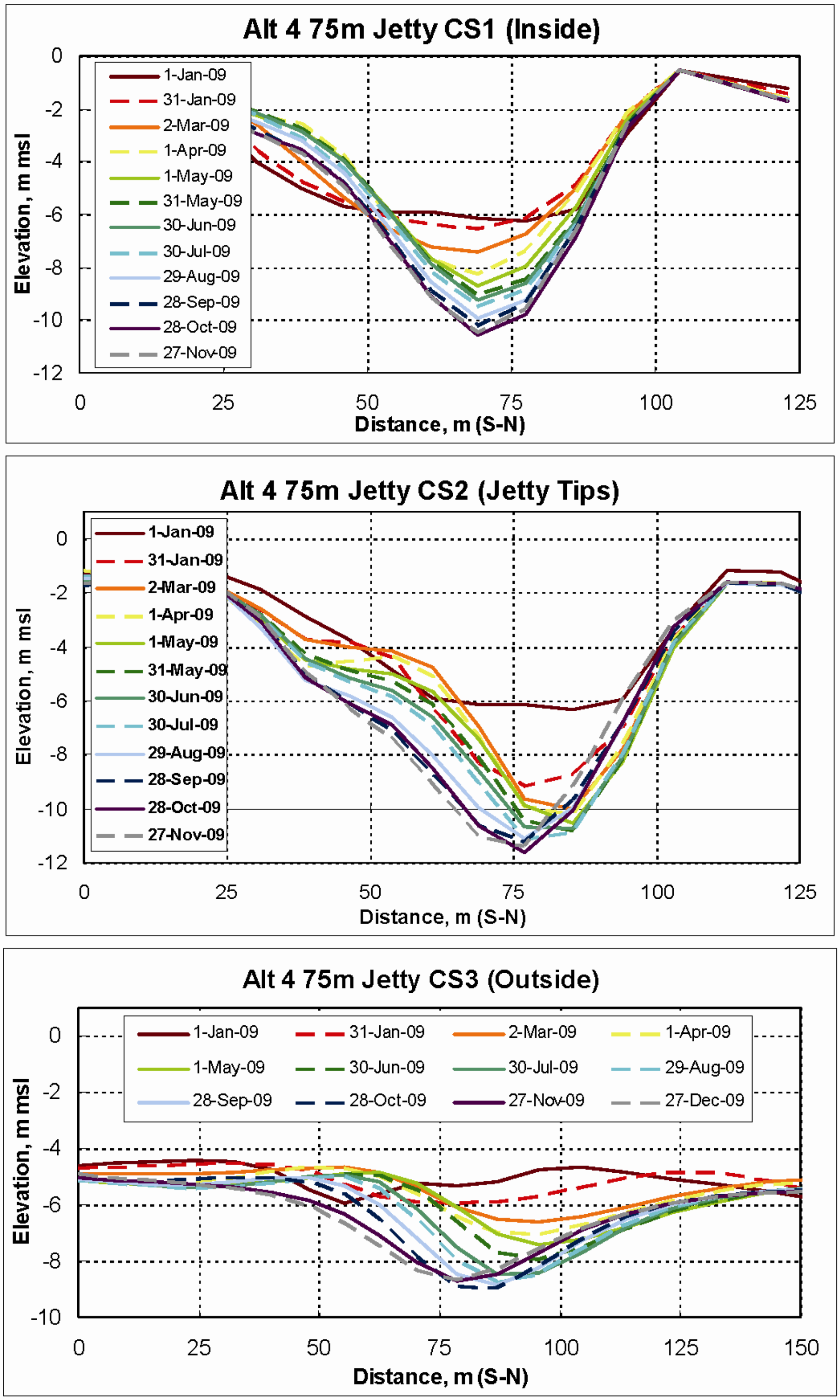

Figure 38. Calculated channel infilling, Alt 4, at three locations across the inlet channel.

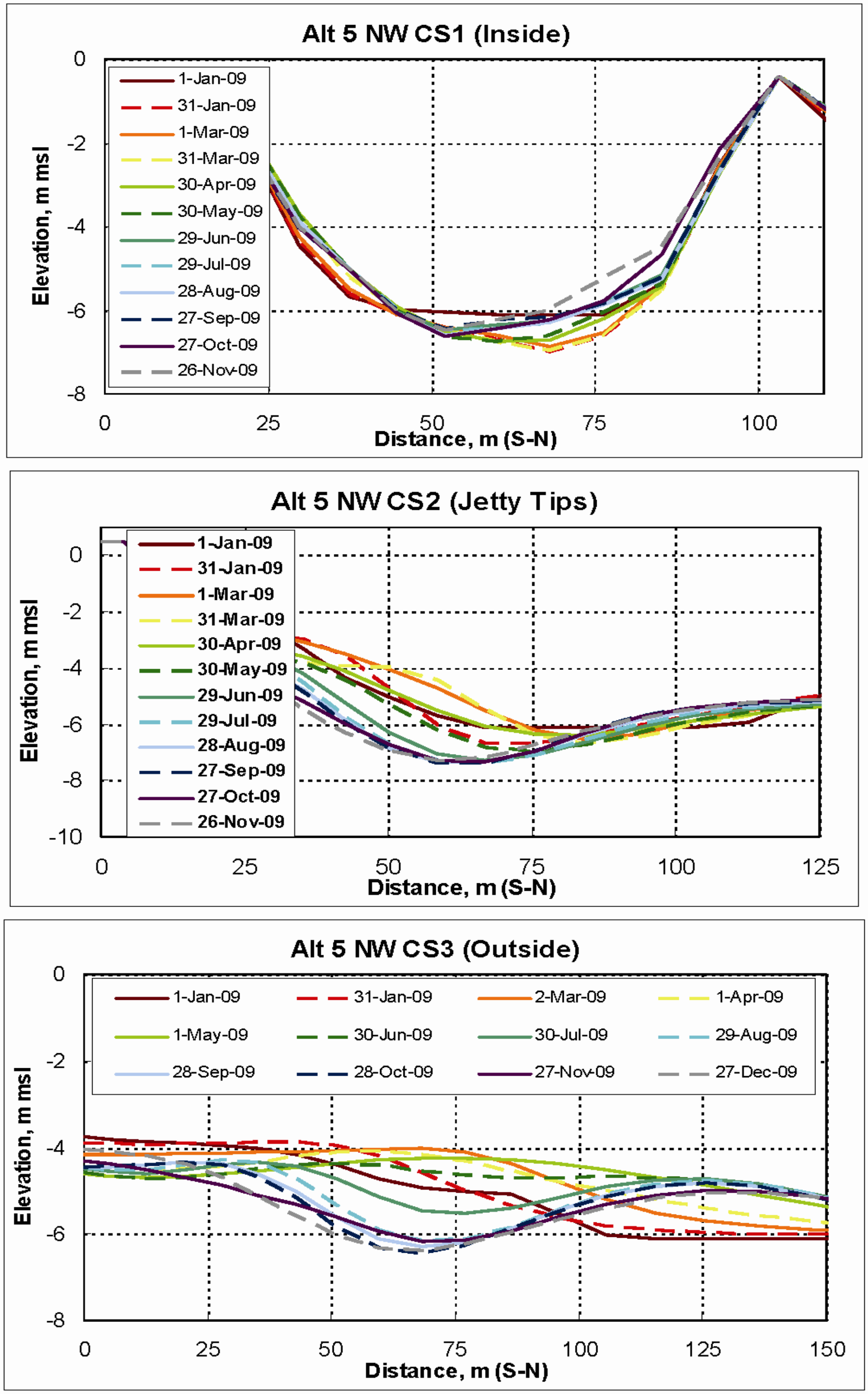

Figure 39. Calculated channel infilling, Alt 5, at three locations across the inlet channel.

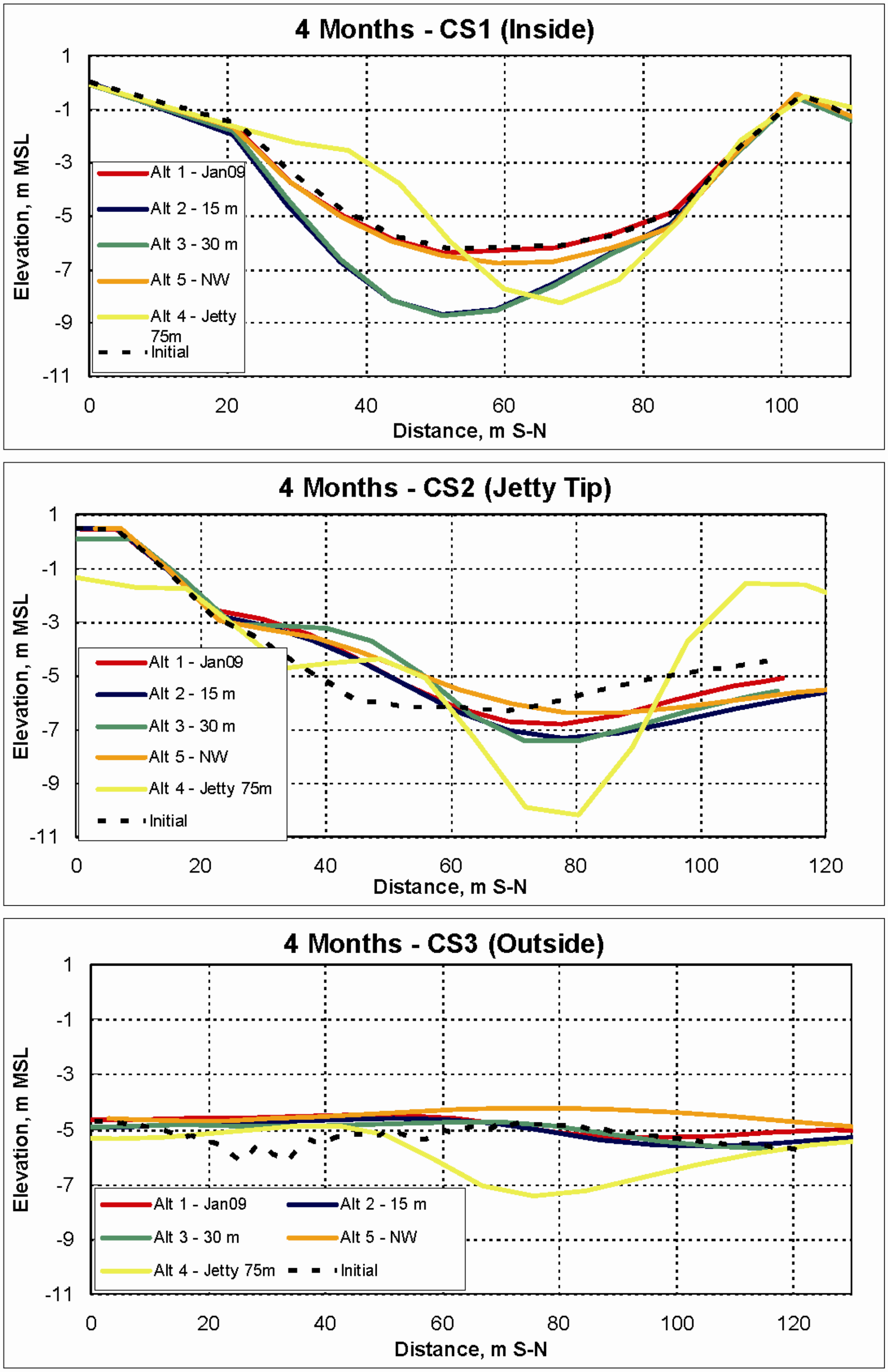

Figure 40. Calculated channel depth of each alternative for 4 months of simulation at three locations across the inlet channel.

6 Discussion and Conclusions

Nourishment of adjacent beaches

For many decades, the entrance navigation channel to Shark River Inlet remained clear of significant sand infiltration. The morphology of Shark River Inlet, with its narrow entrance channel, small estuary, and until recently narrow and sand-deficient adjacent beaches, appears to be unique along the New Jersey and the central Atlantic coast. Persistence of the inlet, despite a relatively small tidal prism (bay surface area) is attributed to its hydraulic efficiency (strong current) with construction of closely spaced jetties and to a lack of sand to fill the channel. A disruption of that balance occurred with the first regional scale nourishment to this part of the coast.

Nourishment of the adjacent beaches supplied the necessary volume of sand to establish a shallow sand platform as the base to form the ebb-tidal delta. The platform formed in the early 2000s and serves as a pathway for sand to be transported around the jetty tips. As observed in recent surveys (Figure 15), the platform has expanded offshore, allowing development of the new ebb delta. However, this development is expected to occur for more than a decade, and the inlet will experience other morphologic changes as it evolves to dynamic equilibrium with a larger rate of sediment transport and seasonal changes in wave direction.

With the present ebb-delta volume, seasonal shoaling from the north in winter and from the south in summer builds an entrance bar, characteristic of wave-dominated inlets along this coast. The entrance bar is presently located close to the jetty tips and serves as a pathway for sand to bypass the inlet channel. Because of the unequal lengths of the jetties, jetty-tip shoaling occurs in an asymmetric morphologic pattern of the entrance bar. The morphologic pattern is further modified by the orientation of the channel, where the direction of current in the form of the ebb jet, in combination with the longshore current (Figure 23).

Dredging practice maintains the channel in a perpendicular orientation, which in turn redirects the ebb jet. The dredging scar lies within the confines of the ebb jet width as it exits from the inlet. Following the dredging, sand filling the newly cut channel can be transported by the strong ebb-tidal current. Under the present ebb-tidal delta size, little sand transport occurs seaward of the vicinity of the jetty tips and, therefore, the strongest tidal current acts on the ebb delta. Dredging of the channel in part interrupts development of natural sand bypassing, but placement practice mechanically transfers this material to the north.

Evolution of ebb-tidal delta and bypassing

The Walton and Adams (1976) empirical prediction relation of ebb delta volume based on tidal prism and degree of wave exposure indicates that Shark River Inlet can support a delta with a volume of 0.92×10^6 m^3. The annual gross sand transport rate at Shark River Inlet is comparable to the total volume of such a delta and, therefore, the rate of sand bypassing is much greater than the rate of accumulation on the delta. According to the Inlet Reservoir Model (Kraus 2000), with a constant annual gross transport rate of 700,000 m^3/year, the ebb-tidal delta will reach 90% of equilibrium volume in about 3 years. In contrast, the total volume presently accumulated in the ebb delta since 1999 is only about 90,000 m^3. Considerably smaller-than-expected ebb volume suggests that the delta is competing with the existing steep beach profile for sand over the region, warranting further investigation and requiring additional survey area coverage. Also, dredging of the channel and bypassing the material to the north limits ebb delta growth.

Volume in the entrance channel increased rapidly from the year 1999 to about 2005, thereafter approaching approximately 40,000 m^3 (Figure 16). Frequent dredging, necessary after 2006, has limited further growth. Approach to equilibrium channel volume indicates that a greater amount of sand will be bypassed. The channel area (18,000 m^2) tends towards a depth of 2.0 m (MLW), so that dredging to a maintained navigation depth of 5.5 m (MLW) accounts for this volume. Here, volumes persistently reach a 20,000-30,000 m^3 limit in the shoaling portion of the channel, following channel infilling of the entrance bar to the limiting depths. Volume calculations do not include areas adjacent to the channel, because of lack of survey coverage.

Short-term benefits and possible solutions

Advance dredging is a possible interim solution that can be implemented at modest cost and examined for performance. It can be continued until a long-term solution is decided. As a potential short-term or interim strategy to increase time between dredging, Kraus and Allison (2009) suggested widening the channel seaward of the jetty tips by 15 m on each side, defined here as Alt 2.

The potential success of the 15-m widener concept led to examination of 30-m wideners (Alt 3). The channel bathymetry from the January 2009 grid was modified to account for equal wideners on the north and south side for each alternative, and it is expected that the channel wideners will serve as extra accommodation space for sand infilling the channel. Inside of the jetties, both alternatives exhibited an enhanced sinuosity of the channel, corresponding to persistent erosion, which is the cause for the continued scouring next to the south jetty. However, seaward of the jetties, the results of the alternatives showed a change in the overall shoaling pattern over the developing platform, of which there was more sand (5,000 m^3) in the channel after a year simulation. However, under the modified channel morphology, the shoaling was inhibited from building a dominant sand-transport pathway and platform and, as a result, the limiting depths along the entrance bar were much greater (CS3 of Figures 36 and 37) than the result of Alt 1, which was essentially an existing condition simulation (no change). Figure 40 compares the results of bathymetry change at three cross sections for each alternative to the initial cross section. Both Alt 2 and Alt 3 show similar cross sections at four months. However, Alt 3 exhibited less deposition than Alt 2 along the distal portion of the ebb delta where the entrance bar typically forms after initial adjustment from the first four to six months after dredging. Less deposition is a result of greater accommodation space from the 30-m widener (Figure 37).

Under the present dredging practice, the ebb current velocity is strongest through the maintained portion of the channel until deflected with the onset of channel shoaling. Morphologic response of the channel beyond four to six months is unknown under frequent dredging. Because the location of shoaling was found to be seasonal, advance dredging in the form of channel wideners affords the channel more time to respond to the shoaling, from either north or south, which begins outside of the tidal current influence and is evidently associated with wave-induced longshore transport. These alternatives are an effective solution with little additional cost as part of ongoing channel maintenance in lengthening the required time between dredging events (reducing mobilization cost). Channel wideners may also be considered as an interim solution that can be adaptively managed while further examining extension of the north jetty (Alt 4).

Long-term solutions

In the context of the new morphodynamics at Shark River Inlet in response to regional beach nourishment, planning with respect to long-term operation of the inlet must be carried out with concern for regional management. The Shark River Inlet navigation channel functioned efficiently for decades with only minor sand shoaling in the entrance. Natural sand bypassing must have occurred, but the limited supply did not allow formation of an ebb delta. About 1 million m^3, about one-fifth of the volume of material placed on the beach for the erosion-control project, is expected to contribute to forming the ebb delta and must be accounted for in the regional sand budget.

Following the first nourishment on the south side in 1997, sand could begin to build a platform for the entrance bar to develop off the tip of the longer jetty. It was not until 2000 that the northern nourishment was completed, after which notable channel shoaling began. Nourishment of the adjacent beaches supplied the necessary volume of sand to establish a shallow sand platform as the base to form the ebb-tidal delta. The platform formed in the early 2000s and serves as a pathway for sediment to be transported around the jetty tips. Surveys from the last decade indicate a seaward expansion of the platform and further development of the ebb-tidal delta as the inlet evolves to dynamic equilibrium under a larger rate of sediment transport. Dredging interrupts development of natural sand bypassing, reorients the channel, and resets the morphology to a condition that responds quickly to the increased sediment transport. A comparison of the modeled alternatives discussed above provides quantitative information for evaluation of the efficiencies of each engineering action.

Presently, the bypassing bar (or platform) is located close to the jetty tips and, because of the unequal lengths of the jetties, jetty-tip shoaling occurs in an asymmetric morphologic pattern of the entrance bar. The morphologic pattern is further modified by the orientation of the channel, where the direction of current in the form of the ebb jet acts in combination with the longshore current. Morphology change calculated for Alt 4 (extended north jetty) predicts a stronger along-channel current in the inlet, resulting in a clear and perpendicular channel scouring beyond the immediate influence of the adjacent, shallow nearshore. Alt 5 (channel reorientation to NE-SW) was the least effective at maintaining navigable channel depths for a longer period of time as opposed to the present dredging practice.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* July 2010	**2. REPORT TYPE** Final report	**3. DATES COVERED** *(From - To)*

4. TITLE AND SUBTITLE Shark River Inlet, New Jersey, Entrance Shoaling: Report 2, Analysis with Coastal Modeling System	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Tanya M. Beck and Nicholas C. Kraus	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Coastal and Hydraulics Laboratory U.S. Army Engineer Research and Development Center 3909 Halls Ferry Road Vicksburg, MS 39180-6199	**8. PERFORMING ORGANIZATION REPORT NUMBER** ERDC/CHL TR-10-4
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Coastal and Hydraulics Laboratory U.S. Army Engineer Research and Development Center 3909 Halls Ferry Road Vicksburg, MS 39180-6199	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report, the second in a series, documents a numerical modeling study performed with the Coastal Modeling System (CMS), supported by field data collection, to quantify alternative plans to reduce navigation channel maintenance cost, at Shark River Inlet, NJ. Since about year 2000, channel maintenance dredging requirements at the inlet have increased. Although Shark River Inlet possesses a small back bay, the current through the inlet is strong because of the small width between jetties. In the past century, this coast was sand deficient. With recent beach nourishment projects placed as part of a federal erosion-control program, the longshore sand transport potential along the coast is being met, allowing an ebb-tidal delta to form at the entrance. This delta is expected to increase in volume over the next two decades to reach about 0.92×10^6 m^3. Therefore, the dredging maintenance strategy must transition to one similar to those at other small tidal inlets along the Atlantic Ocean coasts of New Jersey and New York. This study concluded that 30-m channel wideners, a type of advance maintenance, will increase the time required between scheduled maintenance dredging. Other alternatives evaluated were extension of the north jetty to reach the same effective length as the south jetty, and a channel oriented to the northeast, which appears to be the direction of the natural channel under the present jetty configuration. The CMS proved to be a powerful tool for evaluating alternatives for maintaining the navigation channel in the short term and long term.

15. SUBJECT TERMS Channel dredging Coastal processes	Ebb-Tidal delta Inlet processes Morphology change	Numerical modeling Regional sediment management Shoaling

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED		72	**19b. TELEPHONE NUMBER** *(include area code)*