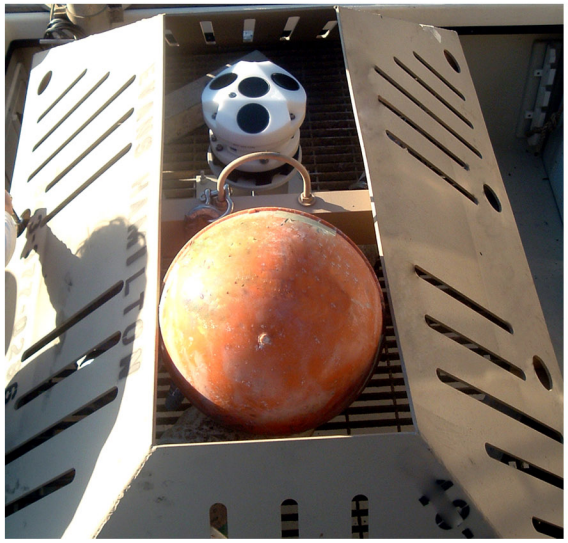
City of Norfolk

MOFFATT & NICHOL

AUGUST 2007

Detailed Study of Bay Oaks Hotspot

FINAL REPORT



EXECUTIVE SUMMARY

The East Ocean View Beach area of the City of Norfolk has been historically eroding. The City has implemented numerous erosion control/mitigation and beach restoration projects along the Ocean View shoreline in the past. Such projects have included beach nourishment and the construction of offshore breakwaters. These efforts have helped eliminate some hotspots and stabilize portions of the shoreline. The construction and extension of the offshore breakwater field from the Little Creek Inlet Jetty along East Ocean View combined with beach nourishment has aided beach retention. However, in recent years, the Bay Oaks area of the shoreline immediately downdrift of the breakwater field, from approximately 22nd Bay Street to 17th Bay Street, has developed an erosion hotspot.

On behalf of the City of Norfolk, Moffatt & Nichol has performed a comprehensive study of the historical and present conditions in the vicinity of the Bay Oaks hotspot to develop potential alternatives to mitigate the hotspot and protect the beach at Bay Oaks. This study involved review and analysis of historical shoreline position information, available beach transect surveys, past engineering works, wave data, and numerical modeling.

An extensive review of historical data and engineering activities along the Ocean View shoreline and the Bay Oaks region was conducted. Historical aerial photography, digitized shorelines, beach transect surveys, available sediment sampling data, and measured wave data were examined to aid in the determination of the erosion hot spot behavior and in modeling of potential alternatives. Cross-shore profile behavior under storm conditions was assessed using SBEACH (Storm-induced BEAch Change). Extensive shoreline change modeling was performed using GENESIS-T (Generalized Model for Simulating Shoreline Change) for the existing conditions and to investigate potential alternatives. The preferred alternative was then modeled using DELTF3D, a three-dimensional hydrodynamic, sediment transport and morphological model.

Analysis of the historical and recent shoreline change indicates that sediment supply to the west of the existing breakwater field is restricted resulting in erosion at Bay Oaks, which is downdrift of the dominant sediment transport direction. The erosion is likely due to a combination of the reduction of natural sediment transport resulting from the Little Creek Inlet jetty construction and the construction of the East Ocean View breakwaters. The East Ocean View area experienced considerable erosion after the jetty was built and before the breakwaters were constructed. The breakwaters act to retain part of the East Ocean View beach in their lee but also as a consequence reduce the sediment moving along the shore from the east toward the Bay Oaks region further interrupting longshore sediment transport. Since the breakwater construction, the erosion hotspot moved west to its present location at Bay Oaks with a current erosion rate of approximately 22 ft/yr.

The basic alternatives examined were to keep existing conditions, beach nourishment, addition breakwaters or some combination of structures and beach nourishment. The GENESIS-T model configuration and runtime allows comparison of various cases simulating years of shoreline change, whereas, the DELFT3D model requires high computational times and is not suitable to testing a large number of scenarios. Numerous alternatives were modeled with GENESIS-T and

the results compared based on the goals of reducing the erosion hot spot, improving the shoreline transition, cost, and maintaining the shoreline aesthetic.

GENESIS-T model results indicate that an improved overall transition of the shoreline from the west end of the current breakwater field across the Bay Oaks hot spot can be achieved but not the total elimination of erosion. GENESIS-T model simulations show the shoreline retreating to the position of the seawall and revetments in the Bay Oaks region after approximately 5 years. Initial and periodic beach nourishment will still be required as part of an ongoing solution to restore and maintain the beach. The amount and frequency of this nourishment can be reduced by stabilizing the shoreline with offshore breakwaters, reducing the wave climate and associated sediment erosion.

Based on the historical shoreline analysis, and the modeling results, the recommended alternative for the Bay Oaks erosion hotspot consists of beach nourishment to mitigate the hotspot and restore the beach combined with a series of smaller offshore breakwaters (extension of the current field) to help retain the beach and improve the overall shoreline transition. The proposed preferred alternative seeks to balance the need to protect the hotspot, improve the transition from the breakwater field to the unprotected beach, and the desire to minimize erosional impacts to the region of the shore west of 17th Bay Street, which historically appears relatively stable. It must be noted, however, that given the configuration of the shoreline and the littoral system, erosion at the edge of the breakwater system cannot be entirely eliminated. The existence of the jetty and current structures reduces the sediment supply available along the beach immediately adjacent. The use of a series of 5 shorter breakwaters with relatively larger spacing is intended to smooth the transition from the existing breakwaters while maintaining improved beach width along Bay Oaks and at the same time allowing more wave energy to penetrate and move sand along the shore. The length of shoreline covered by the 5 additional breakwaters was chosen to end the modeled transition at 17th Bay Street merging with the more historically stable shoreline.

A preliminary opinion of probable cost is approximately $2.7M for 100,000 cubic yards of beach nourishment and the construction of the 5 breakwaters.

The addition of shorter breakwaters with relatively larger gaps at the western end of the existing East Ocean View breakwater field were modeled showing an improved transition in the shoreline and together with beach nourishment can successfully restore the Bay Oaks beach. The use of offshore segmented breakwaters, inline with the current structures will also maintain the current aesthetic of the shoreline and reduce the frequency of future beach nourishment requirements.

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I. PROJECT BACKGROUND & SCOPE OF WORK

A. PROJECT BACKGROUND

The City of Norfolk shoreline lies on the Chesapeake Bay and extends approximately 7.3 miles, from Little Creek Inlet to Willoughby Spit (**Figure I-1**). The East Ocean View Beach section of the Norfolk shoreline, previously defined as a critical area of concern for erosional damage (Andrews, Miller & Assoc., Inc, Jan 1993), extends from Little Creek Inlet approximately 5300 feet northwest towards Willoughby Spit. East Ocean View Beach has suffered severe damage from both long-term erosion and short-term storm-induced erosion. In particular, northeast storms (nor'easters) have significantly impacted this shoreline in the past, resulting in extreme sand loss and threatened properties along the shoreline. Furthermore, construction of the jetties at Little Creek Inlet is believed to have resulted in a loss of sand along the shoreline west of the jetty, due to interruption of the westerly longshore transport of sand in this area (USACE, 1983). Previous efforts by the City of Norfolk to reduce storm-induced erosion along the East Ocean View Beach shoreline have included numerous beach nourishment projects (1953, 1960, 1982, 1984, 1989, 2003), construction of offshore breakwaters (2000, 2001, 2006), and various hard shoreline stabilization projects at specific areas of concern (e.g. placement of concrete rubble on beach).

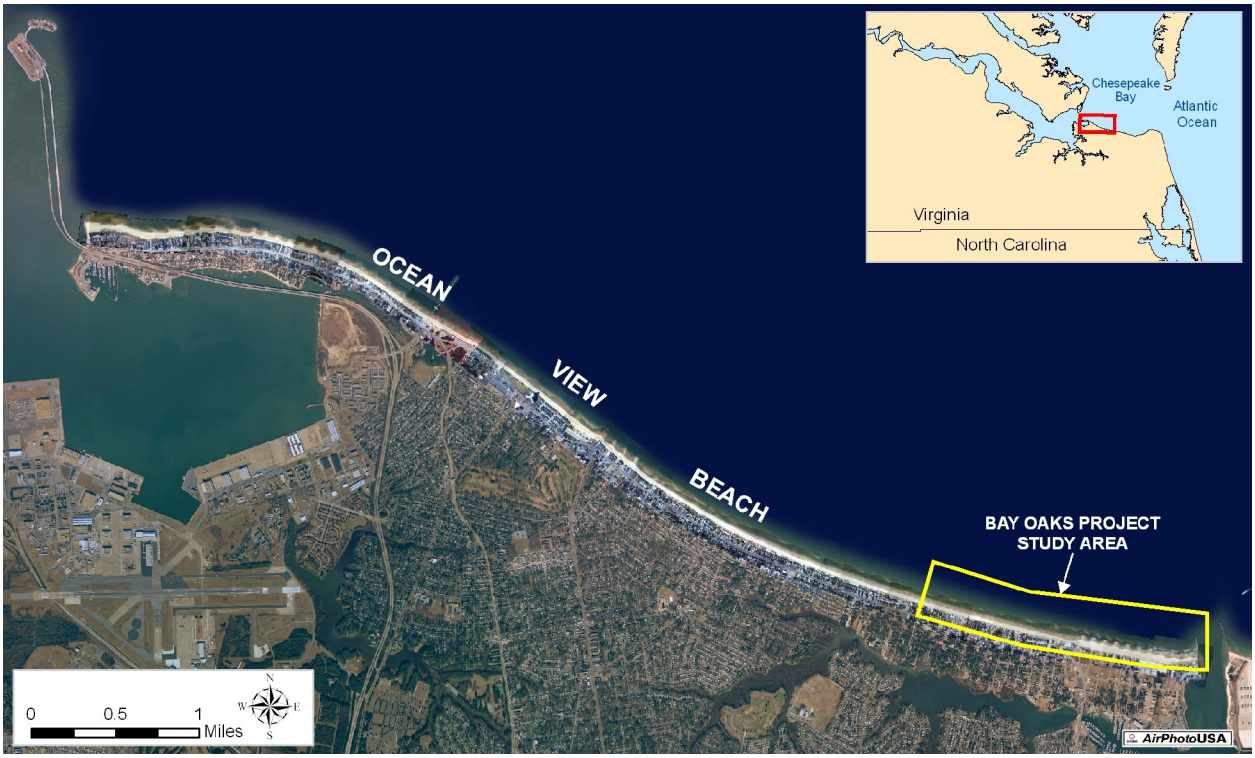

Figure I-1 Bay Oaks Project Location at East Ocean View Beach

The existing East Ocean View shoreline is characterized by an offshore breakwater field which includes ten breakwaters. The breakwater field has greatly improved the quality of shoreline behind it and provided protection for existing structures. However, while the breakwater field

has stabilized the beach behind it, an erosion hotspot has developed directly to the west of the breakwater field, in an area known as Bay Oaks (**Figure I-2**).

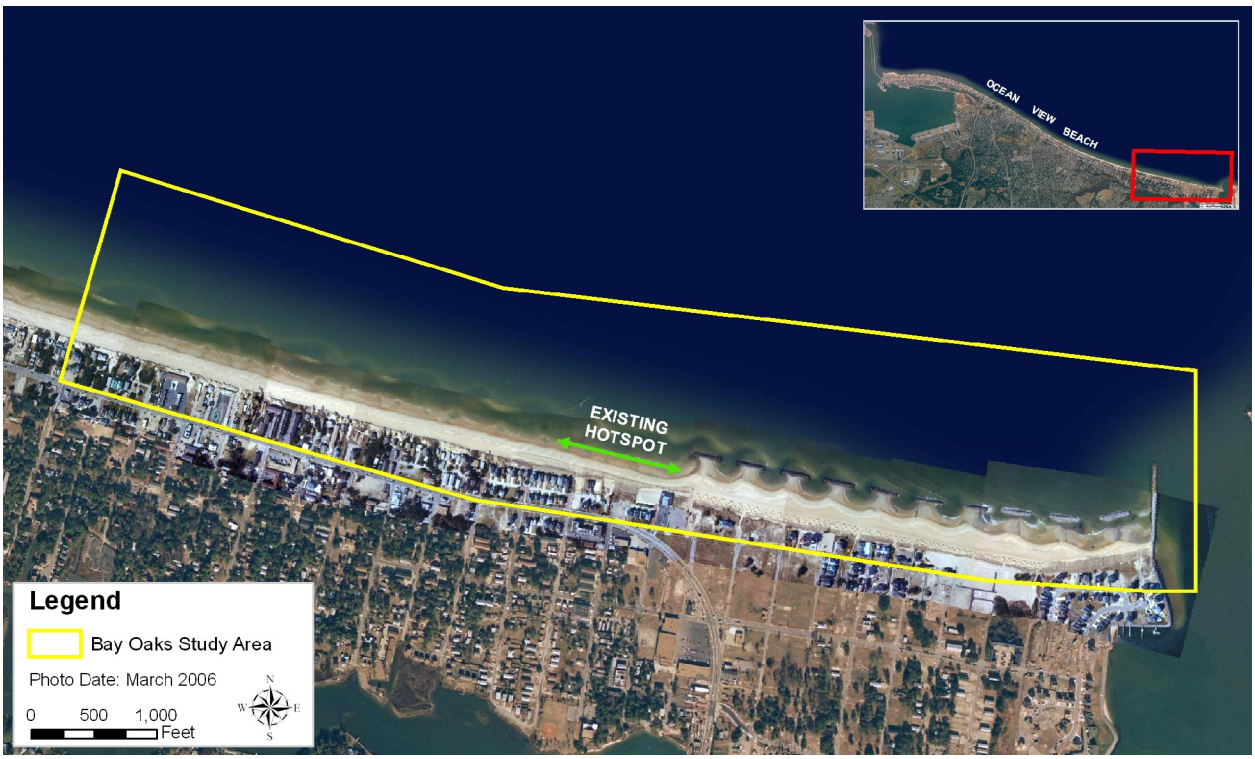

Figure I-2 Bay Oaks Project Study Area

The City of Norfolk has requested a detailed study of shoreline erosion at the Bay Oaks region of East Ocean View Beach and development of recommended alternatives for beach restoration. Previous work done on the East Ocean View area provided extensive shoreline, survey, and sediment data for the area, which was used to evaluate the existing system and predict future performance with various beach restoration alternatives through the use of a variety of models involving short-term storm induced cross-shore change, long-term shoreline change, and 3-dimensional morphological change.

B. SCOPE OF WORK

Moffatt & Nichol was tasked with the detailed study of shoreline erosion within the Bay Oaks region of East Ocean View Beach and development and recommendation of alternatives for beach restoration and stabilization at this location. The scope of work included compilation of existing survey, shoreline, and sediment data, review of historical shoreline trends, analysis and comparison of existing wave data, and modeling of the existing system within the Bay Oaks region to determine the cause of erosion and to develop a list of alternatives for beach restoration. The selected alternatives were also to be modeled to determine the impact and effectiveness of each alternative, thus yielding the recommended alternative. The scope of modeling to be completed was as follows:

1. The SBEACH (Storm-induced BEAch CHange) model was to be used to evaluate cross-shore storm induced impacts and sediment transport patterns for the existing system. The SBEACH model was to be evaluated at selected cross-sections within the Bay Oaks study area. The model was to be run for recent storm events (Tropical Storm Ernesto, October 2006 nor'easter) using measured wave data from the recently deployed wave gage. Measured beach surveys collected in March 2006 and October 2006 (following both storm events) would establish pre- and post-storm (existing) conditions allowing for calibration of the SBEACH model. Once the SBEACH model was adequately calibrated, a new model was to be run to evaluate expected future response of the existing beach profile if no mitigation of the current erosion problem were to take place. An additional model was to be run to test the response of the beach profile to restoration and stabilization alternatives developed involving beach fill only. The model was to be run using measured waves and water levels from recent storm events (Tropical Storm Ernesto, October 2006 nor'easter) to simulate expected short-term storm-induced impacts. Model results would be used to evaluate the effectiveness of beach fill for beach restoration of the Bay Oaks study area.

2. The GENESIS/GENESIS-T shoreline evolution model was to be used to model the existing system (from 7th Bay Street to Little Creek Inlet) to further evaluate the historical shoreline change rate and associated erosion and to estimate future shoreline change. The GENESIS/GENESIS-T model was to be calibrated using the wave data, shoreline structure positions, and historical shoreline position data. The period of calibration was to be chosen carefully to coincide with the presence or absence of shoreline structures which have influenced the rate of change along the shoreline. The wave climate would be fulfilled by utilizing measured gage data from the recently deployed wave gage and a long-term nearshore wave time series developed by transforming wave data from the Duck FRF to a point offshore of East Ocean View. Once the model was adequately calibrated, a new model would be developed using the calibrated parameters and the existing shoreline position to evaluate future shoreline response. The calibrated GENESIS/GENESIS-T model of the existing system would be used to evaluate the selected alternatives for beach restoration along the Bay Oaks study area on a macro scale. The GENESIS/GENESIS-T model would be revised to include the in-place projects (e.g. beach fill, structural alternatives etc.), where applicable, and to model the expected shoreline response to each alternative. The model would be run using the long-term wave time series data to simulate the shoreline impact and predict the design life of each alternative. The model results would be used to evaluate the effectiveness of each alternative for beach restoration.

3. In addition to the larger scale GENESIS/GENESIS-T modeling for the project, the DELFT3D modeling system was to be used to provide insight into hydrodynamic circulation/sediment transport patterns and morphological changes in the immediate vicinity of the Bay Oaks study area. The proposed model extent would likely include a portion of the breakwater field to the east of the hotspot and an equivalent distance west of the hotspot. The model would include a detailed implementation of the existing structures and bathymetry. DELFT3D allows for simulation of multi-dimensional sediment transport patterns occurring directly west of the existing breakwater field in the

Bay Oaks study area, which cannot be simulated using GENESIS/GENESIS-T. The local DELFT3D hydrodynamic model would use hydrodynamic boundary conditions from a regional Chesapeake Bay model previously developed by Moffatt & Nichol. A local, high-resolution wave model would be driven with the finalized nearshore wave climate. Hydrodynamic and wave results would then be used as input to a detailed, two-dimensional, sediment transport model over the same grid. The model would be used to investigate hydrodynamic circulation/sediment transport patterns (including long-shore transport distributed across the profile) and morphological changes for a number of fair weather and storm wave conditions. Assessment of the model was to be based on realistic flow, sediment transport, and morphological change patterns, not on specific comparisons with any available shoreline or bathymetry data. The DELFT3D modeling system would then be used to provide insight into hydrodynamic circulation/sediment transport patterns and morphological changes in the immediate vicinity of the Bay Oaks study area for the selected alternatives and estimates of nearshore impacts of the proposed alternatives.

Moffatt & Nichol would use the results of the SBEACH cross-shore modeling, GENESIS/GENESIS-T shoreline evolution modeling, the DELFT3D sediment transport and morphological modeling, and consultation with City staff, to determine the preferred alternative for beach restoration at the Bay Oaks study area. Other factors which were to be considered included; associated costs of construction and management, potential environmental impacts, potential impacts to adjacent shoreline, and aesthetic impacts on the shoreline.

II. DATA COLLECTION

The East Ocean View Beach shoreline was modeled to determine the cause of erosion in the immediate vicinity of Bay Oaks and provide various alternatives for restoration and stabilization of this area. The modeling effort considered both the cross-shore loss of sand from storm impacts and the overall long-term shoreline erosion. In order to develop such models, an intensive data collection of coastal conditions present around the Bay Oaks study area was necessary. Beach and bathymetric survey data were collected for developing the cross-shore model input profiles. Shoreline position data obtained from aerial photos and historical maps were used to asses historical shoreline change rates and the impact of various engineering activities, develop long-term shoreline evolution model inputs, and to calibrate these models. Additionally, recent sediment data characterizing the current conditions (post December 2003 nourishment) of the sediment at the study area were also acquired. Finally, long-term wave data transformed to the site from an offshore gage at the Duck FRF and wave data from a gage deployed in March 2006 off the Ocean View shoreline was compiled, reviewed, and compared for use in the modeling efforts.

Furthermore, an engineering activities log of erosion control projects and surveys along the entire Ocean View shoreline was developed during previous studies by M&N. This log was updated to include recent engineering activities such as nourishment projects, breakwater construction, and surveys that have taken place since the last revision.

A. SURVEY DATA

Relevant historical and recent beach and bathymetric survey data obtained by the City of Norfolk, Waterway Surveys & Engineering, and McKim & Creed were compiled in a GIS. The dates and sources of all relevant survey data compiled are shown in **Table II-1**. **Appendix A** presents a series of maps showing the coverage and extent of these surveys.

Table II-1 Beach & Bathymetric Survey Data Summary

Date	Source	Coverage
October 1998	City Survey	Entire Ocean View Shoreline
October 1999	City Survey	Entire Ocean View Shoreline
July 2000	City Survey	9th View St to Little Creek Inlet
October 2000	City Survey	12th View St to Little Creek Inlet
October 2001	City Survey	Entire Ocean View Shoreline
July 2002	City Survey	Entire Ocean View Shoreline (excluding Sherwood Pl to Warwock Ave)
October 2002	City Survey	Entire Ocean View Shoreline (no beach or bathymetric survey data)
March 2003	City Survey	East Ocean View Shoreline (19th Bay to Little Creek Inlet)
April 2003	City Survey	East Ocean View Shoreline (17th Bay to Little Creek Inlet)
June 2003	Waterway Surveys & Engineering	East Ocean View Shoreline (17th Bay to Little Creek Inlet)
November-December 2003	Waterway Surveys & Engineering	East Ocean View Shoreline (17th Bay to Little Creek Inlet)
February-April 2004	Waterway Surveys & Engineering	Willoughby Spit to 17th Bay St
September 2005	McKim & Creed Periodic Survey	Entire Ocean View Shoreline
March 2006	McKim & Creed Periodic Survey	Entire Ocean View Shoreline
October 2006	McKim & Creed Periodic Survey	Entire Ocean View Shoreline

Recent survey data was used for developing inputs for the SBEACH model to determine impacts from Tropical Storm Ernesto and an October 2006 nor'easter on cross-shore beach profiles. The use of these survey data sets in specific modeling applications will be discussed further in this report.

B. SHORELINE DATA

In addition to the beach and bathymetric survey data, digitized shorelines were obtained for a number of historical and recent dates. A majority of the shoreline data was obtained from a study completed by Dr. David Basco of Beach Consultants, Inc, as part of a comprehensive shoreline analysis for Ocean View Beach completed in January 2004. This study involved the collection and analysis of historical and recent shoreline positions dating back to 1852. The process involved determining the shoreline positions from historical NOAA NOS "T-sheets" (topographic maps) and aerial photographs. Moffatt & Nichol provided additional shorelines for more recent dates by digitizing the wet/dry line from available aerial photographs. Furthermore, as part of an ongoing periodic surveying contract with the City of Norfolk, VIMS provided additional aerial photographs and digitized shorelines for the March 2006 and October 2006 periodic survey. **Table II-2** lists the dates and sources of the shoreline data collected in the East Ocean View Beach area. **Appendix B** presents each of the shorelines overlain on aerial photographs.

Table II-2 Shoreline Data Summary

Shoreline Date	Source
1852	Basco (NOAA T-Sheet T-507 1:20,000)
1876	Basco (NOAA T-Sheet T-1462a 1:20,000)
1884	Basco (NOAA T-Sheet T-1659 1:20,000)
October 1916	Basco (NOAA T-Sheet T-3647 1:20,000)
1929	Basco (NOAA T-Sheet T-4456 1:20,000)
1937	Basco (VIMS Aerial Photography Archive)
October 1942	Basco (NOAA T-Sheet T-8301,02 1:20,000)
1956	Basco (VIMS Aerial Photography Archive)
1963	Basco (NOAA T-Sheet T-11704 1:20,000)
February 1970	Basco (VIMS Aerial Photography Archive)
1976	Basco (VIMS Aerial Photography Archive)
1980	Basco (VIMS Aerial Photography Archive)
October 1995	Moffatt & Nichol (VIMS Aerial Photography Archive)
March 1999	Moffatt & Nichol (City fo Norfolk Aerial Photographs)
October 1999	Moffatt & Nichol (VIMS Aerial Photography Archive)
Fall 2000	Moffatt & Nichol (AirPhotoUSA)
June 2002	Moffatt & Nichol (VIMS Aerial Photography Archive)
June 2004	Moffatt & Nichol (AirPhotoUSA)
March 2006	VIMS (VIMS Aerial Photography Archive)
October 2006	VIMS/Moffatt & Nichol (VIMS Aerial Photography Archive)

The available shoreline data was used to analyze historical shoreline change rates and assess the impact of coastal structures and nourishment projects done in the East Ocean View area. The digitized shoreline data was also used, where applicable, in the GENESIS long-term shoreline evolution modeling. The historical data sets from 2006 served as a basis for calibrating and validating the GENESIS model. The use of shoreline data in specific applications of this study will be discussed further in the relevant sections of this report.

It is important to note that the original October 2006 digitized shoreline outside of the breakwater field digitized by VIMS was inadvertently shifted seaward from its proper location due to the presence of an offshore bar in the October 2006 aerial photography. Therefore, the shoreline in this region was modified by Moffatt & Nichol to follow the 2 ft contour as the March 2006 shoreline digitized by VIMS had done.

C. SEDIMENT DATA

In April 2004, comprehensive sediment data was collected by Geotechnical Testing Environmental Solutions, Inc. for use in the Willoughby Spit to Central Ocean View restoration project. Sediment samples were obtained every 1000 ft along the Ocean View shoreline at mid dune, mid berm, and between high and low water lines. Sediment samples taken in the Bay Oaks study area were reviewed to determine existing sediment characteristics required for modeling efforts. The characteristic sediment grain size determined for this study was 0.38 mm. This is an average of d50 values for the sediment sample transects (OV31-OV39) which are located within the Bay Oaks Study area. **Table II-3** presents a summary of the d50 values for these sediment samples. **Appendix C** contains the sediment grain size distributions for the post-nourishment East Ocean View study area.

Table II-3 Sediment Data Summary

Station	d50-mid dune (mm)	d50-mid beach (mm)	d50-between high & low water (mm)	d50-avg of mid dune, mid beach, and high waterline (mm)
OV31	0.32	0.28	0.36	0.32
OV32	0.28	0.30	0.41	0.33
OV33	0.31	0.30	0.47	0.36
OV34	0.28	0.29	0.51	0.36
OV35	0.38	0.32	--	0.35
OV36	0.23	0.71	0.28	0.41
OV37	0.42	0.35	0.41	0.39
OV38	0.29	0.49	0.51	0.43
OV39	0.31	0.52	0.63	0.49
AVERAGE	**0.31**	**0.39**	**0.45**	**0.38**

D. WAVE DATA

Previous studies performed for East Ocean View and 800 Block of Willoughby Spit have utilized offshore wave data that was transformed to the site from the Duck FRF through numerical modeling. The resulting long-term wave time series used in these studies spanned 1991 to 2004. In March 2006, the City authorized Evans Hamilton Inc. to deploy a bottom mounted wave and current gage offshore of Ocean View to aid in engineering studies of the shoreline. The gage is serviced every 3 months during which new wave data is downloaded, compiled, and reviewed for accuracy. This new wave data was be used to verify the long-term transformed data utilized in the GENESIS and DELFT3D models. It was also used directly to model storm induced erosion in SBEACH for recent events, calibrate the GENESIS/GENESIS-T model, and develop

appropriate wave conditions to be used in Delft3D. Wave data transformation, review, and analysis will be discussed further in this report.

E. ENGINEERING ACTIVITIES LOG

Information related to engineering projects in the Ocean View area was compiled and was an essential reference for the review of historical data and numerical modeling completed in this study. It is important to consider these activities when examining historical erosional patterns, as shoreline change is significantly impacted by engineering interventions.

The engineering activities log was compiled from previous work and through discussions and verification with the City. **Appendix D** presents engineering activities including structure construction and beach nourishment projects completed for the entire Ocean View shoreline between 1920 to 2006. Those activities impacting the Bay Oaks study area are highlighted in the table.

III. REVIEW & ANALYSIS OF HISTORICAL DATA

A review of historical shoreline data and engineering activities at the Bay Oaks project study area was conducted to develop an initial understanding of the long-term shoreline change trends within the study area and the shoreline response to engineering activities.

A. SHORELINE CHANGE ANALYSIS

The available shorelines from 1852 to October 2006 were placed in ArcGIS. A baseline for measuring shoreline positions was digitized along the East Ocean View Shoreline. Transects running perpendicular to the baseline were placed every 10 ft. **Figure III-1** shows the defined baseline and transects overlain on March 2006 aerial photography. Transects are only shown every 200 ft for visual purposes. The distance from the baseline to the shoreline was measured along each transect. Shoreline change rates were then computed by dividing the change in shoreline position by the amount of time between each data set. Shoreline change was calculated between specific sets of dates dependent on the presence or absence of engineering activities. The resulting plots are presented in **Figure III-2** through **Figure III-10** at the end of this section.

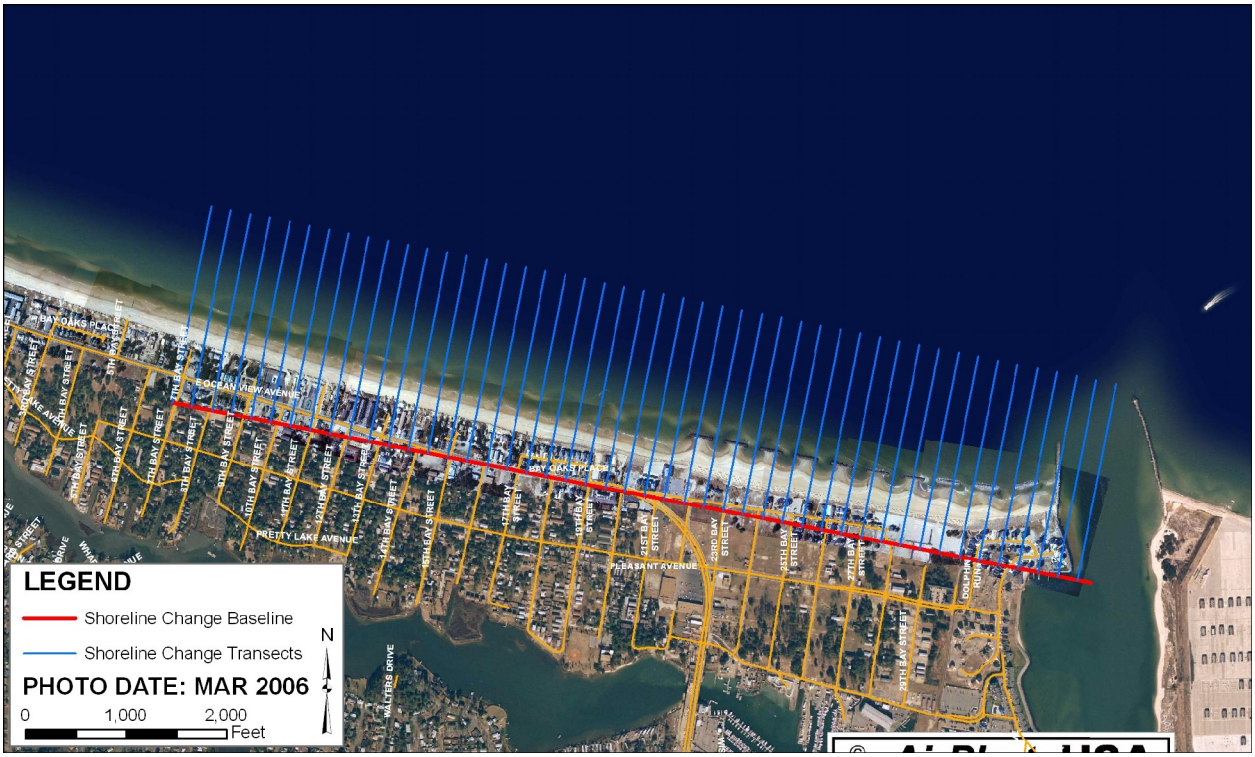

Figure III-1 Shoreline Change Baseline and Transects

Analysis of the shoreline change plots indicates the large influence that engineering activities, including coastal structures and beach nourishment, have had on the Ocean View shoreline over the years. A summary of the key activities that have taken place in the Bay Oaks area of East Ocean View can be seen in **Table III-1.**

Table III-1 East Ocean View Engineering Activities

Date	Project Type	Location	Vol (cy)	Extent (ft)
Dec 1926-Jan 1928	East Jetty Construction	Little Creek Inlet		
Dec 1926-Nov 1928	West Jetty Construction	Little Creek Inlet		
1953	Beach Nourishment	18th Bay St to 27th Bay St (East Ocean View)	1,260,000	3,000
1953	Beach Nourishment	27th Bay St to West Jetty (East Ocean View)	500,000	1,800
1960	Beach Nourishment	East End Parking Lot to West Jetty (East Ocean View)	159,000	900
1982	Beach Nourishment	East Ocean View	400,000	
August-November 1984	Beach Nourishment	21st Bay St to East End Parking Lot (East Ocean View)	400,000	3,000
1989	Beach Nourishment	21st Bay St to East End Parking Lot (East Ocean View)	133,000	3,000
August, 2000	Breakwater Construction (2, 3, 4)	Critical Area 3: 21st Bay St to Little Creek Inlet		
November, 2001	Breakwater Construction (1, 5, 6, 7)	Critical Area 3: 21st Bay St to Little Creek Inlet		
October, 2003	Beach Nourishment	Critical Area 3: 19th Bay St	6,000	545
October, 2003	Beach Nourishment	Critical Area 3: East of 30th Bay St	1,000	150
December, 2003	Beach Nourishment	Critical Area 3: 17th Bay St to Little Creek Inlet	359,000	5,280
January-February, 2006	Breakwater Construction (8, 9, 10)	Critical Area 3: 29th Bay St to Little Creek Inlet		

The following will review the historical shoreline change analysis by presenting for each successive time period, the applicable data sources, relative shoreline positions, coincident engineering activities, and the computed shoreline rates of change across the study area extent. For ease in the presentation of results, all figures referenced in the following discussions are presented at the end of this section.

1. 1852 to October 1916

The 1852 (month unknown) and October 1916 shoreline positions were obtained from the Basco study in which they were delineated from NOAA T-sheets. No known engineering activities in the East Ocean View region took place during this time period. **Figure III-2** presents a comparison of the relative shoreline positions overlain on the aerial photo from 1970 and the computed shoreline change across the study area transects. The natural shoreline had a slightly accretional trend with an average shoreline change rate of 1.68 ft/yr over the entire study area. The Bay Oaks region had an average shoreline change rate of 2.41 ft/yr. The natural migration of the inlet channel to the west is also evident.

2. 1929 to October 1942

The 1929 (month unknown) and October 1942 shoreline positions were obtained from the Basco study in which they were delineated from NOAA T-sheets. The East Ocean View shoreline was first impacted by engineering activities just prior to this time period as the Little Creek Inlet jetties were constructed from 1926 to 1928. Construction of the jetties had a large impact on the shoreline, causing considerable erosion to the immediate west of the jetties, as the natural littoral drift from east to west was interrupted. The impact of the jetties is lessened as distance from them increases. The impact of the jetties, which extends to the Bay Oaks region, is presented in **Figure III-3**. The two shoreline positions are shown overlain on 1970 aerial photography and the computed shoreline change across the study area transects. The average shoreline change rate for the time period from 1929 to 1942 was -4.15 ft/yr. Most of this occurred in the 400 ft immediately west of the jetties with the remainder of the shoreline remaining fairly stable. The average shoreline change rate for the Bay Oaks area was 0.4 ft/yr.

3. October 1942 to 1963

The October 1942 and 1963 (month unknown) shorelines were both taken from the Basco study in which they were delineated from NOAA T-sheets. Engineering projects which took place during this time period include two beach nourishment projects performed in 1953 and one in

1960 with particular emphasis on the area of beach near the jetties. The two beach nourishments completed in 1953 placed a total of 1,760,000 cy of sand on the beach from 18th Bay St to the West Jetty. In 1960, 159,000 cy of material was placed near the West Jetty. The impact of the beach nourishments on the shoreline is apparent in **Figure III-4**, which shows the two shoreline positions overlain on aerial photography from 1970 and the computed shoreline change across the study area transects. The shoreline has not only moved seaward where the nourishment material was placed but also appears to have accreted to the west of the nourishment projects, most likely due to the natural littoral drift of the nourishment material. The average shoreline change for the project area during this time period was 3.63 ft/yr. The average shoreline change in the Bay Oaks region was 3.24 ft/yr.

4. 1963 to 1980

The 1963 (month unknown) and 1980 (month unknown) shorelines were both obtained from the Basco study. However, the 1963 shoreline was delineated from a NOAA T-sheet while the 1980 shoreline was digitized from VIMS aerial photography. During the time period from 1963 to 1980, the East Ocean View area was absent of engineering activities, and thus the shoreline showed an erosional trend as presented in **Figure III-5**, where the two shorelines are overlain on aerial photography from 1970 and the computed shoreline change across the study area transects is shown. The majority of the erosion occurs between the west jetty and 17th Bay Street where the zone of influence of the jetties seems to be lessened. The average shoreline change rate for the entire study area was -3.77 ft/yr. The Bay Oaks region showed worse than average erosion with a rate of -5.27 ft/yr.

5. 1980 to October 1995

As previously mentioned, the 1980 (month unknown) shoreline was obtained from the Basco study where it was digitized from VIMS aerial photography. The October 1995 shoreline was digitized by Moffatt & Nichol from VIMS aerial photography. There were 3 beach nourishment projects during the time period from 1980 to October 1995. In 1982 and 1984, 400,000 cy of material was placed on the beach each time. In 1989, 133,000 cy of material was placed on the beach. The effect of this on the shoreline can be seen in **Figure III-6,** where the two shorelines are overlain on 1995 aerial photography and computed shoreline change across the study area transects is shown**.** It is apparent that the shoreline has seen some accretion most likely due to the nourishment projects. However, only slight accretion is shown for a portion of the study area indicating that the shoreline is most likely in the process of eroding back to the original position before the beach nourishment projects. The average shoreline change rate during this time period was 1.27 ft/yr for the entire study area and 1.68 ft/yr for the Bay Oaks region.

6. October 1995 to October 1999

The October 1995 and October 1999 shorelines were digitized by Moffatt & Nichol from VIMS aerial photography. The study area was absent of any engineering activities during this time period. Thus, the shoreline has an erosional trend as seen in **Figure III-7,** where the two shorelines are overlain on 1999 aerial photography and the shoreline change across the study area transects is shown. The most severe erosion is limited to the portion of the shoreline from the west jetty to the west side of the Bay Oaks hotspot (17th Bay St) while the remainder of the shoreline west of Bay Oaks is fairly stable. This pattern is very similar to the 1963-1980 time

period in which no engineering activities took place, indicating that the jetty influence ends around 17th Bay St. The average shoreline change rate for the study area during this time was -6.13 ft/yr. The Bay Oaks region had a slightly worse than average erosion rate of -7.76 ft/yr with some of the highest erosion rates near the existing hot spot.

7. October 1999 to June 2002

The October 1999 and June 2002 shorelines were digitized by Moffatt & Nichol from VIMS aerial photography. During this time period, construction of the present breakwater field began. In August 2000, three breakwaters were constructed while the other four were completed in November 2001. The addition of the breakwater field in 2000 and 2001 stabilized the shoreline directly behind it compared to the previous time period where no breakwater field existed. The portion of the shoreline west of the breakwater field saw increased erosion from the previous time period. In particular, the Bay Oaks region saw the worst erosion. This is evident in **Figure III-8**, where the two shorelines are overlain on 2002 aerial photography and the shoreline change across the study area transects is presented. The average shoreline change rate for the entire study area was -7.10 ft/yr. The Bay Oaks area experienced severe erosion with an average of -15.93 ft/yr.

8. June 2002 to June 2004

The June 2002 and June 2004 shorelines were both digitized by Moffatt & Nichol. As mentioned previously, the June 2002 shoreline was digitized from VIMS aerial photography while the June 2004 shoreline was digitized from AirPhotoUSA aerial photography. In October and December of 2003, the East Ocean View area underwent a beach nourishment project as a result of damage from a Nor'easter in April 2003 and Hurricane Isabel in September 2003. A total of 366,000 cy of material was placed on the beach, filling out the beach area near the jetty, behind the breakwaters, and slightly west of the breakwater field. The beach fill resulted in substantial seaward movement of the shoreline. This is evident in **Figure III-9** where the shorelines are overlain on 2004 aerial photography and the computed shoreline change across the study area transects is presented. The average shoreline change rate during this time period was 42.5 ft/yr over the entire study area and 41.89 ft/yr in the Bay Oaks region. The accretion/erosion pattern behind the breakwater field is clearly illustrated. Again, the shoreline west of 17th Bay St. appears to be more stable and likely receiving benefit from the nourishment project as littoral drift travels east to west.

9. June 2004 to October 2006

The October 2006 shoreline was digitized by VIMS from their aerial photography and edited by Moffatt & Nichol to the west of the breakwater field so as to avoid using an offshore bar as the shoreline. In February 2006, three more breakwaters were added to the eastern end of the breakwater field. **Figure III-10** presents the shorelines overlain on 2006 aerial photography and computed shoreline change across the study area transects. Although the breakwater field was extended to the east, there is considerable erosion behind the breakwaters. This is most likely due to equilibration of the shoreline after the October and December 2003 beach nourishment project. However, as would be expected, the breakwaters have slowed down erosion of the beach directly behind them, while the area immediately in between breakwaters is somewhat vulnerable to erosion. The average shoreline change rate for the entire study area during this time period was -14.93 ft/yr. The Bay Oaks region experienced a greater than average erosion

rate of -22.05 ft/yr. Again, the high erosion rates are most likely due to adjustment in beach equilibration after the 2003 nourishment projects.

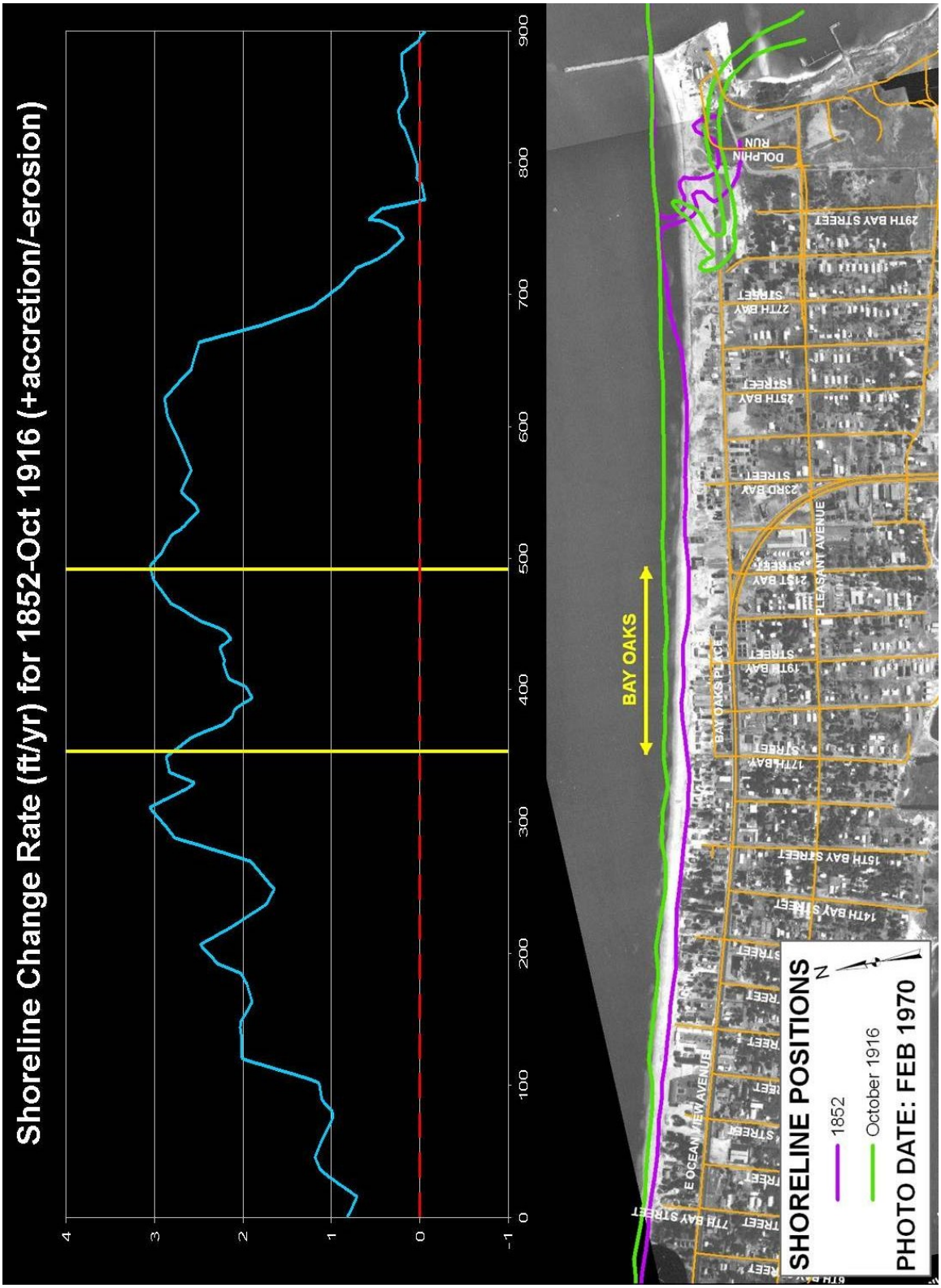

Figure III-2 Shoreline Change Rate (1852- Oct 1916)

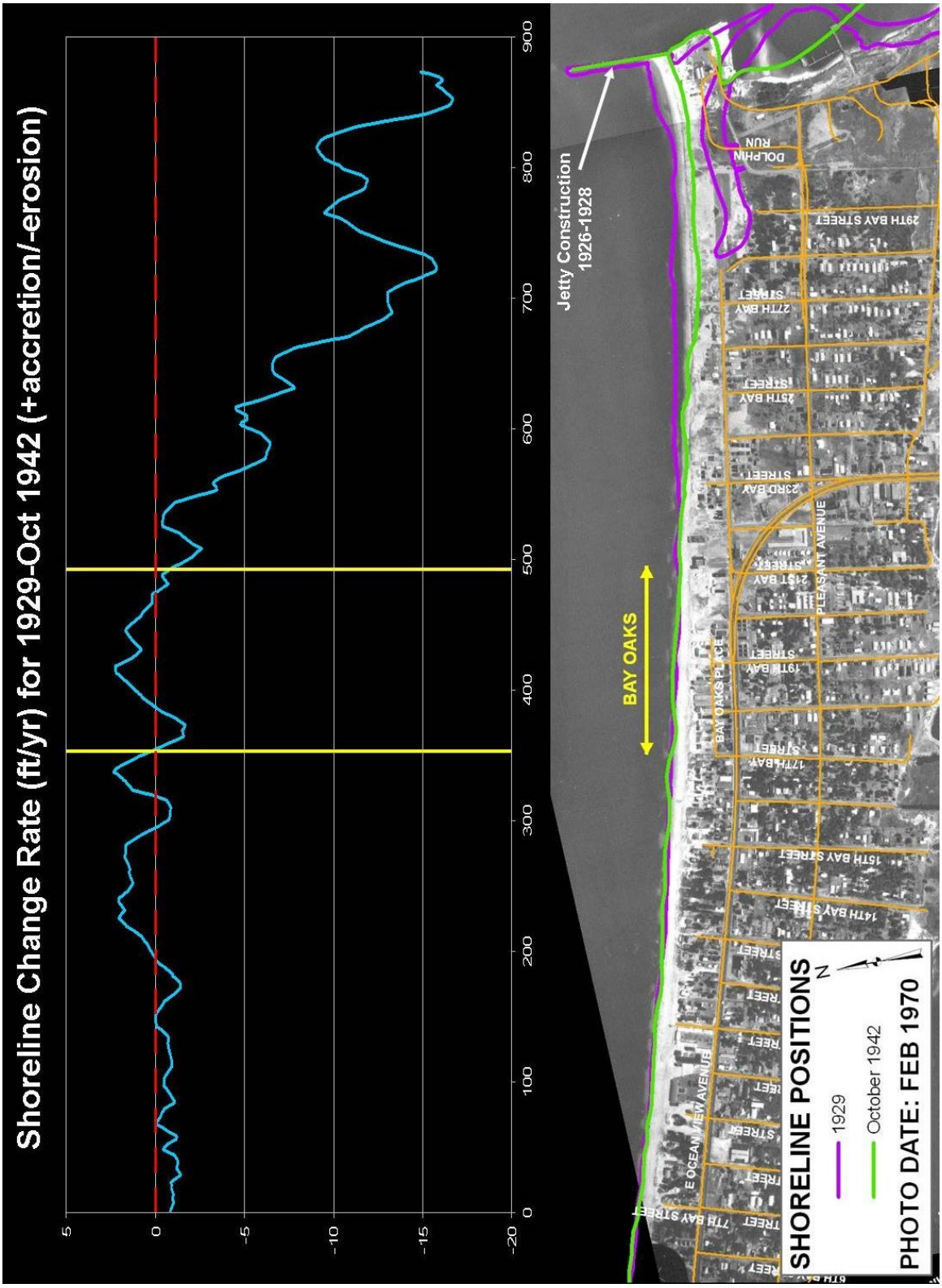

Figure III-3 Shoreline Change Rate (1929- Oct 1942)

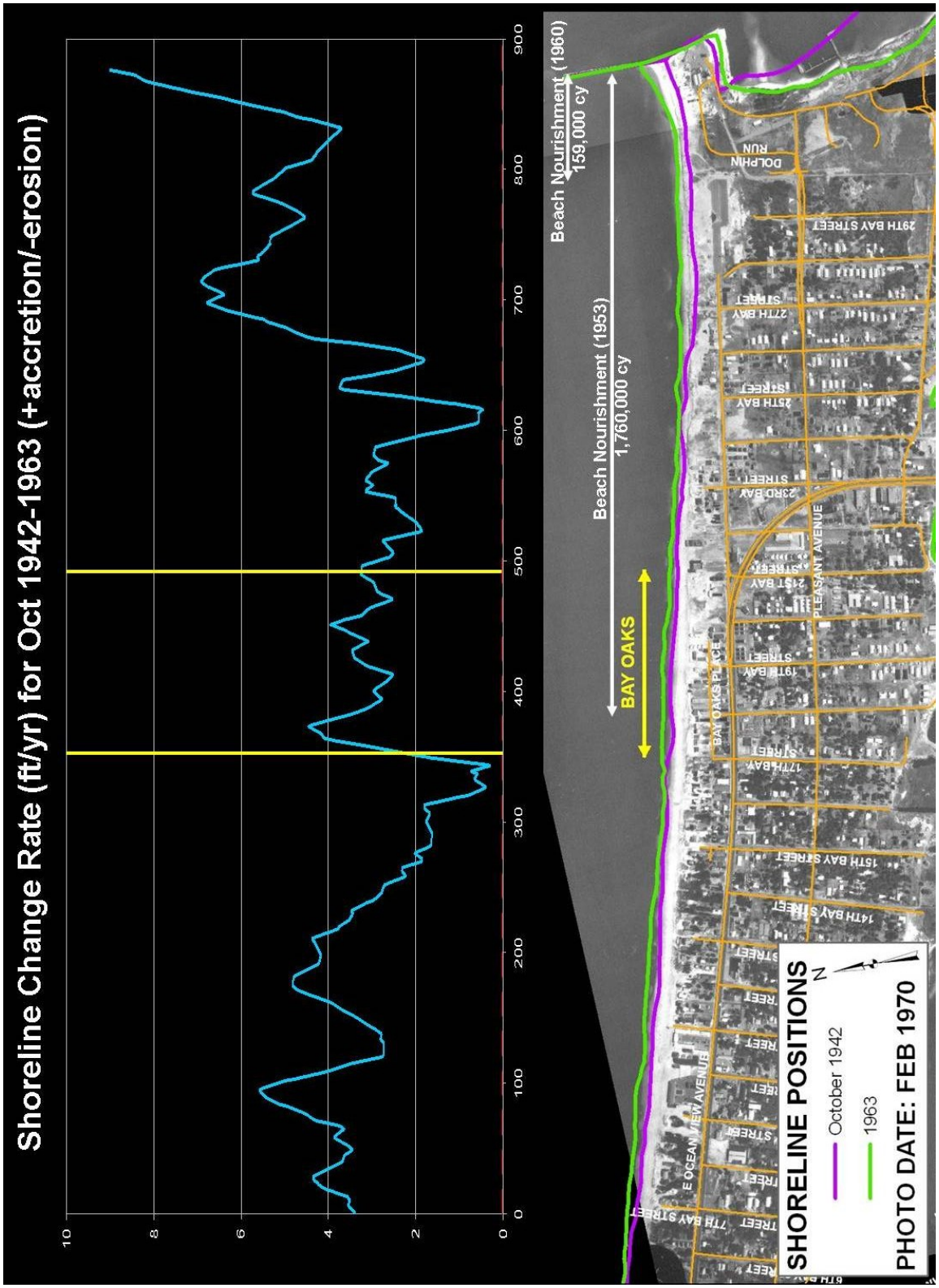

Figure III-4 Shoreline Change Rate (Oct 1942-1963)

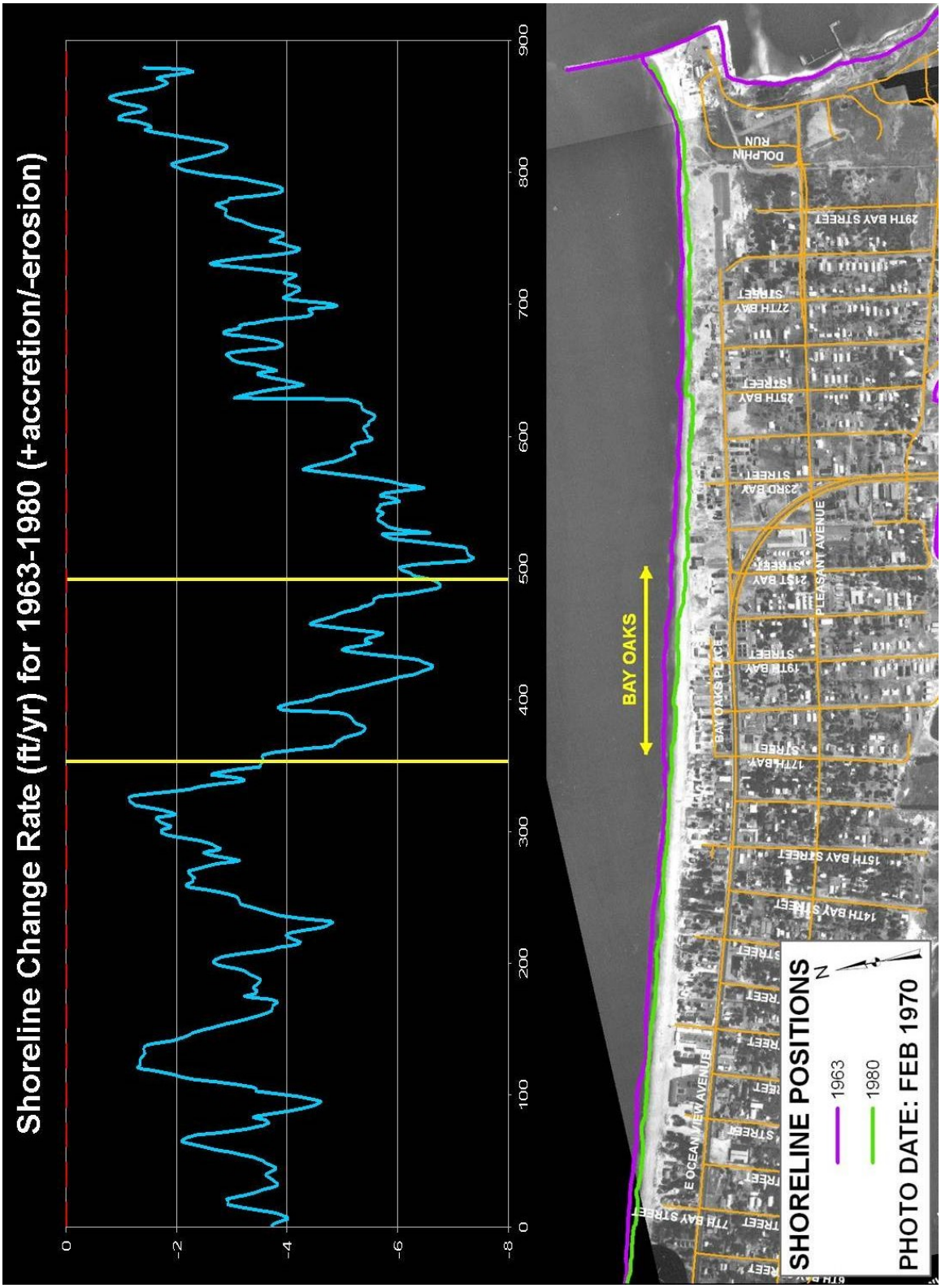

Figure III-5 Shoreline Change Rate (1963-1980)

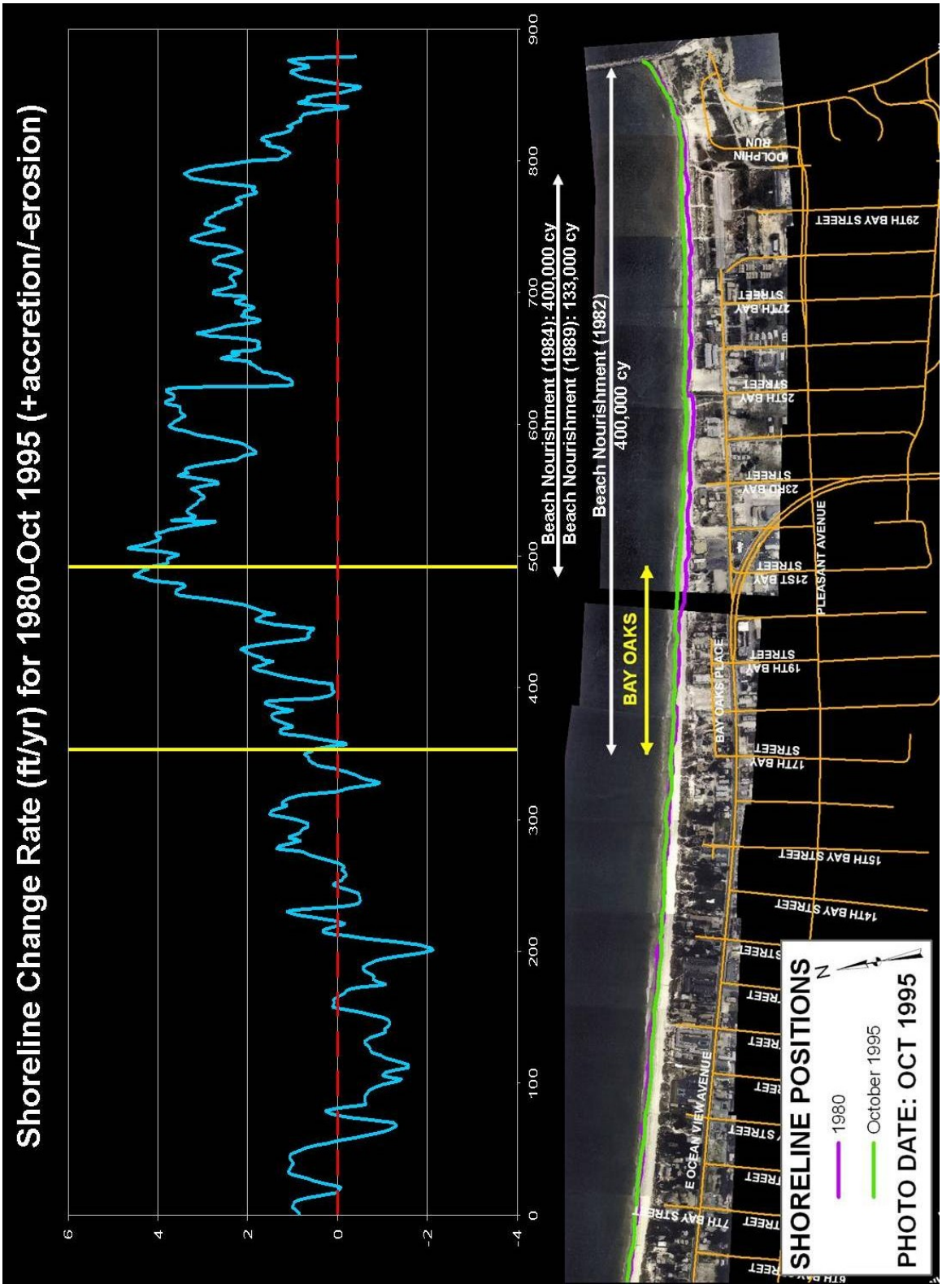

Figure III-6 Shoreline Change Rate (1980-Oct 1995)

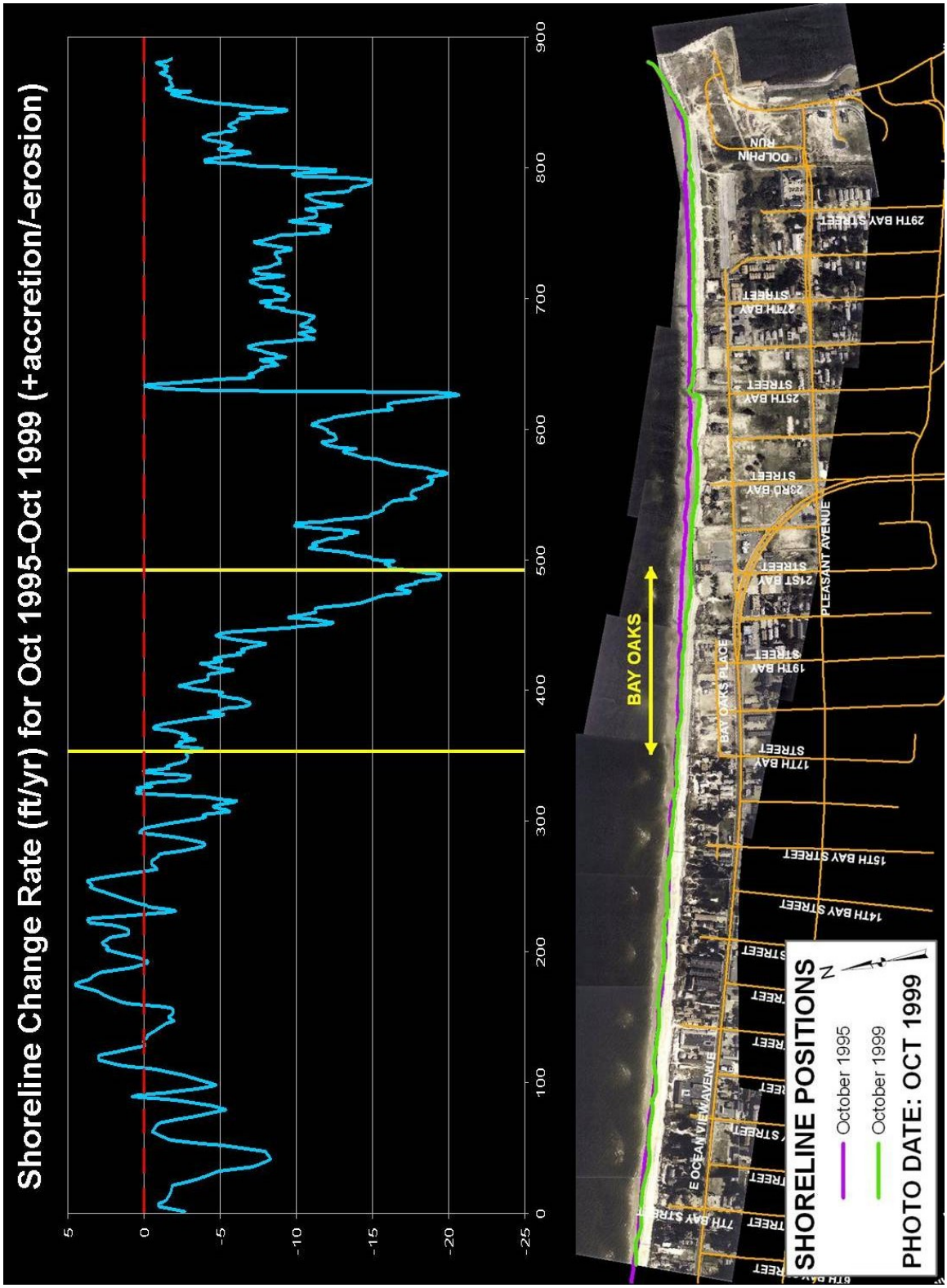

Figure III-7 Shoreline Change Rate (Oct 1995-Oct 1999)

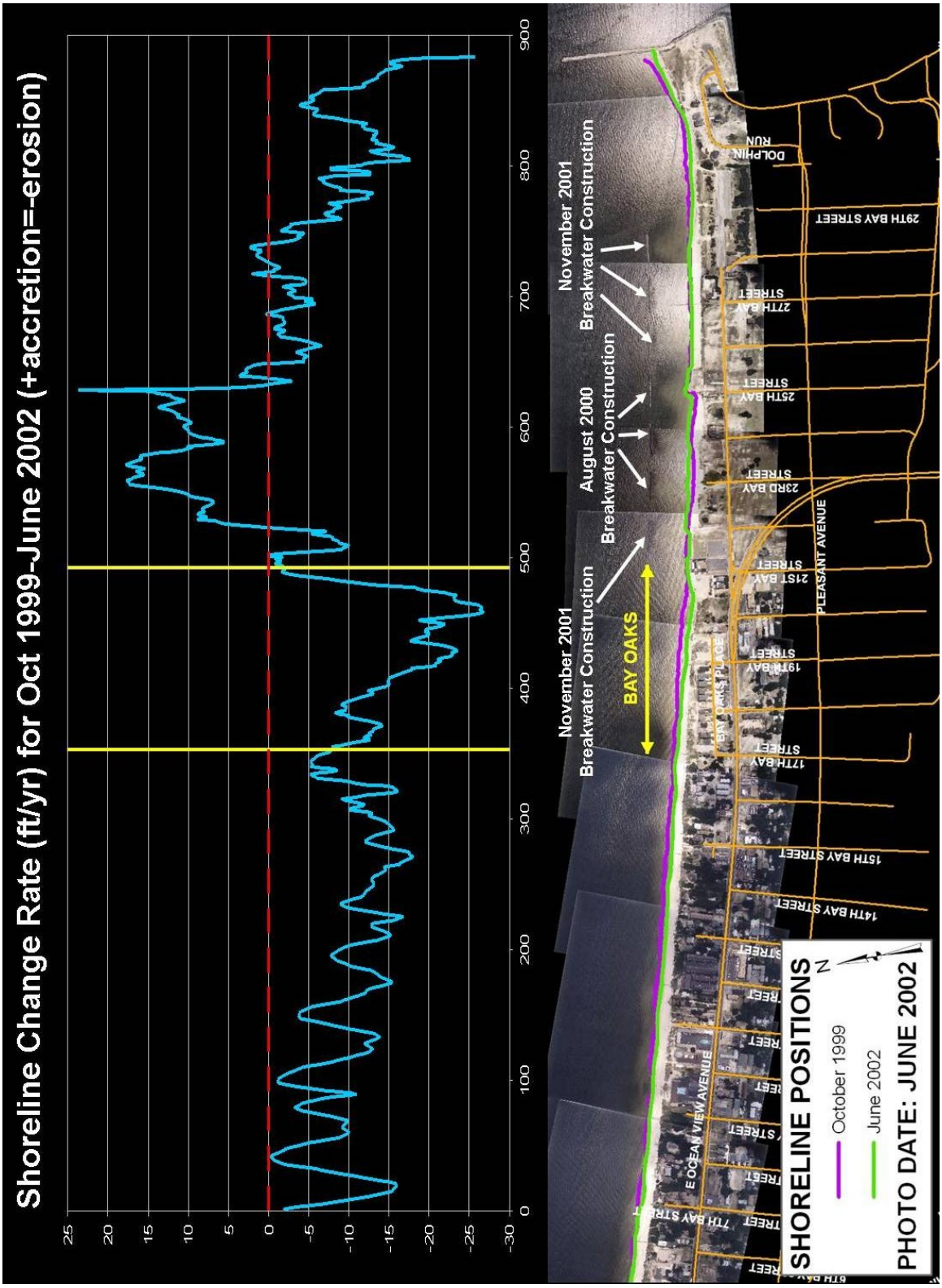

Figure III-8 Shoreline Change Rate (Oct 1999-June 2002)

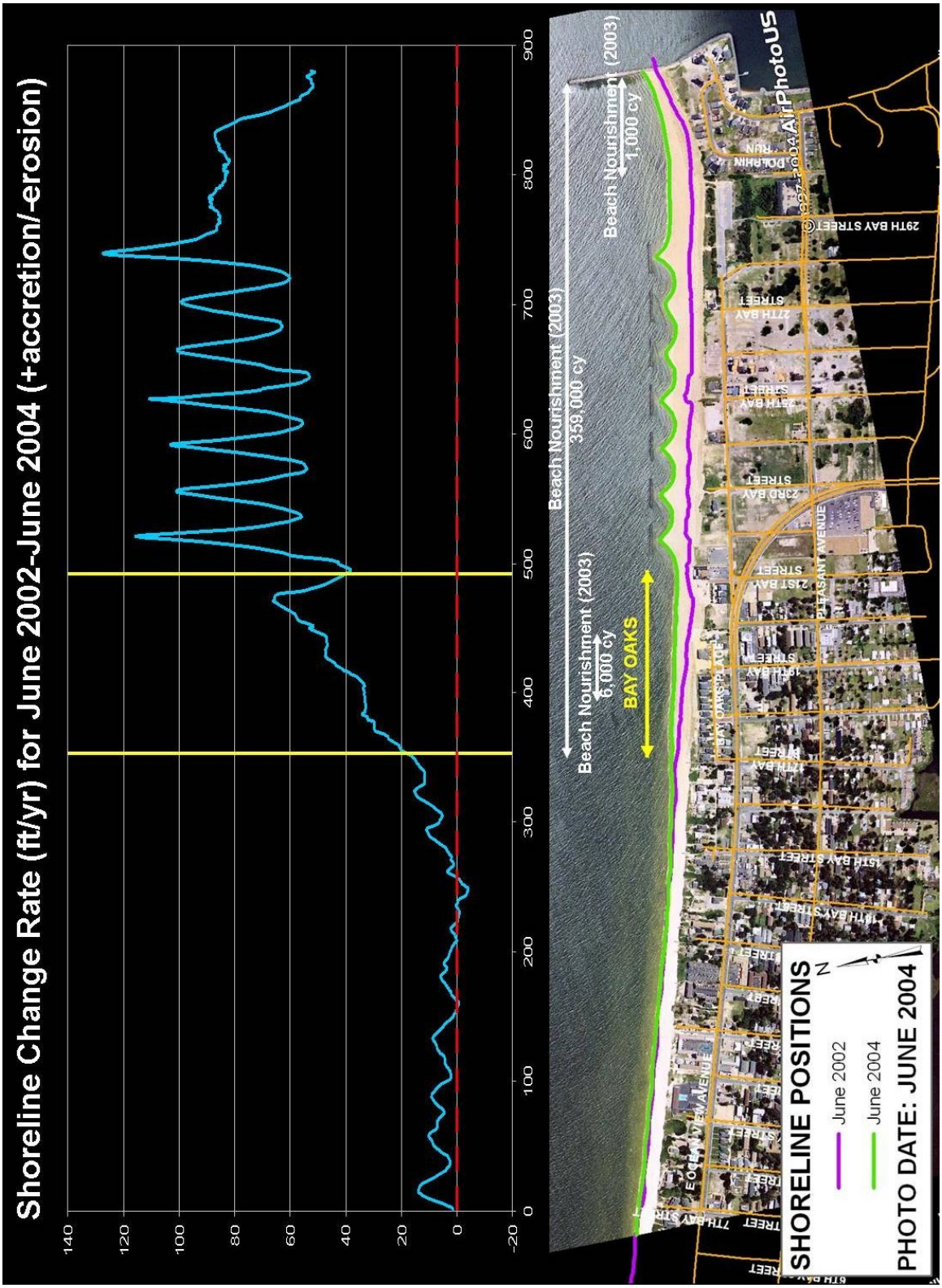

Figure III-9 Shoreline Change Rate (June 2002-June 2004)

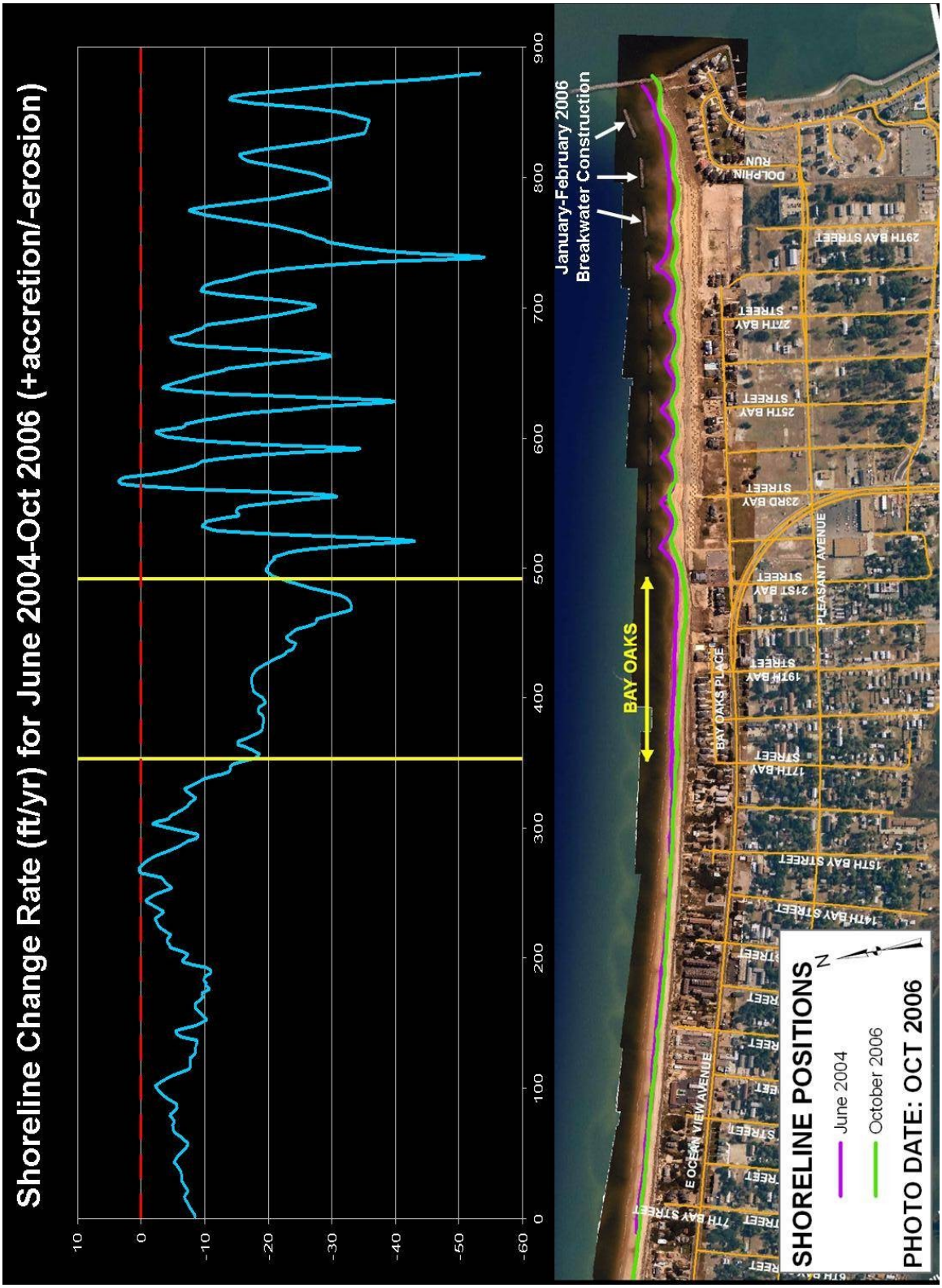

Figure III-10 Shoreline Change Rate (June 2004-Oct 2006)

B. IMPACT OF EXISTING STRUCTURES AND BEACH FILL

Impacts of the most recent engineering activities on the East Ocean View shoreline, which include construction of the breakwater field and the 2003 beach nourishment project, are evident in the shoreline change analysis. The initial construction of the jetties and the subsequent breakwater field are likely significant contributors to the erosional problems at Bay Oaks. From the earliest airphotos after the jetty construction, the interruption of longshore sediment transport and associated erosion west of the jetty is evident along the shoreline. In the time period preceding the construction of the existing breakwater field, there is an apparent erosional hotspot which exists just east of the current Bay Oaks hotspot. This can be seen in **Figure III-5**, depicting the 1963 to 1980 time period and **Figure III-7**, depicting the 1995-1999 time period. Both of these time periods were absent of any engineering activities and thus the 'natural' erosional trend of the shoreline can be seen. After construction of seven breakwaters in 2000 and 2001, the erosional hotspot has shifted slightly west, just beyond the breakwater field to the Bay Oaks area, as seen in **Figure III-8**. While the addition of the breakwater field has greatly improved the stability of the shoreline behind it, there has been a further disruption in long-shore transport patterns creating an erosional hotspot directly to the west of the breakwater field. In addition, accelerated erosion in the Bay Oaks area can be seen after the December 2003 beach nourishment project while the portion of the shoreline behind the breakwater field behaves much better. This demonstrates that a better transition immediately west of the breakwater field needs to be put in place in order to mitigate the existing erosional hotspot. This would be taken into consideration when developing alternatives to stabilize the Bay Oaks area. **It should be noted that since the shoreline west of Bay Oaks (17th Bay St.) appears to be historically more stable, care should be taken to minimize the impact of any alternatives to the west of 17th Bay Street.**

IV. WAVE DATA REVIEW AND ANALYSIS

In order to develop an efficient design and estimate the expected design life of a proposed project, a reasonable estimate of the wave climate at the site is crucial. Previous studies performed for the East Ocean View and 800 Block regions of Ocean View have utilized offshore wave data that was transformed to the site through numerical modeling. The resulting long-term wave time series used in these studies spanned 1991 through 2003. In March 2006, the City authorized Evans Hamilton, Inc. (EHI) to deploy a bottom-mounted wave and current gage offshore of Ocean View to aid in engineering studies of the shoreline. The gage is serviced every 3 months during which new wave data is downloaded, compiled, and reviewed for accuracy. This new wave data was used to verify long-term wave data utilized in the shoreline change (GENESIS-T) and 3D morphological modeling (DELFT 3D). It was also used directly to model storm-induced erosion (SBEACH) from recent events (Tropical Storm Ernesto, October 2006 nor'easter).

A. NUMERICALLY TRANSFORMED OFFSHORE WAVE DATA

Previous studies for East Ocean View and the 800 Block regions of the Norfolk shoreline utilized wave data that was transformed to the site through numerical modeling. The resulting long-term wave time series used in these studies spanned the time period of 1991 through 2003. This transformed wave data is based on the nearest appropriate long-term wave record gathered by the US Army Corps of Engineers research station at Duck, NC. Previously existing wave data sets within Chesapeake Bay were of short duration or incomplete. This station is located on the Atlantic Coast just south of the mouth of Chesapeake Bay. Waves measured there were transformed back offshore to the entrance of the Bay and then propagated into the Bay and to the Norfolk shoreline using a numerical wave transformation model. Locally generated sea waves were approximated using a scaling of the wind fetch lengths (distance over the water which the wind blows generating waves) from the Duck location to the Norfolk shoreline project site. The previous East Ocean View Beach Nourishment Project report (M&N, 2004) fully documents the methods used to transform the waves measured at Duck, NC to a representative long term wave time series along the East Ocean View shoreline. The USACE Duck Field Research Facility (FRF) had available measured directional wave spectral data from 1991 to present. This was concluded to be the most appropriate longterm wave data available in the region. A long period of wave data is required for GENESIS-T modeling of shoreline evolution over many years.

Past wave data searches and analysis have shown that the waves offshore of the Bay Oaks shoreline have a bimodal distribution, divided into fairly distinct sea and swell components. The sea waves, typically of shorter period steeper waves, are more dominant in the winter months arriving from the north, generated by local storm winds within Chesapeake Bay. In contrast, the swell waves, typically longer period flatter waves, arrive year round mainly from the east to northeast quadrant propagating through the Chesapeake Bay mouth from the Atlantic Ocean. The sea and swell components of the wave climate can be derived from directional wave spectral data, which is a measure of wave energy by frequency (period) and direction.

Through analysis and inspection of the wave data, the sea and swell wave data were divided at a wave period of 5.5 seconds. That is, all energy corresponding to periods less than or equal to 5.5

seconds was considered sea and all energy above 5.5 seconds was considered swell. Since this data was nearshore at Duck it was first refracted offshore prior to being propagated back into Chesapeake Bay. The swell waves were transformed to the nearshore region of East Ocean View within the bay using a numerical wave transformation model (the Danish Hydraulic Institute's MIKE21 Nearshore Spectral Wave (NSW) model). The sea waves are a product of local winds so a different approach was used to transform the sea wave climate to the site based on the relative fetch distance over which the wind blows as waves approach the Duck FRF site and the East Ocean View shoreline contained within Chesapeake Bay. The methodology is outlined in detail in the previous report (M&N, 2004).

B. NORFOLK MEASURED NEARSHORE WAVE DATA

Understanding of the wave climate immediately offshore of the Norfolk shoreline is vital for the design, monitoring, and understanding of projects along the shoreline and the behavior of the beach. In March 2006, a bottom-mounted wave gage (**Figure IV-1**) was deployed by Evans Hamilton Inc. (EHI) for the City to measure the wave climate offshore of Ocean View to aid in improving knowledge of the nearshore wave climate. The Nortek AWAC-AST wave gage was placed on the sea floor and looks upward measuring currents through the water column and tracks the water surface elevation above it. The AWAC (Acoustic Wave And Current) gage is a combination acoustic Doppler current profiler and directional wave gage employing a unique Acoustic Surface Tracking (AST) vertical beam to measure the surface waves from a subsurface location. The data is collected at regular intervals (every 20 minutes for currents and hourly for waves) and stored in the instrument for later retrieval during quarterly servicing when the data collected is downloaded and analyzed. The wave gage is centrally located along the Norfolk Ocean View shoreline, in 23 feet of water, and far enough offshore to not be shielded by the spit (see **Figure IV-2**). Further details of the instrumentation, sampling scheme, and the measured wave data are documented by deployment period (quarterly during the first year) in reports submitted to the City of Norfolk. These wave measurements are still ongoing and will provide an important basis for future analysis and coastal engineering works along the shoreline.

Figure IV-1 Wave Gage and Bottom Mount

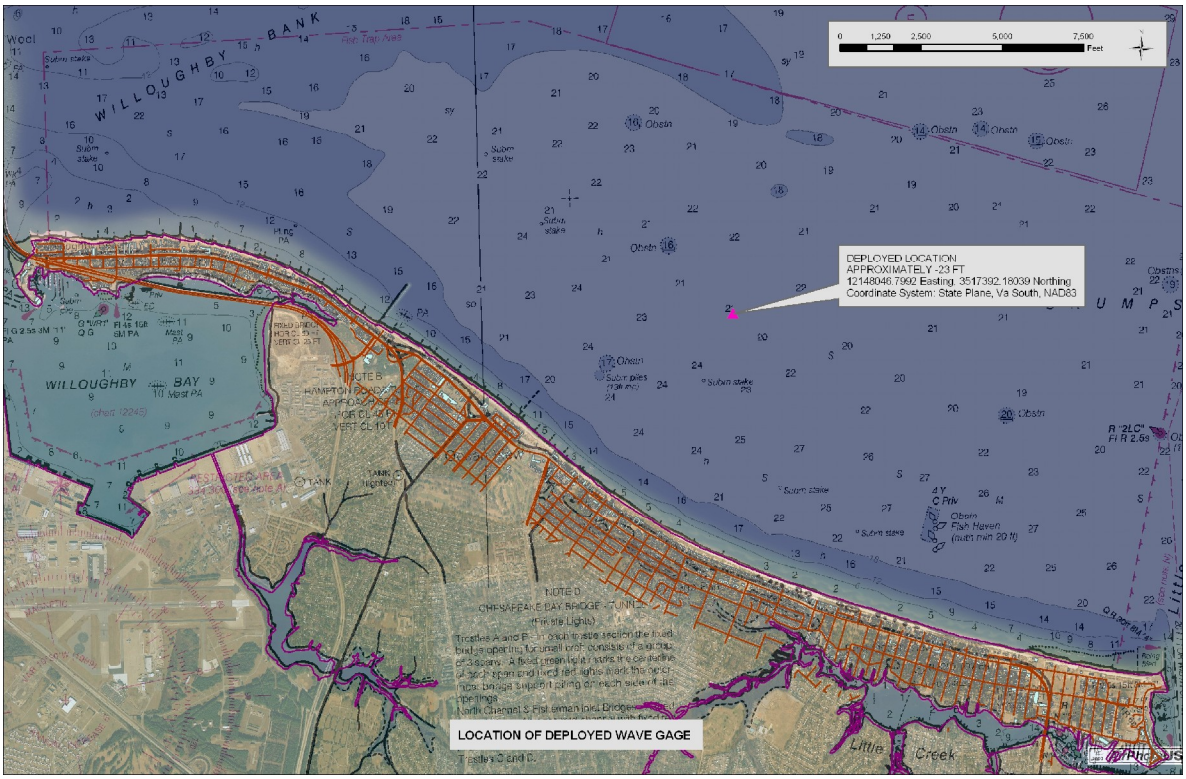

Figure IV-2 Wave Gage Deployment Location

The measured wave gage data over the first full year of deployment exhibits some clear overall trends. The wave climate is divided between waves traveling from the Atlantic Ocean through the mouth of Chesapeake Bay (swell) and waves generated within Chesapeake Bay by winds (sea). The swell waves tend to exist throughout the year and are of longer period. The second component of the wave climate is generated by winds blowing over the waters of Chesapeake Bay. These locally-generated sea waves within the Bay tend to have shorter wave periods. During storm events, especially those with a northerly wind blowing across the longest fetch of the Bay toward the Norfolk shore (extratropical nor'easters common to the area), these sea waves have the largest wave heights impacting the beach. It is these storm waves that drive the largest motion of sand both along and across (on and offshore) the shoreline.

The measured directional spectra (**Figure IV-3**) illustrate the division in the wave energy between local wind generated sea (higher frequency/shorter period waves generally generated within Chesapeake Bay coming from northerly directions) and the transformed swell entering form the Atlantic Ocean (lower frequency/longer period waves generally coming from easterly directions).

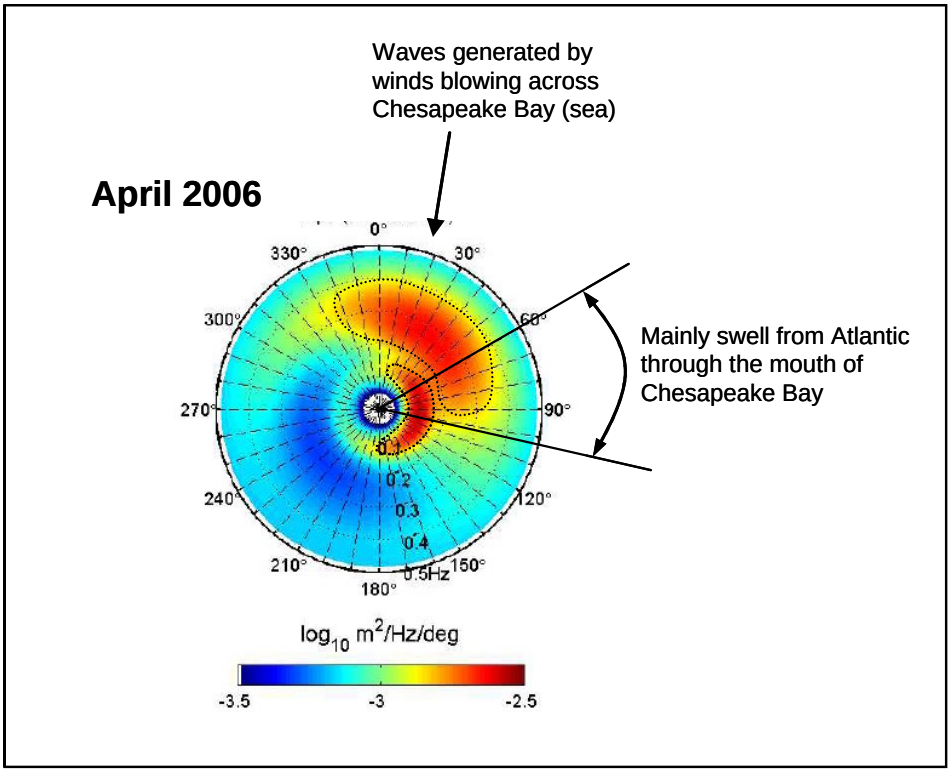

Figure IV-3 Measured Directional Wave Spectrum

For analysis, comparison, and modeling, the measured directional spectra were decomposed into sea and swell components similarly to the numerically transformed data using a wave period of 5.5 seconds as the division between sea and swell energy. This provides a representative locally measured wave climate along the shoreline. The availability of such high quality local data is a significant asset to this and future studies along the Ocean View shore.

C. COMPARISON OF TRANSFORMED AND MEASURED WAVE DATA

Wave data collected from the new gage was compiled, reviewed and compared with the transformed offshore wave data. Direct comparison of overlapping time periods (approximately March to November, 2006) was performed to evaluate the accuracy of the transformed offshore wave data. This comparison was completed to determine whether the transformed wave data should be adjusted to reflect measured conditions as determined from the new gage.

Measured Norfolk wave data from March to November, 2006 were compared to wave data transformed to the East Ocean View shore from the Duck FRF station. The measured and transformed data exhibit extremely similar trends. A comparison of the measured and transformed wave heights and periods is provided in **Table IV-1** and illustrated in **Figure IV-4** and **Figure IV-5**.

Table IV-1 Wave Comparison (March to November, 2006)

Wave Data	Average Sea		Average Swell	
	Significant Wave Height (ft)	Peak Wave Period (s)	Significant Wave Height (ft)	Peak Wave Period (s)
Measured Norfolk Wave Gage	1.08	3.5	0.51	7.8
Transformed Wave Data	0.89	4.8	0.44	9.6
Long-term Transformed Wave Data (1991-2003)	1.01	4.0	0.45	9.1

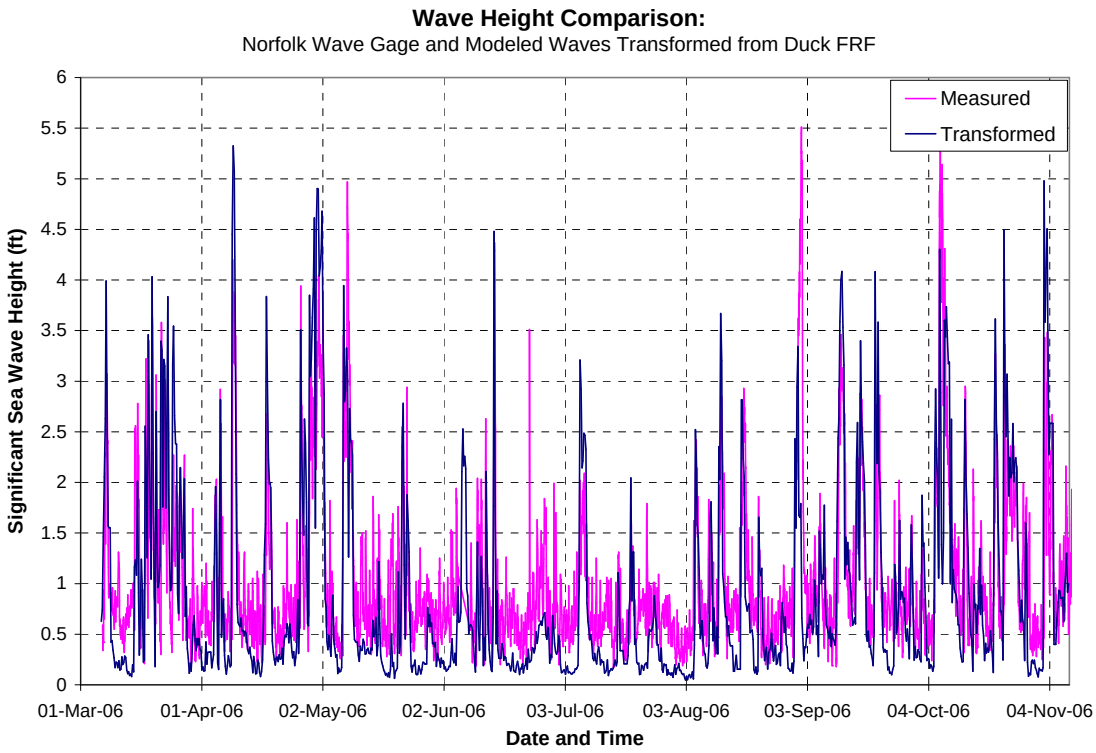

Figure IV-4 Comparison of Sea Wave Heights

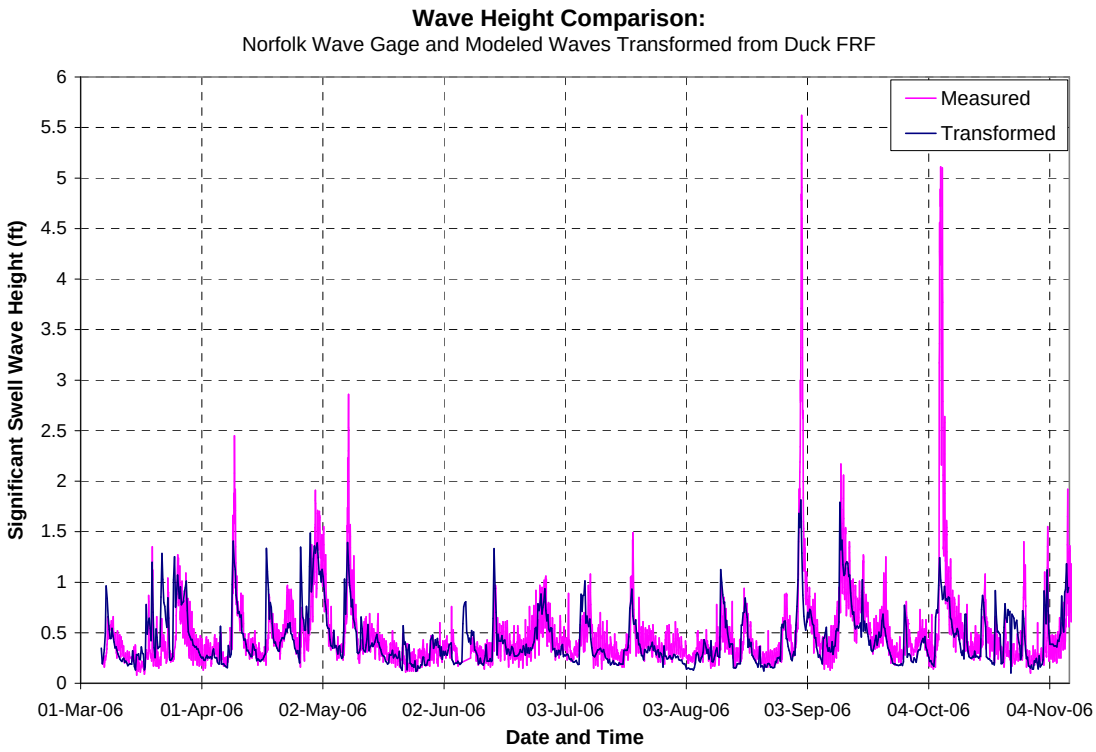

Figure IV-5 Comparison of Swell Wave Heights

The swell waves closely match except during the passage of Tropical Storm Ernesto at the beginning of September and the October Nor'easter. During these two periods the measured swell is significantly larger. This likely mainly due to the choice of 5.5 seconds as the wave period at which the swell and sea energy were divided in the analysis. During these storm events, the winds were strong and blowing across the longest fetch of Chesapeake Bay from the north resulting in locally generated wind sea waves with peak periods greater than 5.5 seconds.

The sea wave climate appears to be slightly underestimated using the transformation techniques during daily conditions, but the overall trend matches the measured data. However, the transformed data still captures the larger storm wave events.

D. WAVE DATA DISCUSSION

The understanding of coastal processes and the design of coastal projects requires a reasonable estimate of the wave climate. Along a beach, water level variations and waves drive the hydrodynamics of the sand movement. Properly assessing the wave climate is essential to developing suitable solutions to beach erosion and evaluating the potential design life of a project. Both storm and long-term wave data is required for use in the SBEACH, GENESIS-T and DELFT3D models to accurately predict beach changes due to storms and shoreline evolution over time.

The wave data from the gage at Norfolk provides the best available wave information since the data is directly measured and site-specific. This data together with survey transects and digitized shoreline data from the corresponding time period will be used to calibrate and verify the numerical modeling and assess the impact of storms. Two fairly significant storms, Tropical Storm Ernesto and the October Nor'easter, are contained within the recent measurements.

Since the study and analysis of shoreline change and methods to reduce the erosion along the shore at Bay Oaks require modeling of the longer time frames than currently available with the measured data, the transformed long-term wave data was used to assess the future conditions and potential alternatives. The measured wave data is currently of insufficient length to use as representative of longer term conditions. It also appears to represent a fairly energetic period with several large storms, which may not be representative of long-term average conditions required to assess the behavior of existing conditions and proposed alternatives over several years. Based the need for longer term data for the GENESIS-T shoreline change modeling and the comparison of the measured and transformed wave data, it was decided that the long-term transformed wave time series, spanning 1991 through 2003, would be used for long-term model simulations. No adjustments were made to the transformed data since it appears to reflect measured conditions adequately based on comparison to the current measured data.

V. MODELING OF CROSS-SHORE CHANGE WITH SBEACH

SBEACH (Storm-induced BEAch CHange) is an empirically based numerical simulation model which was developed at the U.S. Army Corps of Engineers (USACE) Waterways Experiment Station (WES) Coastal & Hydraulics Laboratory (CHL). The purpose of the model is to calculate two-dimensional, cross-shore beach, berm, and dune erosion under single-storm surge, wave, and wind action. The SBEACH model is based on a fundamental assumption that profile change is produced only by cross-shore processes. Therefore, longshore processes are considered uniform and neglected in calculating profile change. The cross-shore sediment transport processes are governed by empirical equations defined for four distinct zones in the nearshore: swash, broken wave, breaker transition, and prebreaking. For a more detailed description of the sediment transport mechanisms governing SBEACH, the reader is referred to a series of USACE reports published on the model (Larson and Krauss, 1989, Larson et al., 1990, Rosati et al., 1993).

The most recent version of SBEACH, released in 2002, operates under the Coastal Engineering Design and Analysis System (CEDAS), a suite of tools developed by Veri-Tech, based on various numerical models and codes developed at WES. The CEDAS suite also includes GENESIS/GENESIS-T (Generalized Model for Simulating Shoreline Change), which was also utilized in this study.

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

The main inputs to the SBEACH model include:

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

A. MODELING SCOPE

The SBEACH model serves as a basis for understanding cross shore loss of sand in the berm and/or dune following storm activity. Using the March 2006 and October 2006 beach surveys, the SBEACH model was calibrated with measured wave data, which includes Tropical Storm Ernesto and the October 2006 nor'easter, from the recently deployed wave gage. Once the SBEACH model was calibrated, the new model would be run to evaluate expected future response of the existing beach profile.

The calibrated SBEACH model would then be used to evaluate the performance of selected alternatives which consist of beach fill only. The same measured waves and water levels from recent storm events (Tropical Storm Ernesto and October 2006 Nor'easter) which were used for

calibration would be used to simulate expected short-term storm induced impacts for similar wave conditions.

B. STUDY AREA

Within the Bay Oaks project study area, specific transects from the March 2006 and October 2006 surveys were selected to evaluate cross shore storm induced impacts. **Figure V-1** shows the location of the selected beach profiles which were modeled in SBEACH. The profile stationing is in accordance with the city surveys.

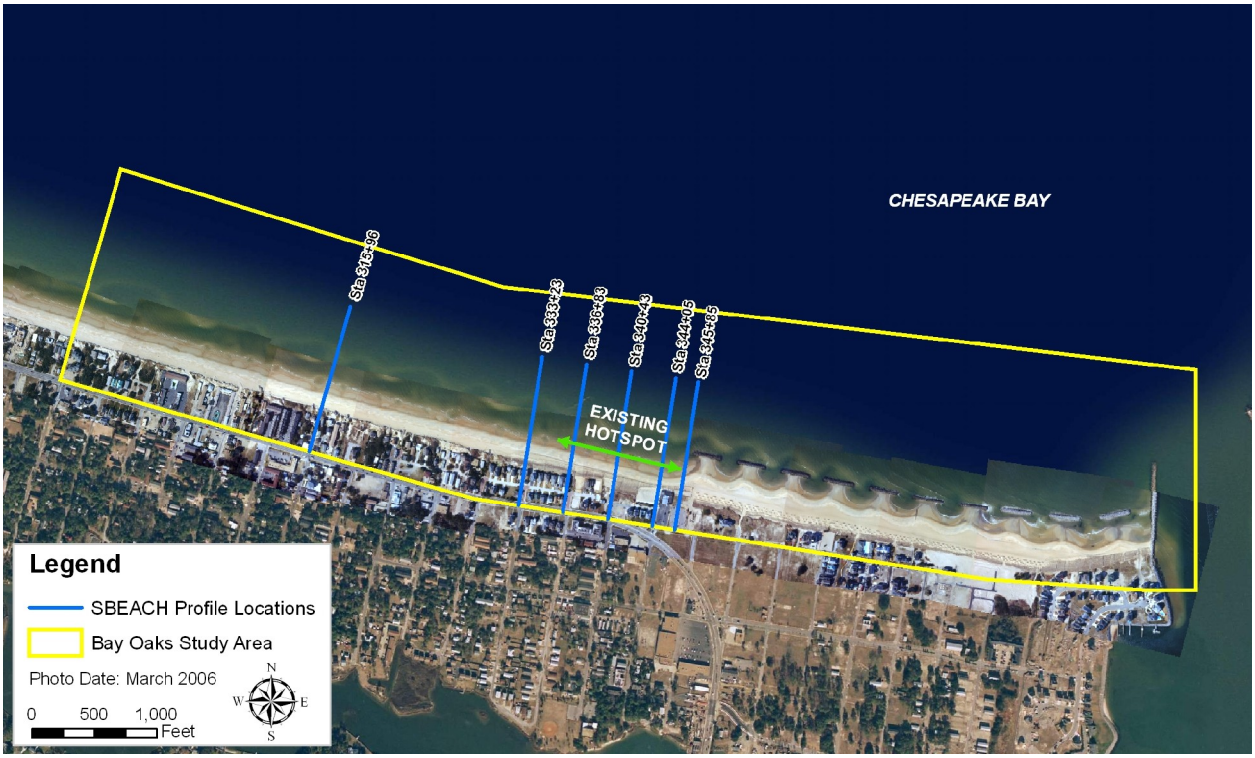

Figure V-1 Location of Modeled SBEACH Profiles

C. CALIBRATION MODEL

The SBEACH model was calibrated to reflect the storm induced impacts which have occurred as a result of an active storm period between the March 2006 and October 2006 surveys. The overall calibration time period was based on the availability of quality measured survey data and measured wave gage data. An overall calibration time period was selected where no engineering activities took place, allowing for structural conditions on the beach to remain consistent. This was necessary as SBEACH does not allow for time-varying structural configurations in an individual model (i.e. structures are either present or absent).

SBEACH is typically calibrated by adjusting the model calibration parameters, which include a number of sediment transport characteristics and other beach characteristics that influence sediment transport. For this study, the general calibration procedure involved:

1. establishing known model inputs including profile data, storm data, and sediment data
2. establishing initial sediment transport parameters and adjusting these parameters until the predicted profiles best match the measured profiles
3. establishing initial beach characteristic parameters and adjusting these parameters until the predicted profiles best match the measured profiles

This calibration sequence was followed using known inputs and initial parameters based on the East Ocean View study. Then, particular input parameters (sediment transport parameters and beach characteristics) were revisited and the sensitivity of the model response to changes in these parameters was tested. In many cases, a given parameter was adjusted to yield a more accurate profile response. The final input data for the calibration model will be presented in the following sections.

1. Profile Data (Calibration Model)

The profile data was obtained from the City of Norfolk surveys done in March 2006 and October 2006. Six profiles were selected for the calibration model based on their location relative to the Bay Oaks hotspot. The measured March 2006 profile became the initial beach profile for the SBEACH model input. The measured October 2006 profile was also loaded into the model to serve as a reference profile position for the model calibration.

2. Storm Data (Calibration Model)

Typical storm data input for SBEACH includes storm hydrographs of total water elevation, wave conditions, and wind conditions. For this analysis, the simulation involved a 6-month time series of wave gage data. The wave gage information used included significant wave height, peak wave period, wave angle, and water elevation data for a duration spanning from March 29, 2006 to October 10, 2006. Wind data is an optional input in the SBEACH model, but was not used in this application, since typical wind conditions are not likely to result in waves causing significant loss of sediment from the berm or dune. **Figure V-2** through **Figure V-5** show the significant wave height, peak period, water level, and wave angle time series, respectively.

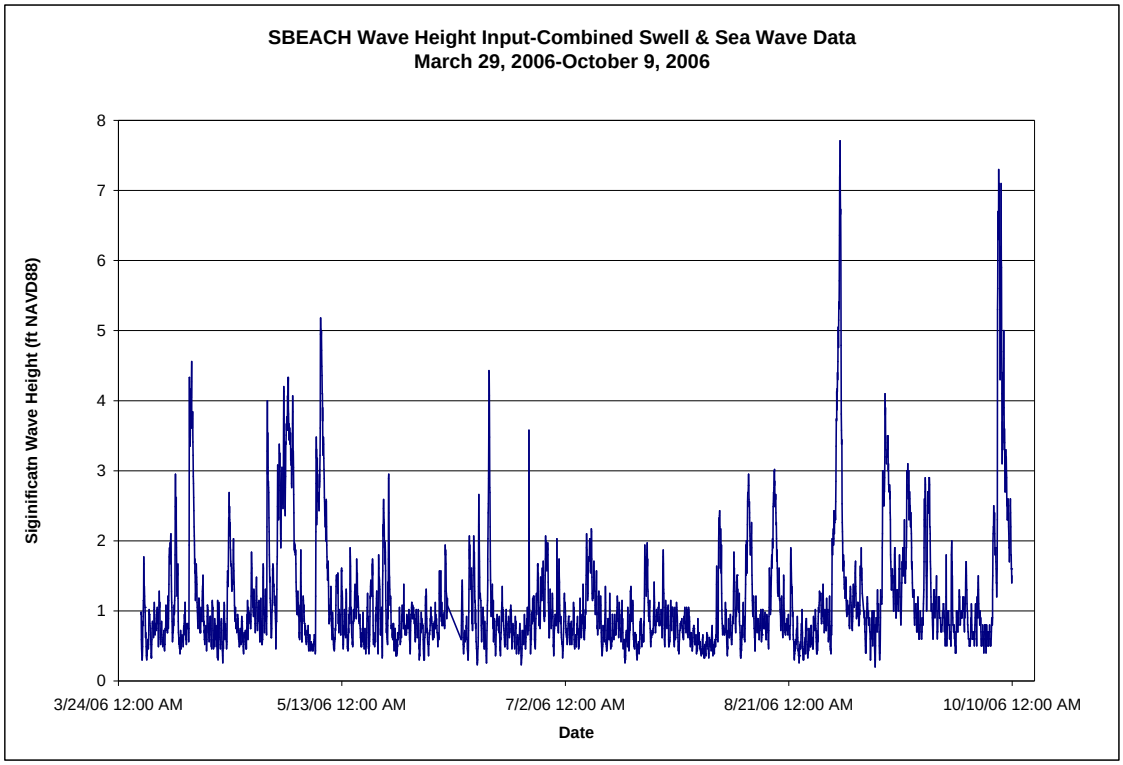

Figure V-2 Significant Wave Height

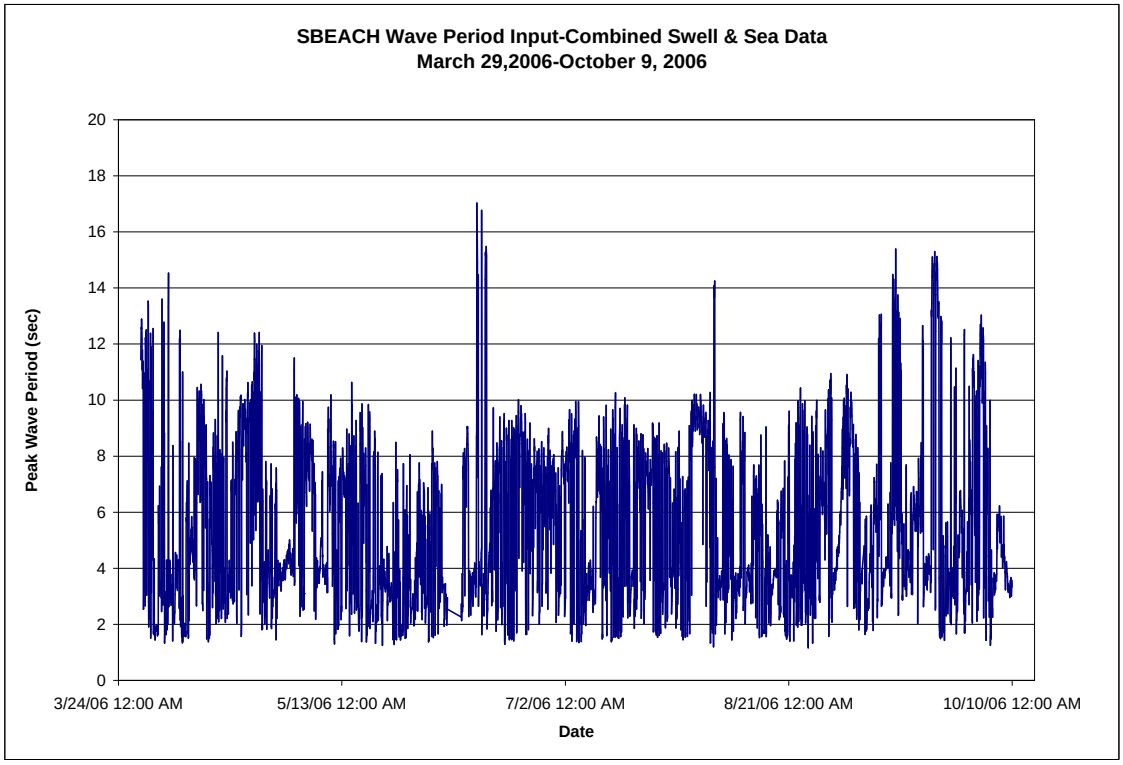

Figure V-3 Peak Wave Period

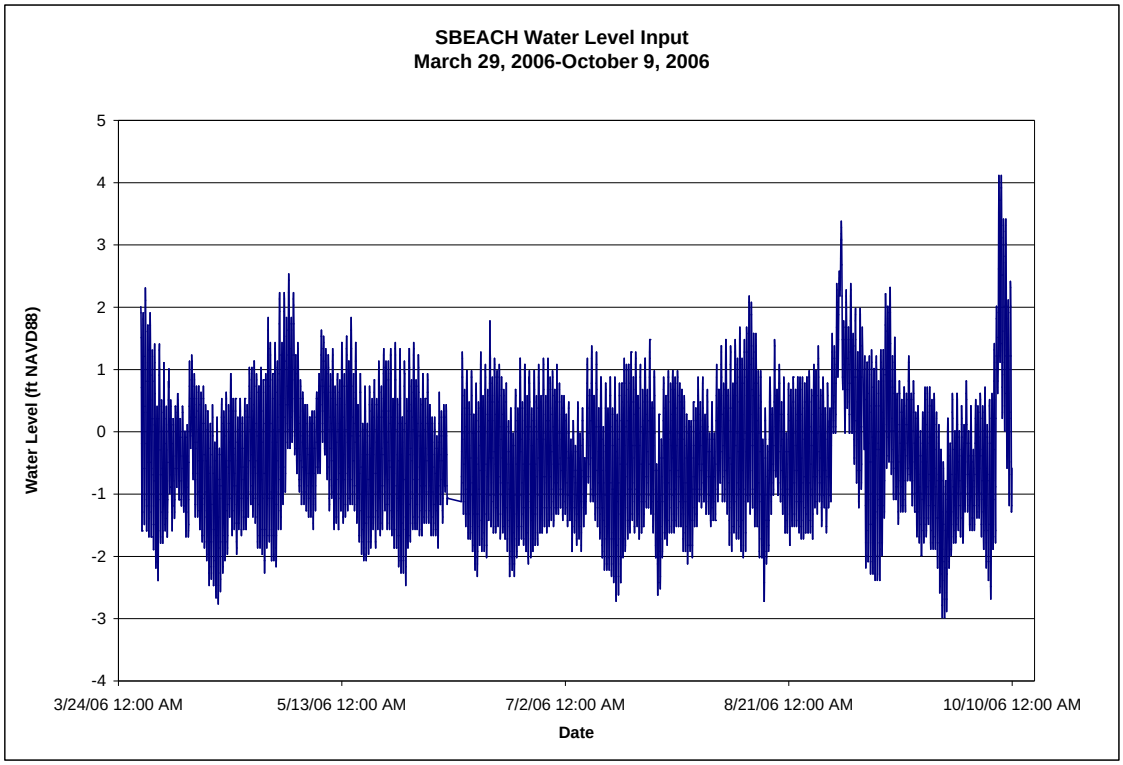

Figure V-4 Water Level

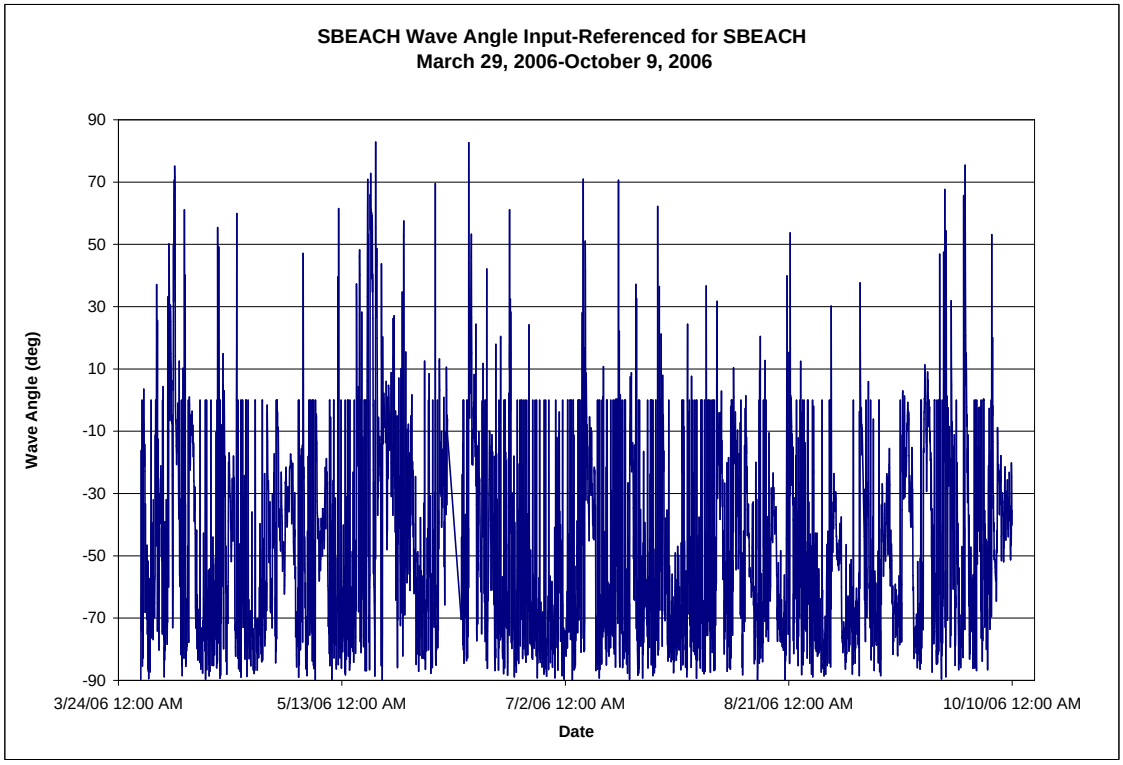

Figure V-5 Wave Angle

3. Sediment Data (Calibration Model)

For this analysis, the effective grain size used for the model profile was 0.38 mm. As mentioned in **Section II.C**, this is the median grain size computed from a comprehensive April 2004 post nourishment sediment study.

4. Model Calibration Coefficients (Calibration Model)

SBEACH is typically calibrated by adjusting the sediment transport characteristics or beach characteristics. Sediment transport characteristics include Transport Rate Coefficient, K (m^4/N), Coefficient for Slope Dependent Term, Eps (m^2/s), Overwash Transport Parameter, Transport Rate Decay Coefficient Multiplier, and Water Temperature (°C). Beach characteristics include Landward Surf Zone Depth and Avalanche Angle (Deg). The initial model was run using the parameters established for the June 2004 East Ocean View study. Then, each parameter was adjusted individually, within the recommended range, to determine its influence on model output. The appropriate model coefficients were determined by comparing the SBEACH final output profile with the corresponding measured October 2006 profile.

After running a number of model scenarios, it was determined that the following model parameters yielded the most accurate final profile.

- Transport Rate Coefficient, K (m^4/N) = 2.5×10^{-6},
- Coefficient for Slope-Dependent Term, Eps (m^2/s) = 0.001,
- Overwash Transport Parameter = 0.005,
- Transport Rate Decay Coefficient Multiplier = 0.3,
- Water Temperature=20º C,
- Landward Surf Zone Depth = 1.6, and
- Avalanche Angle = 30º

5. Model Output (Calibration Model)

A comparison of the final SBEACH model profile and the measured final profile for October 2006 is shown in **Figure V-6**. The final SBEACH profile matched well with the measured October 2006 profile above -5 ft NAVD88. The offshore bar movement below -5 ft NAVD88 was not able to be replicated due to the limits of SBEACH. The SBEACH model simulates change in the berm and dune region of the profile, holding offshore profiles fairly consistent over time. Additionally, the SBEACH model does not account for longshore sediment transport, which may have been significant during the relatively stormy period modeled. The inshore migration of the offshore bar was observed in the Delft3D model discussed in a later section, which includes both cross and longshore sediment transport processes. SBEACH model output for the remaining cross sections is presented in **Appendix E**.

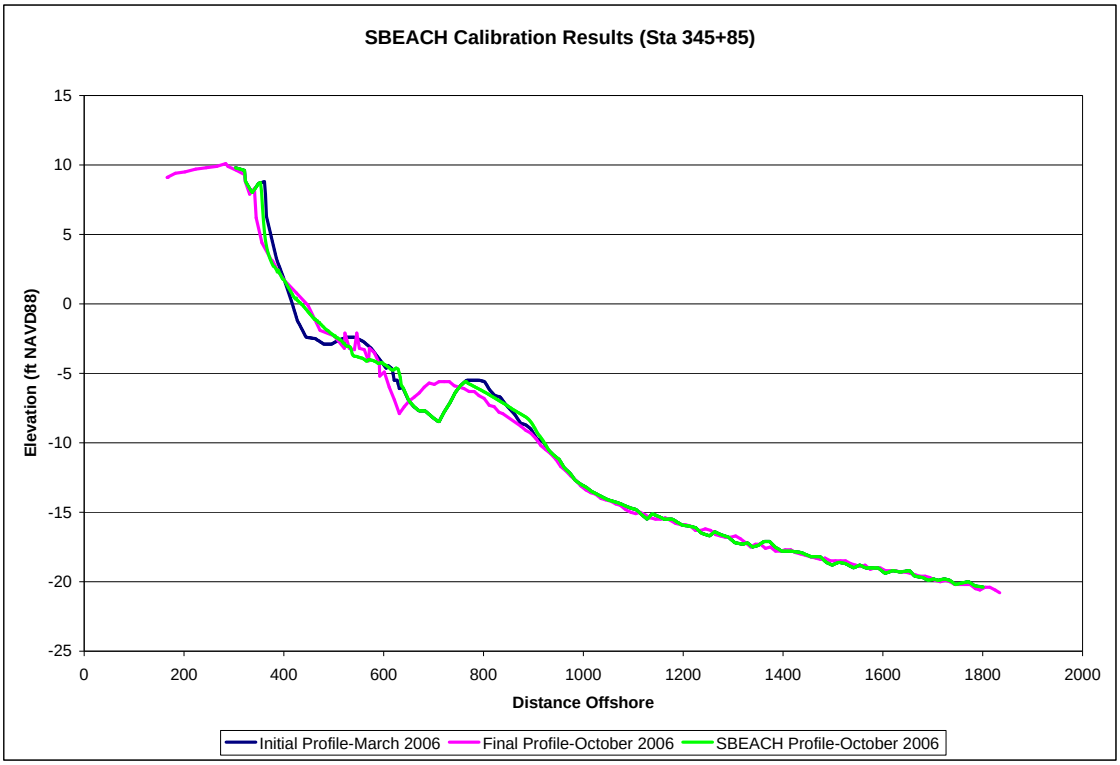

Figure V-6 Comparison of SBEACH Final Profile and Measured Profile for Calibration Model

D. EXISTING CONDITIONS MODEL

After setting the SBEACH calibration coefficients, an existing conditions model was developed to estimate the initial cross shore beach change that the East Ocean View study area would be expected to experience following the same wave and water level impacts. The resulting profile indicates what would happen if the existing erosion problem at Bay Oaks were not addressed.

1. Profile Data (Existing Conditions Model)

The input profiles for the existing conditions model were taken from the October 2006 City of Norfolk survey. This survey was taken immediately after the October 2006 Nor'easter. Profiles were extracted from the same locations as used in the calibration model (**Figure V-1**).

2. Sediment Data (Existing Conditions Model)

The same sediment data as was used for the calibration model was input into SBEACH. As stated previously, the median grain size for this project was 0.38 mm. This was the post nourishment grain size as determined from the April 2004 study.

3. Storm Data (Existing Conditions Model)

The same time series of wave data which was used for the calibration model was used for the existing conditions model. The results provide predicted beach profiles if nothing was done to the beach and the same storm conditions (Tropical Storm Ernesto and October 2006 nor'easter) were to repeat themselves.

4. Model Calibration Coefficients (Existing Conditions Model)

The sediment transport parameters and beach characteristics as defined by the model calibration analysis were used. Therefore, the existing conditions model was run using the following parameters:

- Transport Rate Coefficient, K (m^4/N) = 2.5 x 10^{-6},
- Coefficient for Slope-Dependent Term, Eps (m^2/s) = 0.001,
- Overwash Transport Parameter = 0.005,
- Transport Rate Decay Coefficient Multiplier = 0.3,
- Water Temperature=20º C,
- Landward Surf Zone Depth = 1.6, and
- Avalanche Angle = 30º

5. Model Output (Existing Conditions Model)

The SBEACH model indicates that if no erosion control alternatives were put in place, the impact of another storm season similar to the fall of 2006 on the cross shore profile would result in some minor smoothing. The profile is probably in equilibrium for storms of this type. This however does not necessarily indicate that no erosion or recession of the shoreline would occur but merely the general cross shore profile shape would remain similar. The results of one of the SBEACH model runs is presented in **Figure V-7**. SBEACH Model output for the remaining cross sections is presented in **Appendix E**.

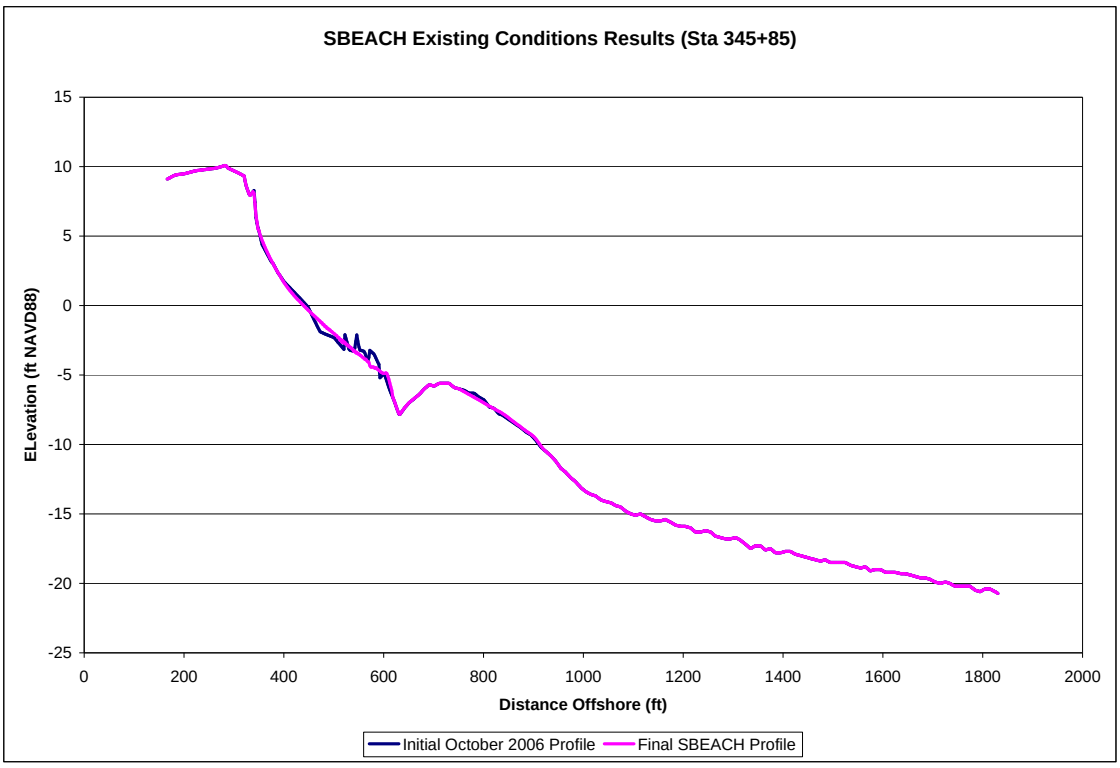

Figure V-7 Existing Conditions SBEACH Model Results

E. MODELING OF PROPOSED ALTERNATIVES

One of the proposed alternatives, as will be explained in **Section VI.F**, is to perform a beach fill project extending from the westernmost existing breakwater to 17th Bay St. A plan view representation of the beach fill extents is presented in **Figure V-8**.

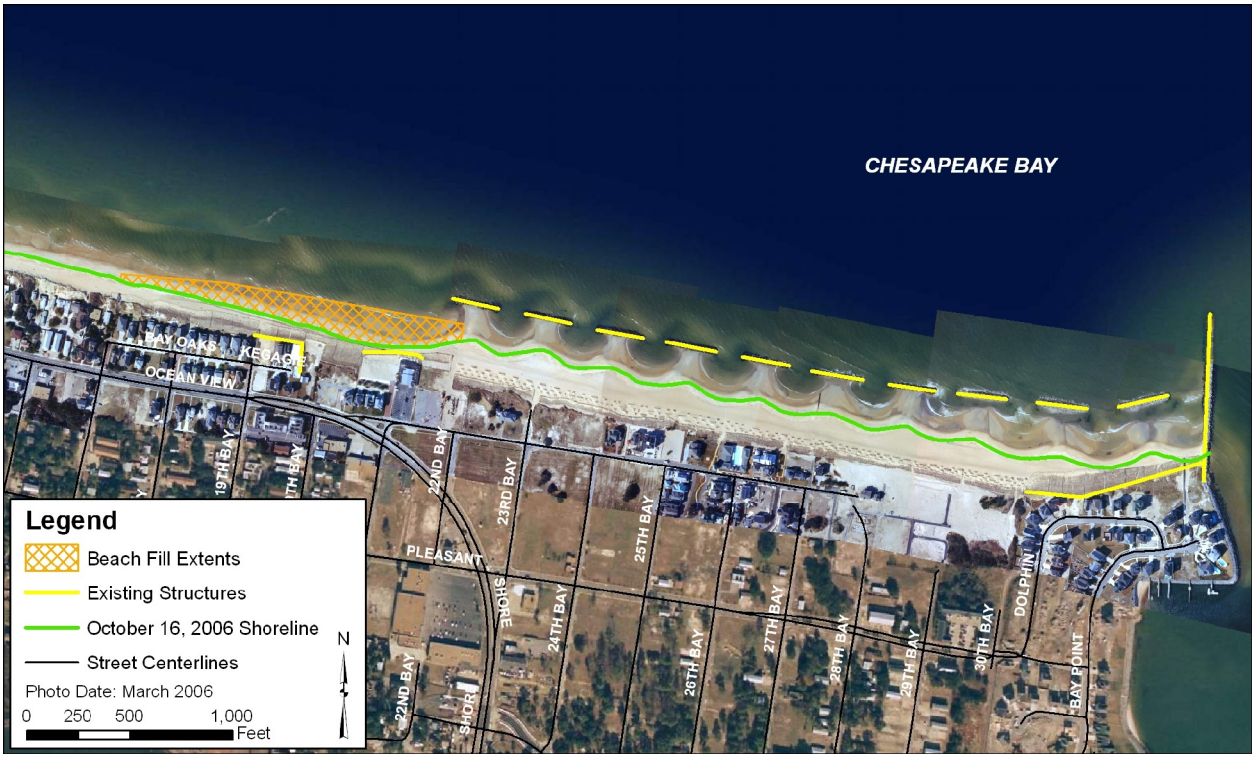

Figure V-8 Beach Fill Alternative

1. Profile Data (Proposed Alternative Model)

The October 2006 profiles from the city survey were modified to include a beach nourishment project in which the berm was extended out to an average shoreline position corresponding to that behind the existing breakwater field with a slope of 1:10 (V:H). An example nourished profile is presented in **Figure V-9**.

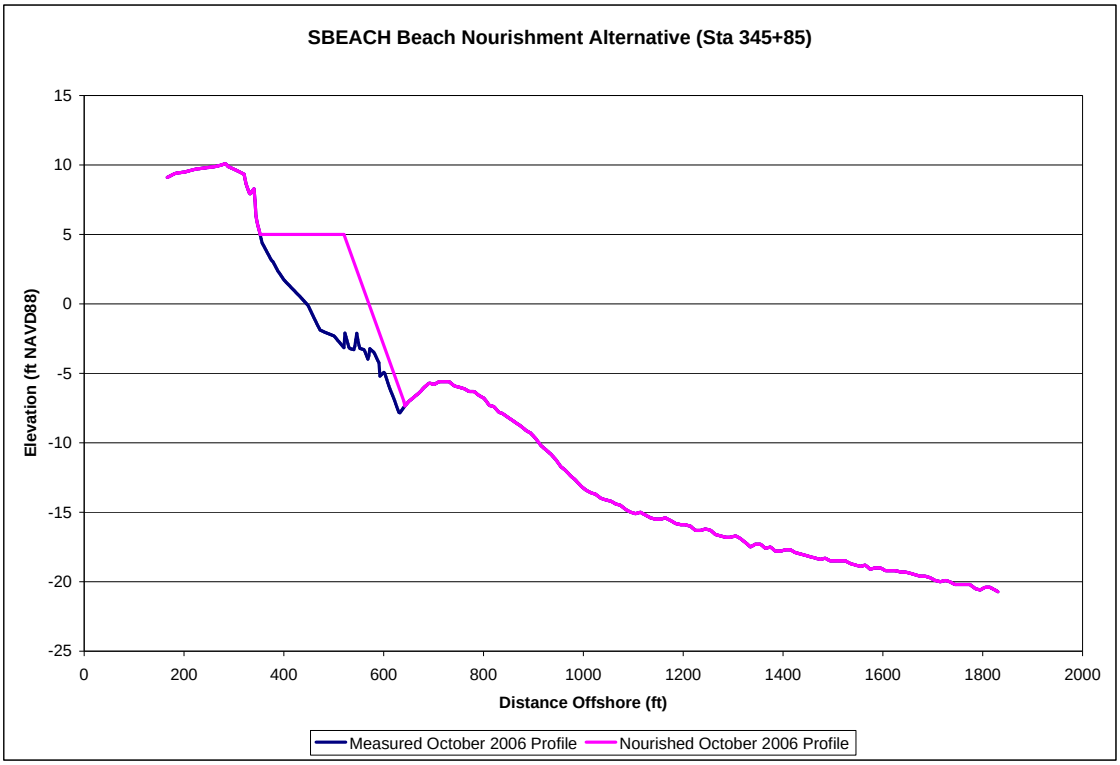

Figure V-9 Example Beach Profile with Nourishment

2. Sediment Data (Proposed Alternative Model)

The same sediment data as was used for the calibration model was input into SBEACH. As stated previously, the median grain size for this project was 0.38 mm. This was the post nourishment grain size as determined from the April 2004 study.

3. Storm Data (Proposed Alternative Model)

The same time series of wave data which was used for the calibration model and existing conditions model was used. The results provide predicted beach profiles if a beach nourishment project was completed and the same storm conditions (Tropical Storm Ernesto and October 2006 nor'easter) were to repeat themselves.

4. Model Calibration Coefficients (Proposed Alternative Model)

The sediment transport parameters and beach characteristics as defined by the model calibration analysis were used.

5. Model Output (Proposed Alternative Model)

As shown in **Figure V-10**, approximately 1/3 of the added berm width remains after the nourished beach is impacted by Tropical Storm Ernesto and the October 2006 nor'easter. SBEACH Model output for the remaining cross sections is presented in **Appendix E**. Over the long term the beach profile shape will likely smooth eventually returning to the pre-nourishment equilibrium profile.

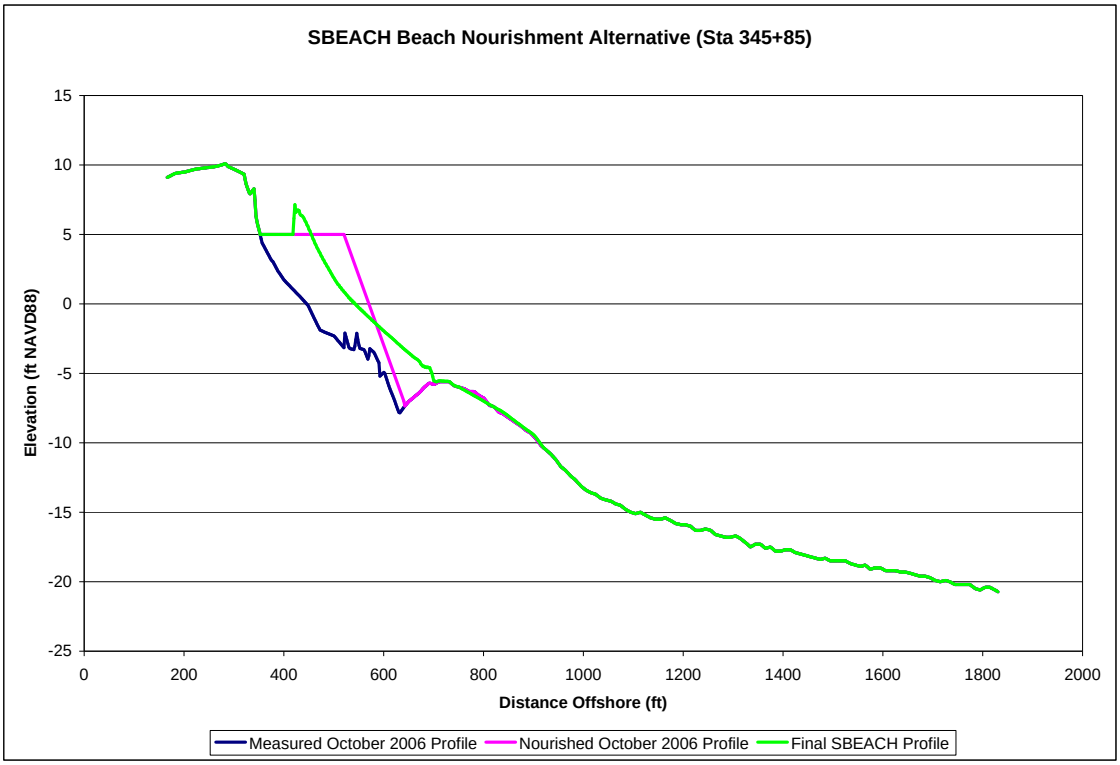

Figure V-10 SBEACH Results for Beach Fill Only Alternative

VI. MODELING OF LONG-SHORE CHANGE WITH GENESIS-T

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

GENESIS-T is a recent release that expands on the modeling capabilities of GENESIS, allowing for the formation of tombolos at detached breakwaters and/or T-groins. After a comparison of GENESIS and GENESIS-T, it was decided to use GENESIS-T for this study, due to the capability of tombolo formation, which is a distinct possibility given the behavior of the shoreline in response to the existing breakwater field.

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

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

The main inputs to the GENESIS and GENESIS-T model include:

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

A. MODELING SCOPE

The GENESIS-T model served as the basis for developing an understanding of the historical sediment transport and erosional patterns along the Bay Oaks study area and for evaluating numerous erosion control alternatives. The GENESIS-T modeling task involved evaluating the long-term change in shoreline position based on a long-term period of wave action (1991-2004). The GENESIS-T model was selected in favor of the GENESIS model used in earlier studies of the Norfolk shoreline due to the model's improved capability to handle potential tombolo formation behind detached breakwaters. Absent the presence of such formations, the simulated model results should be nearly identical. For the Bay Oaks region, existing conditions were simulated using both the GENESIS and GENESIS-T models for a 5 year time period. **Figure VI-1** illustrates the results with both models yielding almost identical predicted shoreline positions.

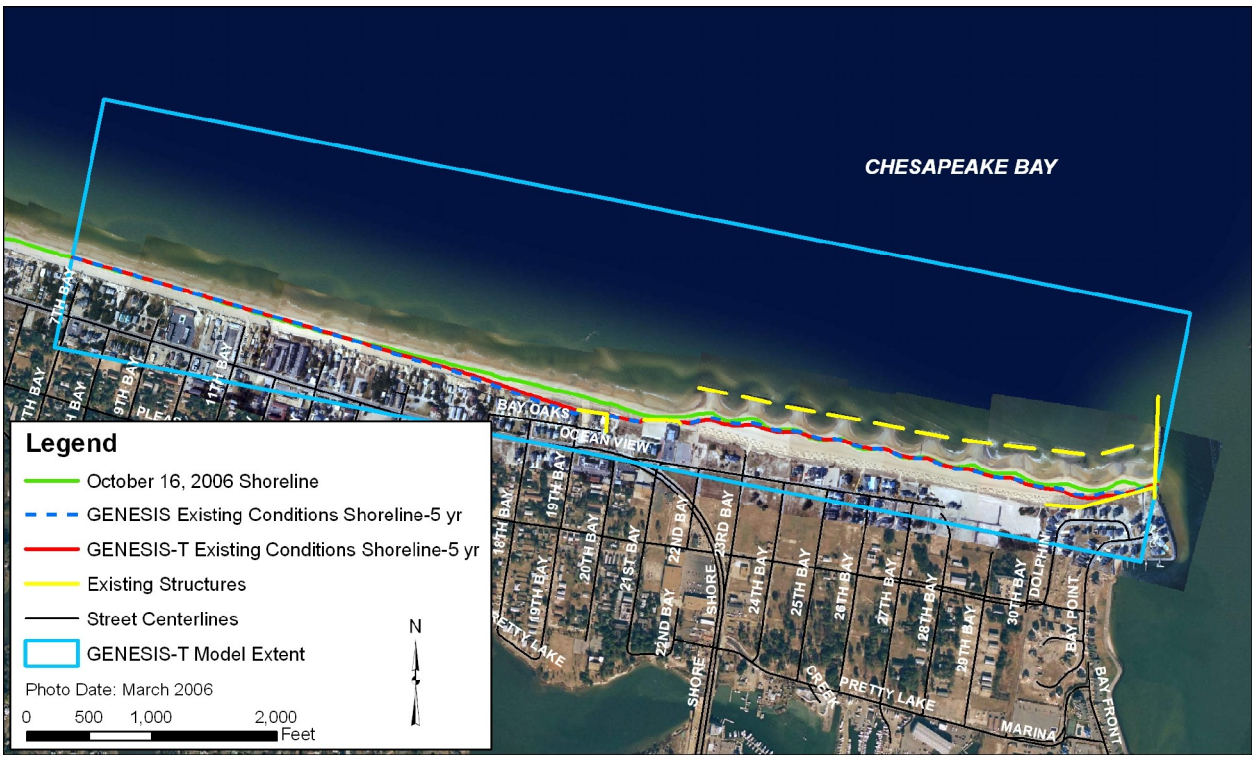

Figure VI-1 GENESIS vs. GENESIS-T Comparison

To establish the appropriate model parameters, the GENESIS-T model was calibrated for a March 2006 to October 2006 time period using historical shoreline positions and coinciding wave data from the wave gage. GENESIS-T is primarily calibrated by adjusting the longshore sand transport coefficients (K_1 and K_2). Additionally, the model may be calibrated by adjusting the characteristic transmissivity or permeability of offshore breakwaters, groins or jetties.

Once a calibrated model was developed, the model was run for a number of conditions using the established calibration coefficients. First, an existing conditions model was developed and run for a future 5 year time period to determine the impacts with no mitigation of the existing erosion problem. Then, the calibrated model was used to simulate future long-term shoreline change with numerous erosion control/beach nourishment alternative improvements in place. The

selected alternatives were evaluated based on comparisons against the predicted existing shoreline case.

B. STUDY AREA

The GENESIS-T model extended from approximately 7th Bay Street to the West jetty, which includes a portion of Central Ocean View and all of East Ocean View. **Figure VI-2** shows the GENESIS-T model extent and existing structure locations. The model extends from the West jetty to a stable point along the Central Ocean View shoreline, as decided from previous periodic surveying evaluations.

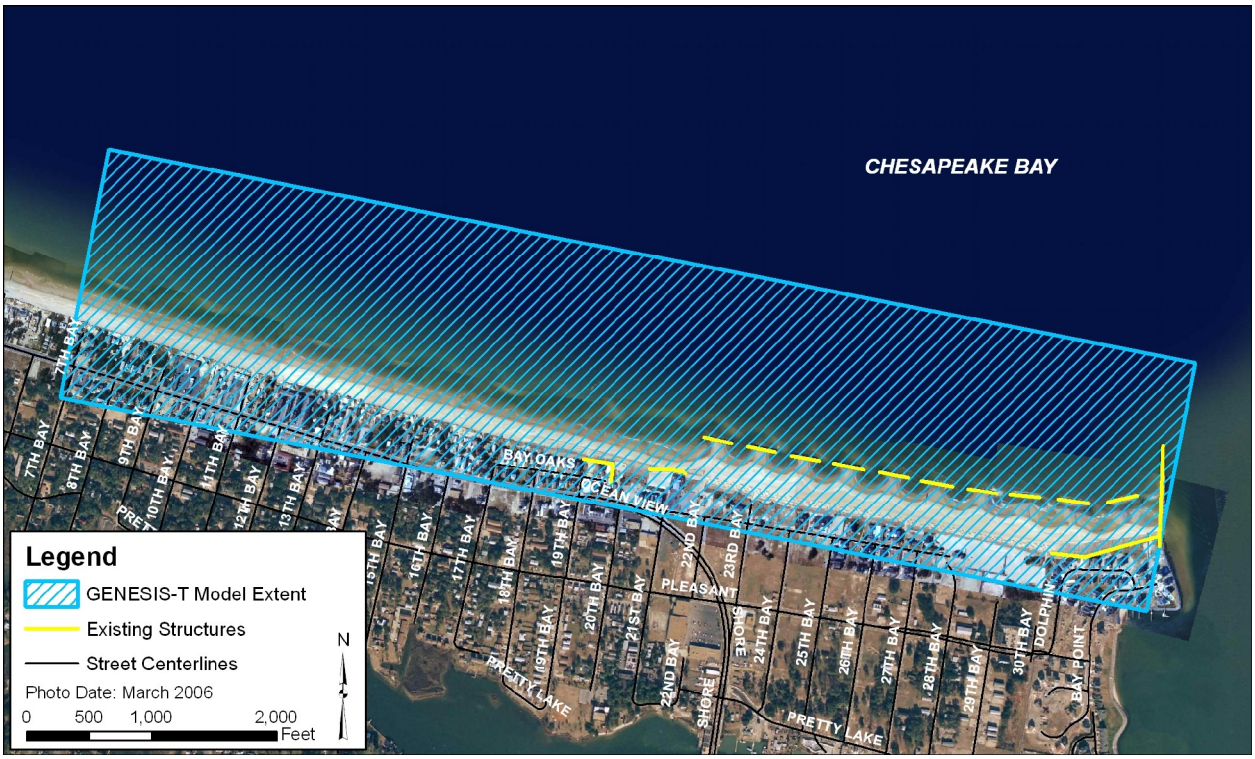

Figure VI-2 GENESIS-T Model Extent and Existing Structure Locations

C. CALIBRATION MODEL

The GENESIS-T model was calibrated to reflect the historical trends of longshore sediment transport and the resulting shoreline change over the study area. The overall calibration time period was based on the availability of quality measured shoreline data and measured wave gage data. An overall calibration time period was selected where no engineering activities took place, allowing for structural conditions on the beach to remain consistent. This was necessary as GENESIS-T does not allow for time-varying structural configurations in an individual model (i.e. structures are either present or absent).

As stated previously, GENESIS-T is typically calibrated by adjusting the sediment transport parameters, K_1 and K_2, which characterize longshore sediment transport across the region. If structures are present, the calibration process may also involve adjustment of the transmission

coefficients for breakwaters, and the permeability coefficients for groins until an accurate shoreline response is achieved. Several other boundary condition parameters (e.g. smoothing, wave input adjustments) may be altered to achieve a particular shoreline response, or to test the model sensitivity. For this study, the general calibration procedure involved:

1. establishing known model inputs including shoreline position, waves, locations of structures, sediment and beach characteristics, and boundary conditions
2. establishing initial sediment transport parameters and adjusting these parameters until the relative shoreline response (erosion/accretion) matched historical trends, and
3. working in the direction of sediment transport (east to west), adjusting the groin permeability and breakwater transmissivity coefficients until the shoreline response (e.g. updrift/downdrift, and salient/embayment formations) matched historical trends.

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

The calibration period was selected based on availability of survey data, wave data, and the presence or absence of engineering activities in the Bay Oaks region. The period of time between the two most recent surveys (March 2006 and October 2006) was absent of any engineering activities that may have a large influence on shoreline change and also had available wave data from the recently deployed wave gage. Therefore, it was decided to use this time period for calibration.

1. Shoreline Position Data (Calibration Model)

For shoreline input, GENESIS-T requires the shoreline be specified in a station-offset formulation whereby the station represents a position along a landward baseline and the offset is the perpendicular distance from this baseline to the shoreline. The initial shoreline used in the GENESIS-T model was the March 2006 shoreline, digitized by VIMS from aerial photos of the study area. The final reference shoreline to which the model was calibrated was the October 2006 shoreline, which was digitized by VIMS and modified by Moffatt & Nichol from aerial photography. **Figure VI-3** shows the shorelines, initial and reference, used in the GENESIS-T model calibration runs overlain on the March 2006 aerial photograph.

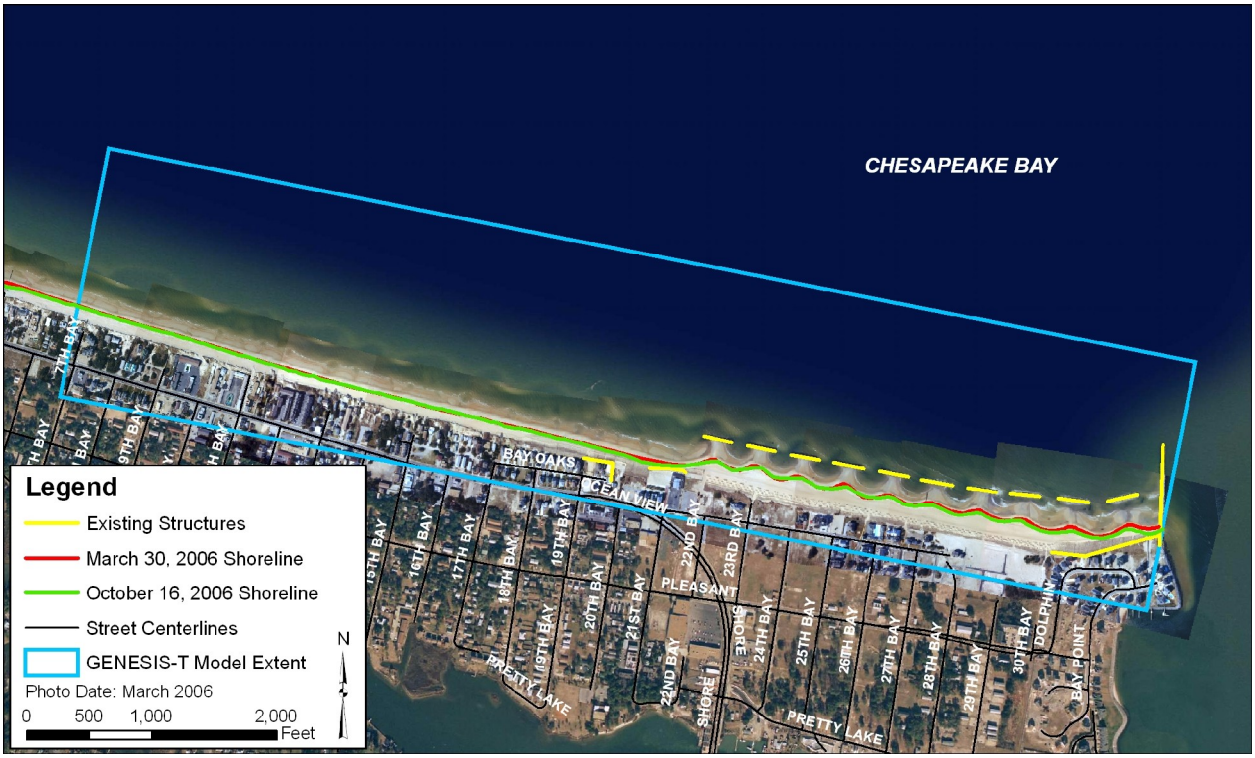

Figure VI-3 GENESIS-T Calibration Model Setup

2. Wave Data (Calibration Model)

The wave data used in the GENESIS-T calibration was measured data from the wave gage located off of the Ocean View shoreline. Data was available for the time period from March 6, 2006 to November 28, 2006. The gage data was divided into offshore sea and swell time series where sea waves had periods less than 5.5 seconds and swell waves had periods greater than 5.5 seconds. Wave height (ft), wave period (seconds), and wave direction (degrees) were specified as model inputs for each time series.

The GENESIS-T model used the defined gage data as a lookup table to transform a given wave condition from the offshore to the nearshore. Then, an internal wave model was applied in GENESIS-T to bring the nearshore waves to the breaking point.

3. Coastal Structures (Calibration Model)

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

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

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

Wave transmission through and over breakwaters is controlled by the user-specified transmission coefficient (Kt). The transmission coefficient is defined as the ratio of wave heights on the shoreward side of the breakwater to the incident wave heights on the seaward side of the breakwater and may range from 0 (no transmission) to 1 (complete transmission). Transmission coefficients applied in the Bay Oaks model were determined through numerous model iterations, in which the Kt value for each detached breakwater was adjusted for a given set of longshore transport rate coefficients until the observed shoreline response matched closely with historical trends. The breakwaters incorporated in the calibration models are known to be moderately to highly porous with low crest elevations (+2 ft NAVD88), yielding transmission coefficients ranging from 0.3 to 0.5 (30% to 50% wave transmission through and over the structure).

Similar to detached breakwaters, a non-diffracting or diffracting jetty implemented in GENESIS-T must have a defined permeability which controls the transmission of sand over and through the structure. The permeability can range from 0, implying an impermeable structure to 1, implying a completely transparent structure. The permeability of the existing jetty was set at 0.0 since there is no transmission through this structure from the inlet.

4. Sediment and Beach Characteristics (Calibration Model)

The selected effective grain size (d50) assumed in the GENESIS model was 0.38 mm. This grain size was determined based on analysis of measured sediment data collected near the study area in April 2004 as detailed in **Section II.C**. This grain size is a result of post-fill conditions at East Ocean View, making it larger than the grain size used in the previous East Ocean View study (M&N, June 2004).

The average berm height was defined as +5 ft NAVD88 and the closure depth was set to -15 ft NAVD88. These values were determined based on observations of measured survey data during the calibration time period.

5. Sediment Transport Parameters (Calibration Model)

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

The calibration models were initially run with the K_1 and K_2 coefficients used in the East Ocean View study (M&N, June 2004), where $K_1 = 0.25$ and $K_2 = 0.18$. The resulting October 2006 model shoreline was compared with the measured October 2006 shoreline and the coefficients were adjusted to achieve the closest match in the model results and the measured shoreline position. Through this procedure, it was determined that reducing the K_1 value and maintaining the K_2 value resulted in shoreline response which was most indicative of historical patterns. The final calibration coefficient values were $K_1 = 0.18$ and $K_2 = 0.18$.

6. Boundary Conditions (Calibration Model)

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

a) Seaward Boundary Conditions

As stated, two wave components, swell and sea, were implemented in the GENESIS-T model. Within the seaward boundary conditions, the user may modify the input wave conditions (wave height and direction) to analyze the impact modeled wave conditions have on the resulting shoreline response. Since the wave data utilized in this study were derived from measured wave conditions at the offshore gage, the wave conditions were not modified.

It is also possible to modify the angle with which waves are applied across the boundary of the model. To better represent diffraction around the West jetty, an angle offset of 5 degrees was used.

The smoothing factor applied with the seaward boundary conditions is an indication of how the offshore contour moves relative to the shoreline and is used to prevent unrealistic wave transformation that may occur if the shoreline changes relatively abruptly (e.g. at a groin). The smoothing value may range from 0 to 50, with a lower value indicating the offshore contour follows the shoreline position and a higher value implying that the contour is straighter than the shoreline. After numerous trials, a smoothing factor of 35 was applied in the GENESIS-T model based on the effect that this parameter was observed to have on the resulting shorelines.

b) Lateral Boundary Conditions

The left (west) boundary of the model was located at a fairly stable shoreline position which was far enough from the hotspot, so as not to influence sediment transport in this area. Therefore, the boundary was defined as pinned, indicating that the shoreline position should not change during simulations. The right (east) boundary of the model was defined as a gated jetty, allowing for a small range of shoreline movement.

7. Calibration Model Results

Figure VI-4 shows the final shoreline resulting from the GENESIS-T calibration modeling against the initial shoreline position (March 2006) and the comparable measured shoreline position (October 2006).

As shown, the model output reproduces the erosion hotspot in the Bay Oaks area, just west of the breakwater field. The calibration shoreline also matches the pattern behind the breakwaters with the exception of the easternmost portion of shoreline near the jetty. The diffraction pattern created by the jetty was not able to be exactly matched, creating a slight shift in the shoreline. However, erosion and accretion patterns are very similar to the measured shoreline. Based on these results, all future model runs utilized the defined parameters for coastal structures (breakwater transmission and groin permeability), sediment transport (K_1 and K_2), and boundary conditions (wave angle offset and smoothing factor) which were set during the calibration modeling.

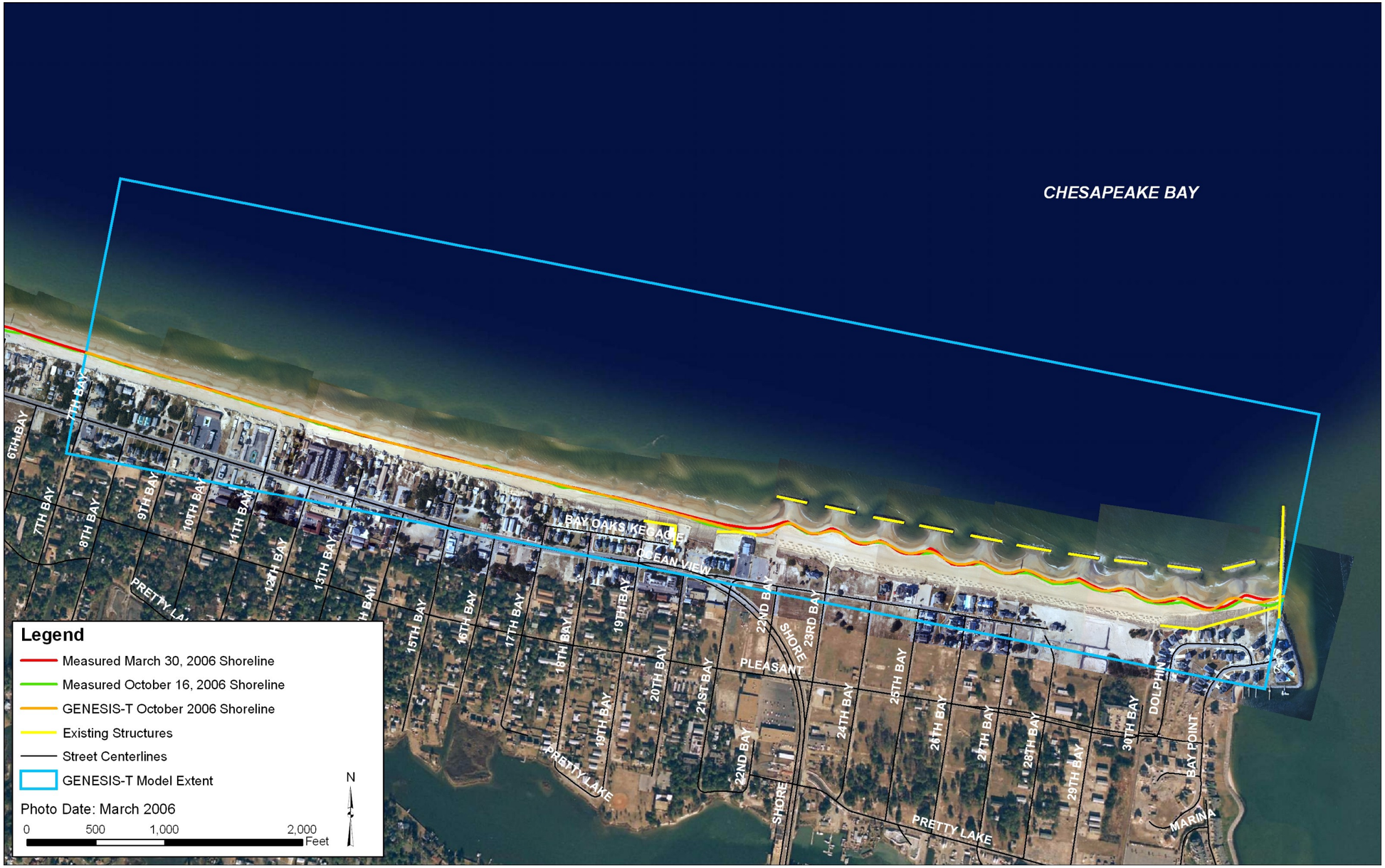

Figure VI-4 GENESIS-T Calibration Model Results

D. EXISTING CONDITIONS MODEL

An existing conditions model was run to determine the changes of the study area with no mitigation of the existing erosion problem. This model also served as the basis for decision making and comparison of proposed erosion control alternatives. The existing conditions model run involved a 5 year simulation representing the predicted future response of the shoreline under long-term typical wave action, using the long-term wave series of transformed Duck FRF data developed for the previous East Ocean View study (M&N, June 2004). The initial shoreline in the existing conditions model was the measured October 2006 shoreline. The existing structural configuration at East Ocean View was implemented in this model. All other parameters in the GENESIS-T model were the same as defined for the calibration model including the structural characteristics, sediment and beach characteristics, sediment transport coefficients, and boundary conditions.

Figure VI-5 shows the structural configuration implemented in this model run and the predicted shoreline position after a 5-yr time period. The resulting shoreline is compared against the initial shoreline position. As shown, the relative differences between the initial and predicted 5-yr shoreline position indicates considerable erosion in the Bay Oaks area. The maximum beach loss is approximately 225 ft near 21st Bay Street. If the existing problem is not mitigated, the shoreline would reach its post Hurricane Isabel position within approximately 5 years. Within 5 years, the model also predicts the retreat of the shoreline to the existing seawall and revetment protecting portions of Bay Oaks as seen in **Figure VI-5**.

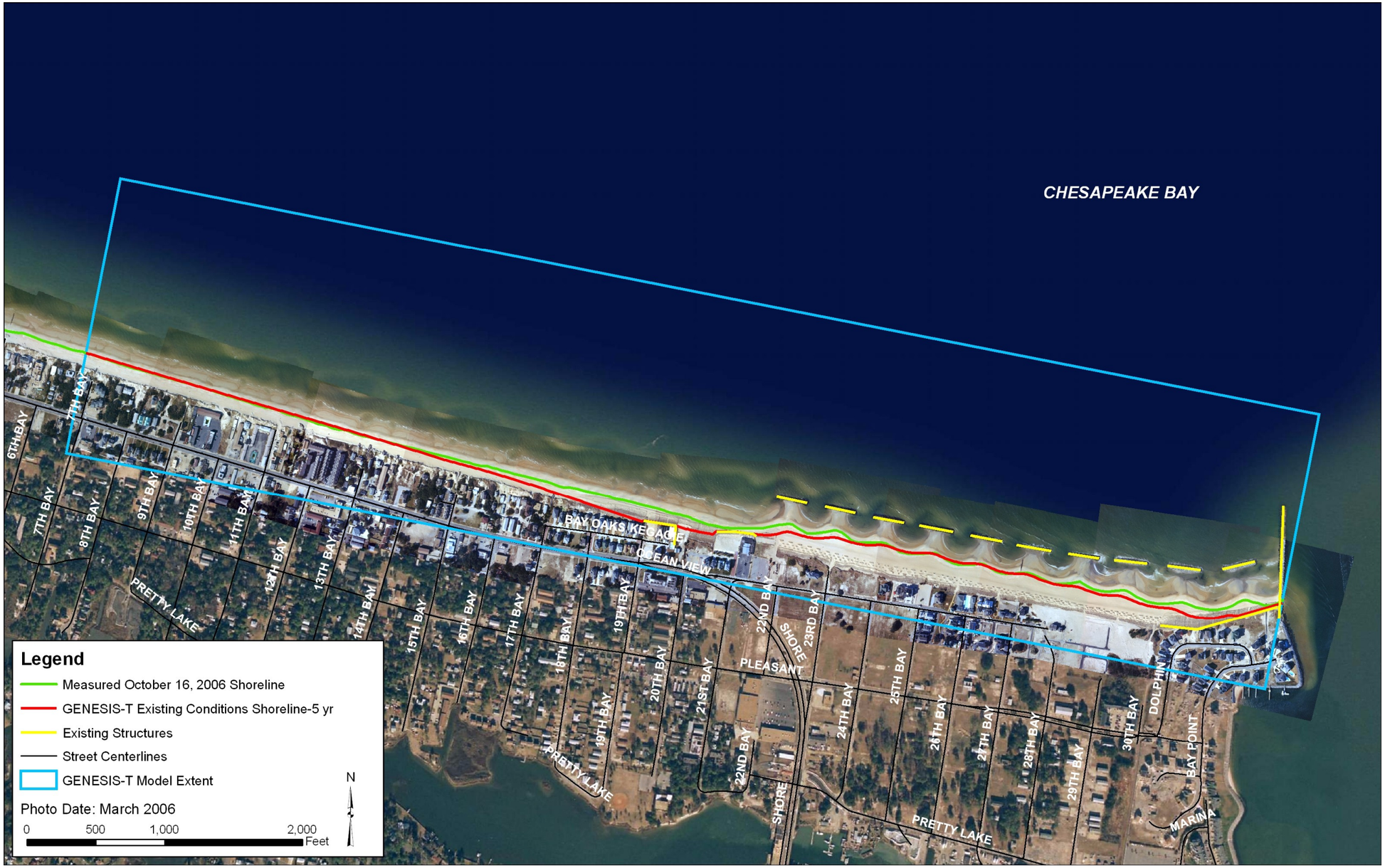

Figure VI-5 GENESIS-T Existing Conditions Model Results

E. DEVELOPMENT OF EROSION CONTROL ALTERNATIVES

The review of historical data at the Bay Oaks study area (see **Section III**) revealed that the persistent erosion at the hotspot is largely dependent on the structural modifications that have been implemented in past years. It was concluded that the general location of the hotspot along a portion of the shoreline originally impacted by construction of the jetties, makes the area vulnerable to erosion problems. The results of the existing conditions model indicate that the existing breakwater field performs very well, slowing erosion of the beach behind the breakwaters. However, the buildout of beach behind the breakwater field has likely caused a reduction of longshore sediment transport creating an erosion hotspot to the west of the breakwater field at Bay Oaks.

Given these conclusions, the goal of the proposed erosion control/beach restoration alternatives is to improve the overall transition at the Bay Oaks study area and induce a more uniform shoreline response along the study area. Proposed options for improving the structural transition generally involved shortening the length of breakwaters to improve sediment transport through the region while still allowing for protection of the beach within the hotspot area.

In May 2007, a meeting was held with the City and M&N to present the preliminary results of the historical data review and analysis and to discuss initial proposed alternatives for erosion control at the hotspot. The preliminary erosion control alternatives, which were presented by M&N, included the following structural modifications, improvements, and additions, to be implemented individually or in combination, where practicable:

- Beach nourishment
- Extending the breakwater field slightly to protect the erosional hotspot to the immediate west of the existing breakwater field
- Extending the breakwater field considerably to protect the entire Bay Oaks region
- Adjusting the length, spacing, distance from the shore, and angle of new breakwaters to improve the sediment transport transition while maintaining shoreline protection

In response to the above alternatives and the evidence presented as part of the review of historical data, the City made additional requests for modeling which included:

- Adjusting structural modifications so the effects on the downdrift shoreline west of 17th Bay Street, where the apparent historical zone of influence of the jetties ends, are minimized
- To examine possible phasing of the beach nourishment and structural modification portions of the project

Given the historical behavior at the site and its location along the shoreline within the zone of influence of the jetties, it is felt that this area will always require beach nourishment due to lack of sediment entering the system and reduced transport due to the existing breakwater field. However, with additional shoreline protection and an improved transition it is hoped that the magnitude and frequency of nourishment could be reduced from existing conditions.

F. MODELING OF ALTERNATIVES

The calibrated GENESIS-T model was used to simulate future long-term shoreline change with numerous erosion control/beach restoration alternative improvements in place. The modeled erosion control alternatives involved addition of new erosion control/beach stabilization structures (i.e. breakwaters) and/or beach nourishment.

Each proposed structural configuration was modeled in GENESIS-T for a future 20-yr time period utilizing the swell and sea wave data time series created from the transformation of data from the Duck FRF. The initial shoreline was the October 2006 shoreline. The characteristic transmissivity and permeability of existing structures were set based on the defined values determined in the calibration model. The estimation of these parameters for new, proposed structures will be discussed for the applicable options presented herein. All other parameters in the GENESIS-T model were the same as defined for the calibration model including the sediment and beach characteristics, sediment transport coefficients, and boundary conditions.

A number of selected alternatives will be presented herein, providing an overview of the range of alternatives analyzed and to present the process of optimization used to determine the final proposed alternative. Each selected alternative was evaluated through comparison of the predicted future 5 year shoreline position determined from the existing conditions model and the predicted 5 year shoreline position with comparable alternatives in place. The 5 year shoreline position was used since that is when existing conditions (do nothing alternative) would reach post-Isabel conditions. Two final alternatives were selected and recommended for additional hydrodynamic modeling using DELFT3D. For ease in the presentation of results, all figures referenced in the following discussions are included at the end of this section.

1. Option 1

Option 1 involves beach nourishment only. Roughly 100,000 cy of material would be placed on the beach, extending the initial October 2006 shoreline seaward to the approximate location of the shoreline behind the existing breakwater field. **Figure VI-6** shows the structural configuration implemented in this model run (existing structures), the beach nourishment placement extents, and the predicted shoreline position after a 5-yr time period. The resulting shoreline is compared against the existing conditions model shoreline position after a 5-yr time period.

Based on the model results, this option allows the beach to maintain a reasonable width west of 20th Bay St. However, it does not solve the problem of the erosional hotspot to the immediate west of the existing breakwater field. In addition, this option provides limited protection to Bay Oaks. However, it does perform better than the existing conditions along the shoreline to the west of the existing breakwater field.

2. Option 2

Option 2 consists of adding one breakwater to the western end of the existing field with a length of 190 ft and a spacing of 125 ft. The objective of this option is to improve the hotspot to the immediate west of the existing field. The breakwater was shortened slightly from the existing breakwaters to ease in the transition of the shoreline. In addition, beach nourishment would be performed similar to Option 1. **Figure VI-7** shows the structural configuration implemented in

this model run and the predicted shoreline position after a 5-yr time period. For comparison, the 5-yr shoreline is also shown for the existing conditions model.

Option 2 does slightly improve conditions within the original hotspot area but moves the problem further to the west in front of a vacant lot and does not improve the transition from the portion of the shoreline protected by structures to the downdrift shoreline. In addition, this option provides limited protection to Bay Oaks. However, it does perform better than the existing conditions along the shoreline to the west of the existing breakwater field.

3. Option 3

In Option 3, the breakwater field is extended to the west with 5 short breakwaters with a length of 120 ft and a gap of 140 ft. Beach nourishment similar to Option 1 would also be performed. The objective of this option is to provide some protection to Bay Oaks while smoothing the transition of the shoreline by increasing transport rates through the area compared to breakwaters of the same size as the existing breakwater field. **Figure VI-8** shows the structural configuration implemented for Option 3 and the resulting predicted shoreline position after a 5-yr time period. For comparison, the 5-yr shoreline is also shown for the existing conditions model.

Based on the model results, Option 3 provides a more gradual transition of the shoreline while providing some protection to Bay Oaks. It minimizes the effects that the end of a breakwater field typically has by lessening the erosional hotspot. It also performs as well as or better than the existing conditions along the shoreline with the existing condition and alternative shoreline being nearly coincidental from 17th Bay St. westward. This option also provides a more equivalent beach width along a majority of the study area so that all areas have comparable protection.

4. Option 4

Option 4 is a variation of Option 3 in which the last breakwater is angled. The objective of this model run was to test whether angling of the westernmost breakwater would improve the overall transition to the immediate west of the last breakwater. **Figure VI-9** shows the structural configuration implemented for Option 4 and the resulting predicted shoreline position after a 5-yr time period. For comparison, the 5-yr shoreline is also shown for the existing conditions model.

Based on the model results, Option 4 also provides a fairly gradual transition of the shoreline. However it has a downdrift effect with slightly increased erosion beyond 17th Bay St as compared to Option 3. This option is also more difficult to construct and would change the visual aesthetics of the breakwater field.

5. Option 5

Option 5 involves completely protecting the existing hotspot region by placing 3 breakwaters similar to the existing ones with a length of 230 ft and spacing of 125 ft immediately to the west of the existing breakwater field followed by 3 more breakwaters that taper in length. Beach nourishment would also be included. The objective of this option was to provide maximum protection to the entire existing hotspot shoreline with the larger breakwaters and then smooth out the transition along the shoreline with the smaller breakwaters. **Figure VI-10** shows the

structural configuration implemented in this model run and the predicted shoreline position after a 5-yr time period. For comparison, the 5-yr shoreline is also shown for the existing conditions model.

Based on model results, this option provides the largest beach in front of Bay Oaks. However, it performs much worse than the existing conditions west of 17th Bay Street. By creating such effective breakwaters in front of Bay Oaks, the sand transport has been reduced through the area, causing more erosion downdrift of the breakwater field essentially shifting the erosional hot spot further along the beach.

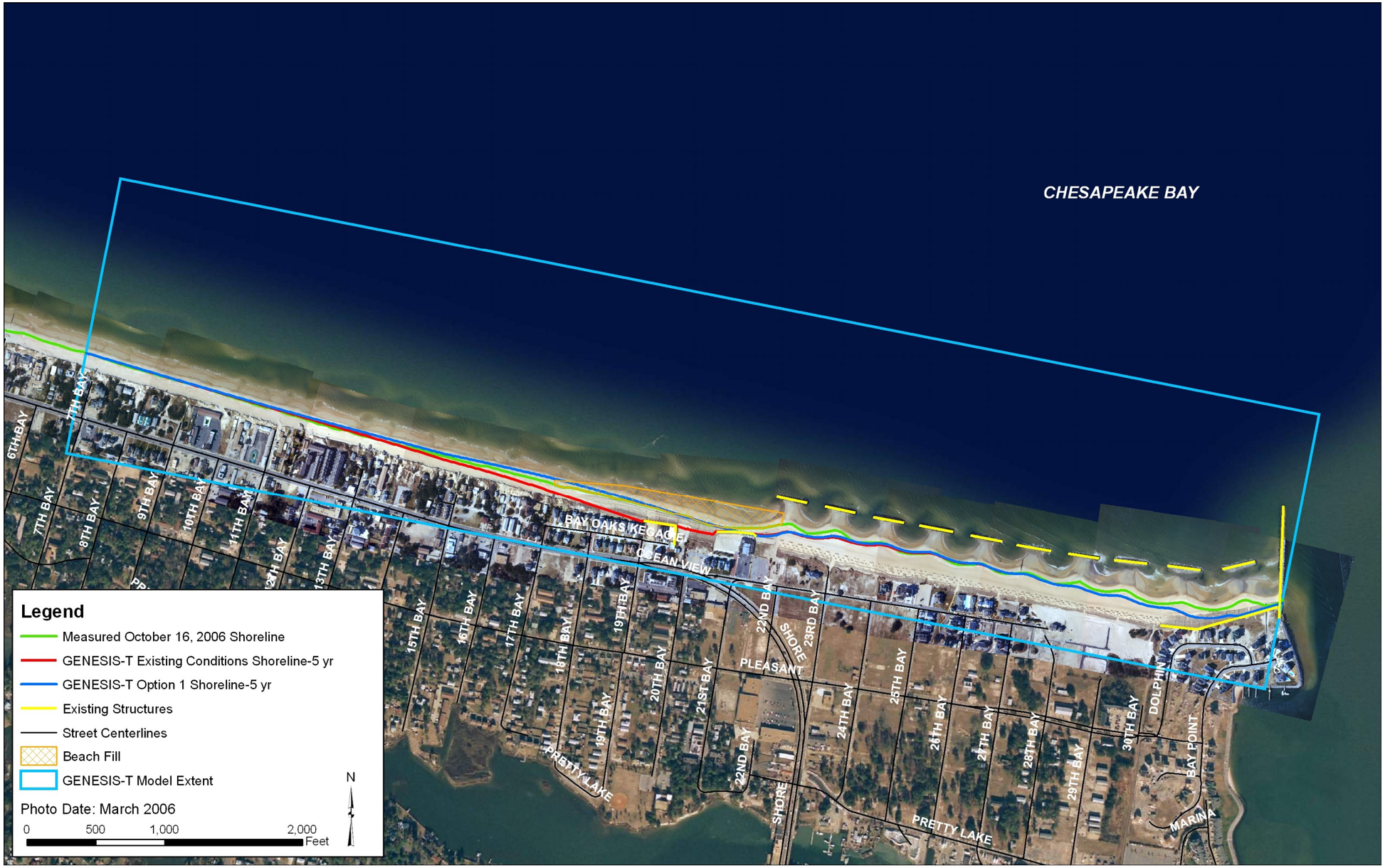

Figure VI-6 Option 1 GENESIS-T Model Results (Beach Fill Only)

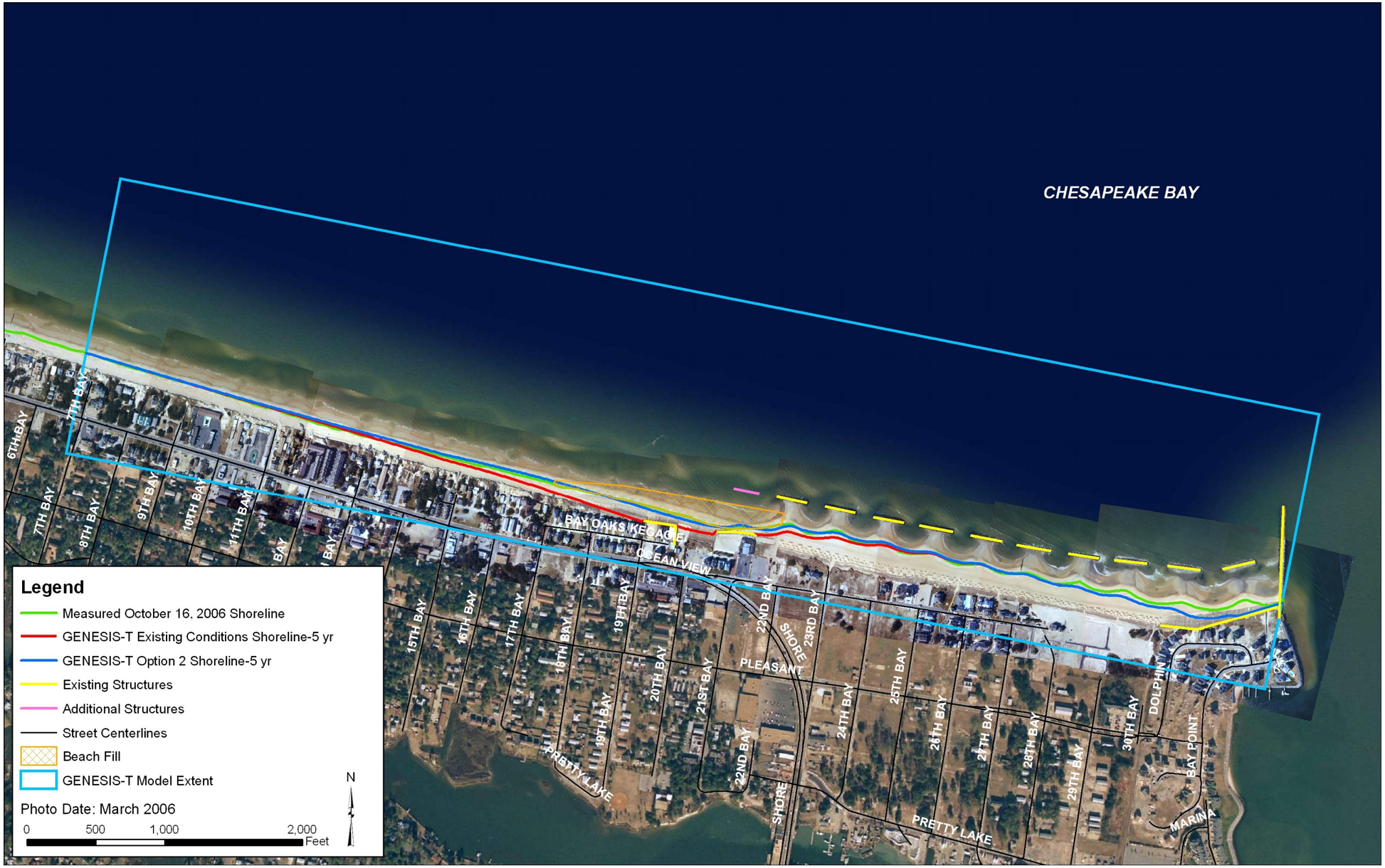

Figure VI-7 Option 2 GENESIS-T Model Results (1 Breakwater to Protect Hotspot w/ Beach Nourishment)

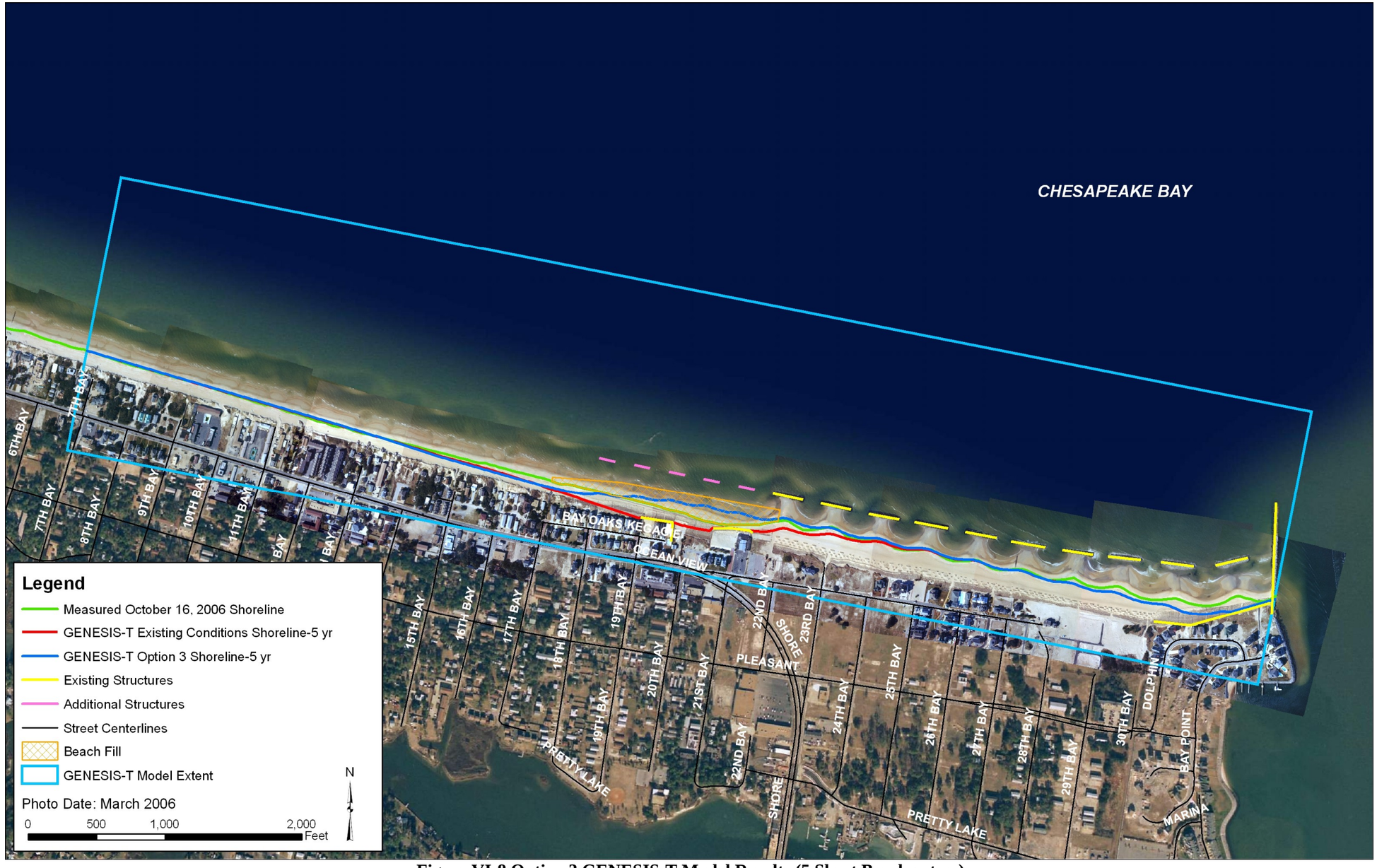

Figure VI-8 Option 3 GENESIS-T Model Results (5 Short Breakwaters)

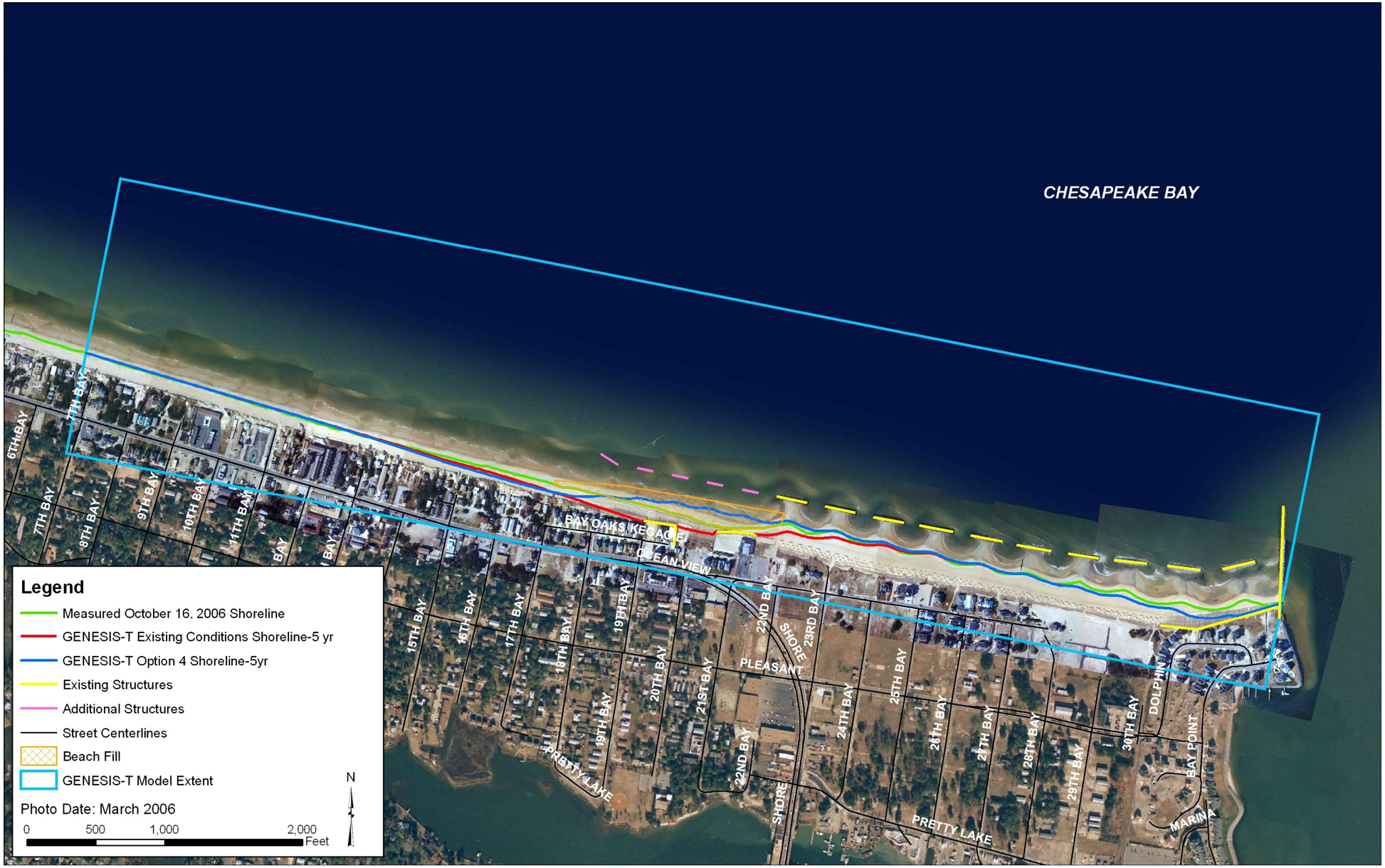

Figure VI-9 Option 4 GENESIS-T Model Results (5 Short Breakwaters w/ Angle)

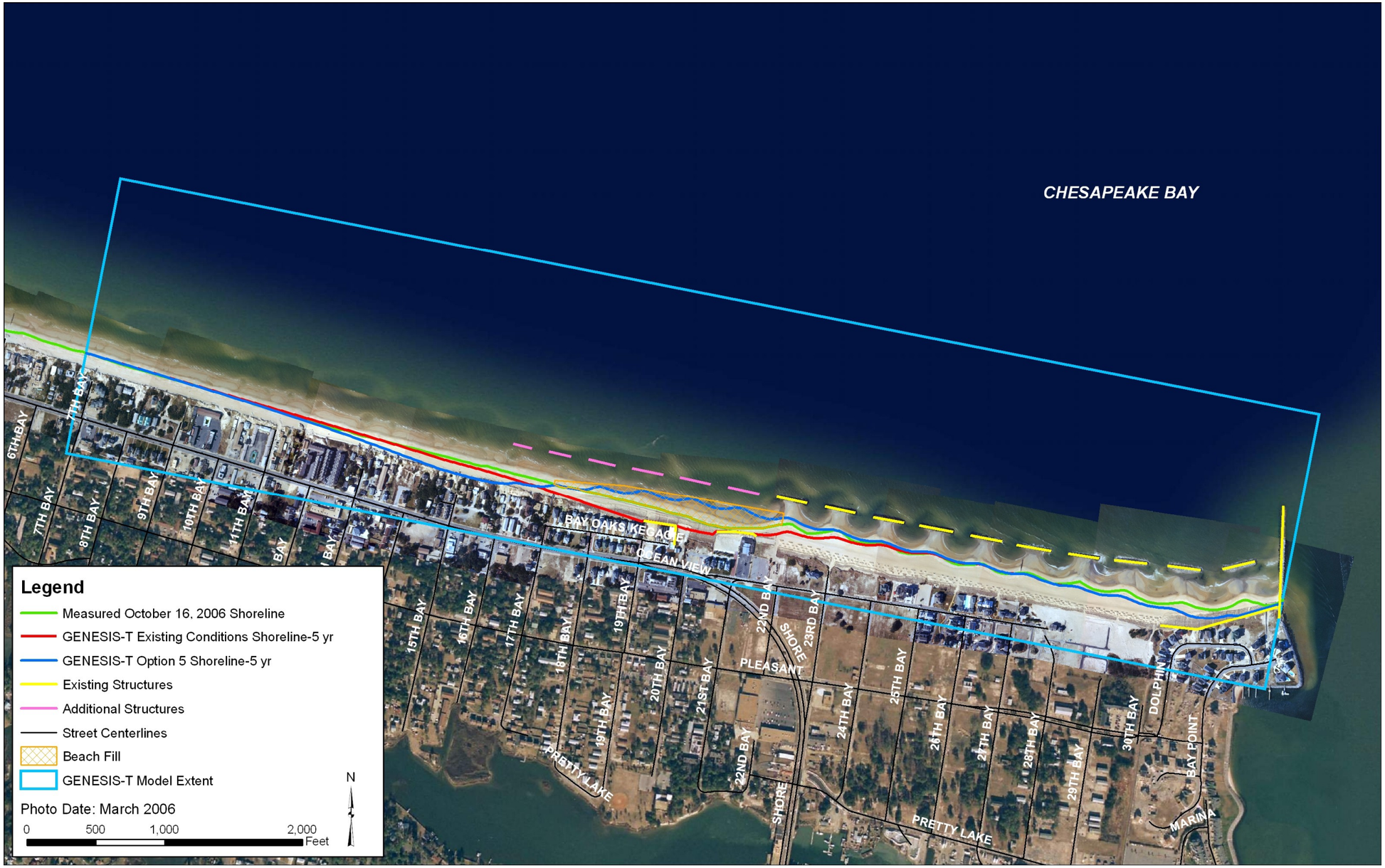

Figure VI-10 Option 5 GENESIS-T Model Results (6 Breakwaters)

G. OPINION OF PROBABLE COSTS FOR MODELED ALTERNATIVES

A preliminary opinion of probable costs was developed for each of the proposed alternatives and is presented in **Table VI-1**. Details of the preliminary opinions of probable costs are presented in **Appendix F**. The unit costs used in the opinions of probable cost were provided by local contractors familiar with constructing these types of projects. Please note that the unit cost utilized for beach nourishment does assume that this project will be part of a larger project utilizing a hopper dredge.

Table VI-1 Opinions of Probable Costs for Modeled Alternatives

OPTION	DESCRIPTION	PROBABLE COST
1	Beach Nourishment Only	$1,590,000
2	Add 1 190' Breakwater w/ Beach Nourishment	$1,960,000
3	Add 5 120' Breakwaters w/ Beach Nourishment	$2,670,000
4	Add 5 Breakwaters (4 @ 120', 1 @ 150' Angled) w/ Beach Nourishment	$2,710,000
5	Add 6 Breakwaters (3 @ 230', 1 @ 200', 1 @ 170', 1 @ 140') w/ Beach Nourishment	$3,560,000

H. SELECTION OF PREFERRED ALTERNATIVE

Option 3 was selected as the preferred alternative for further analysis in DELFT3D based on GENESIS-T modeling results and a comparison of probable costs. The existing breakwater field was lengthened by 5 breakwaters with lengths of 120 ft and gaps of 140 ft. Beach nourishment was included from the end of the existing breakwater field to 17th Bay St. **Figure VI-11** shows the proposed structural configuration for this option and the resulting predicted shoreline position after 5 years. For comparison, the existing conditions shoreline is also shown for a 5 year simulation. The GENESIS-T modeling results revealed that this option provided the smoothest transition from the existing breakwater field to the unprotected shoreline. **In addition, the zone of influence of the alternative predicted by the model ended at approximately 17th Bay St, avoiding the creation of problems outside the apparent historical zone of influence of the original jetty construction**. The opinion of probable cost for this option is $2,670,000. The option was also modeled in DELFT3D as will be discussed in the following **Section VII**.

At the request of the City of Norfolk, the selected alternative was also run in two different phases with the beach nourishment occurring first and then the structures being placed one year later. The GENESIS-T model results from phasing of construction are presented in **Figure VI-12**. The shoreline 1 year after nourishment, before any structures are constructed, and the shoreline 4 years after construction of structures (5 years after beginning of alternative construction) are both presented. The phasing causes a slight setback of approximately 15 ft in the shoreline between 18th Bay St. and 16th Bay St as compared to the model results for when the beach nourishment and breakwater construction were performed at the same time. This can be seen in **Figure VI-13**. Other than this area, the phased alternative performs nearly identically to the unphased alternative. Of course the risk of placing the beach nourishment without the breakwaters is that a large storm may occur resulting in greater than average erosion.

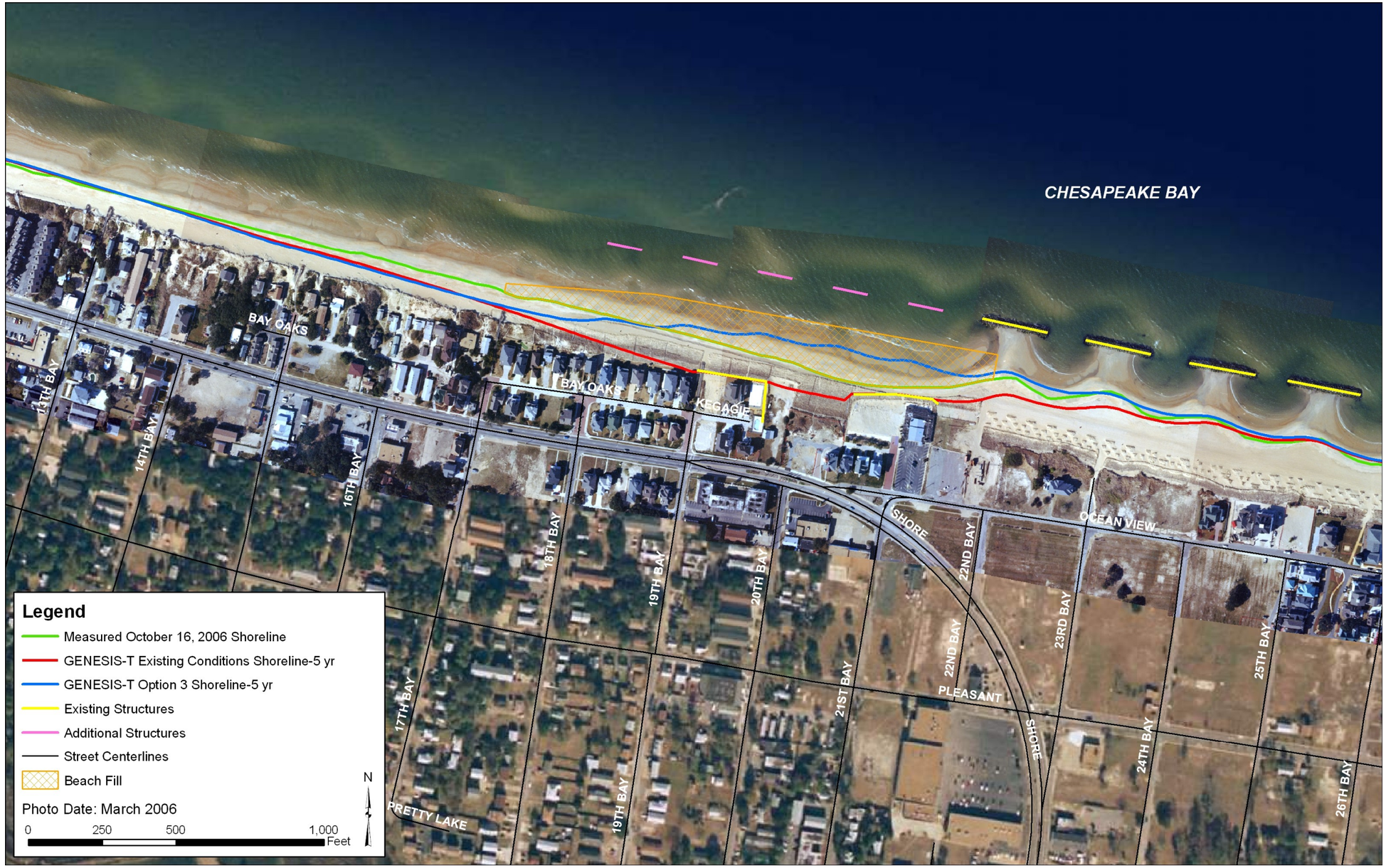

Figure VI-11 GENESIS-T Model Results for Preferred Alternative (Option 3)

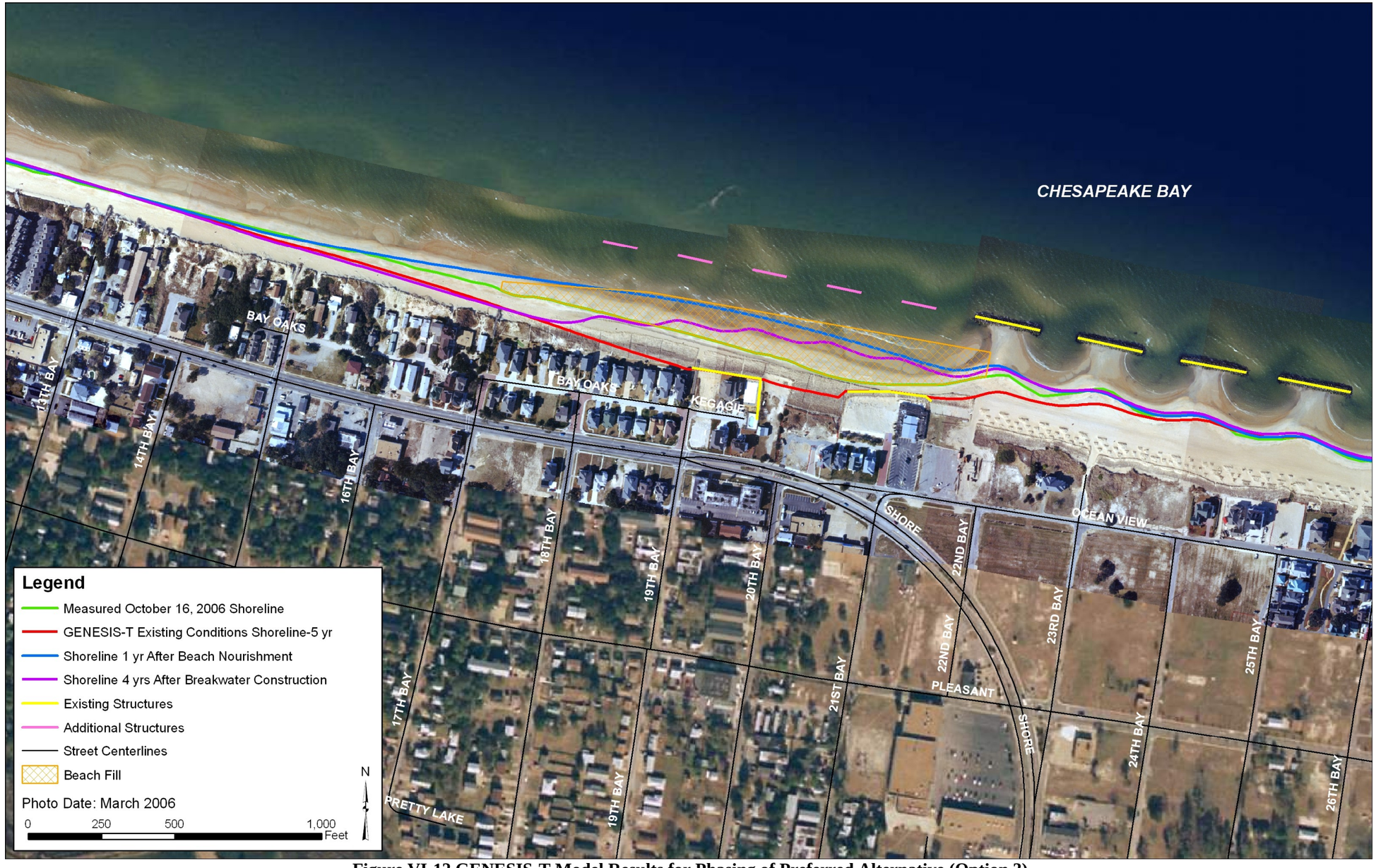

Figure VI-12 GENESIS-T Model Results for Phasing of Preferred Alternative (Option 3)

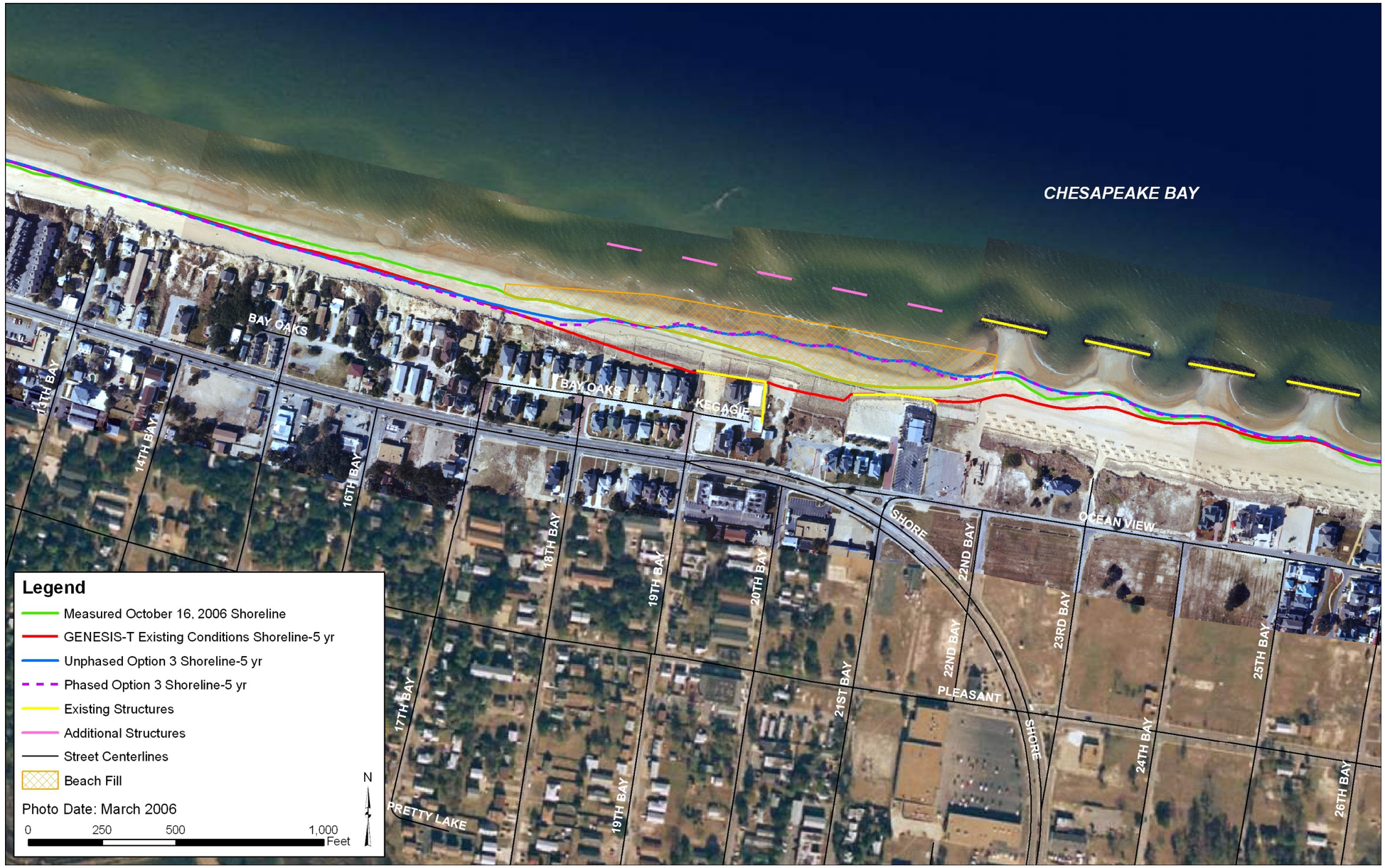

Figure VI-13 Phased and Unphased Shoreline Comparison for Preferred Alternative (Option 3)

VII. MODELING OF COASTAL PROCESSES WITH DELFT3D

This section describes the development of a suite of models and a simulation approach used to examine coastal processes (i.e., hydrodynamics, waves, sediment transport, and morphological changes) under existing, pre-construction (2006), and future with project conditions for the selected design alternative presented previously.

It should be noted that while the Delft3D model cannot specifically simulate a long-term time series of waves and water levels, it can be used to assess and compare the relative performance of various alternatives under representative hydrodynamic conditions. The Delft3D modeling system is a good complement to a long-term one-dimensional shoreline simulation model.

A. OVERVIEW OF THE DELFT3D MODELING SYSTEM

Modeling of coastal processes for this part of the study was performed using the Delft3D modeling system. Delft3D is an integrated surface water modeling system developed by WL|Delft Hydraulics in the Netherlands. The system is based on a flexible framework which simulates two- and three-dimensional flow, waves, water quality, ecology, sediment transport and bottom morphology and the interactions between those processes. The package gives direct access to state-of-the-art process knowledge, accumulated and developed at one of the world's oldest and most renowned hydraulic institutes. Delft3D consists of a number of well-tested and validated modules, which are linked to and integrated with one-another. Descriptions of the modules used in this study are provided in the following sections.

1. Hydrodynamics: Delft3D-FLOW

The hydrodynamic module Delft3D-FLOW simulates two-dimensional (2D, depth averaged) or three-dimensional (3D) unsteady flow and transport phenomena resulting from tidal and/or meteorological forcing, including the effect of density differences due to a non-uniform temperature and salinity distribution (density-driven flow). This model can be used to predict the flow in shallow seas, coastal areas, estuaries, lagoons, rivers and lakes. When the fluid is vertically homogeneous, a depth-averaged approach is appropriate. Delft3D-FLOW is able to run in two-dimensional mode (one computational layer), which corresponds to solving the depth-averaged equations.

Delft3D-FLOW's system of equations consists of the horizontal equations of motion, the continuity equation and the transport equations for conservative constituents. The equations are formulated in orthogonal curvilinear coordinates. The flow is forced by tide at the open boundaries, wind stress at the free surface, and pressure gradients due to free surface gradients (barotropic) or density gradients (baroclinic). Delft3D-FLOW solves the Navier Stokes equations for an incompressible fluid, under the shallow water and the Boussinesq assumptions.

2. Waves: SWAN Wave Model

The SWAN wave model, developed at Delft University of Technology in Netherlands, is based on the discrete spectral action balance equation and is fully spectral (in all directions and frequencies). The latter implies that short-crested random wave fields propagating simultaneously from widely different directions can be accommodated (e.g. a wind sea with super-imposed swell). SWAN computes the evolution of random, short-crested waves in coastal

regions with deep, intermediate and shallow water and ambient currents. The SWAN model accounts for (refractive) propagation due to current and depth and represents the processes of wave generation by wind, dissipation due to whitecapping, bottom friction and depth-induced wave breaking and non-linear wave-wave interactions explicitly with state-of-the-art formulations. The SWAN model has successfully been validated and verified in several laboratory and complex field cases (Ris et al., 1999).

The SWAN model also has a dynamic interaction with the flow module of Delft3D (i.e. two way wave-current interaction). By this the effect of waves on current (via forcing, enhanced turbulence and enhanced bed shear stress) and the effect of flow on waves (via set-up, current refraction and enhanced bottom friction) are accounted for if the SWAN model is applied within Delft3D.

3. Sediment Transport and Morphology: Delft3D-FLOW

Three-dimensional transport of suspended sediment is calculated in Delft3D by solving the three-dimensional advection-diffusion (mass-balance) equation for the suspended sediment. The local flow velocities and eddy diffusivities are based on the results of the hydrodynamic computations.

Delf3D computes the sediment transport and morphological changes at the hydrodynamic computational time-step. At each time-step, the change in the mass of bottom sediment that has occurred as a result of the sediment sink and source terms is calculated. This change in mass is then translated into a change in thickness of the bottom sediment layer using the density of the bed material. This change in thickness is equivalent to a change in bed elevation, which is applied to the depth values stored at computational points.

The hydrodynamic model implementation used in the sediment transport and morphology model includes the effects of the waves on both nearshore hydrodynamics (i.e., longshore currents and wave setup) and sediment transport (i.e., increased bottom shear stresses and turbulence). It should be noted, however, that the model does not include all of the physics affecting beach profile changes during storm conditions, such as the three-dimensional wave and hydrodynamic processes that generate undertow and offshore sand transport. Nonetheless, this model will provide additional insight into erosion and accretion patterns along Ocean View Beach in the Bay Oaks project area.

B. MODELING SCOPE AND APPROACH

In addition to the larger scale GENESIS-T modeling for the project, the Delft3D modeling system was used in order to provide insight into sediment transport patterns and morphological changes in area of influence of the East Ocean View Beach offshore structures.

Two hydrodynamic computational models were developed, namely: a large *regional* model of Chesapeake Bay and a *local* model. **Figure VII-1** shows the relative location of both models. The regional model was used to provide hydrodynamic boundary conditions to the local model which was used to simulate hydrodynamics as well as sediment transport and morphological processes at a higher resolution.

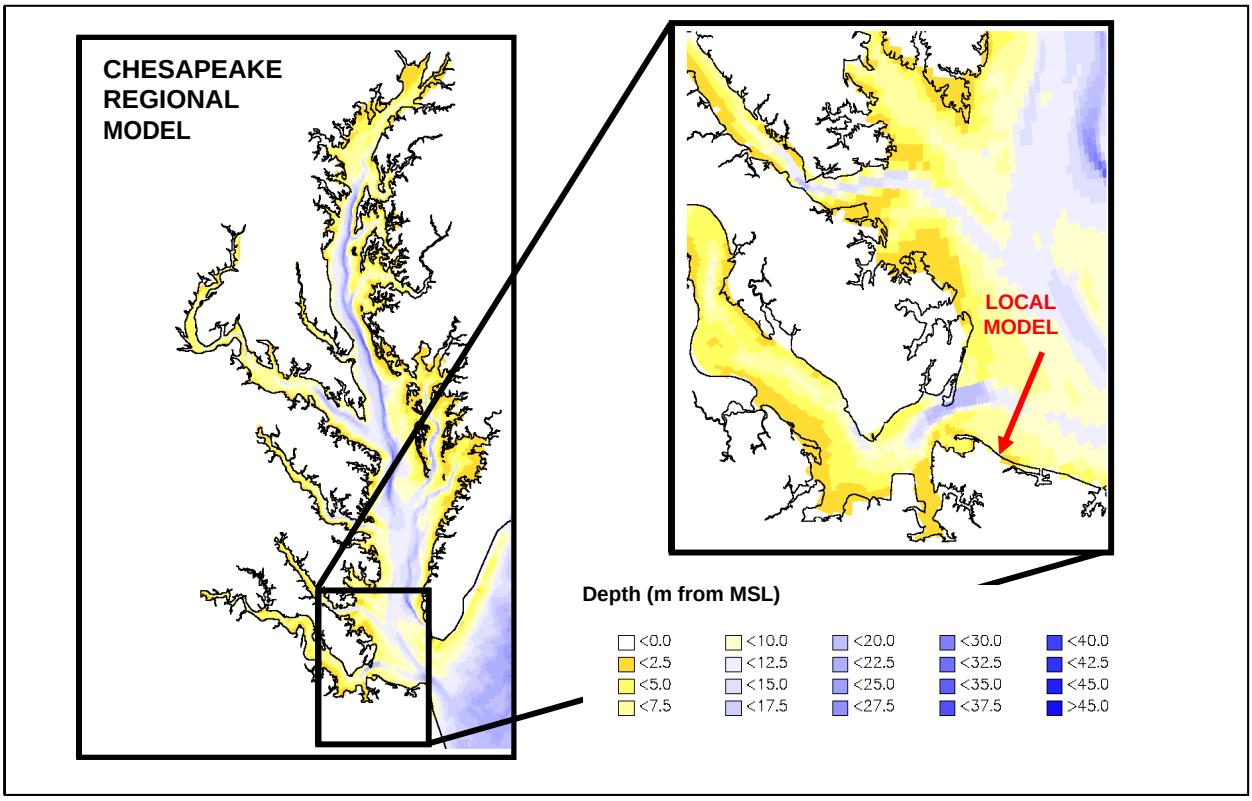

Figure VII-1 Relative Locations of Delft3D Regional and Local Models

It should be noted that while the Delft3D model cannot specifically simulate a long-term time series of waves and water levels due to the high computational demand associated with this type of simulations, it can be used to assess and compare the relative performance of various alternatives under representative wave/surge conditions. The Delft3D modeling system is a good complement to a long-term one-dimensional shoreline simulation model.

C. REGIONAL HYDRODYNAMICS

The Moffatt & Nichol 3D Hydrodynamic model of the Chesapeake Bay was used as the regional model. This model was used in 2D mode to create time series of boundary conditions for the local morphological model of Ocean View Beach. The Chesapeake Bay model extends in the north from the entrance of the C&D canal on the Elk River approximately 200 miles south to the Chesapeake Bay bridge tunnel and then approximately further 100 miles offshore into the Atlantic Ocean. The model is built on a curvilinear computational grid. Over 23,000 computational grid points define the entire model. The grid resolution is variable throughout the model domain. The highest resolution is found at the offshore boundary throat: 11 km grid spacing along the axis of the shoreline and 3.5 km spacing cross shore.

Regional model bathymetry was developed using NOAA data, particularly the NOS estuarine bathymetry for the bay area and the National Geophysical Data Center's GEODAS data sets. These data sources are integrated within the Delft3D modeling system by interpolating the values into the model grid using triangular interpolation. In areas of overlap, the most recent

data was used. **Figure VII-1** presents the regional model bathymetry derived from the above sources.

Open boundaries to the model were defined at two locations – at the southern offshore boundary and at the northern most location at the junction of the Elk River with the C&D canal. The offshore boundary is defined as time series of water surface elevations. These time series were constructed from nine major tidal constituents extracted from the *Eastcoast 2001* database of tidal elevation and velocity constituents (Mukai et al, 2002). This database was developed to allow surface-water elevation and currents to be quickly and easily defined in open waters within the Western North Atlantic Tidal (WNAT) domain. The northern most boundary location of the model is where the C&D canal joins the Elk River at Welch point. Current velocity time series based on NOAA constituents were applied at the boundary. In addition, the major contributions of fresh water into the system are also included. These contributions include the Susquehanna River, Potomac River, and James River.

Simulated and observed water levels and currents were compared at various locations within the bay. Locations were selected so as to assess the model performance to the maximum possible spatial extent. All the calibration data were obtained from NOAA/NOS predictions. After the model calibration, it was concluded that the regional model performs well for both water level and current predictions.

D. LOCAL MORPHOLOGICAL MODEL

Modeling of nearshore hydrodynamics, waves, sediment transport and morphology requires a grid with a relatively fine resolution. The regional grid used for modeling of regional hydrodynamics and waves is not well-suited for this task because increasing resolution in such a large grid would require extremely long simulation times. Therefore, a local high-resolution grid was developed to resolve these nearshore coastal processes in the vicinity of Ocean View Beach.

Figure VII-2 and **Figure VII-3** present the local grid and bathymetry, respectively. The grid extends approximately 6700 feet from east to west; 1500 feet north to south. The offshore boundary is located in a water depth of 20 feet. The grid sizes range from 13 feet at the breakwater field to 150 feet near the offshore open boundary. A total of over 12,000 computational points comprise the local grid. The regional grid was used to drive the local grid during model simulations.

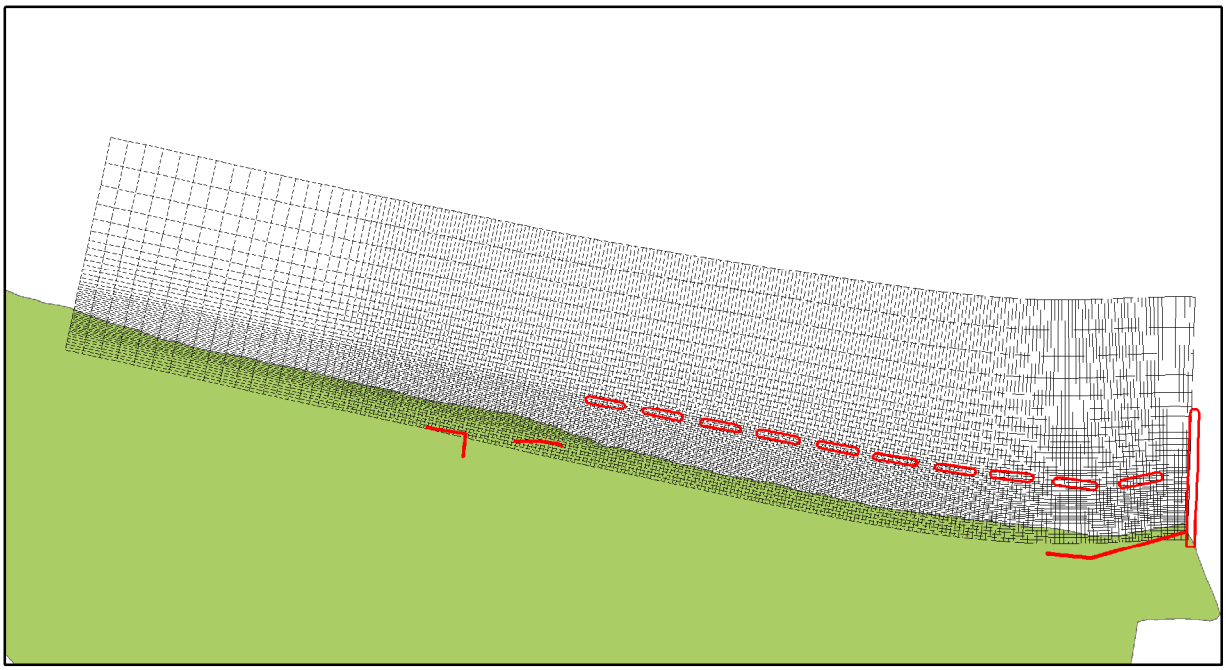

Figure VII-2 Delft3D Local Model Grid and Extent

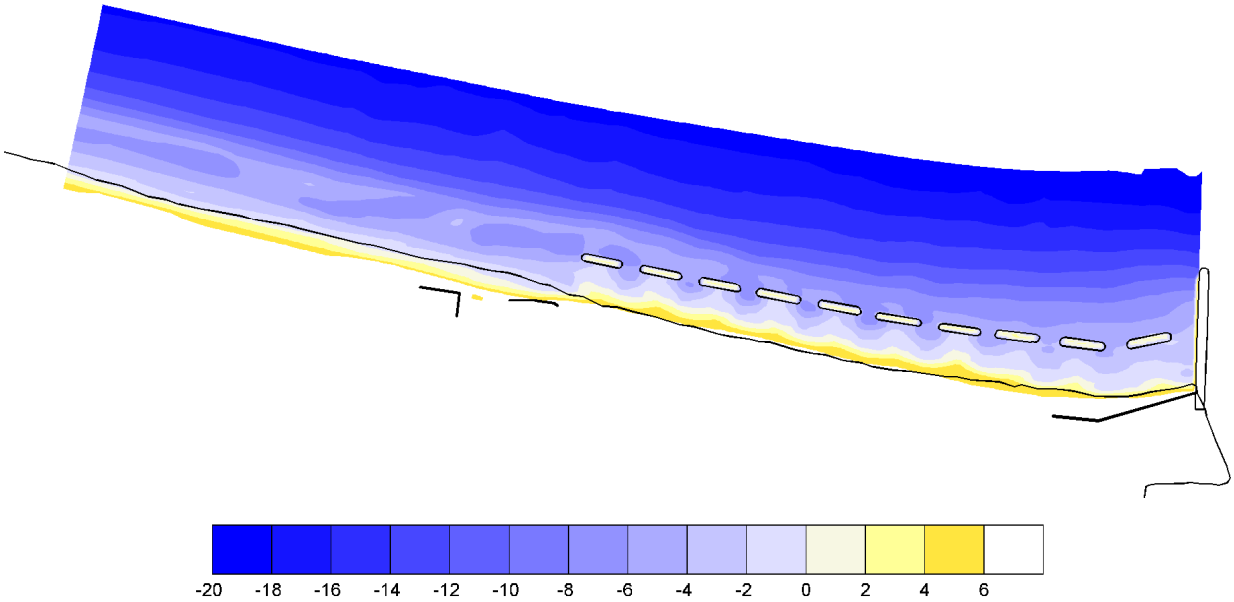

Figure VII-3 Delft3D Local Model Bathymetry, March 2006 (ft NAVD88)

For this application of the Delft3D sediment transport and morphology model, a constant grain size representing the average for the study area was applied throughout the domain: D_{50}=0.38 mm. This value is based on the median grain size of samples from the project site. Sand was modeled with a specific density of 2650 kg/m^3 and a dry bed density of 1600 kg/m^3. Boundary conditions are only required at the open boundaries. Separate boundary conditions are required for suspended and bed load transport. For the suspended sediment transport, the boundary condition

during inflow is defined as a concentration equal to equilibrium concentration, and during outflow it is equal to upstream concentration. For the bed load transport, a bed level condition is imposed where the bed level remains constant at the boundary segment.

The Delft3D morphological model integrates the effects of waves, currents and sediment transport on morphological developments. The different processes (hydrodynamics, waves, sediment transport and morphology) are coupled via a bottom evolution model based on sediment conservation, and therefore, the flow fields are always calculated using the latest updated bathymetry. Hence, a local wave model must be developed so that the effects of the waves may be incorporated in the morphological model. The local wave model grid used in SWAN is based on the grid presented in **Figure VII-2** but extended further to the east and to the west. When the incoming wave direction is not perpendicular to the offshore boundary, the wave solution computed by SWAN near the lateral boundaries is not correct, due to the lost of energy through the boundary. Because the wave grid extends further to the east and west than the hydrodynamic model grid, the solution of the wave model is correct throughout the whole hydrodynamic model extent.

E. SIMULATED SCENARIOS

The local Delft3D model was run for two structural configurations.

- Existing Conditions: This scenario is based on the existing structural configuration.
- Alternative 1: This alternative represents the best solution obtained from all the alternatives tested using GENESIS-T (**Section VI.H**).

The local model bathymetry was developed using beach profiles collected during March 2006. In addition, a bathymetry using measured beach profiles from November 2006 was also developed to estimate the morphological changes that occurred during the period March-October 2006. The breakwater structures were defined in the model according to their geometry.

F. LOCAL MODEL VALIDATION

The morphological model performance was validated for the period of available bathymetric information (profiles collected in March and October 2006). Because detailed modeling over large space and time scales requires excessively long simulation times, wave and water level data must be schematized. This approach reduces computational intensity by selecting a limited number of representative hydrodynamic conditions to use as input to the morphological model. During the March-October 2006 period only a limited number of events with significant wave heights higher than 4 ft were observed in the project area. Because sediment transport and consequently morphological changes during periods with small waves are very small, simulating the most significant events only, could lead to a very similar morphological changes than if the whole period is simulated. Therefore, a four day simulation with an offshore wave with a significant wave height of 5.2 ft, a 5.1 second period and a 45 degree direction (average wave conditions during storms) would generate similar morphological changes to those observed during the March-October 2006 period. In addition a 1.87 ft surge was added to the tidal forcing to represent the observed surge during storm conditions during this period. It is not expected that

this simplified wave condition will represent all the observed morphological features but it should be able to reproduce the main erosion/deposition patterns of the system. **Figure VII-4** presents the model results from the previously mentioned simulation and the observed erosion/deposition patterns based on the measured profiles. The model is not able to reproduce the erosion and deposition of the bar at the same location because of the unique surge value specified in the model, while the real value varies during the storm. It can be observed that the area with the largest erosion down drift of the last breakwater, took place during storms with higher surge than the simulated, since the erosion occurred at the 3 to 8 ft contours. However, the model can represent the bar displacement (areas of erosion deposition parallel to the shore) and also the erosion/ deposition patterns west of the last breakwater though the amount of erosion of the shoreline is less than the observed. Note, that Delft3D does not include all the processes that affect profile evolution.

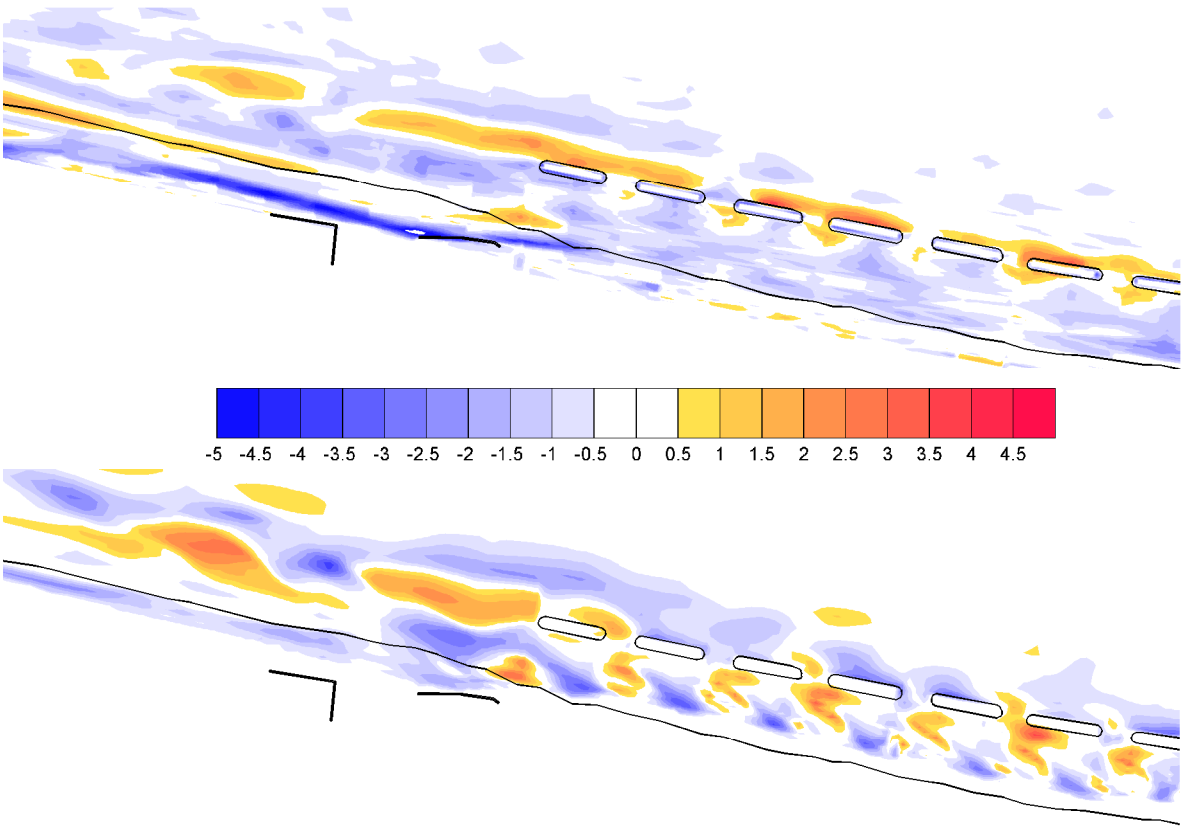

Figure VII-4 Measured and Simulated Bathymetric Changes (in ft) March to October 2006 Surge 1.84 ft – Tide Range MHW to MLW

G. SIMULATION OF THE OCTOBER 2006 NOR'EASTER

Between the data collection of the two beach profiles that took place in 2006, measured wave data was also collected. Within this period (March to November) a very large nor'easter storm was observed in October. **Figure VII-5** shows the significant wave height, peak period and mean direction observed during the event. During the peak of the storm, significant wave height was in the order of 5 feet and the waves were coming from the northeast (45 degrees from

North). After the storm, significant wave height was generally smaller than 1 ft. In addition, **Figure VII-6** presents the predicted tides, surge and total water levels near the project area, used as local model boundary conditions. During the peak of the storm, surge was in the order of 3.5 feet, and the total water level reached values near 5 feet.

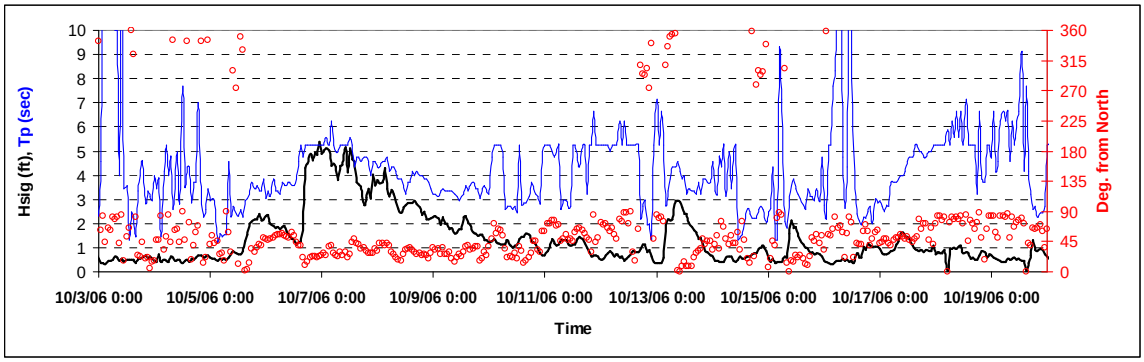

Figure VII-5 Boundary Wave Conditions for the Nor'easter Simulation

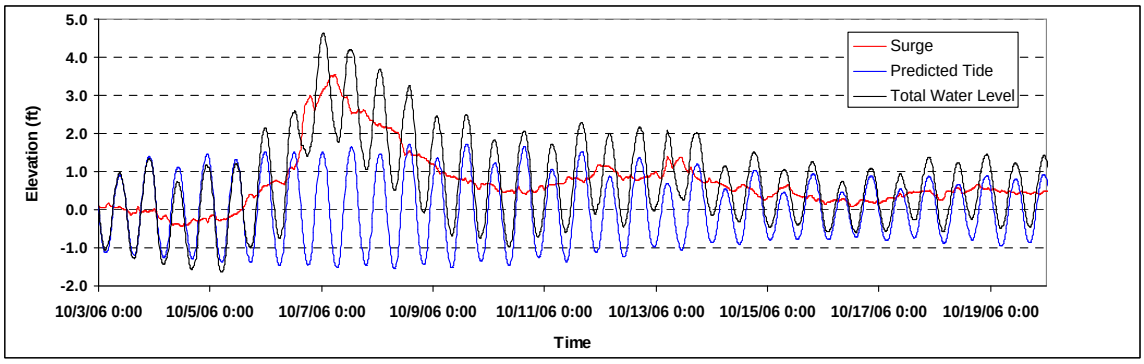

Figure VII-6 Water Level Boundary Conditions for the Nor'easter Simulation

H. EXISTING CONDITIONS AND PREFERRED ALTERNATIVE SIMULATION

The 10/03/06 – 10/20/06 period which includes the October 2006 Nor'easter was simulated with the existing breakwater configuration and also with the preferred alternative. Hydrodynamic and wave boundary conditions are presented in **Figure VII-5** and **Figure VII-6.**

Initial model bathymetry was created using the profile information collected in March 2006. **Figure VII-7** and **Figure VII-8** show the initial model bathymetry for the existing and preferred alternative breakwater configuration. Model results indicated that morphological changes during the simulated period take place mainly during the storm, when wave conditions are stronger. Changes after 10/11/06 are very small, since the significant wave height during that period rarely exceeds 1 ft, therefore model results are presented only after the storm, and results at the end of the simulation are omitted.

Simulation results of the October 2006 Nor'easter under existing conditions are presented in **Figure VII-9** and **Figure VII-10**. **Figure VII-9** shows the post-storm bathymetry and **Figure VII-10** presents the morphological changes that were simulated during the storm. It is observed in the figures an area of significant erosion downdrift of the westernmost breakwater and some

areas of shoreline erosion west of the breakwater field. **Figure VII-11** and **Figure VII-12** present the simulation results for the preferred alternative, Option 3. Results indicate that in the area protected by the new breakwaters, erosion of the shoreline is significantly reduced. On the other hand, the area downdrift of the westernmost structure of Option 3 presents a similar behavior as the one observed at the end of the breakwater field under existing conditions, i.e. erosion near the structure and shoreline erosion to the west. However, it is observed by comparing **Figure VII-10** to **Figure VII-12** that the erosion at the hot spot downdrift of the westernmost structure is smaller for the case of Option 3, indicating a better transition from the last breakwater to the unprotected shoreline.

In order to analyze the performance of the breakwaters under existing conditions and with Option 3 removing any possible influence of the existing variability along the shore of the selected initial conditions (March 2006), an ideal bathymetry with a constant profile everywhere in the project domain was developed. **Figure VII-13** and **Figure VII-14** show this initial bathymetry for existing conditions and Option 3, respectively. Post storm bathymetry and morphological changes caused by the storm are presented in **Figure VII-15** and **Figure VII-16** for the existing conditions case and in **Figure VII-17** and **Figure VII-18** for Option 3. Results from these simulations indicate that for Option 3, erosion of the shoreline west of the last breakwater is slightly less than for existing conditions and that the erosion at the hot spot downdrift of the westernmost structure is significantly smaller than for existing conditions. Finally simulation results also indicate that there is less accumulation of sand behind the last breakwaters for Option 3 which could indicate that the transition from Option 3 to the shoreline is smoother than the transition from the existing conditions structures.

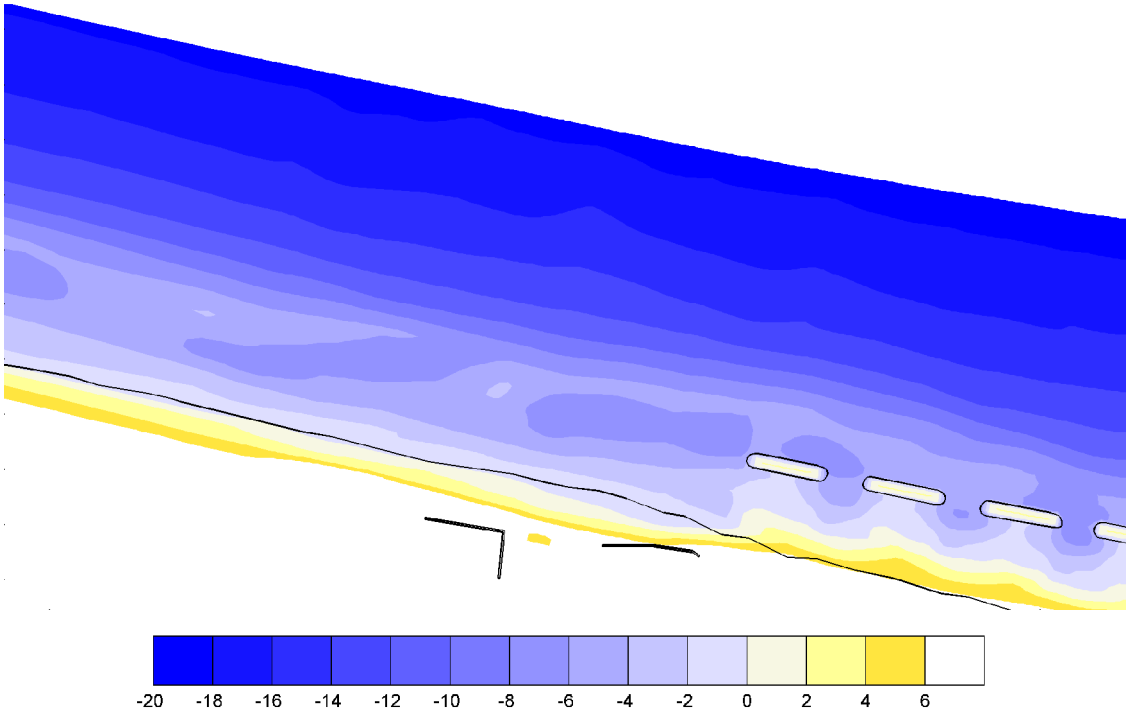

Figure VII-7 Initial Model Bathymetry (March 2006), Existing Conditions Simulation (values in ft from MSL)

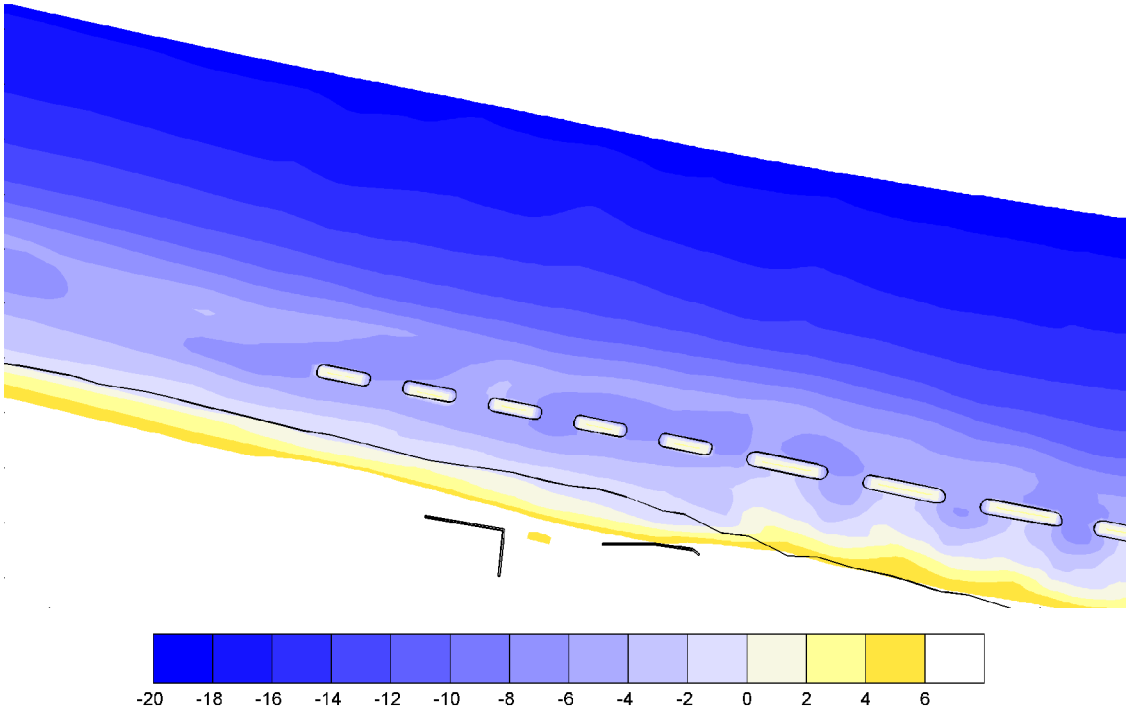

Figure VII-8 Initial Model Bathymetry (March 2006), Option 3 Simulation (values in ft from MSL)

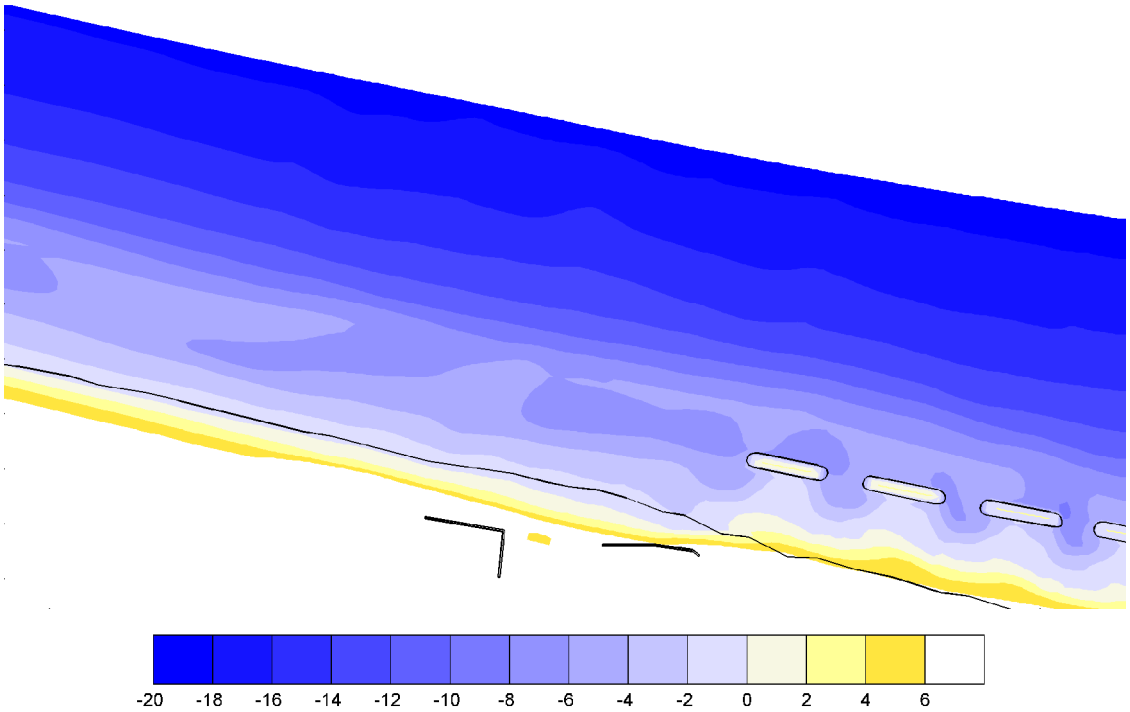

Figure VII-9 Post Storm Bathymetry for Existing Conditions Simulation (10/11/2006) (values in ft from MSL)

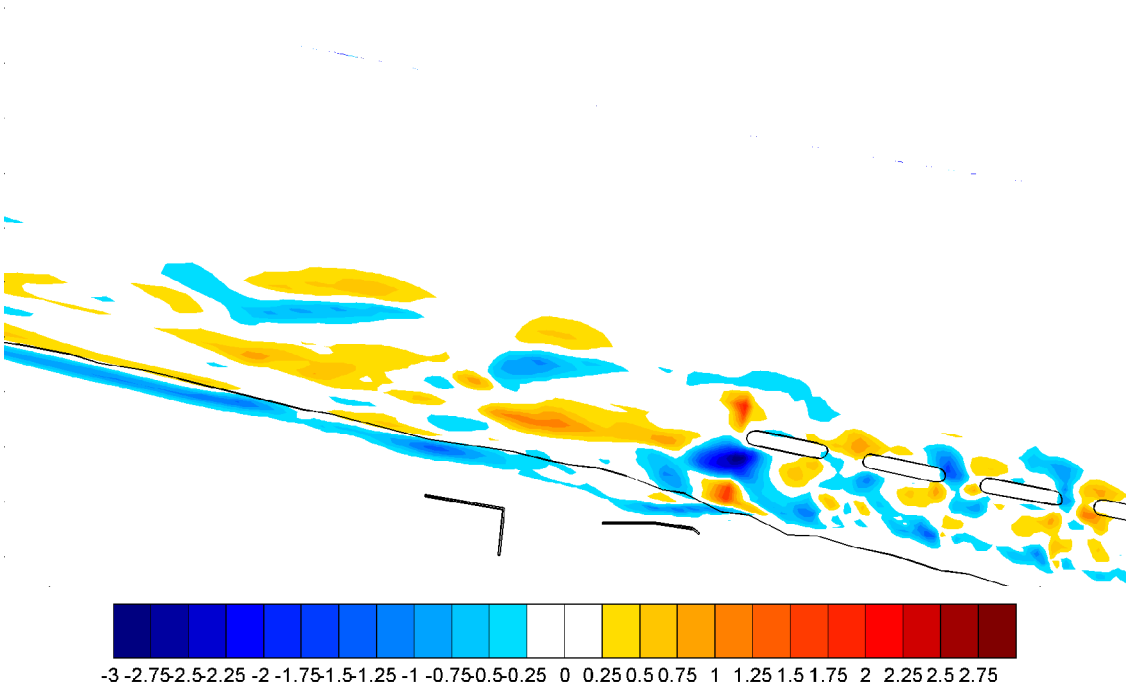

Figure VII-10 Post Storm Morphological Changes (in ft) for Existing Conditions Simulation (10/11/2006)

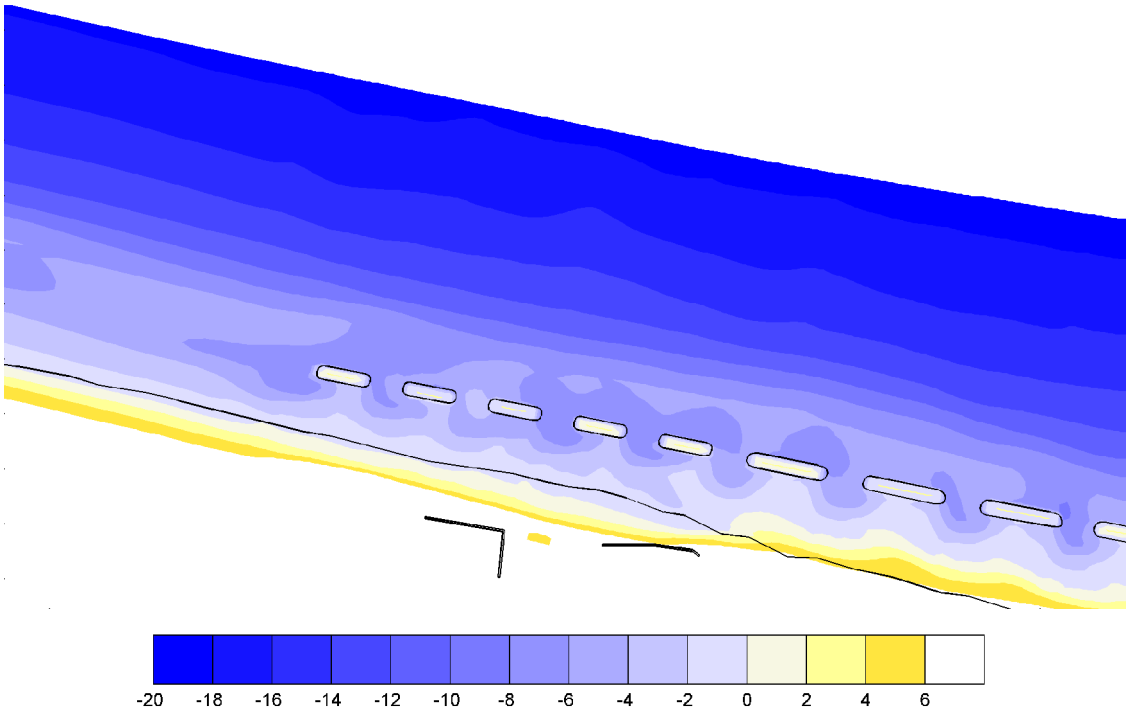

Figure VII-11 Post Storm Bathymetry for Option 3 Simulation (10/11/2006) (values in ft from MSL)

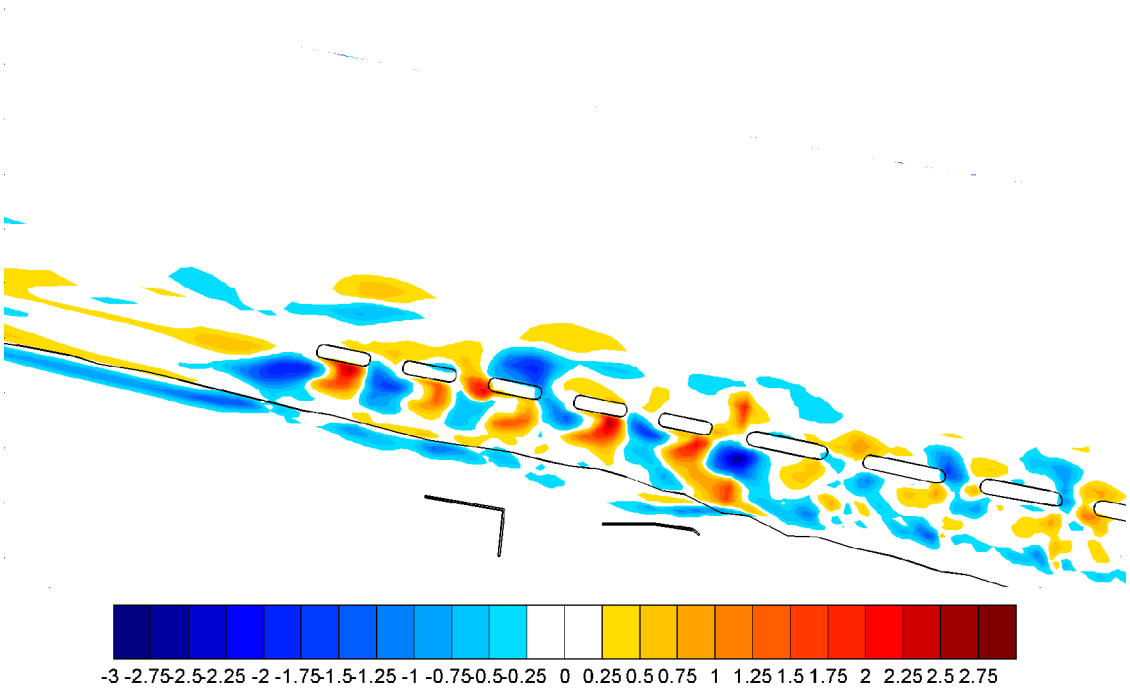

Figure VII-12 Post Storm Morphological Changes (in ft) for Option 3 Simulation (10/11/2006)

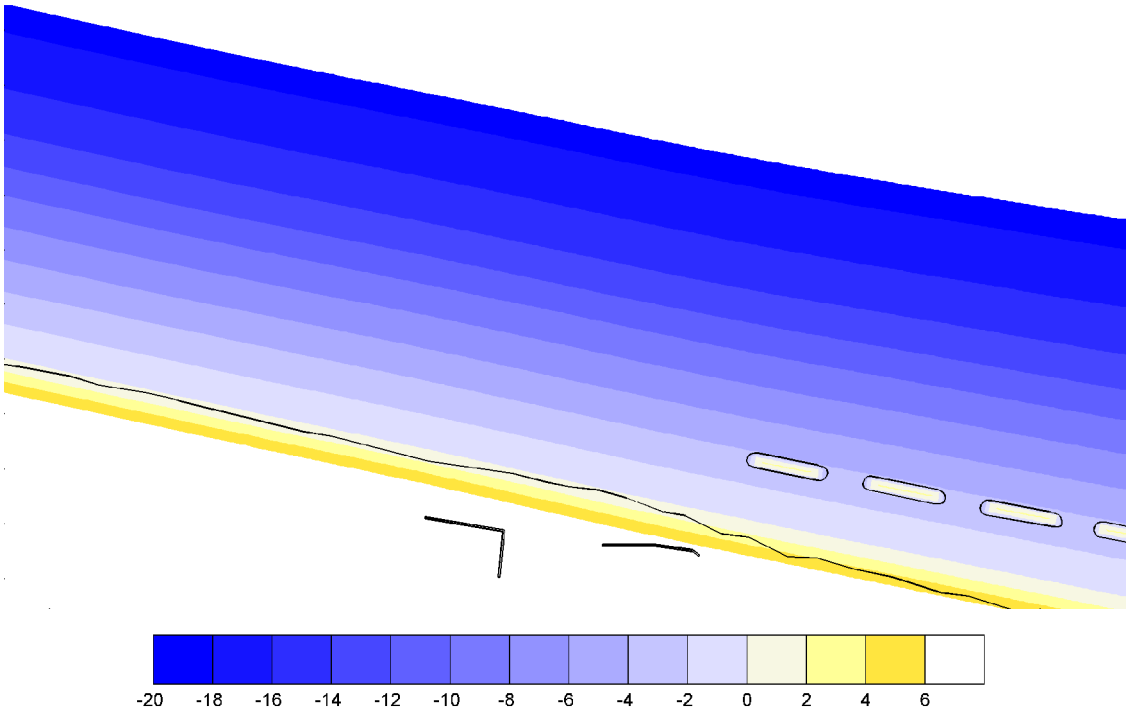

Figure VII-13 Initial Model Bathymetry Based on a Constant Profile. Existing Conditions Simulation (values in ft from MSL)

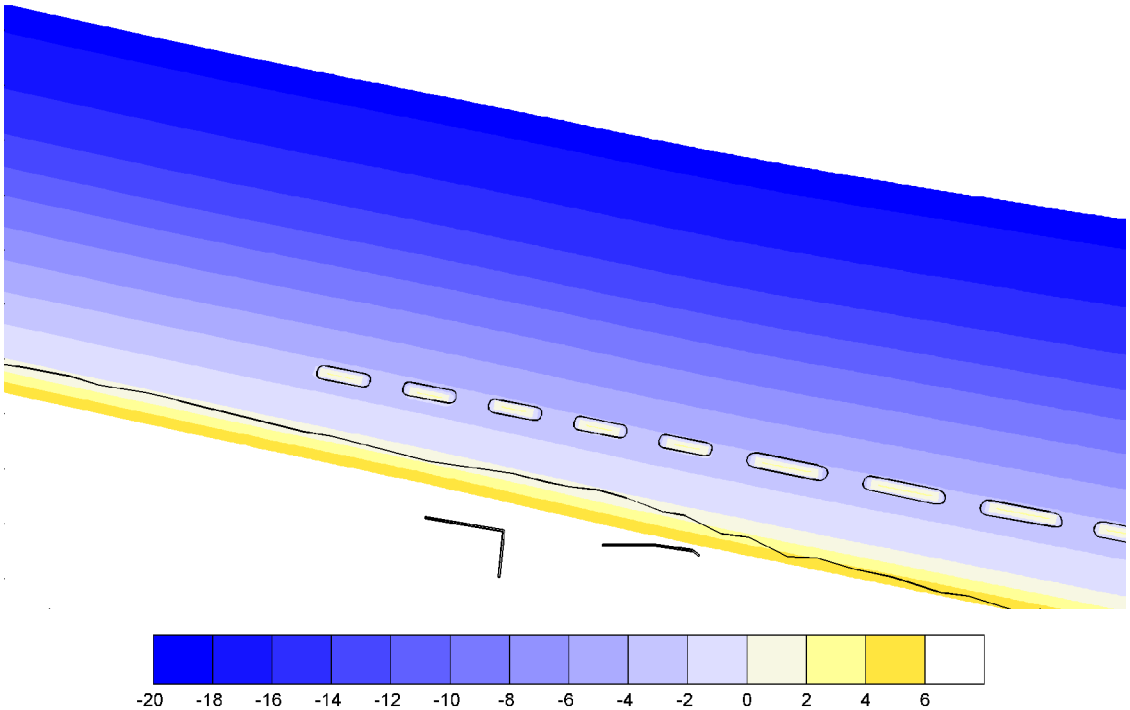

Figure VII-14 Initial Model Bathymetry Based on a Constant Profile. Option 3 Simulation (values in ft from MSL)

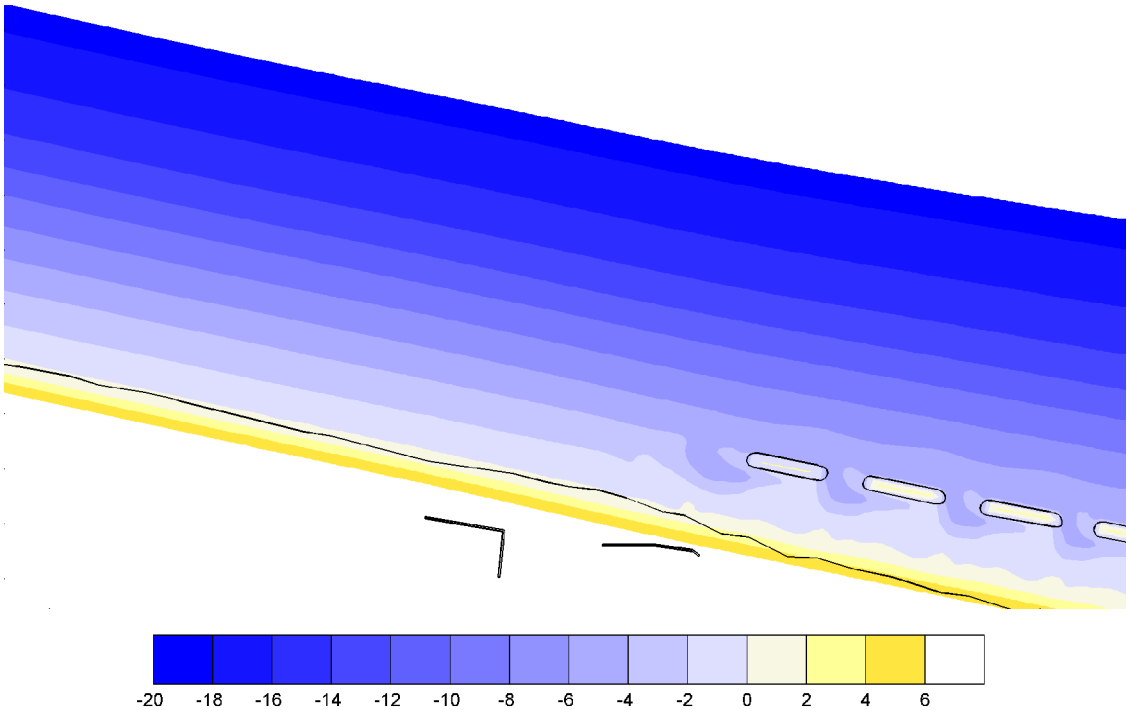

Figure VII-15 Post Storm Bathymetry for Existing Conditions Simulation (10/11/2006) From a Constant Profile Bathymetry (values in ft from MSL)

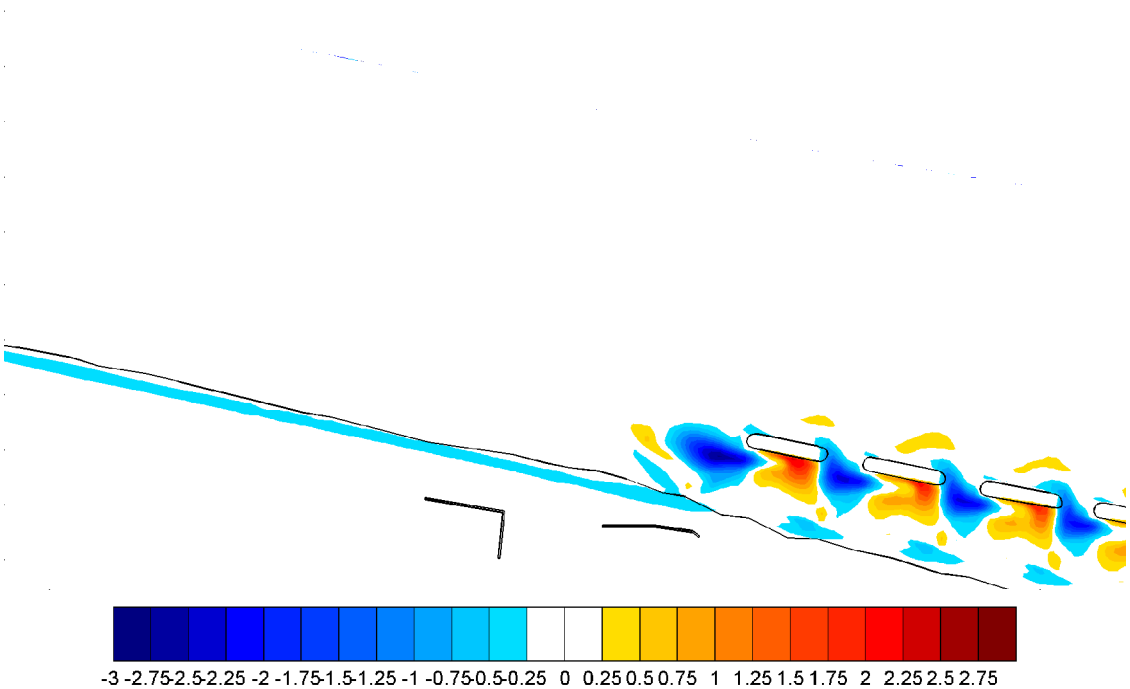

Figure VII-16 Post Storm Morphological Changes (in ft) for Existing Conditions Simulation (10/11/2006) From a Constant Profile Bathymetry

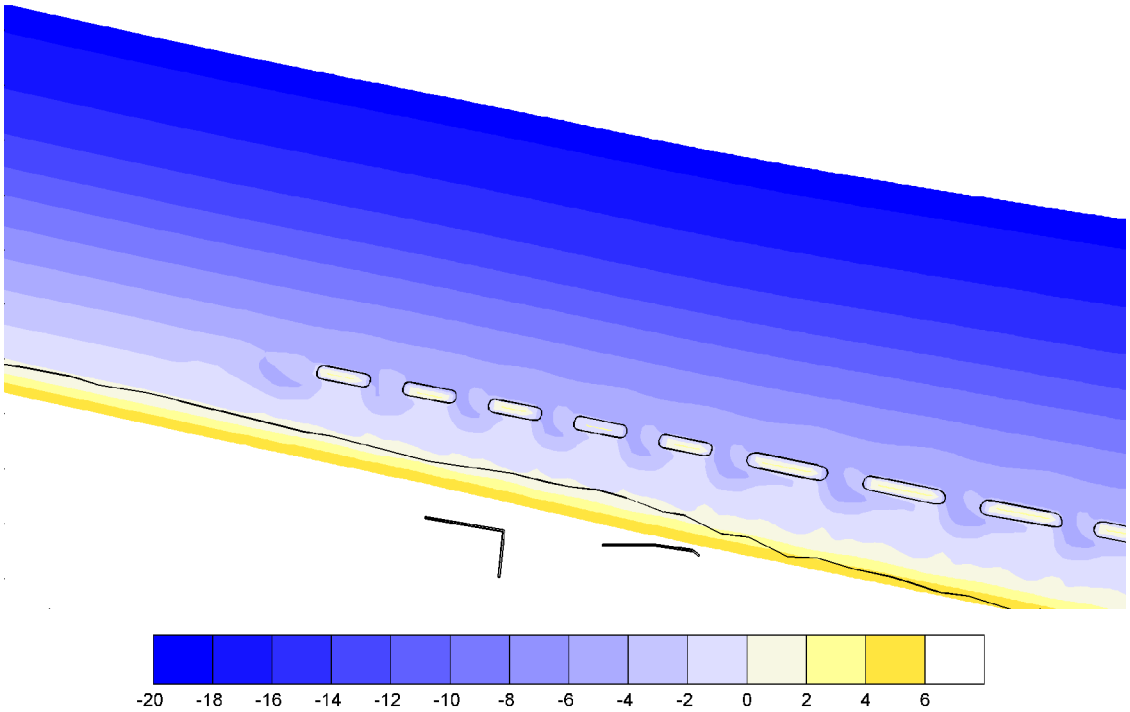

Figure VII-17 Post Storm Bathymetry for Option 3 Simulation (10/11/2006) From a Constant Profile Bathymetry (values in ft from MSL)

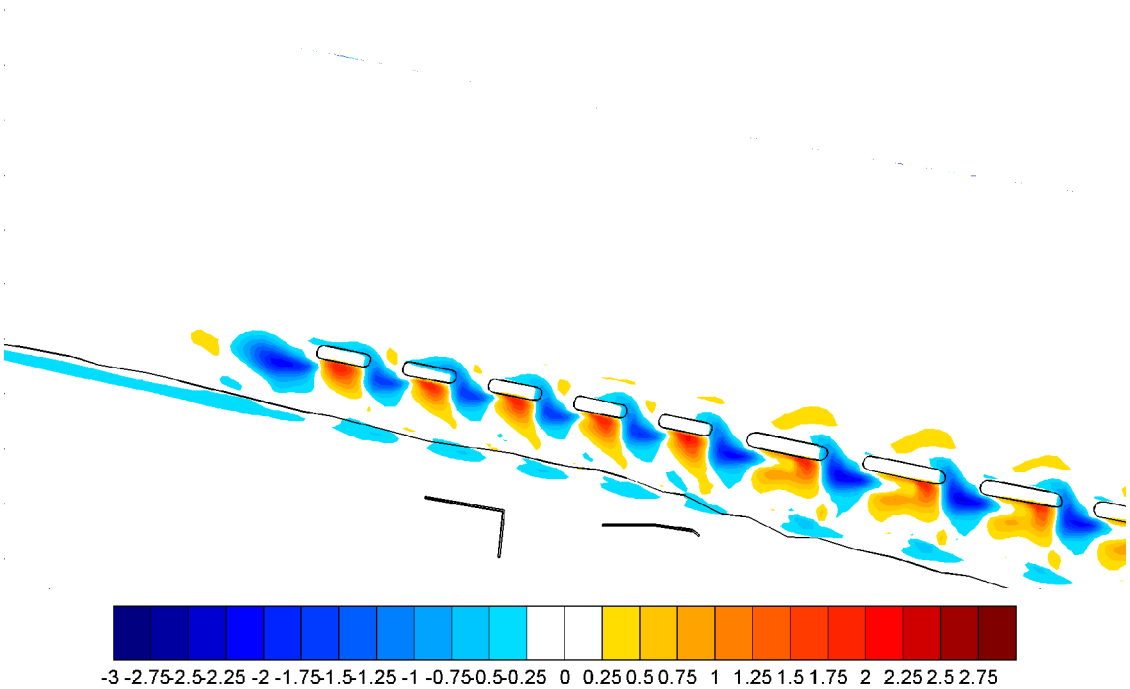

Figure VII-18 Post Storm Morphological Changes (in ft) for Option 3 Simulation (10/11/2006) From a Constant Profile Bathymetry

VIII. STUDY FINDINGS & RECOMMENDATIONS

This study involved an extensive review of historical data and engineering activities along the Ocean View shoreline and the Bay Oaks region in particular. The Bay Oaks erosion hotspot, between 17th Bay St. and 22nd Bay St., and shoreline behavior in the region was investigated to develop a solution to mitigate the hotspot and improve sediment transport patterns. In recent years, numerous shoreline protection projects consisting of beach nourishment and the construction of offshore breakwaters have been completed in the region to reduce erosion along the East Ocean View shoreline. However, an erosion hotspot has developed at the western end of the current breakwater field depleting the beach and threatening bayfront structures and property along the shoreline.

Historical aerial photography, digitized shorelines, beach transect surveys, available sediment sampling data, and measured wave data were examined to aid in the determination of the erosion hot spot behavior and in modeling of potential alternatives. Extensive GENESIS-T shoreline change modeling was performed for the existing conditions and dozens of potential alternatives and variations to determine a preferred alternative.

Analysis of the historical and recent shoreline change indicates that sediment supply to the west of the existing breakwater field is restricted resulting in erosion at Bay Oaks. The Bay Oaks shoreline is downdrift of the dominant sediment transport direction – east to west. The erosion is therefore likely due to a combination of the jetty construction which blocks sediment and the construction of the existing breakwaters. The East Ocean View area experienced considerable erosion after the jetty was built and before the breakwaters were constructed. The breakwaters act to retain part of the East Ocean View beach in their lee but also as a consequence reduce the sediment moving along the shore from the east toward the Bay Oaks region further interrupting longshore sediment transport. Since the breakwater construction, the erosion hotspot moved west to its present location at Bay Oaks with a current erosion rate of approximately 22 ft/yr.

The main goals in developing alternatives were to eliminate or minimize the hotspot at Bay Oaks while improving the transition from the existing breakwater field to a more uniform shoreline response minimizing impacts to the downdrift shoreline. The basic alternatives examined were to keep existing conditions, add beach nourishment, add additional breakwaters or some combination of structures and beach nourishment.

Erosion typically occurs in the immediate area downdrift of structures. The primary objectives of an offshore breakwater system are to increase the longevity of a nourished beach, provide a wider beach for recreation and provide protection to upland areas from waves and flooding. It is important to seek to minimize negative impacts of structures on the downdrift shoreline by allowing some movement of longshore transport through the project area. The resulting shoreline configuration depends on the sediment size, supply, and transport, beach slope, wave climate, currents, tidal range and breakwater configuration (length, gap, distance from shore, depth). These parameters were all modeled during this study.

The GENESIS-T model configuration and runtime allows comparison of various cases simulating years of shoreline change whereas the Delft3D model requires high computational times and is not suitable to testing a large number of scenarios. Numerous alternatives were modeled with GENESIS-T and the results compared based on the goals of reducing the erosion hotspot, improving the shoreline transition, cost, and maintaining the shoreline aesthetic.

GENESIS-T model results indicate that an improved overall transition of the shoreline from the west end of the current breakwater field across the Bay Oaks hotspot can be achieved but not the total elimination of erosion. GENESIS-T model simulations show the shoreline retreating to the position of the seawall and revetments in the Bay Oaks region after approximately 5 years. Initial and periodic beach nourishment will still be required as part of an ongoing solution to restore and maintain the beach. The amount and frequency of this nourishment can be reduced by stabilizing the shoreline with offshore breakwaters, reducing the wave climate and associated sediment erosion.

Based on the GENESIS-T model results, Option 3 is the recommended alternative for the Bay Oaks erosion hotspot. The proposed preferred alternative seeks to balance the need to protect the hotspot, improve the transition from the breakwater field to the unprotected beach, and the desire to minimize impacts to the region of the shore west of 17th Bay Street, which historically appears relatively stable. It must be noted, however, that given the configuration of the shoreline and the littoral system, erosion at the edge of the breakwater system cannot be entirely eliminated. The existence of the jetty and current structures reduces the sediment supply available along the beach immediately adjacent. The use of a series of 5 shorter breakwaters with relatively larger spacing is intended to smooth the transition from the existing breakwaters while maintaining improved beach width along Bay Oaks and at the same time allowing more wave energy to penetrate and move sand along the shore. The length of shoreline covered by the 5 additional breakwaters was chosen to end the modeled transition at 17th Bay Street merging with the more historically stable shoreline. This option also provides an equivalent beach width along the region west of the existing breakwater field.

The DELFT3D model results further verify the expected erosion and accretion patterns. These patterns indicate that while erosion will continue and end effect erosion west of the breakwaters added in the alternative still exists, the transition of the shoreline is improved and any beach nourishment along Bay Oaks is better retained.

The addition of shorter breakwaters with relatively larger gaps at the western end of the existing East Ocean View breakwater field were modeled showing an improved transition in the shoreline and together with beach nourishment can successfully restore the Bay Oaks beach. The use of offshore segmented breakwaters, inline with the current structures will also maintain the current aesthetic of the shoreline.

IX. REFERENCES

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APPENDIX A

Historical Survey Data Coverage

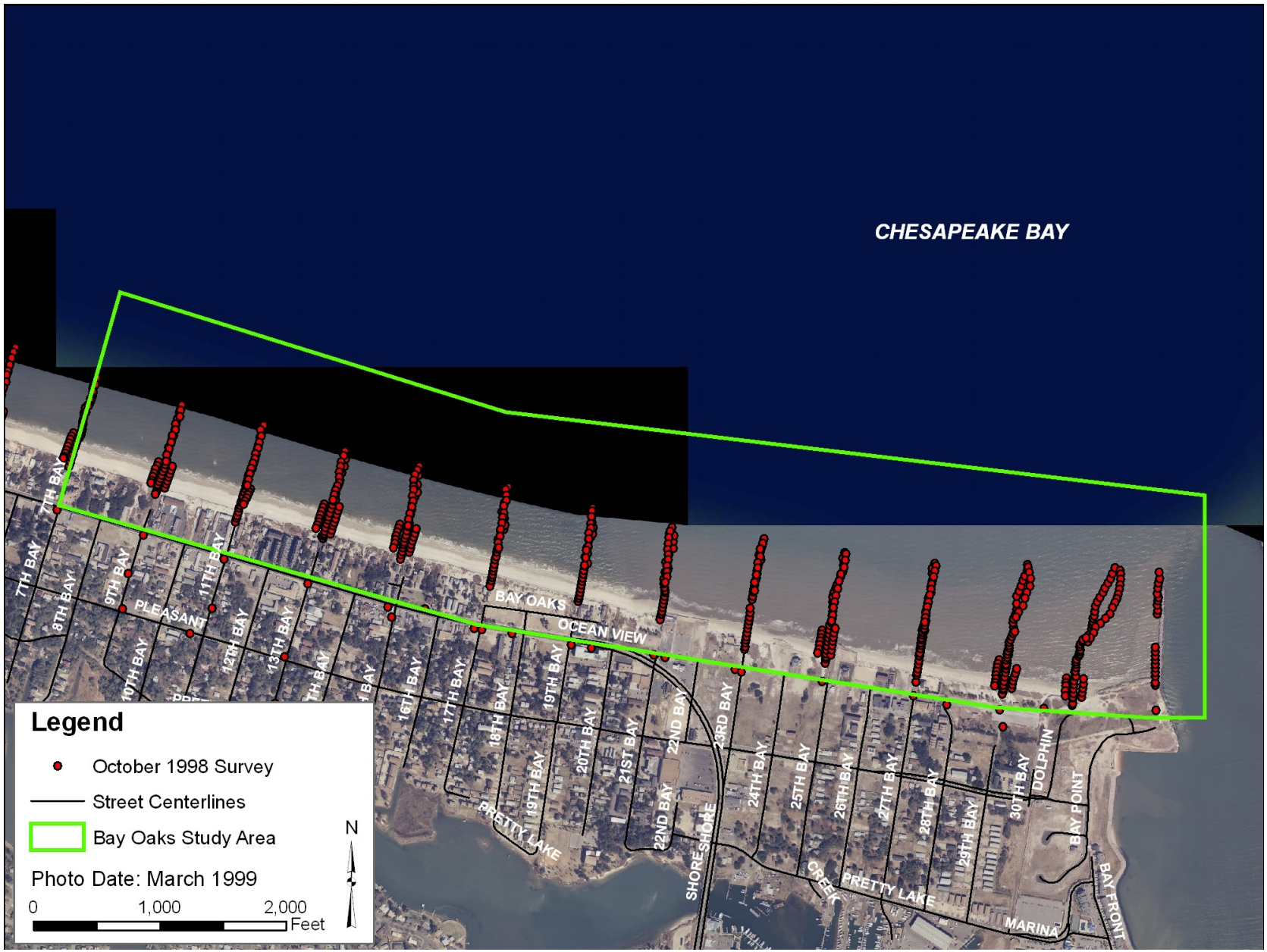


Figure A-1. October 1998 Survey Coverage

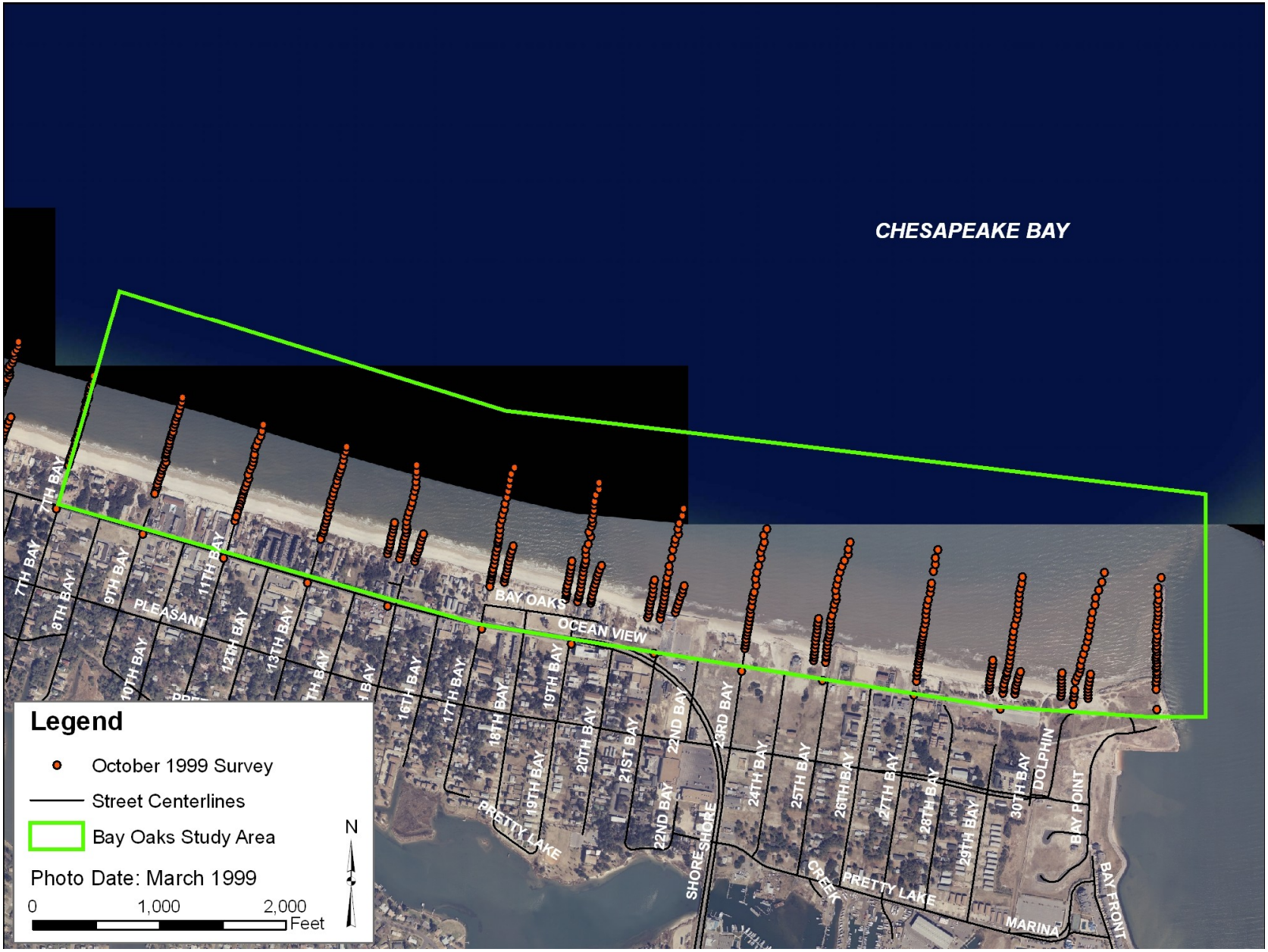


Figure A-2. October 1999 Survey Coverage

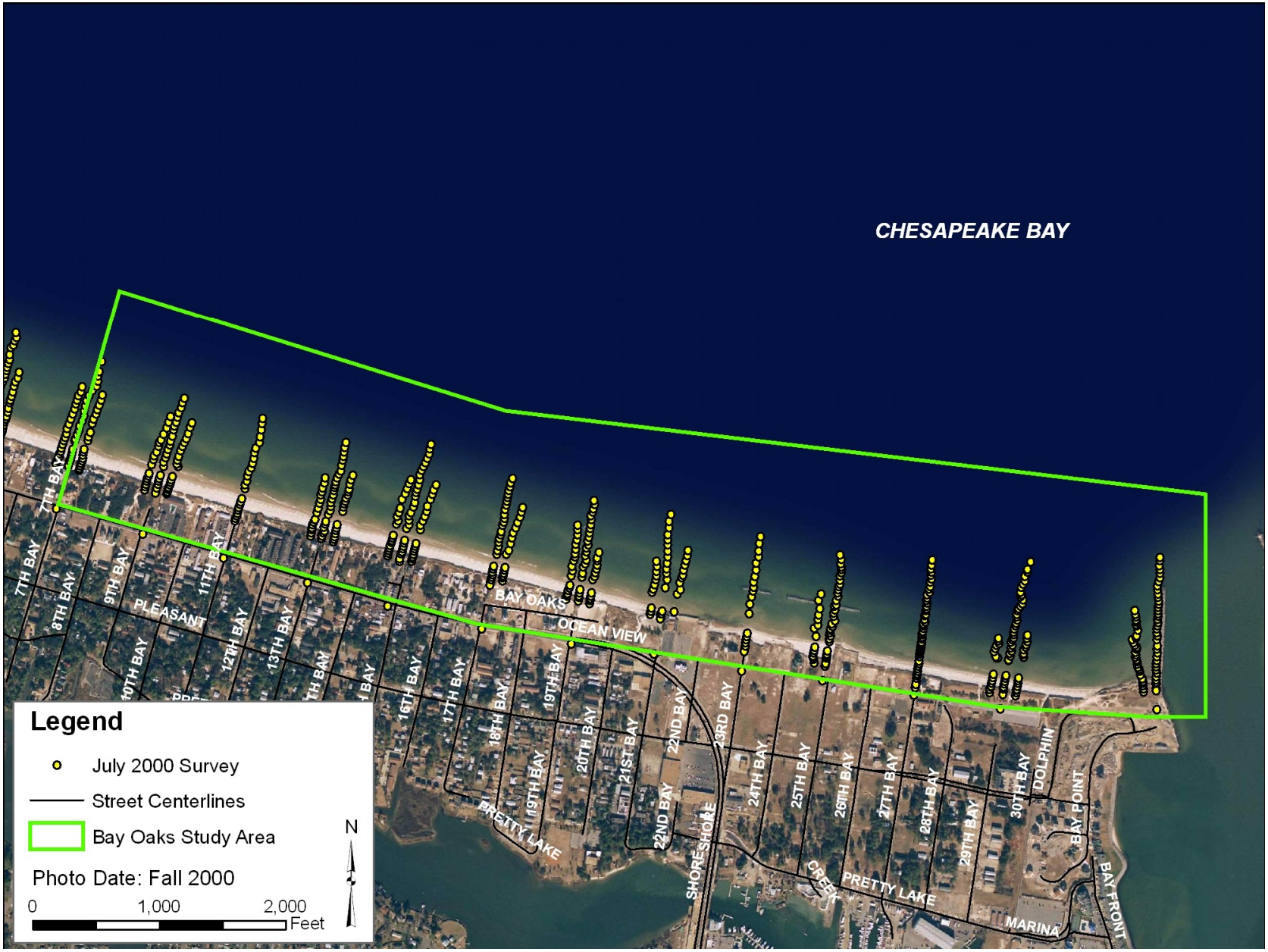


Figure A-3. July 2000 Survey Coverage

Figure A-4. October 2000 Survey Coverage

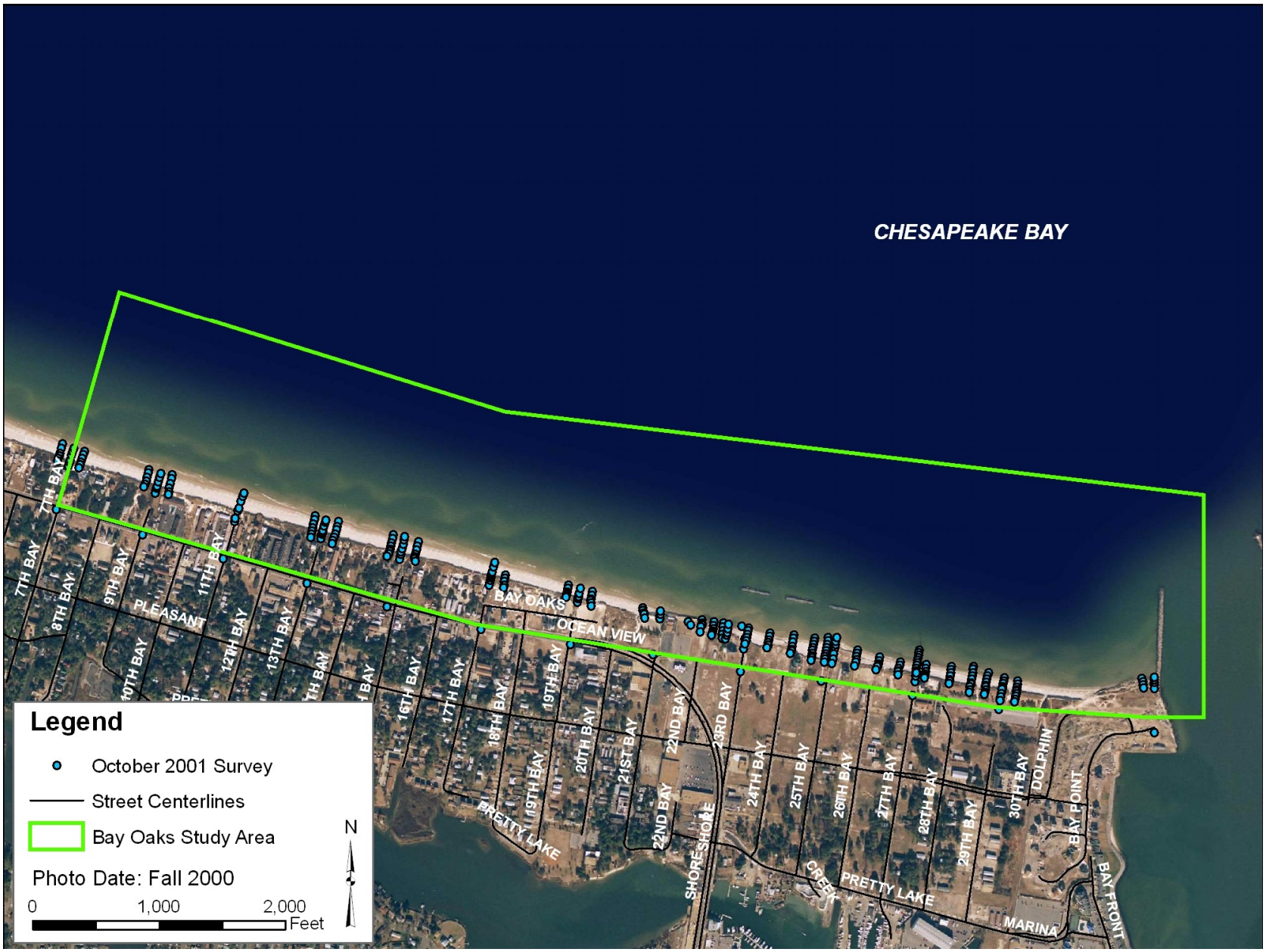


Figure A-5. October 2001 Survey Coverage

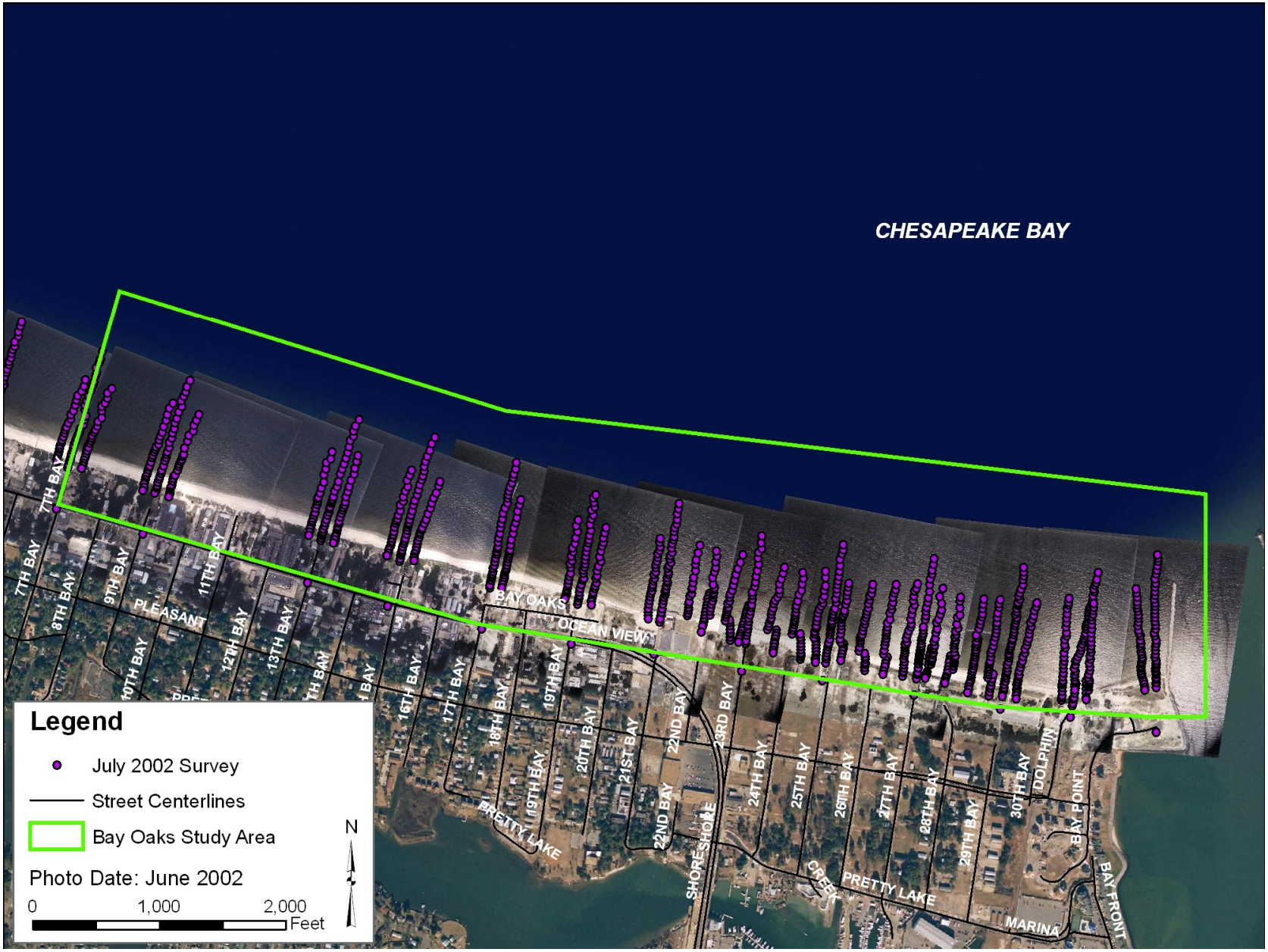


Figure A-6. July 2002 Survey Coverage

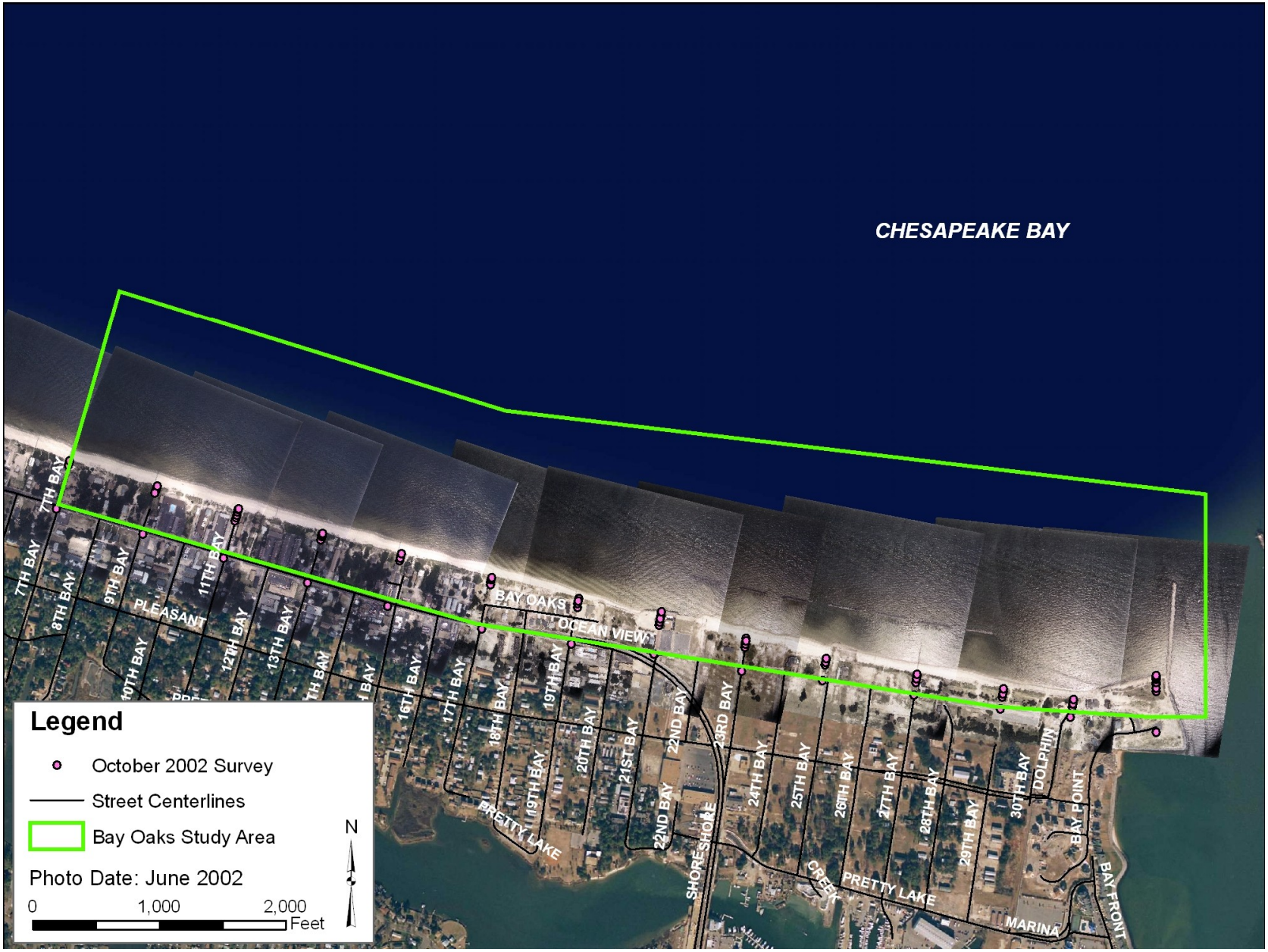


Figure A-7. October 2002 Survey Coverage

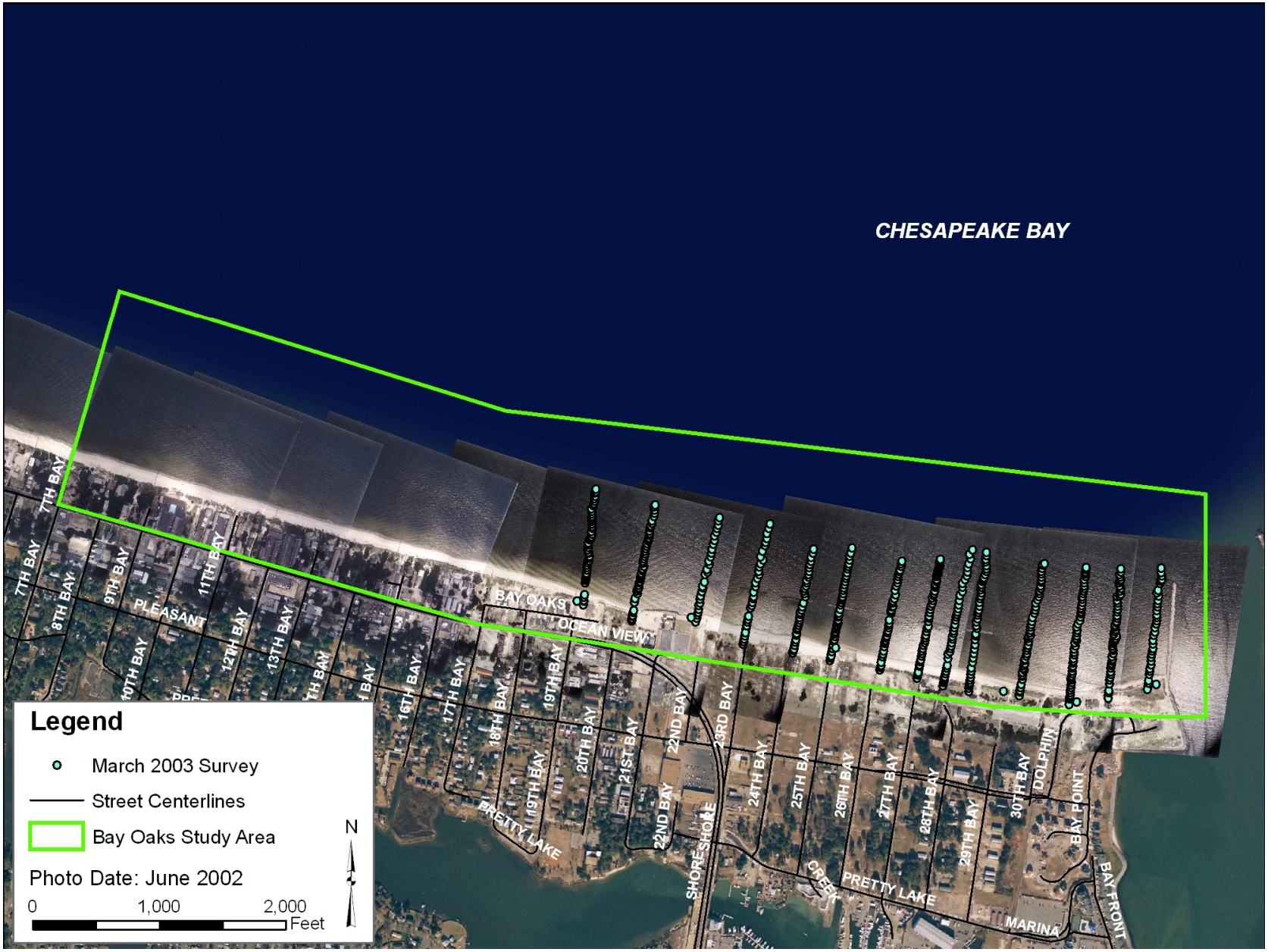


Figure A-8. March 2003 Survey Coverage

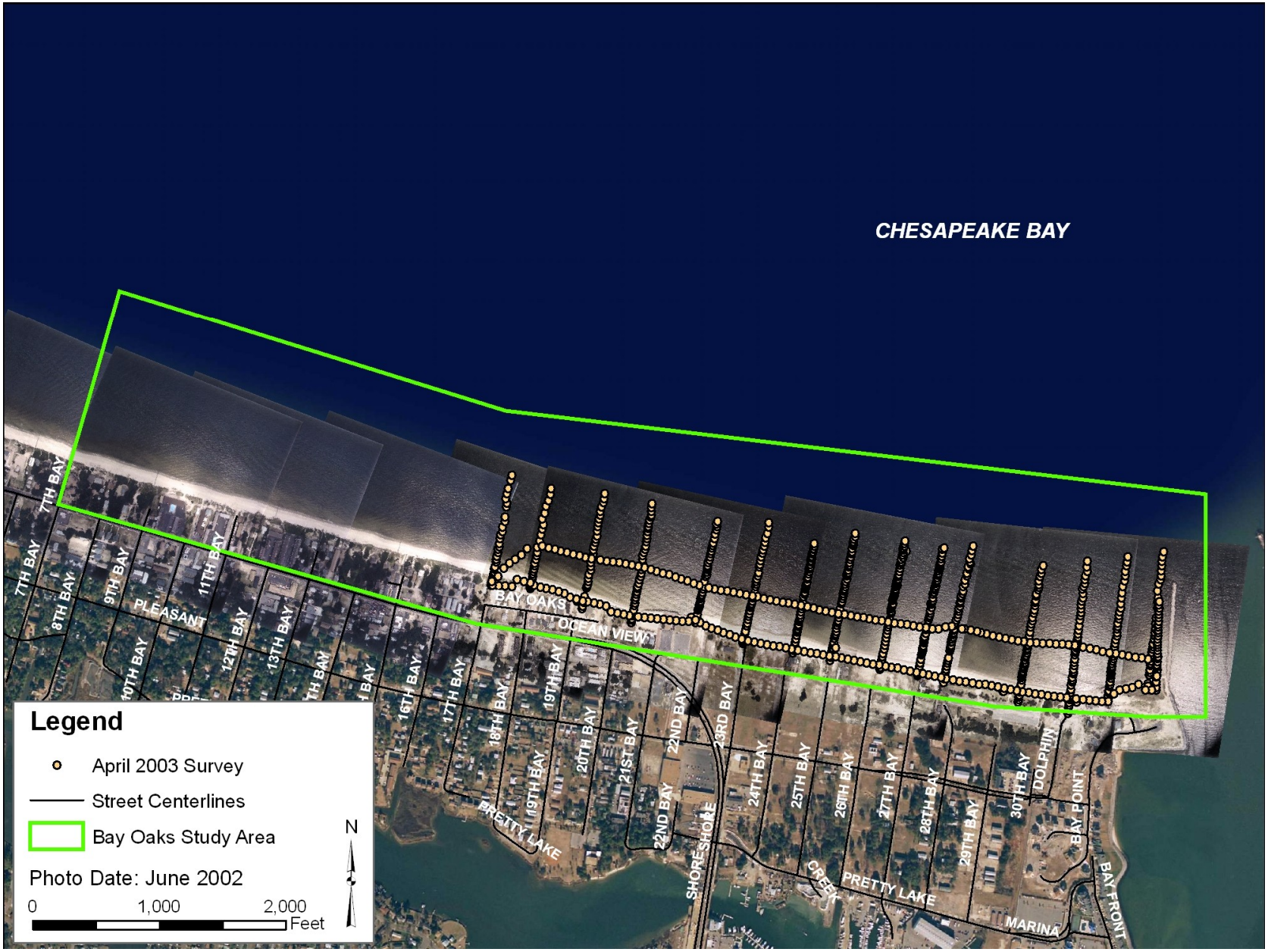


Figure A-9. April 2003 Survey Coverage

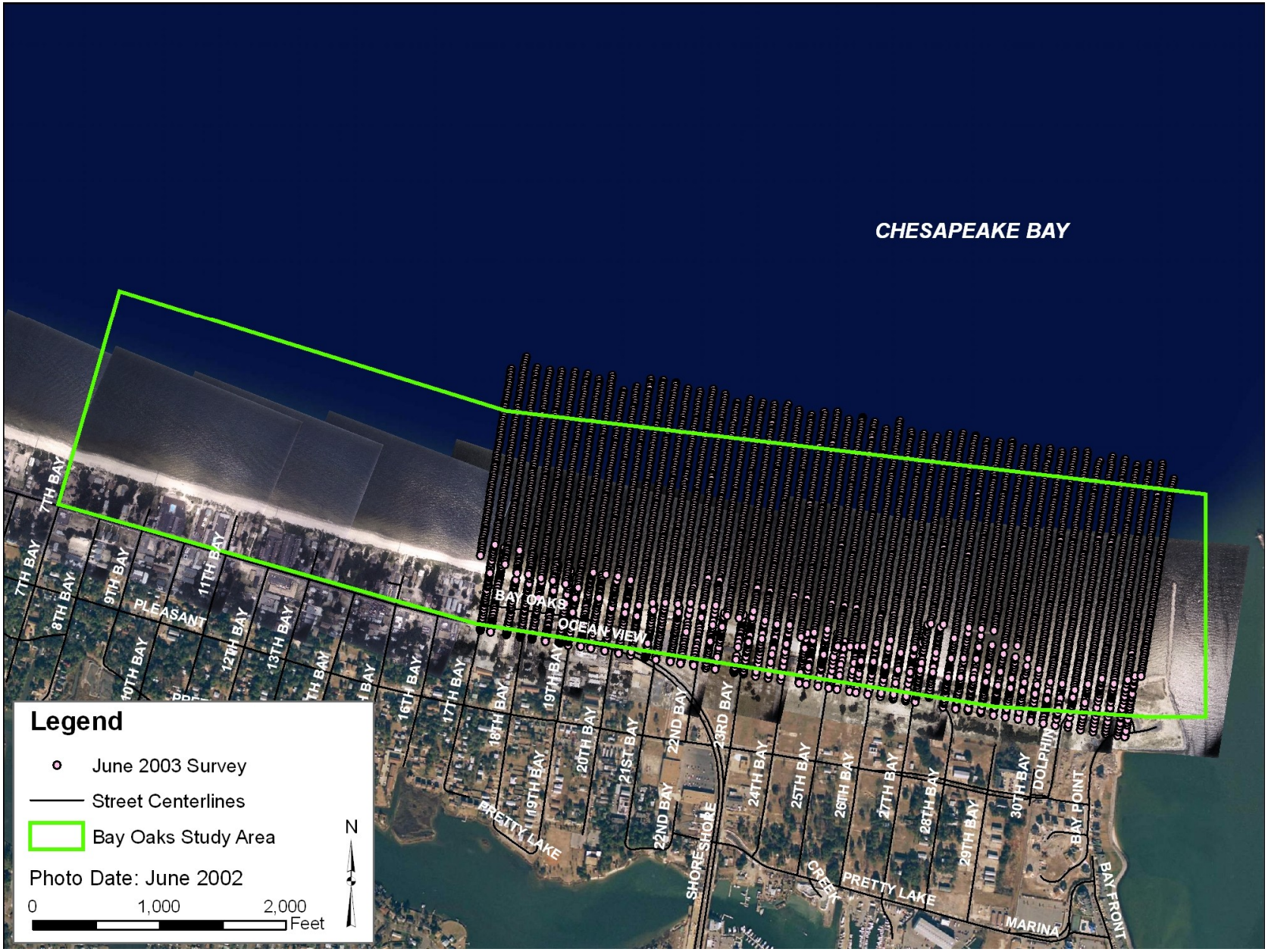


Figure A-10. June 2003 Survey Coverage

Figure A-11. December 2003 Survey Coverage

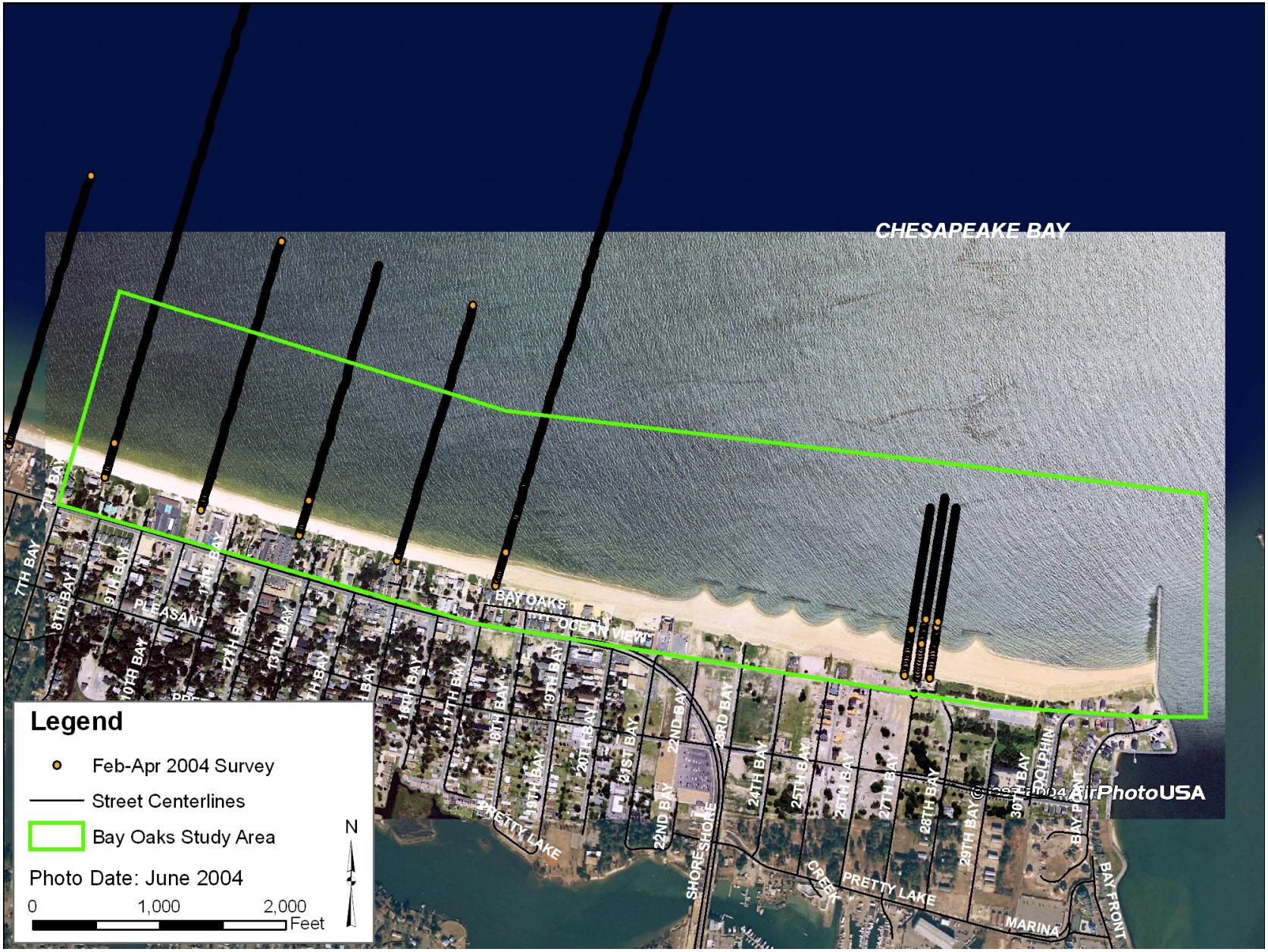


Figure A-12. February-April 2004 Survey Coverage

Figure A-13. September 2005 Survey Coverage

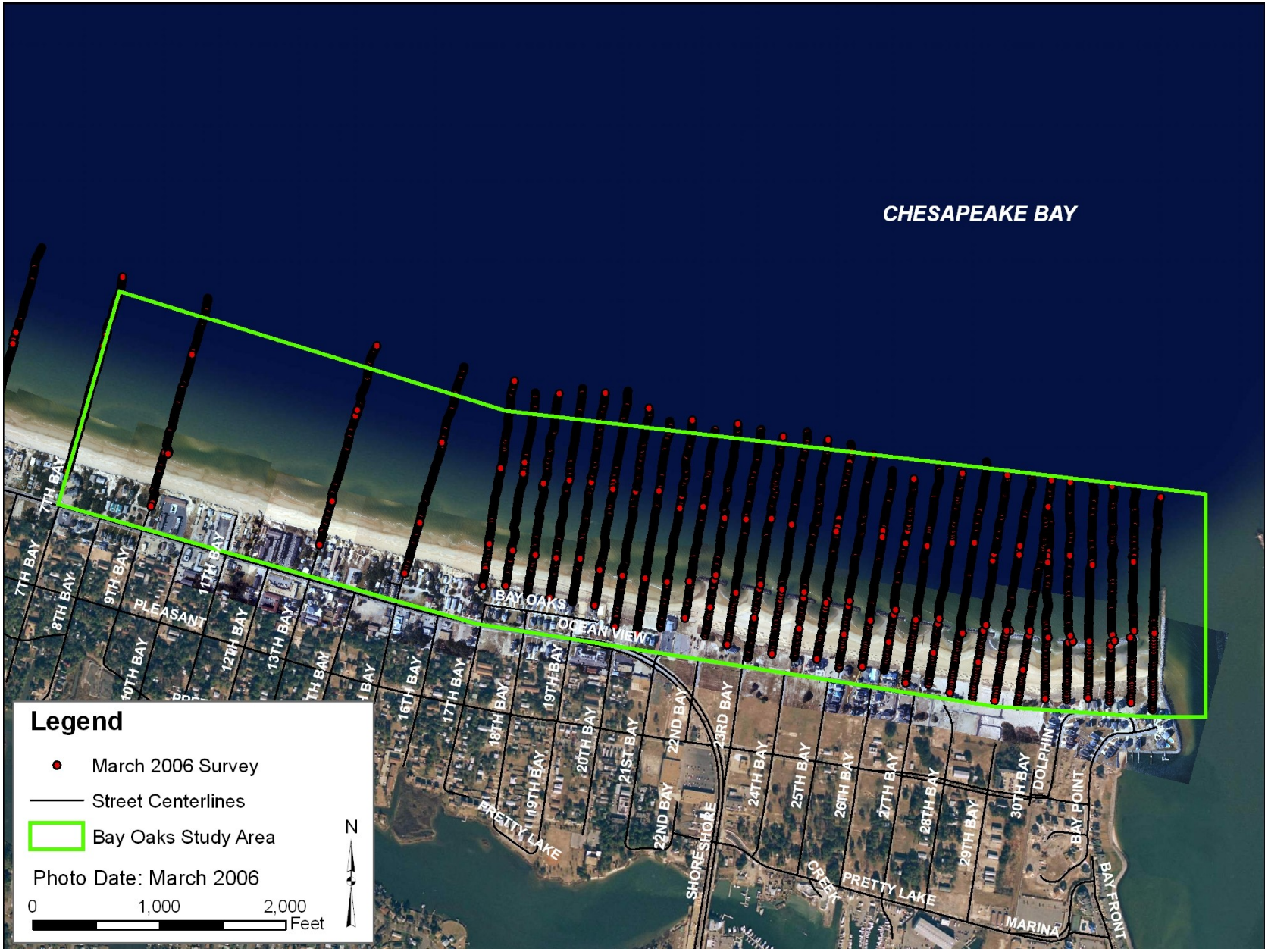


Figure A-14. March 2006 Survey Coverage

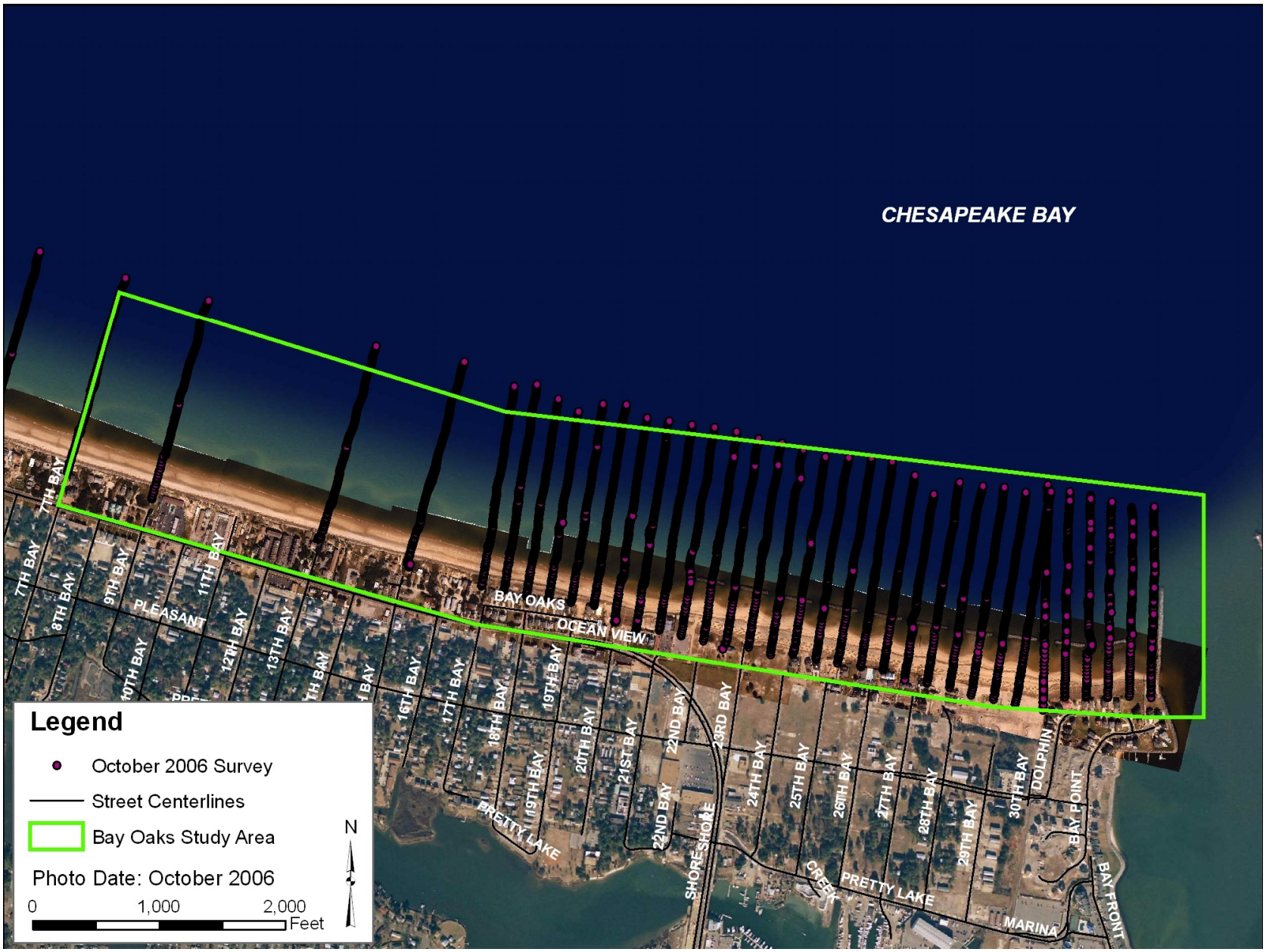


Figure A-15. October 2006 Survey Coverage

APPENDIX B

Historical Digitized Shorelines

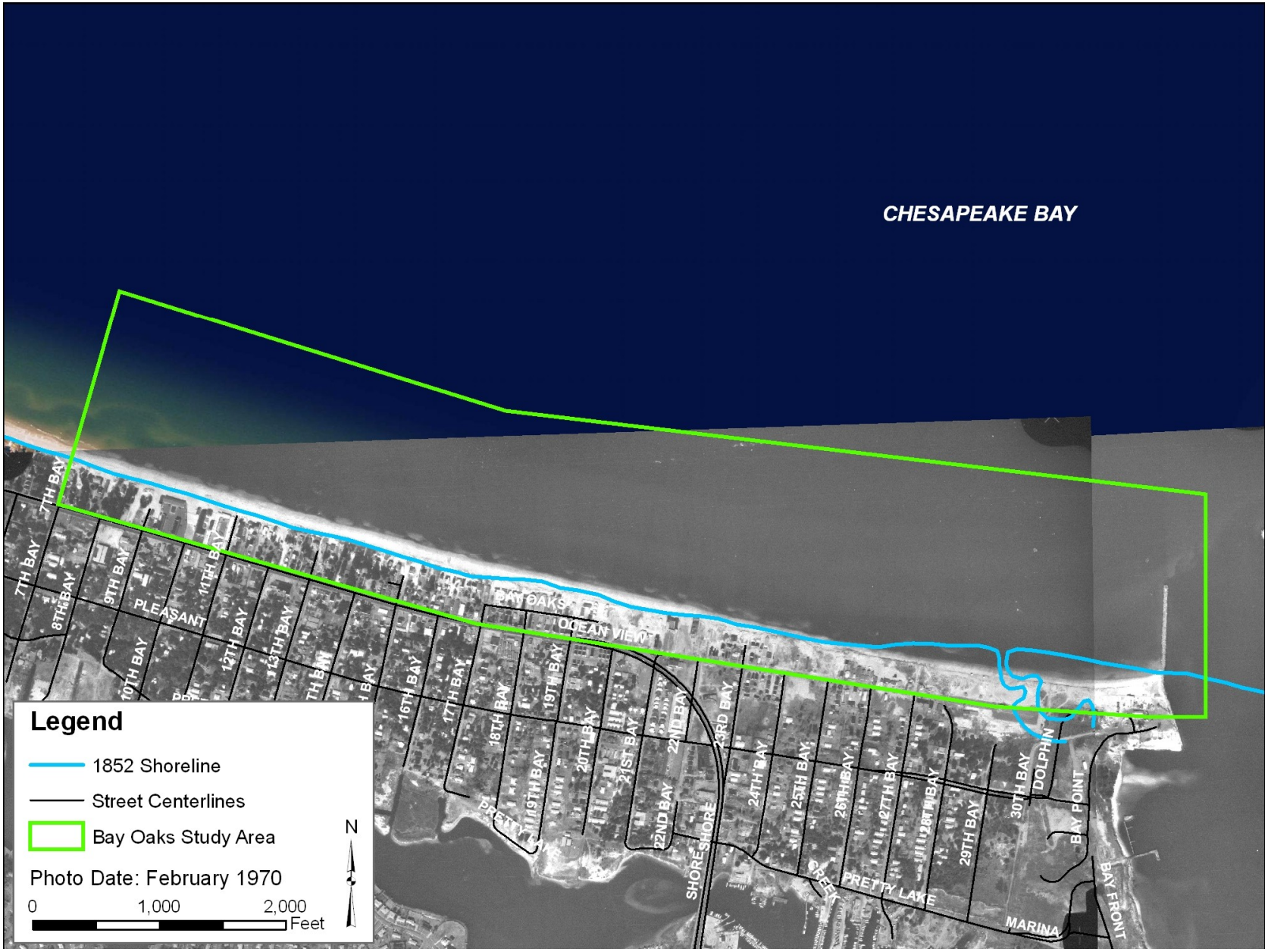


Figure B-1. 1852 Shoreline

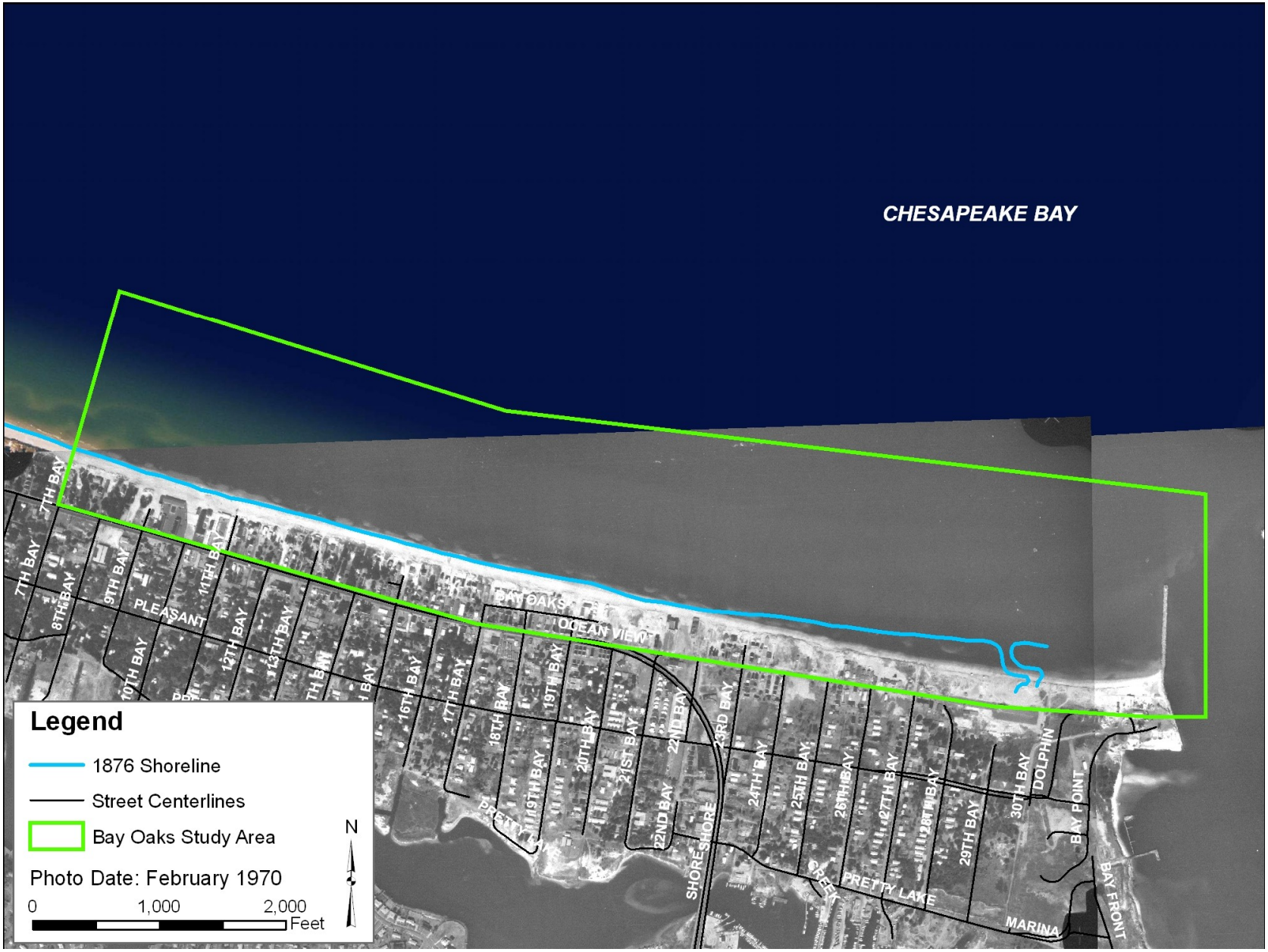


Figure B-2. 1876 Shoreline

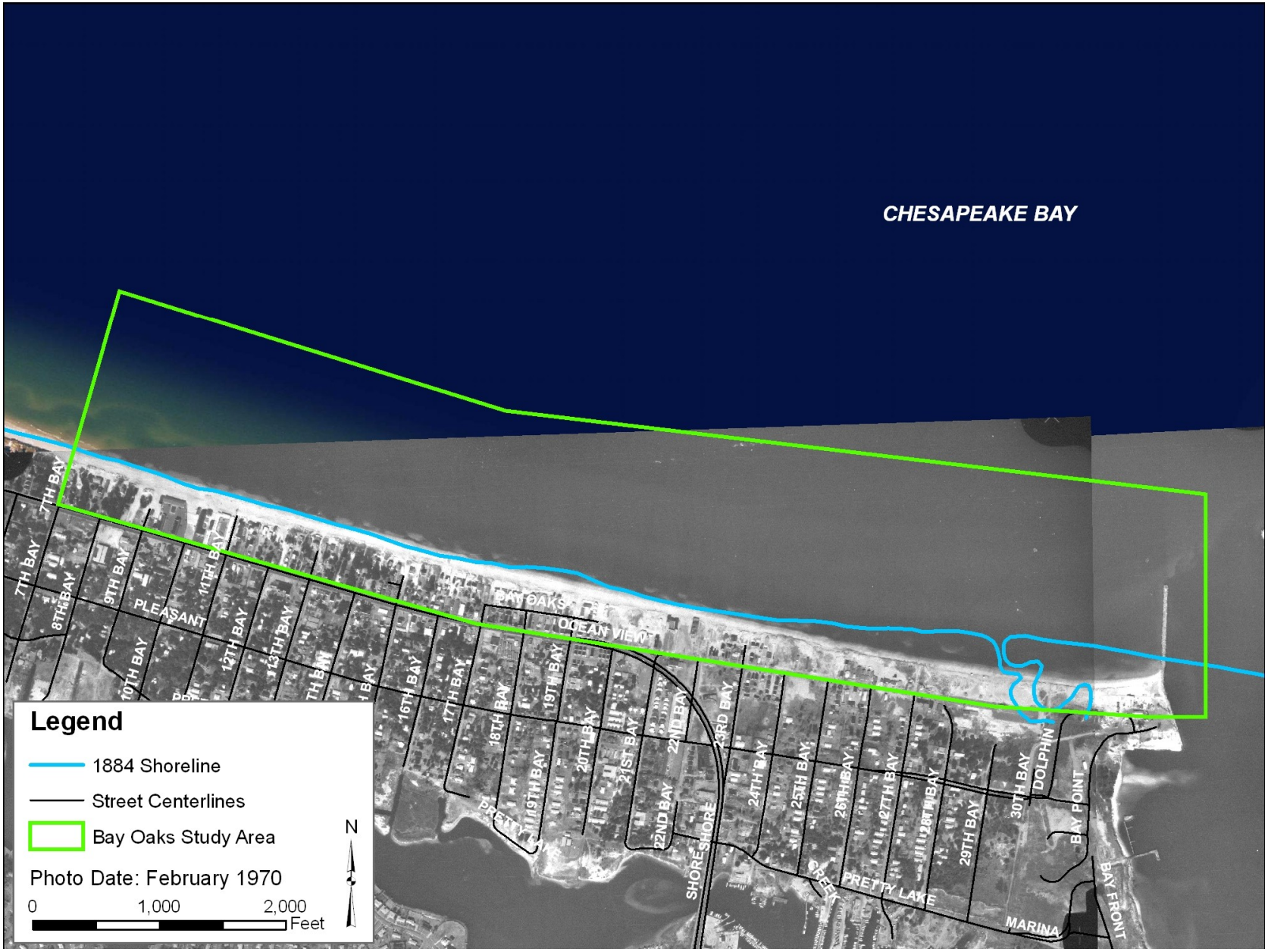


Figure B-3. 1884 Shoreline

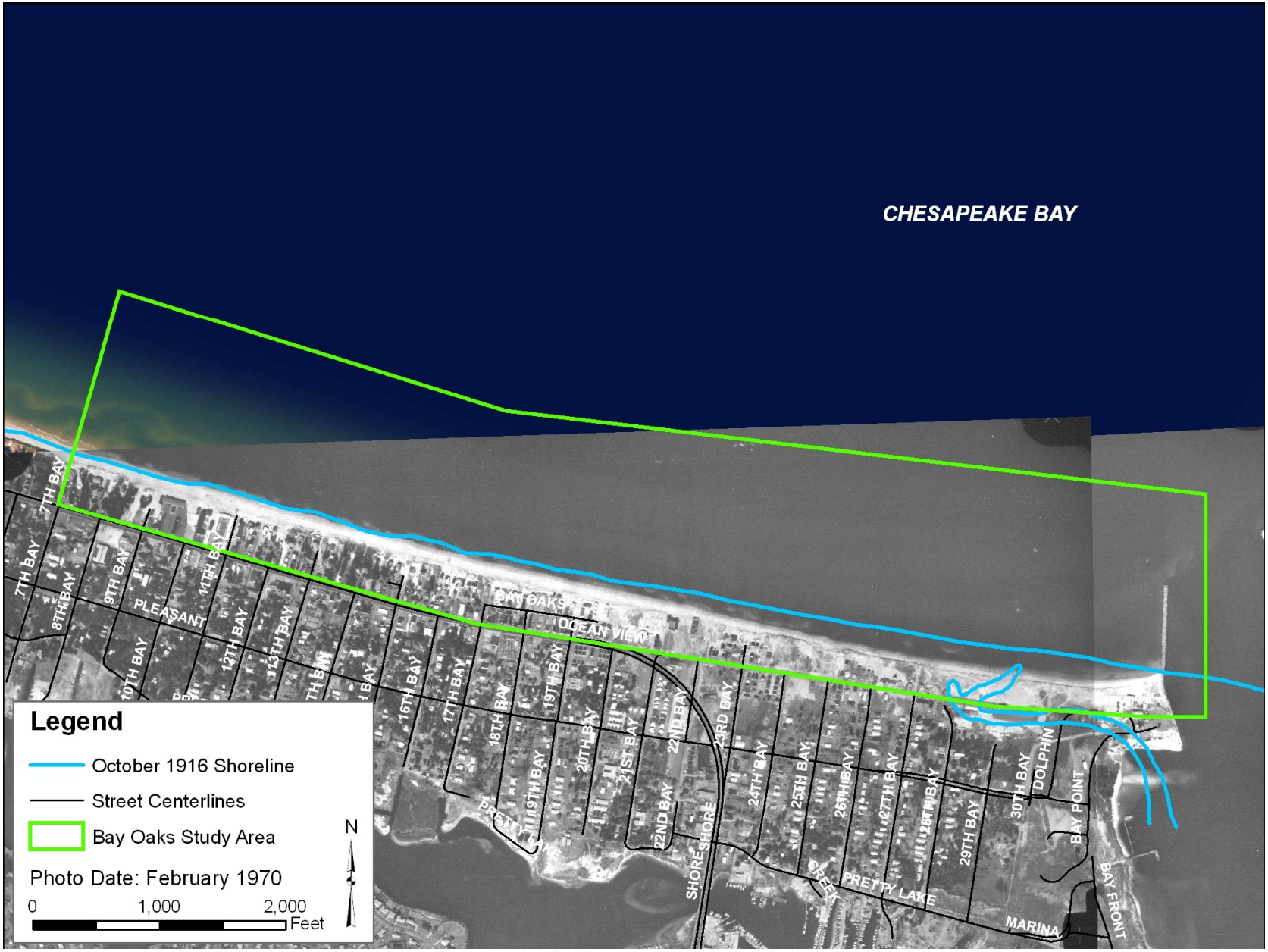


Figure B-4. 1916 Shoreline

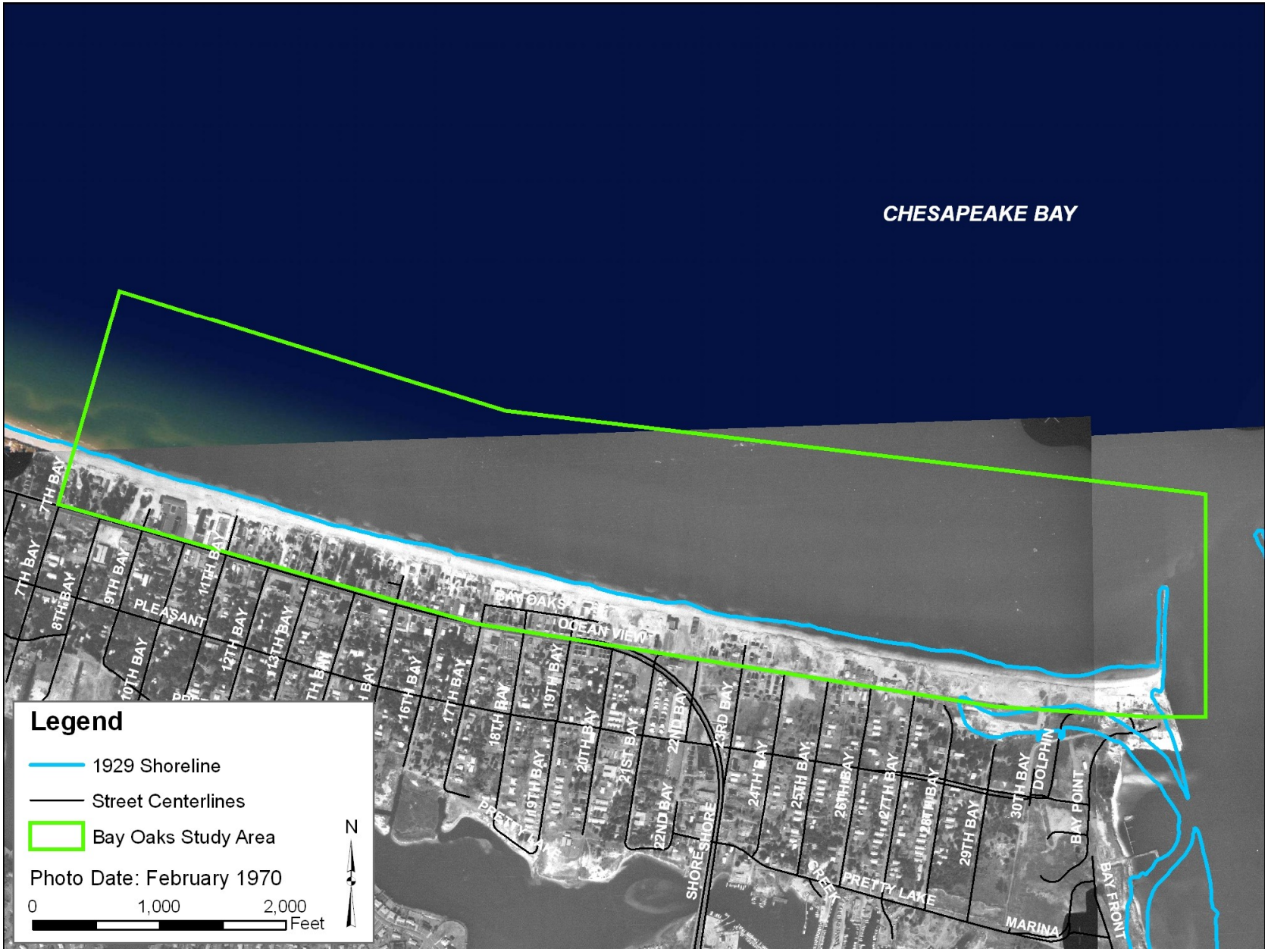


Figure B-5. 1929 Shoreline

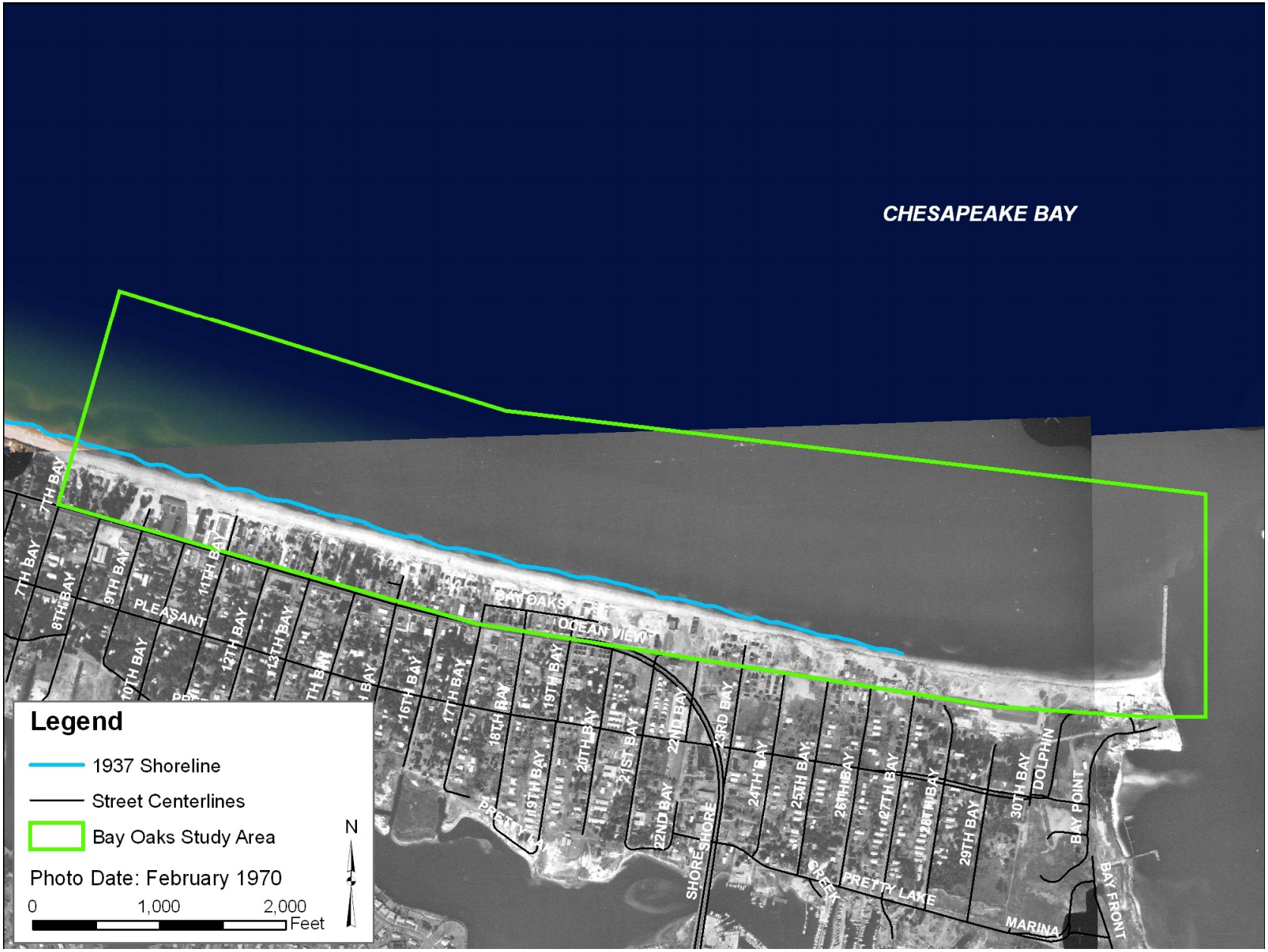


Figure B-6. 1937 Shoreline

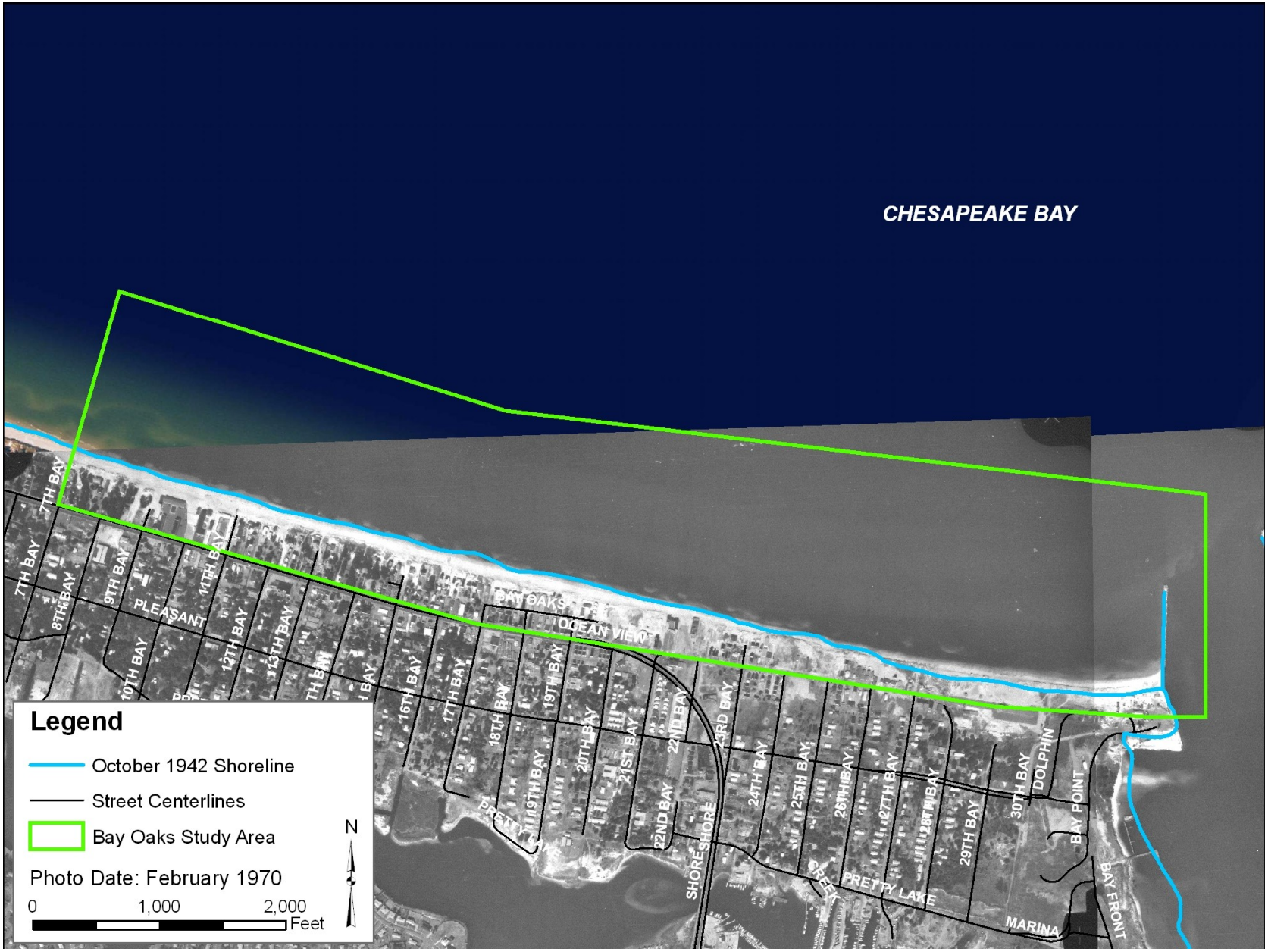


Figure B-7. 1942 Shoreline

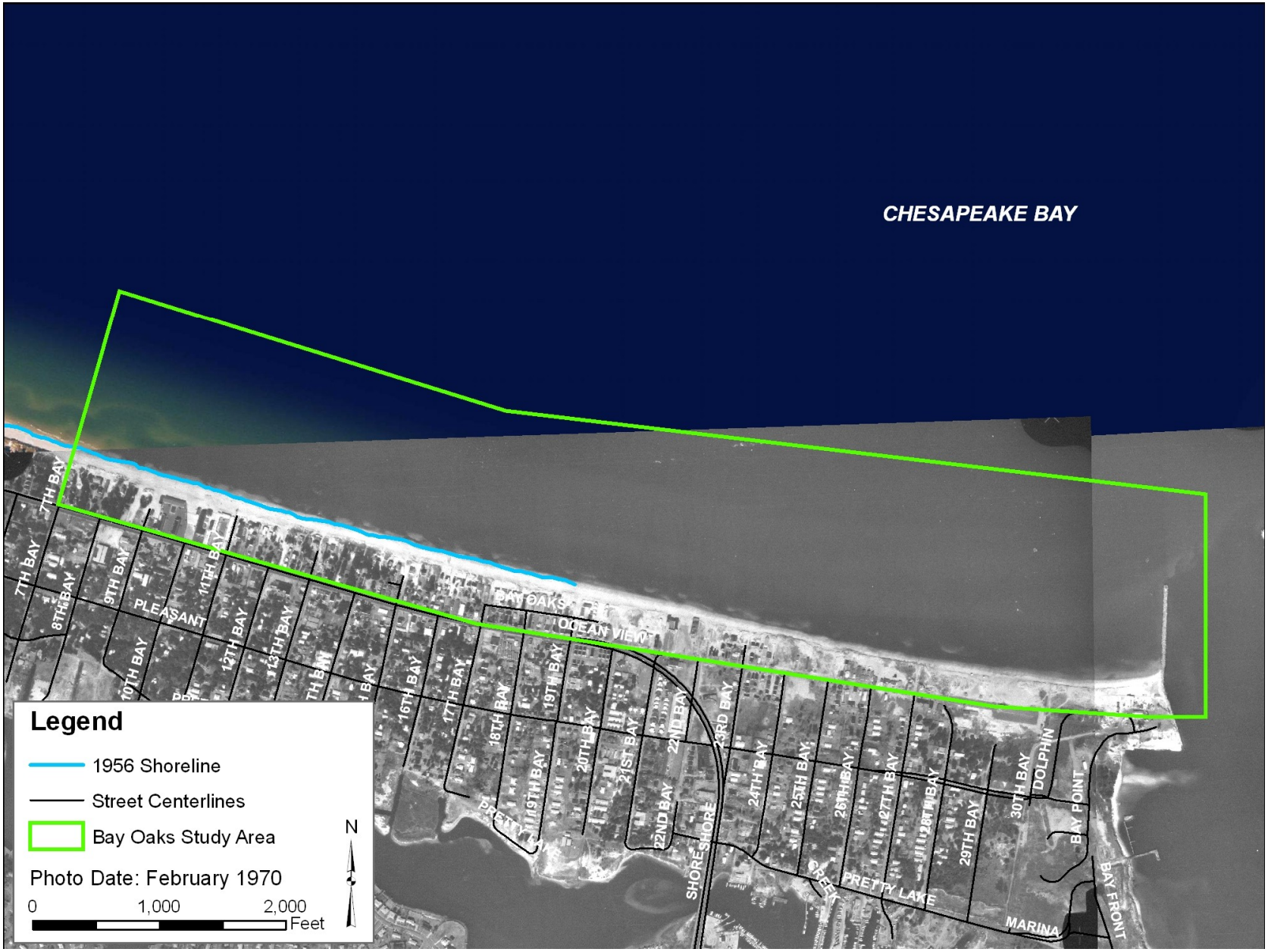


Figure B-8. 1956 Shoreline

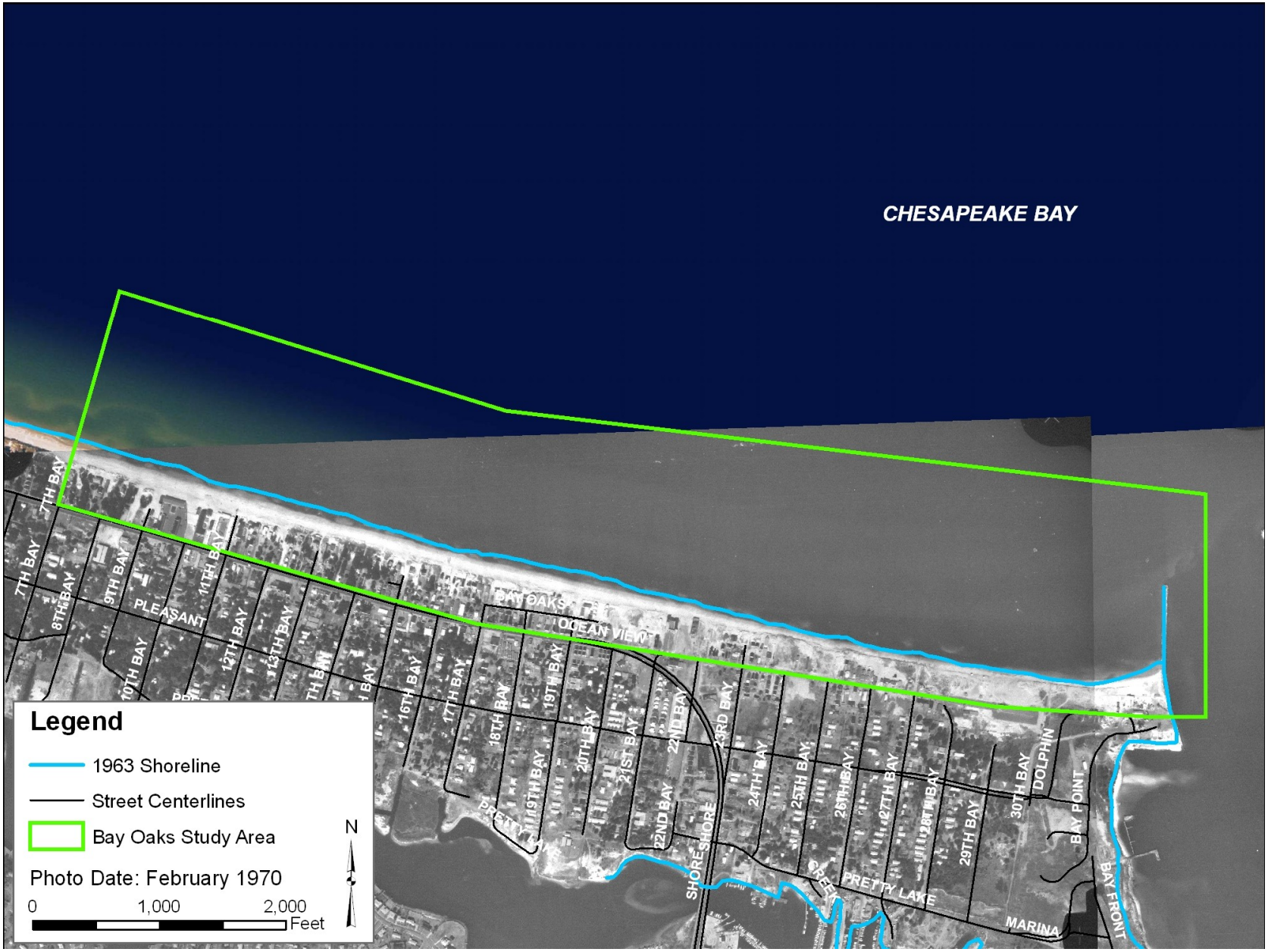


Figure B-9. 1963 Shoreline

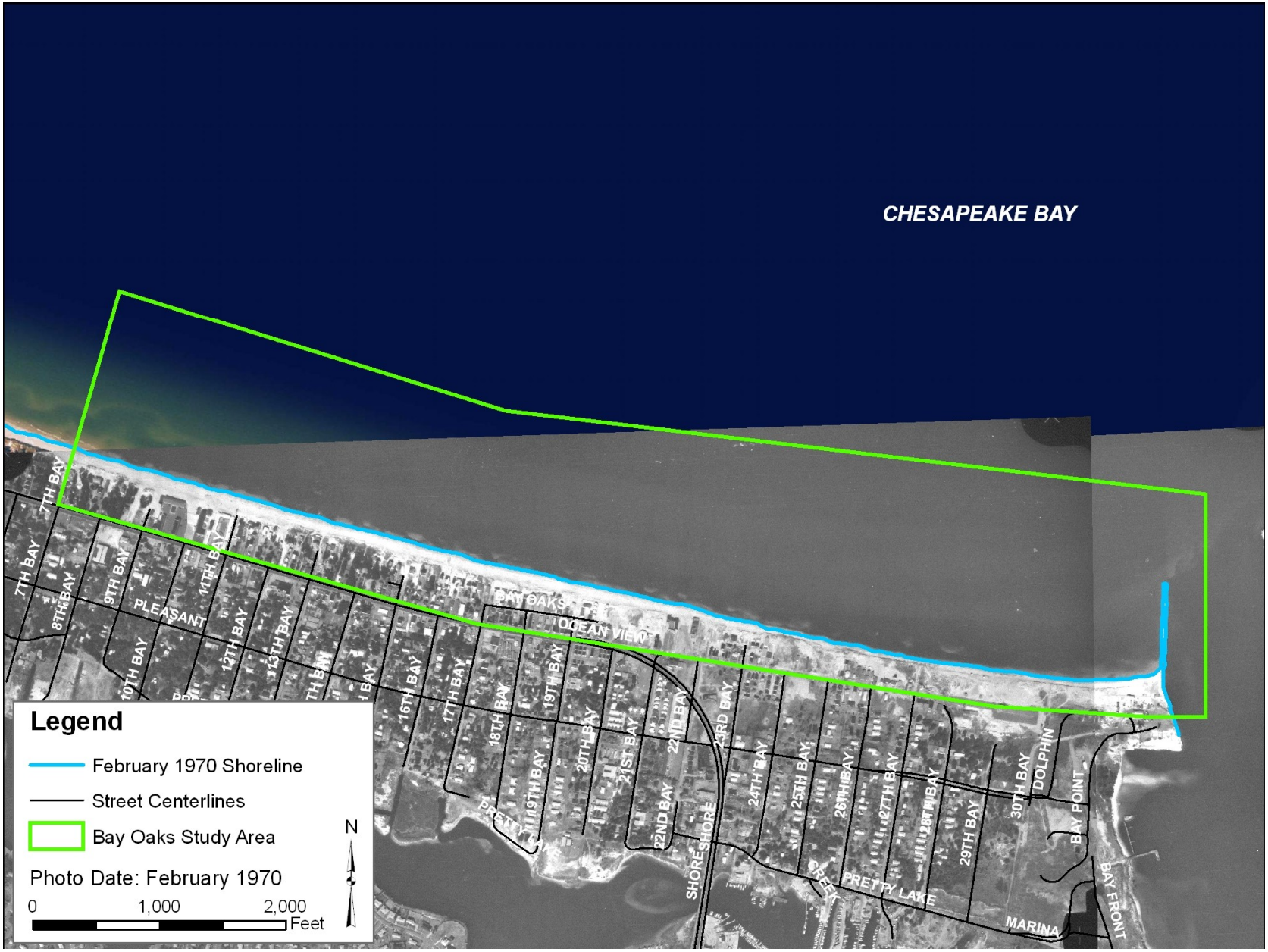


Figure B-10. 1970 Shoreline

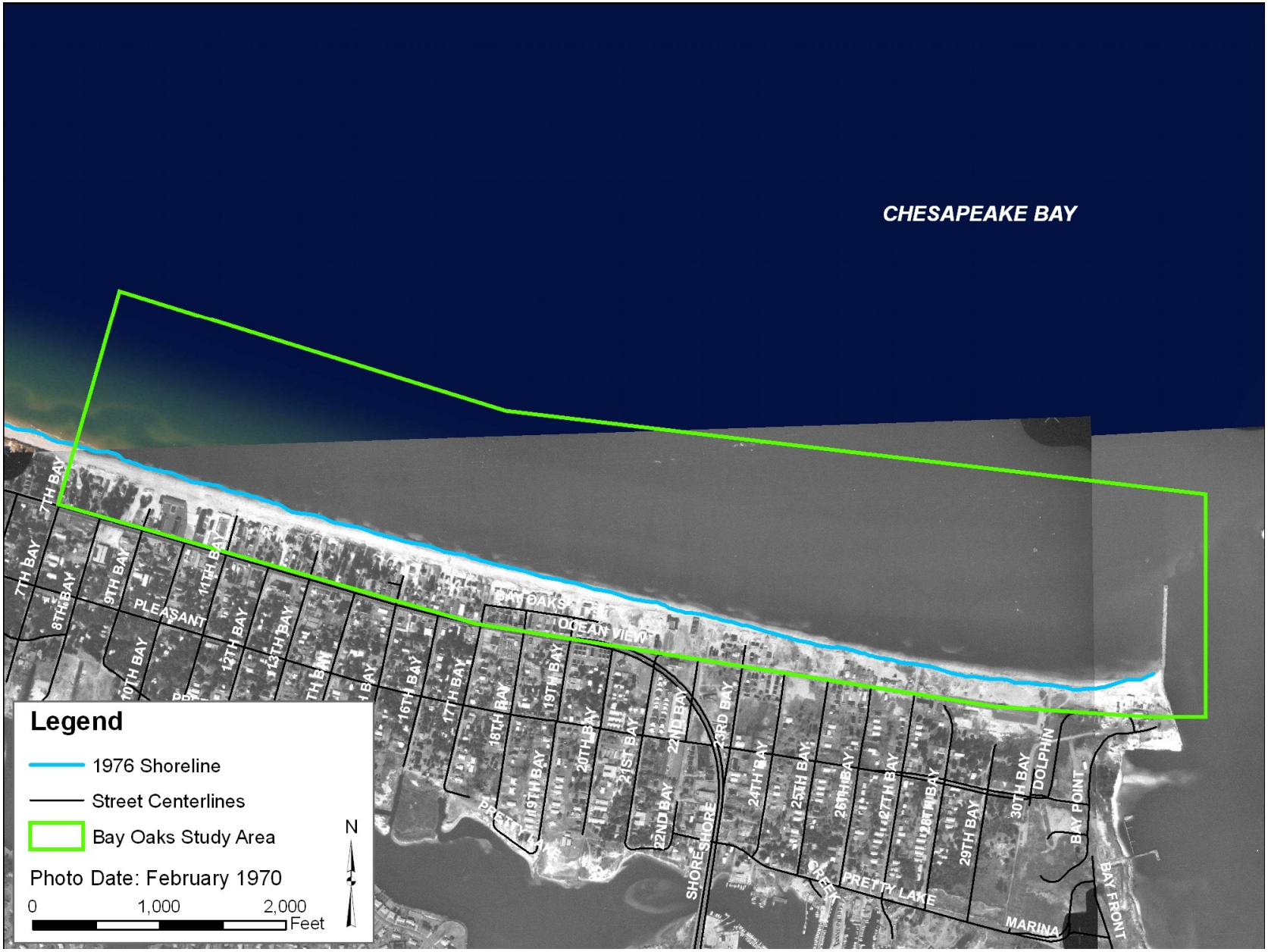


Figure B-11. 1976 Shoreline

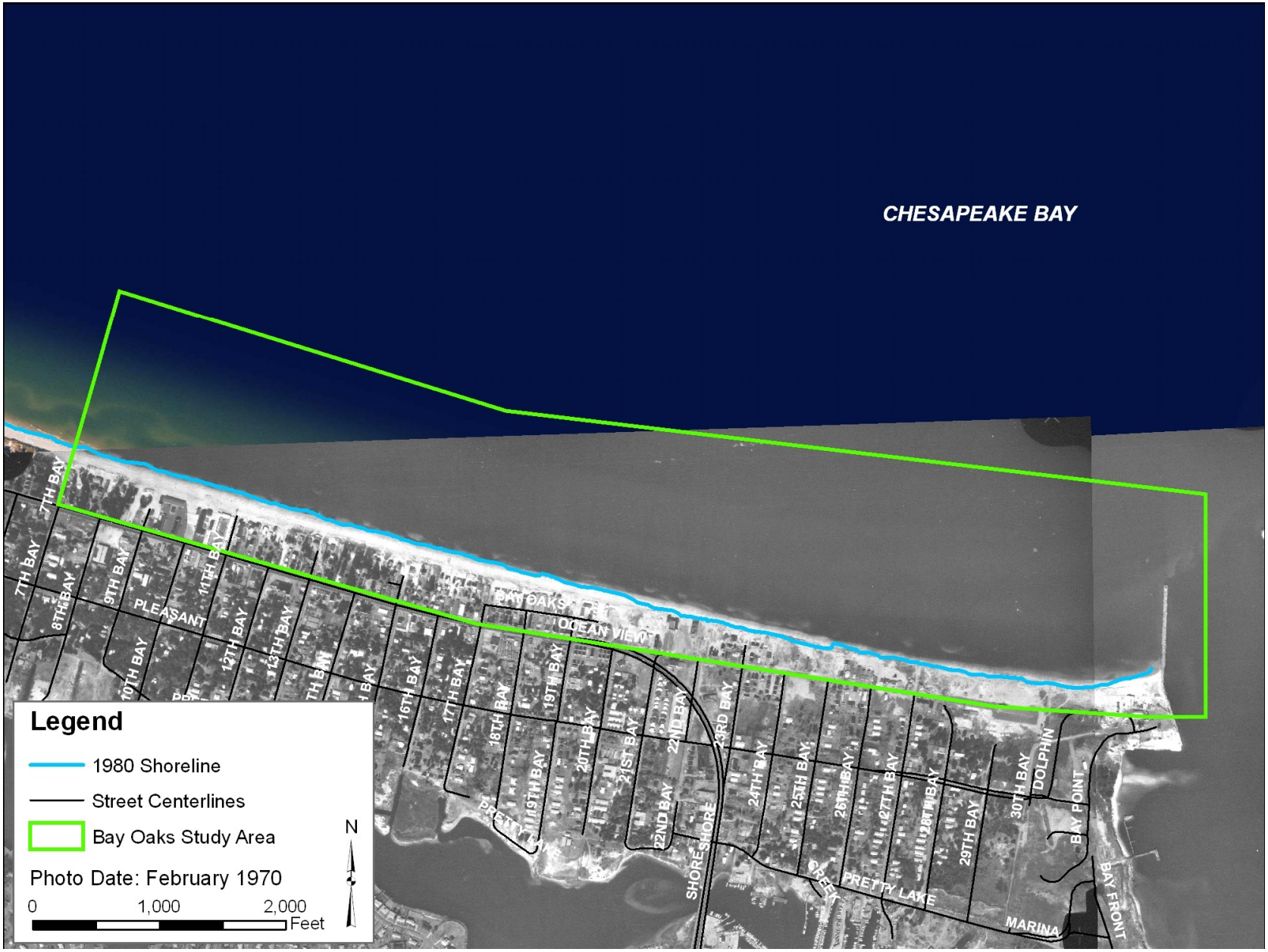


Figure B-12. 1980 Shoreline

Figure B-13. 1995 Shoreline

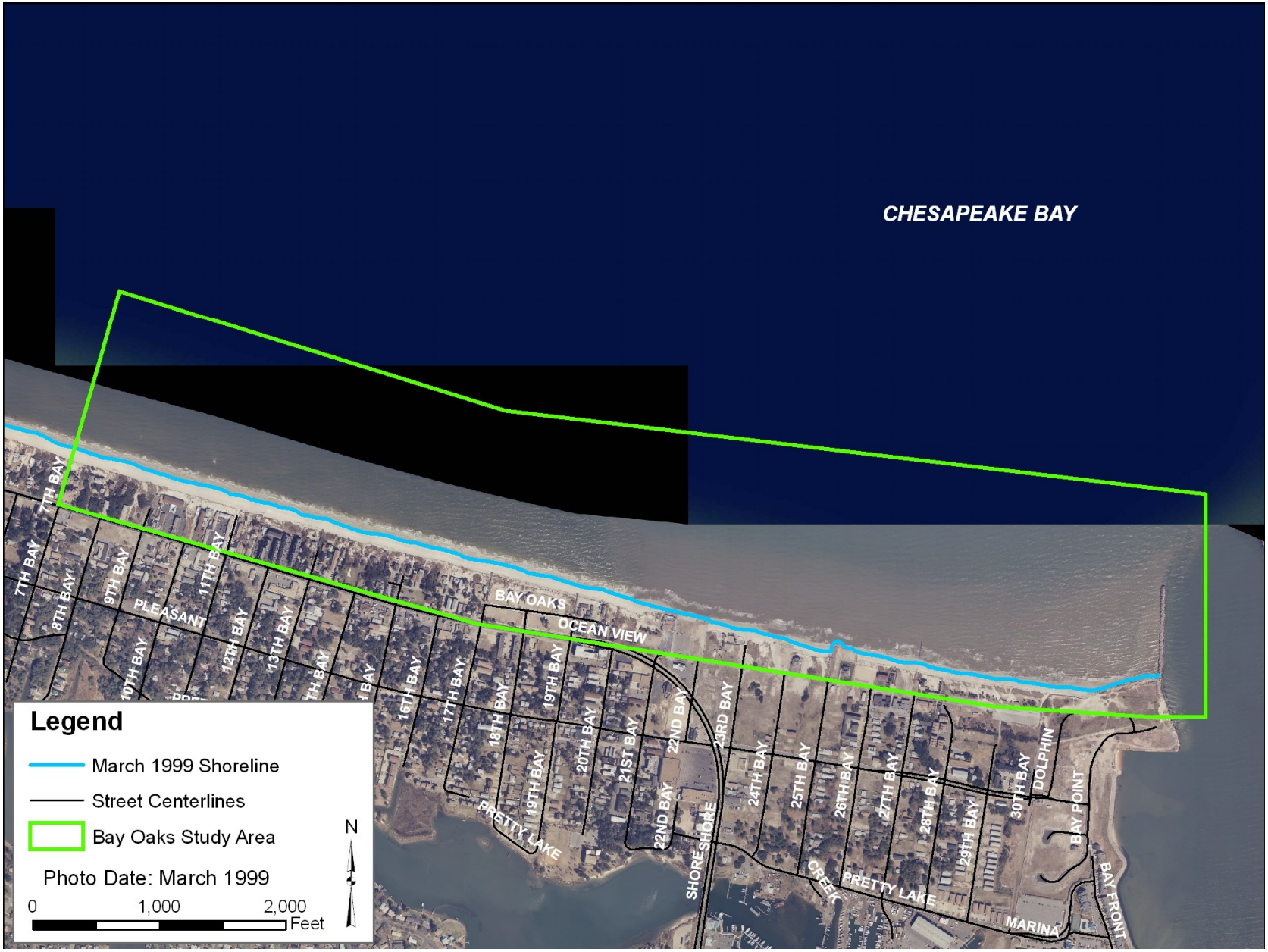


Figure B-14. March 1999 Shoreline

Figure B-15. October 1999 Shoreline

Figure B-16. 2000 Shoreline

Figure B-17. 2002 Shoreline

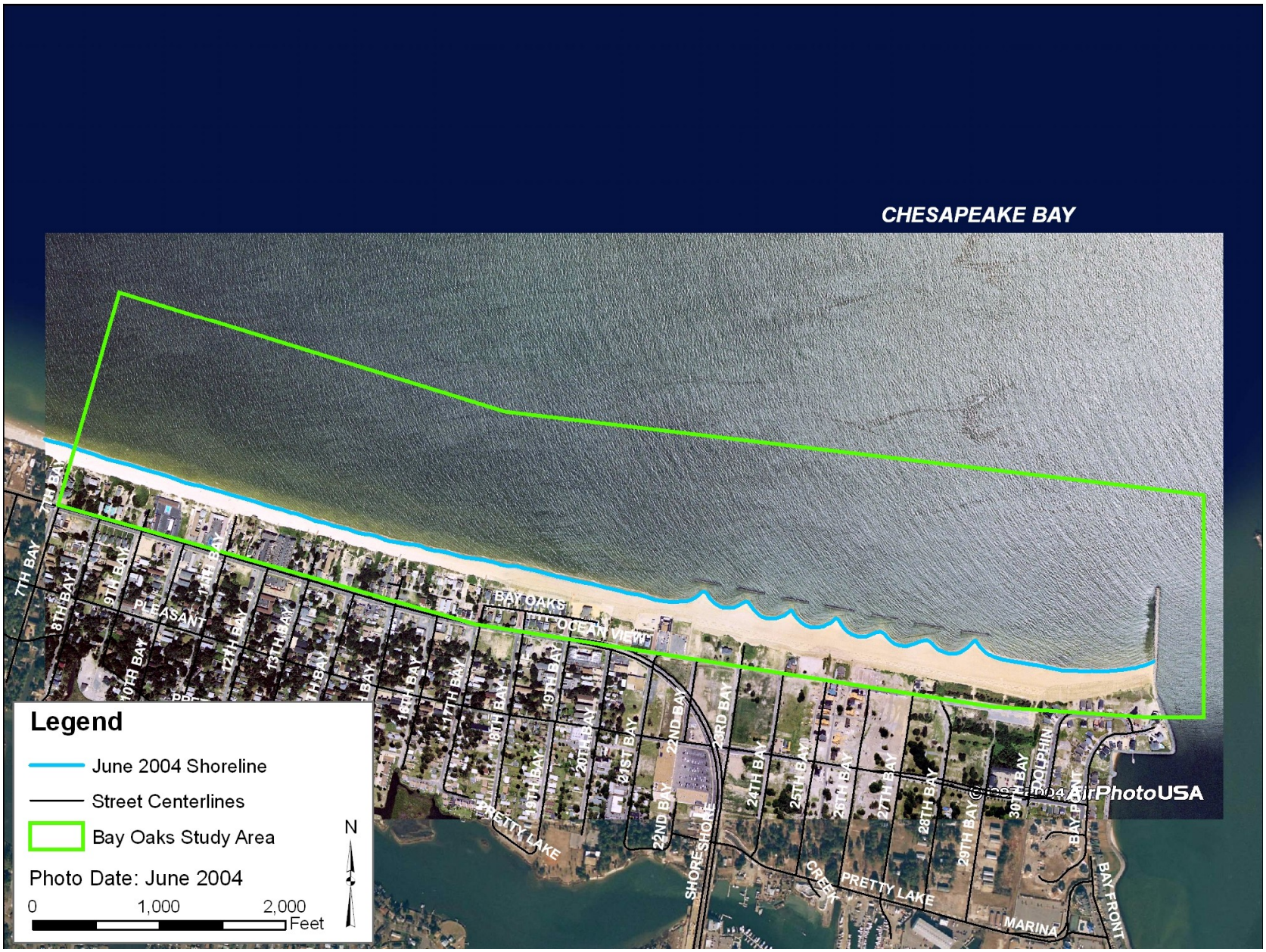


Figure B-18. 2004 Shoreline

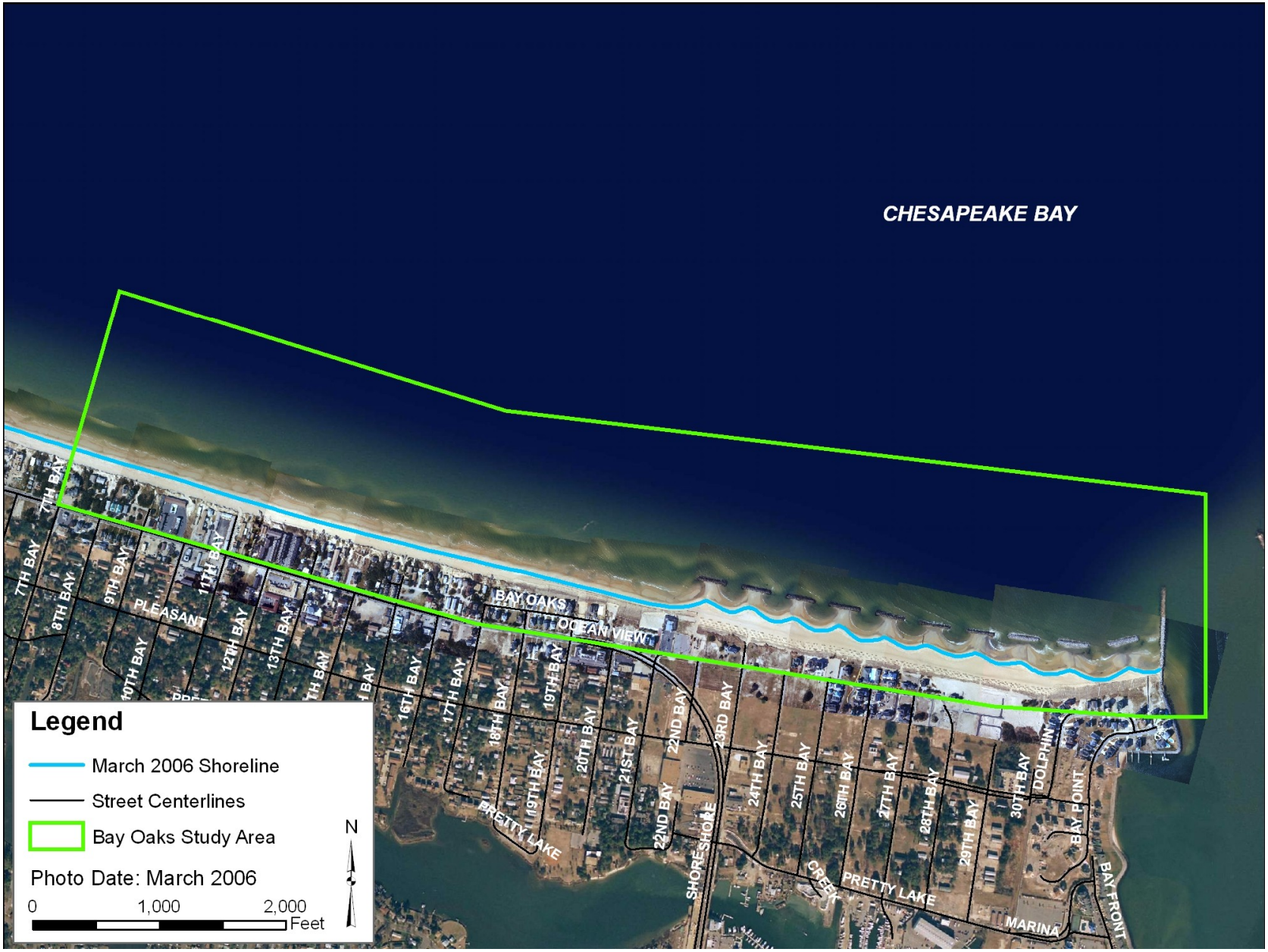


Figure B-19. March 2006 Shoreline

Figure B-20. October 2006 Shoreline

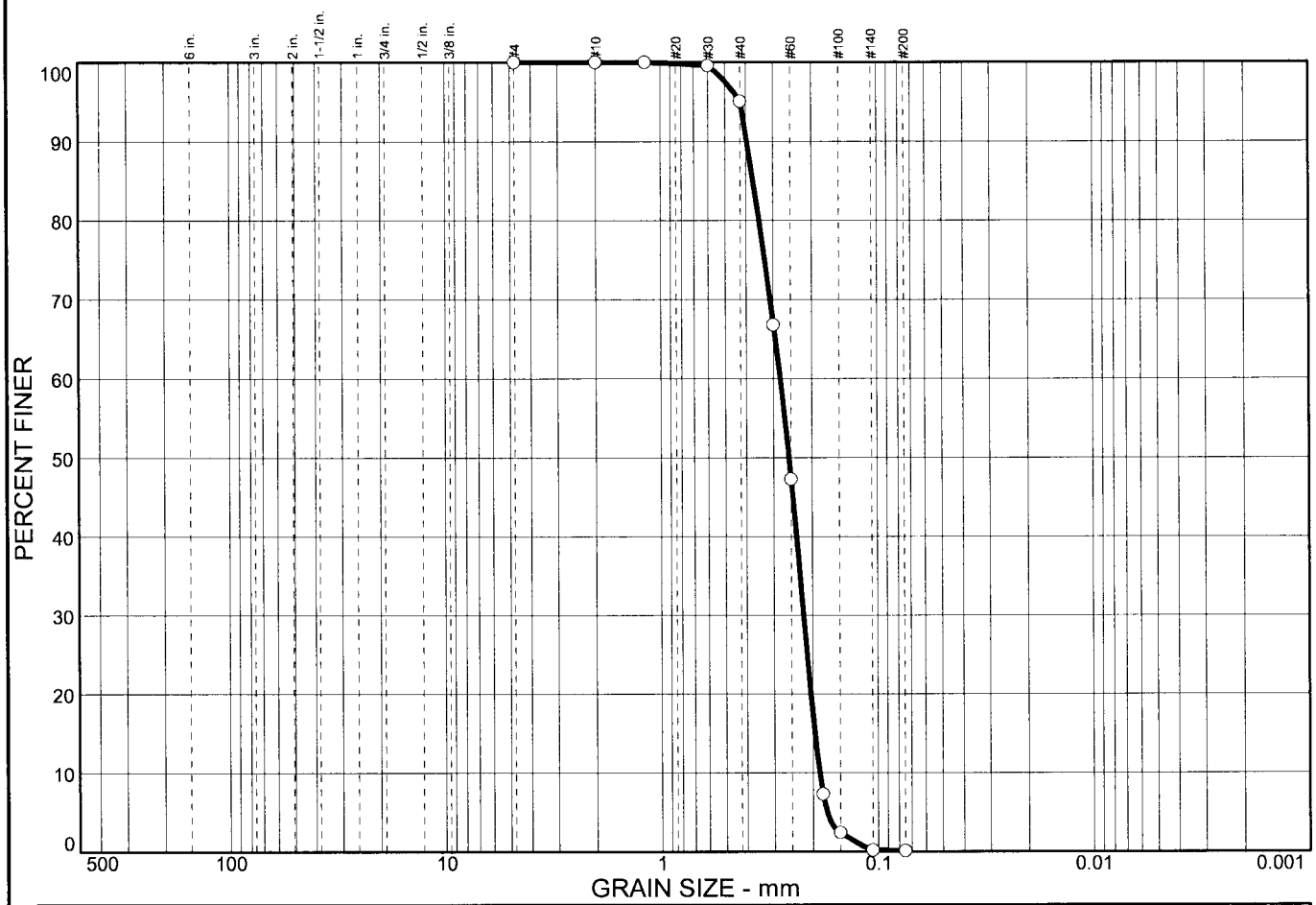
APPENDIX C

East Ocean View Sediment Data

Laboratory Testing Services
Ocean View Sediment Analysis
Norfolk, Virginia
GET Project No: VB04-131G
April 29, 2004
Prepared for: Waterway Surveys and Engineering, LTD

GET Solutions, Inc.

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.9	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	99.6		
#40	95.1		
#50	66.8		
#60	47.3		
#80	7.3		
#100	2.4		
#140	0.2		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.372 D_{60}= 0.280 D_{50}= 0.256
D_{30}= 0.220 D_{15}= 0.196 D_{10}= 0.186
C_u= 1.50 C_c= 0.93

Classification

USCS= SP AASHTO= A-3

Remarks

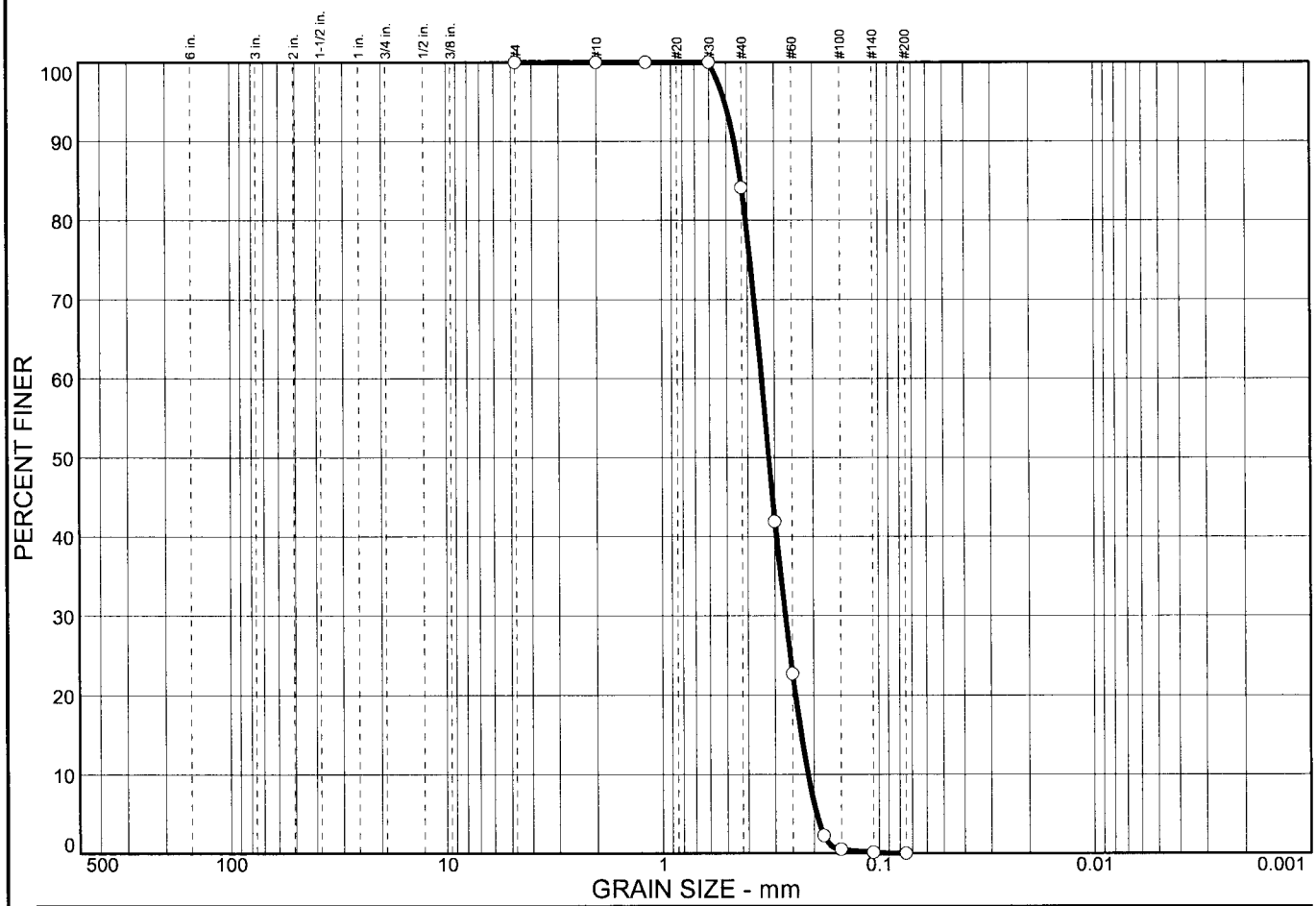
OV-31
Sample A

Sample No.: A **Source of Sample:** **Date:** 4/2/04
Location: OV-31 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 31A

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	100.0	0.0	0.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	100.0		
#40	84.1		
#50	41.9		
#60	22.7		
#80	2.2		
#100	0.5		
#140	0.1		
#200	0.0		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NA LL= NA PI= NA

Coefficients

D_{85}= 0.429 D_{60}= 0.345 D_{50}= 0.320
D_{30}= 0.270 D_{15}= 0.228 D_{10}= 0.213
C_u= 1.62 C_c= 0.99

Classification

USCS= SP AASHTO= A-3

Remarks

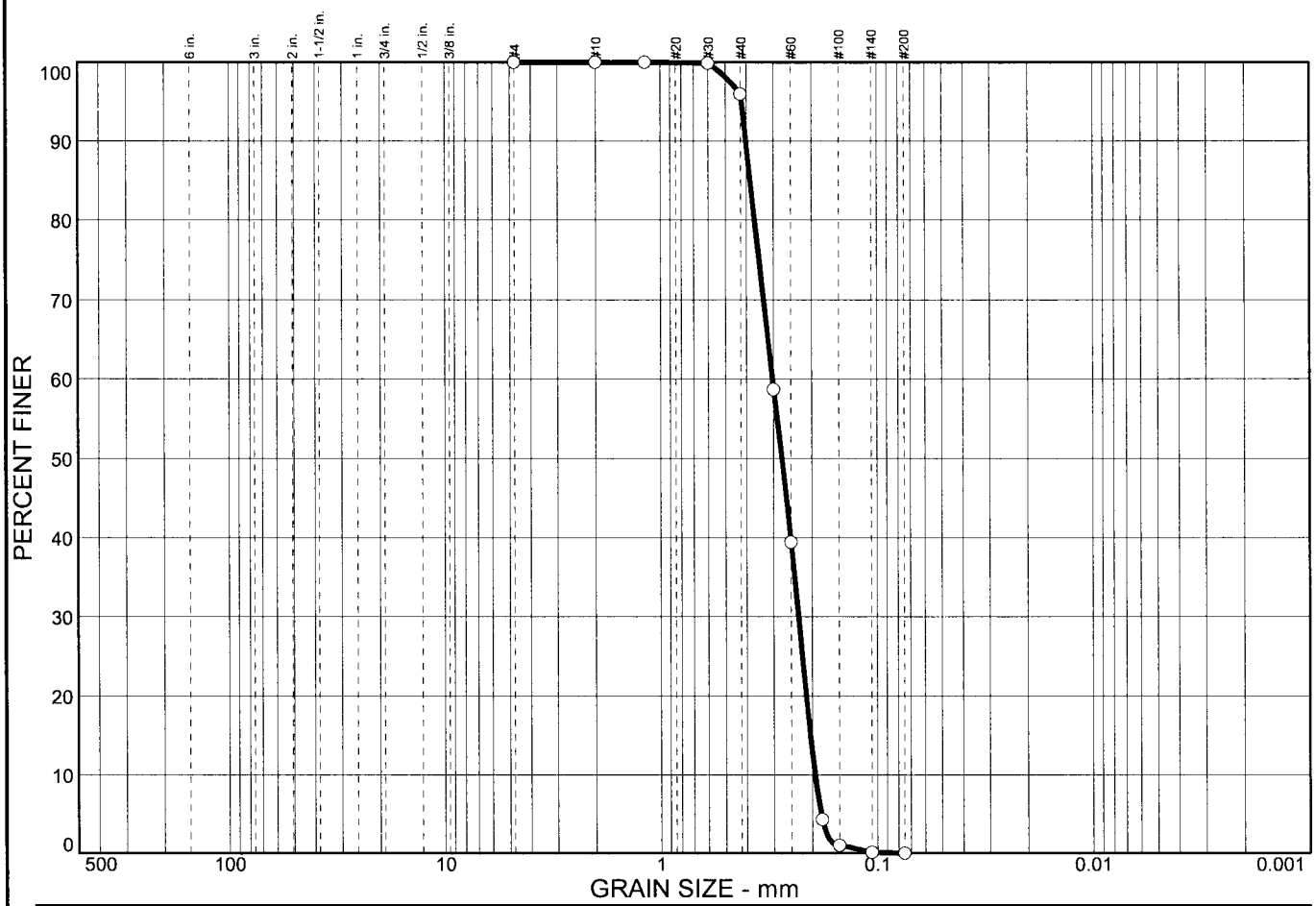
OV-31
Sample B

Sample No.: B **Source of Sample:** **Date:** 4/2/04
Location: OV-31 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 31B

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	100.0	0.0	0.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	99.9		
#40	95.9		
#50	58.7		
#60	39.4		
#80	4.3		
#100	1.0		
#140	0.1		
#200	0.0		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.384 D_{60}= 0.304 D_{50}= 0.276
D_{30}= 0.232 D_{15}= 0.204 D_{10}= 0.194
C_u= 1.56 C_c= 0.91

Classification

USCS= SP AASHTO= A-3

Remarks

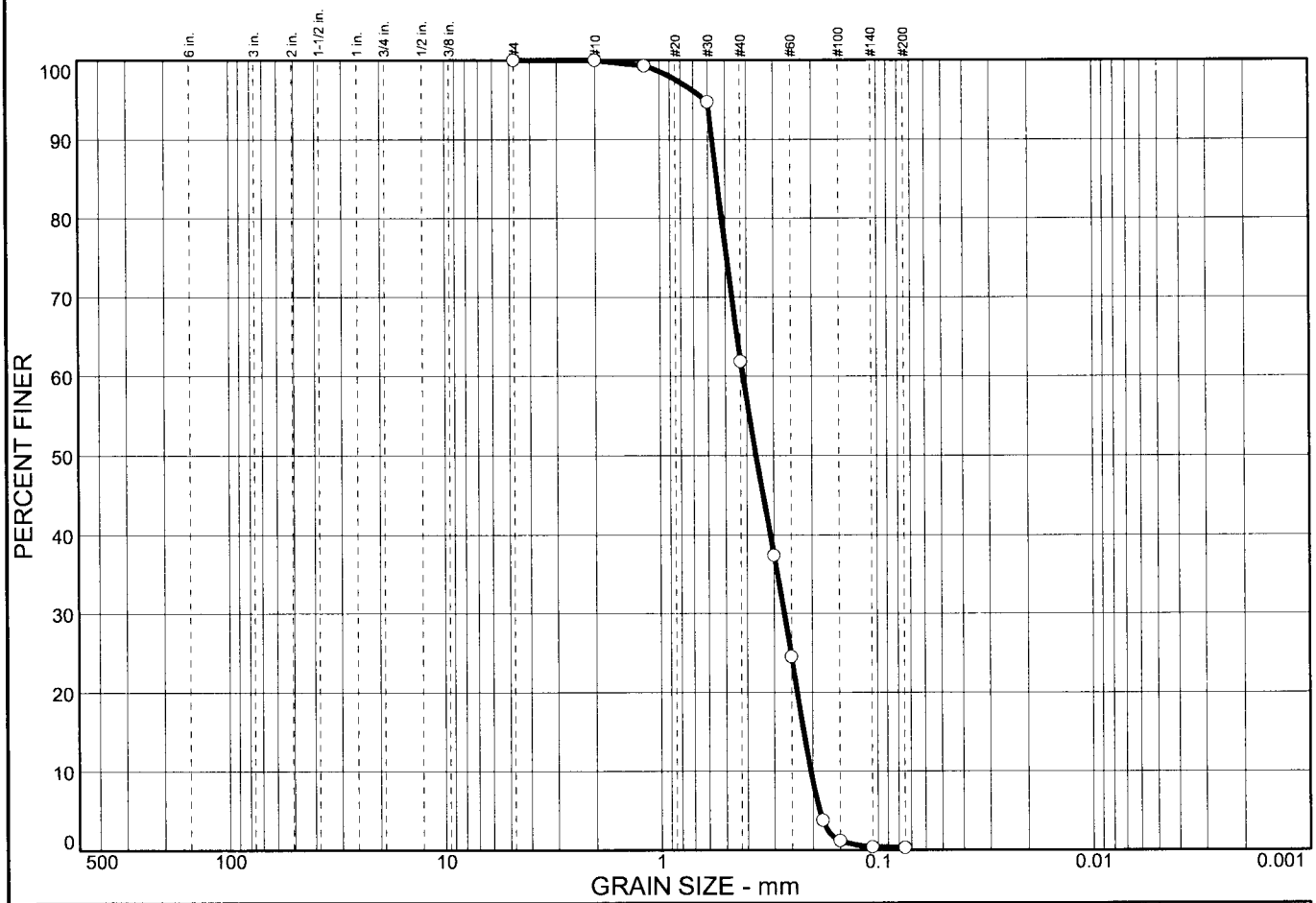
OV-31
Sample C

Sample No.: C **Source of Sample:** **Date:** 4/2/04
Location: OV-31 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 31C

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.7	0.3	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	99.3		
#30	94.7		
#40	61.9		
#50	37.4		
#60	24.5		
#80	3.8		
#100	1.2		
#140	0.4		
#200	0.3		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.545 D_{60}= 0.415 D_{50}= 0.362
D_{30}= 0.270 D_{15}= 0.220 D_{10}= 0.204
C_u= 2.03 C_c= 0.86

Classification

USCS= SP AASHTO= A-3

Remarks

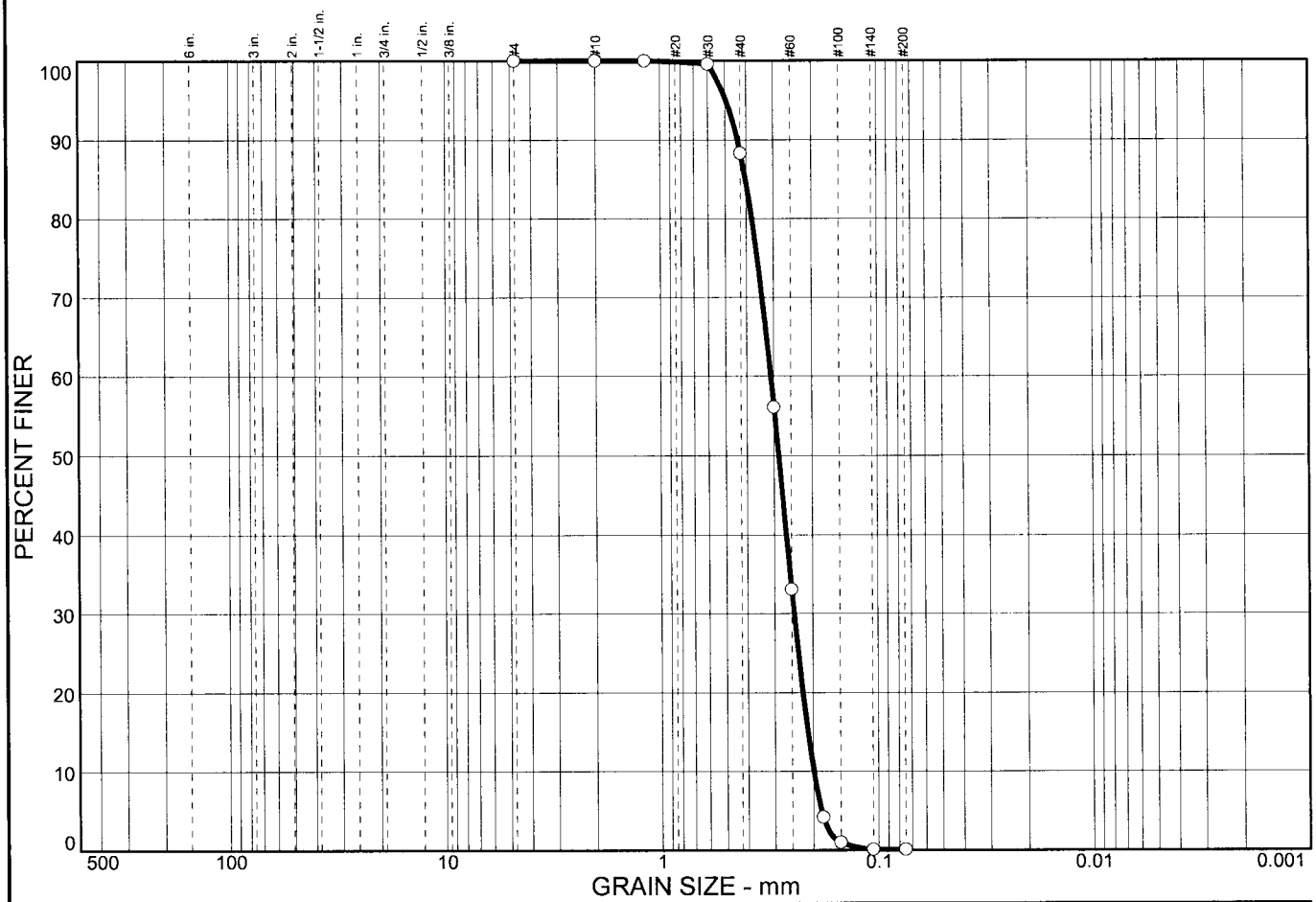
OV-31
Sample D

Sample No.: D **Source of Sample:** **Date:** 4/2/04
Location: OV-31 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 31D

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.9	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	99.6		
#40	88.3		
#50	56.1		
#60	33.1		
#80	4.2		
#100	1.0		
#140	0.1		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.404 D_{60}= 0.310 D_{50}= 0.286
D_{30}= 0.244 D_{15}= 0.211 D_{10}= 0.199
C_u= 1.56 C_c= 0.96

Classification

USCS= SP AASHTO= A-3

Remarks

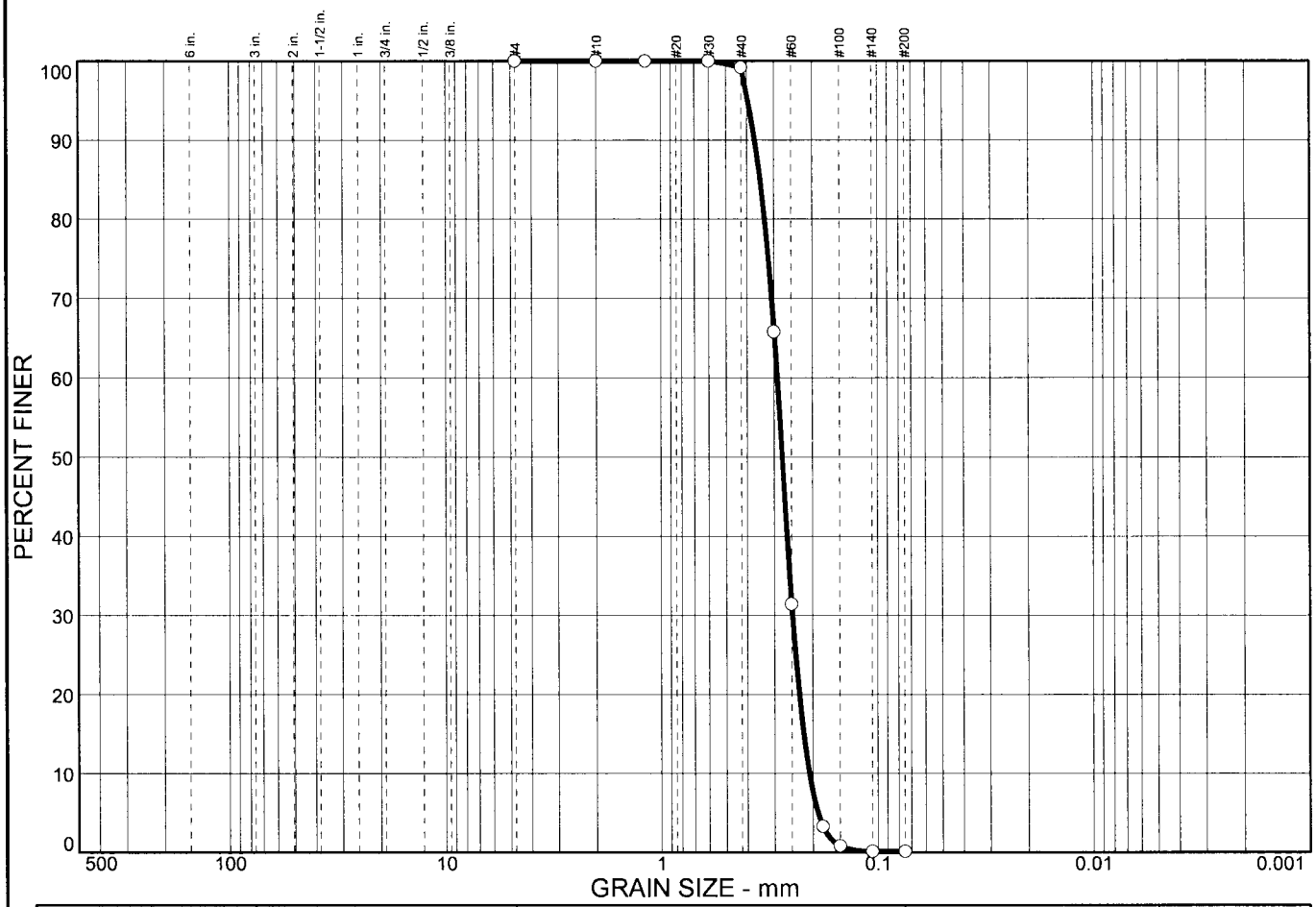
OV-32
Sample A

Sample No.: A **Source of Sample:** **Date:** 4/2/04
Location: OV-32 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 32A

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.9	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	100.0		
#40	99.2		
#50	65.8		
#60	31.4		
#80	3.3		
#100	0.8		
#140	0.1		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.348 D_{60}= 0.290 D_{50}= 0.276
D_{30}= 0.248 D_{15}= 0.221 D_{10}= 0.208
C_u= 1.40 C_c= 1.02

Classification

USCS= SP AASHTO= A-3

Remarks

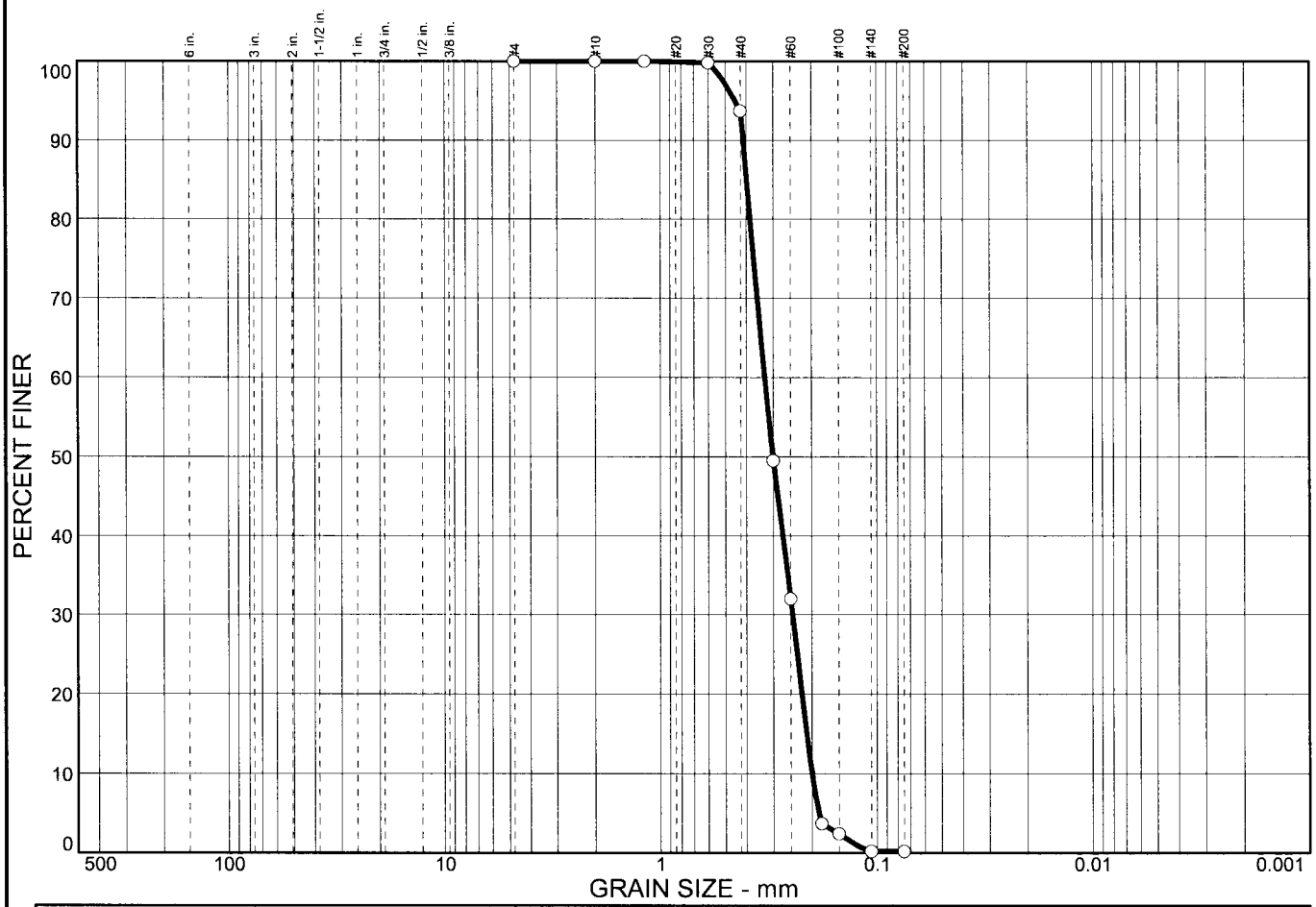
OV-32
Sample B

Sample No.: B **Source of Sample:** **Date:** 4/2/04
Location: OV-32 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 32B

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.8	0.2	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	99.8		
#40	93.7		
#50	49.5		
#60	32.0		
#80	3.7		
#100	2.4		
#140	0.2		
#200	0.2		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.399 D_{60}= 0.329 D_{50}= 0.301
D_{30}= 0.245 D_{15}= 0.211 D_{10}= 0.200
C_u= 1.65 C_c= 0.91

Classification

USCS= SP AASHTO= A-3

Remarks

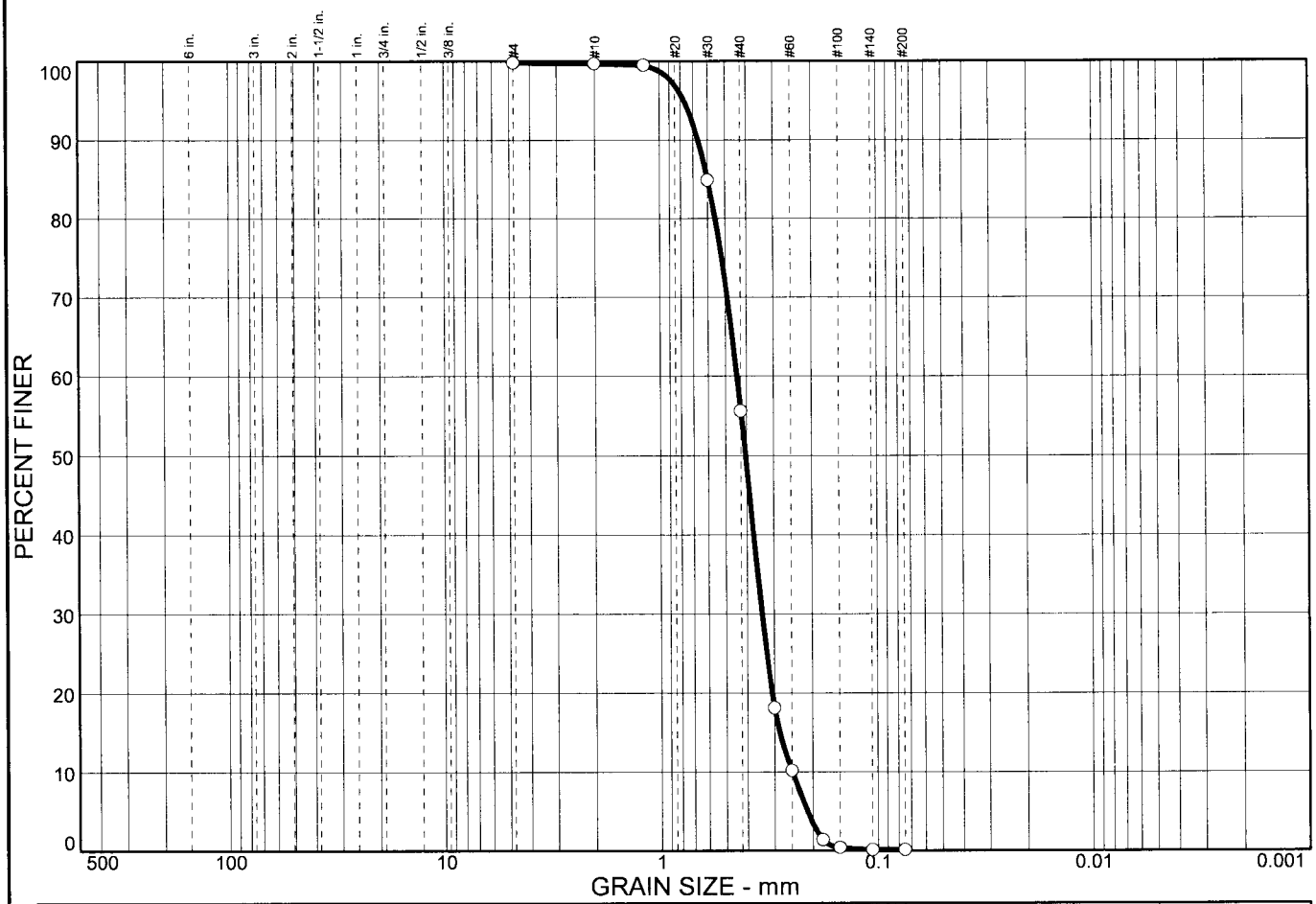
OV-32
Sample C

Sample No.: C **Source of Sample:** **Date:** 4/2/04
Location: OV-32 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 32C

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		99.7	0.3	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	99.8		
#10	99.7		
#16	99.5		
#30	84.9		
#40	55.6		
#50	18.1		
#60	10.2		
#80	1.4		
#100	0.4		
#140	0.1		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.601 D_{60}= 0.442 D_{50}= 0.405
D_{30}= 0.342 D_{15}= 0.284 D_{10}= 0.248
C_u= 1.78 C_c= 1.06

Classification

USCS= SP AASHTO= A-3

Remarks

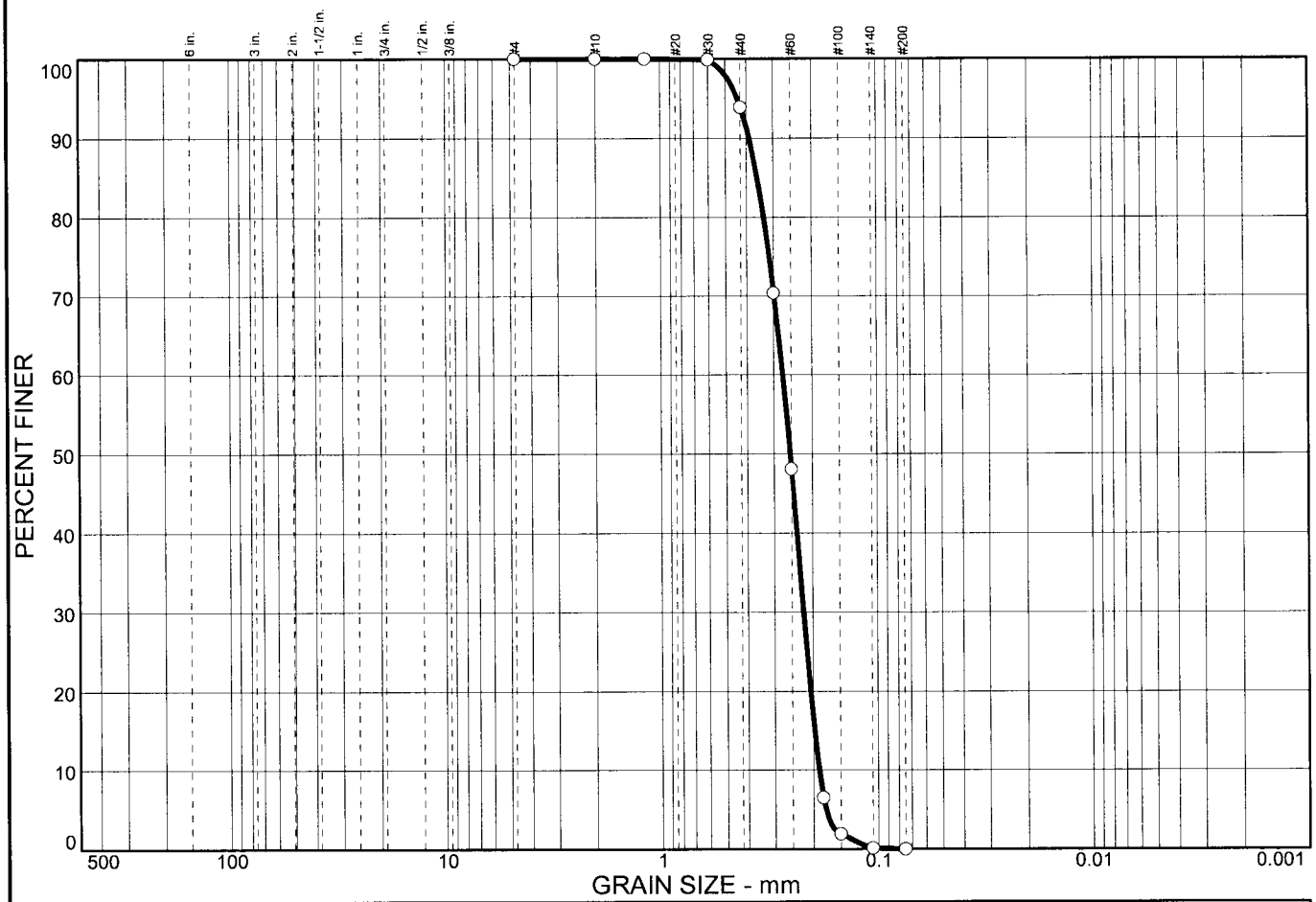
OV-32
Sample D

Sample No.: D **Source of Sample:** **Date:** 4/2/04
Location: OV-32 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 32D

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	100.0	0.0	0.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	99.9		
#40	93.9		
#50	70.4		
#60	48.1		
#80	6.5		
#100	1.9		
#140	0.1		
#200	0.0		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.357 D_{60}= 0.274 D_{50}= 0.253
D_{30}= 0.221 D_{15}= 0.197 D_{10}= 0.188
C_u= 1.45 C_c= 0.95

Classification

USCS= SP AASHTO= A-3

Remarks

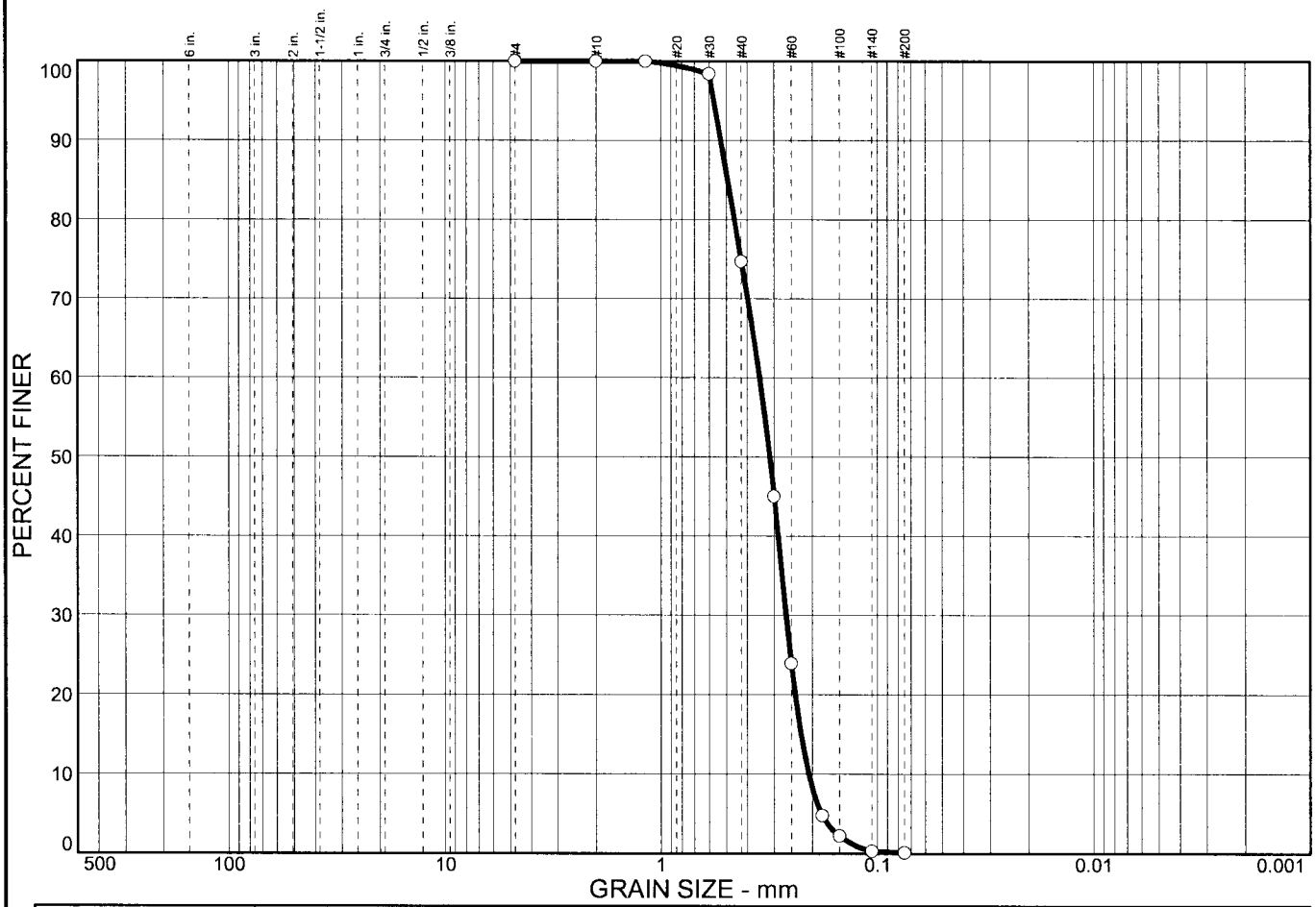
OV-33
Sample A

Sample No.: A **Source of Sample:** **Date:** 4/21/04
Location: OV-33 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 33A

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.9	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	98.4		
#40	74.7		
#50	45.0		
#60	23.9		
#80	4.8		
#100	2.2		
#140	0.3		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.493 D_{60}= 0.350 D_{50}= 0.314
D_{30}= 0.264 D_{15}= 0.226 D_{10}= 0.208
C_u= 1.69 C_c= 0.96

Classification

USCS= SP AASHTO= A-3

Remarks

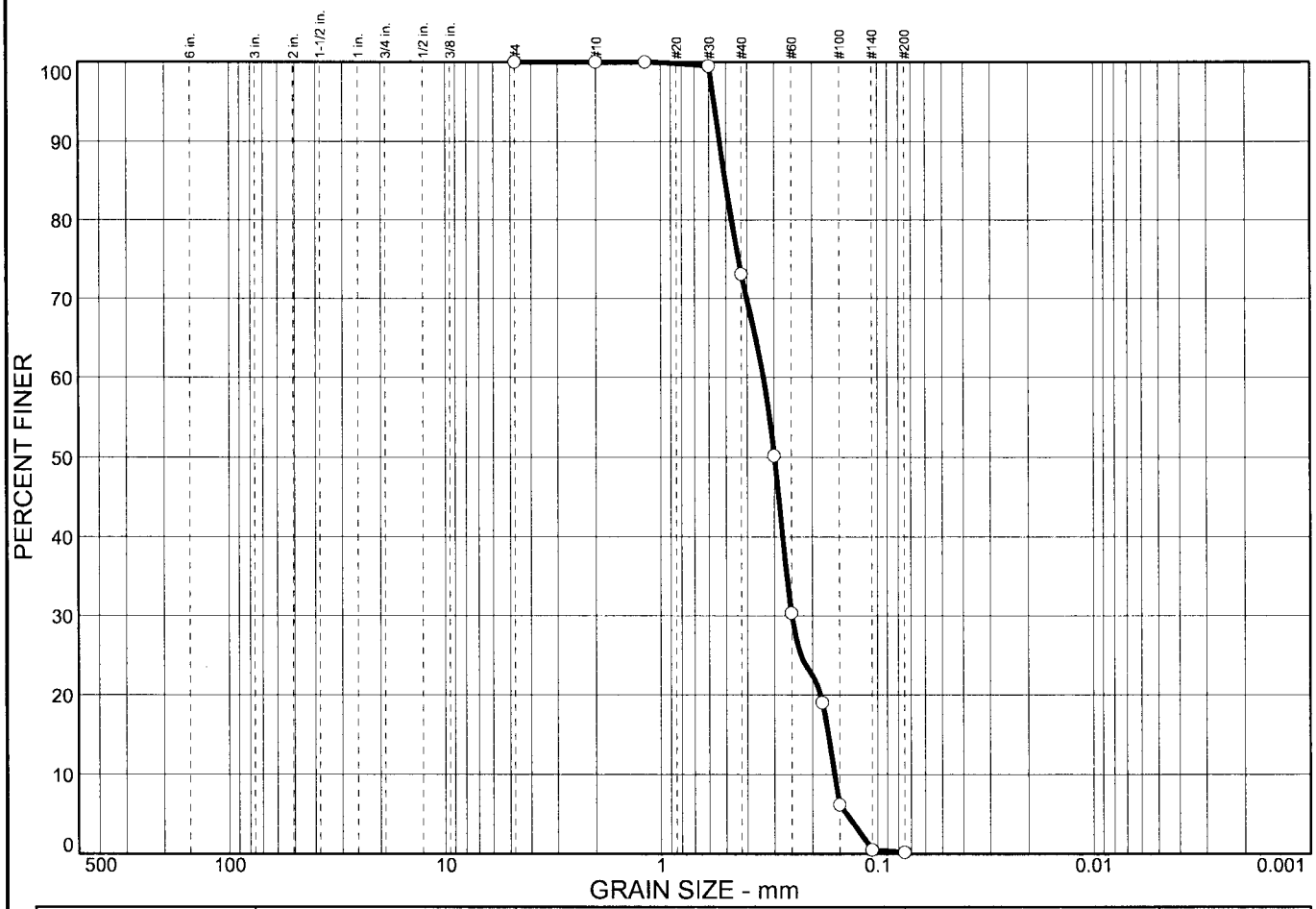
OV-33
Sample B

Sample No.: B **Source of Sample:** **Date:** 4/21/04
Location: OV-33 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 33B

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.8	0.2	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	99.5		
#40	73.1		
#50	50.2		
#60	30.3		
#80	19.0		
#100	6.2		
#140	0.5		
#200	0.2		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.504 D_{60}= 0.337 D_{50}= 0.299
D_{30}= 0.249 D_{15}= 0.169 D_{10}= 0.158
C_u= 2.13 C_c= 1.16

Classification

USCS= SP AASHTO= A-3

Remarks

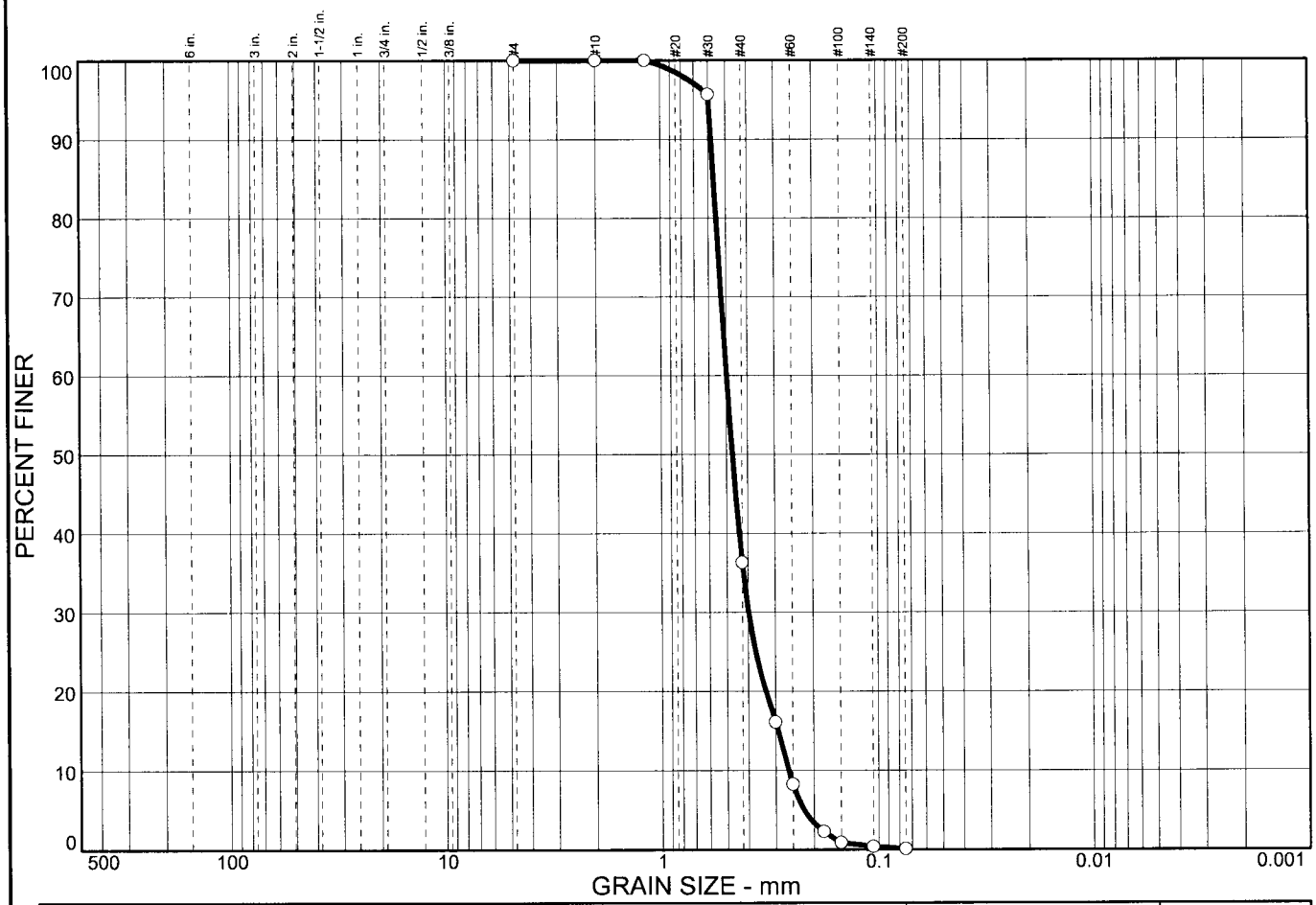
OV-33
Sample C

Sample No.: C **Source of Sample:** **Date:** 4/21/04
Location: OV-33 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 33C

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.9	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	95.7		
#40	36.3		
#50	16.1		
#60	8.3		
#80	2.3		
#100	0.9		
#140	0.4		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.569 D_{60}= 0.499 D_{50}= 0.470
D_{30}= 0.398 D_{15}= 0.292 D_{10}= 0.261
C_u= 1.91 C_c= 1.22

Classification

USCS= SP AASHTO= A-1-b

Remarks

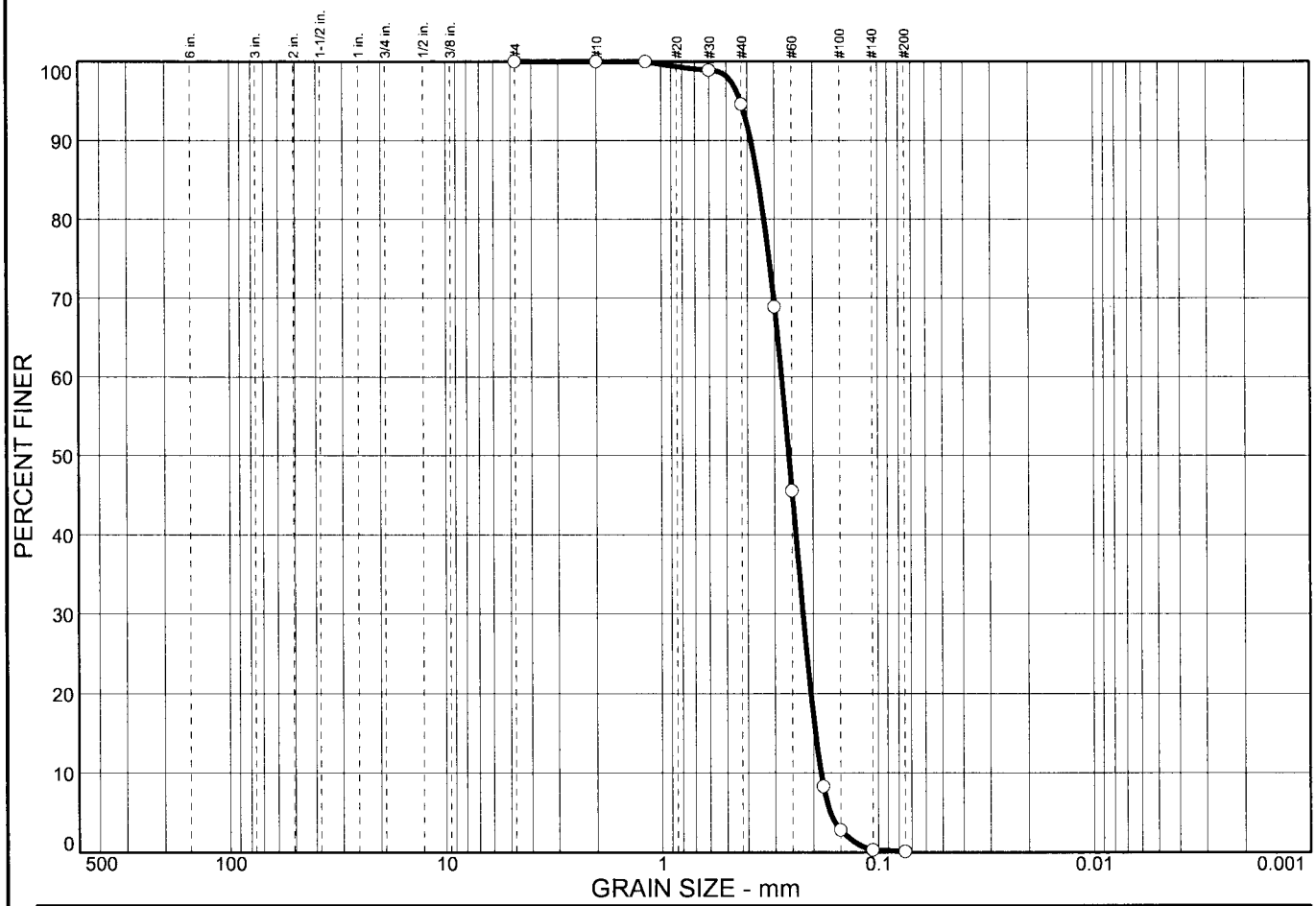
OV-33
Sample A

Sample No.: D **Source of Sample:** **Date:** 4/21/04
Location: OV-33 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 33D

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.9	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	98.9		
#40	94.6		
#50	68.9		
#60	45.5		
#80	8.3		
#100	2.8		
#140	0.3		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.357 D_{60}= 0.279 D_{50}= 0.258
D_{30}= 0.223 D_{15}= 0.196 D_{10}= 0.185
C_u= 1.51 C_c= 0.97

Classification

USCS= SP AASHTO= A-3

Remarks

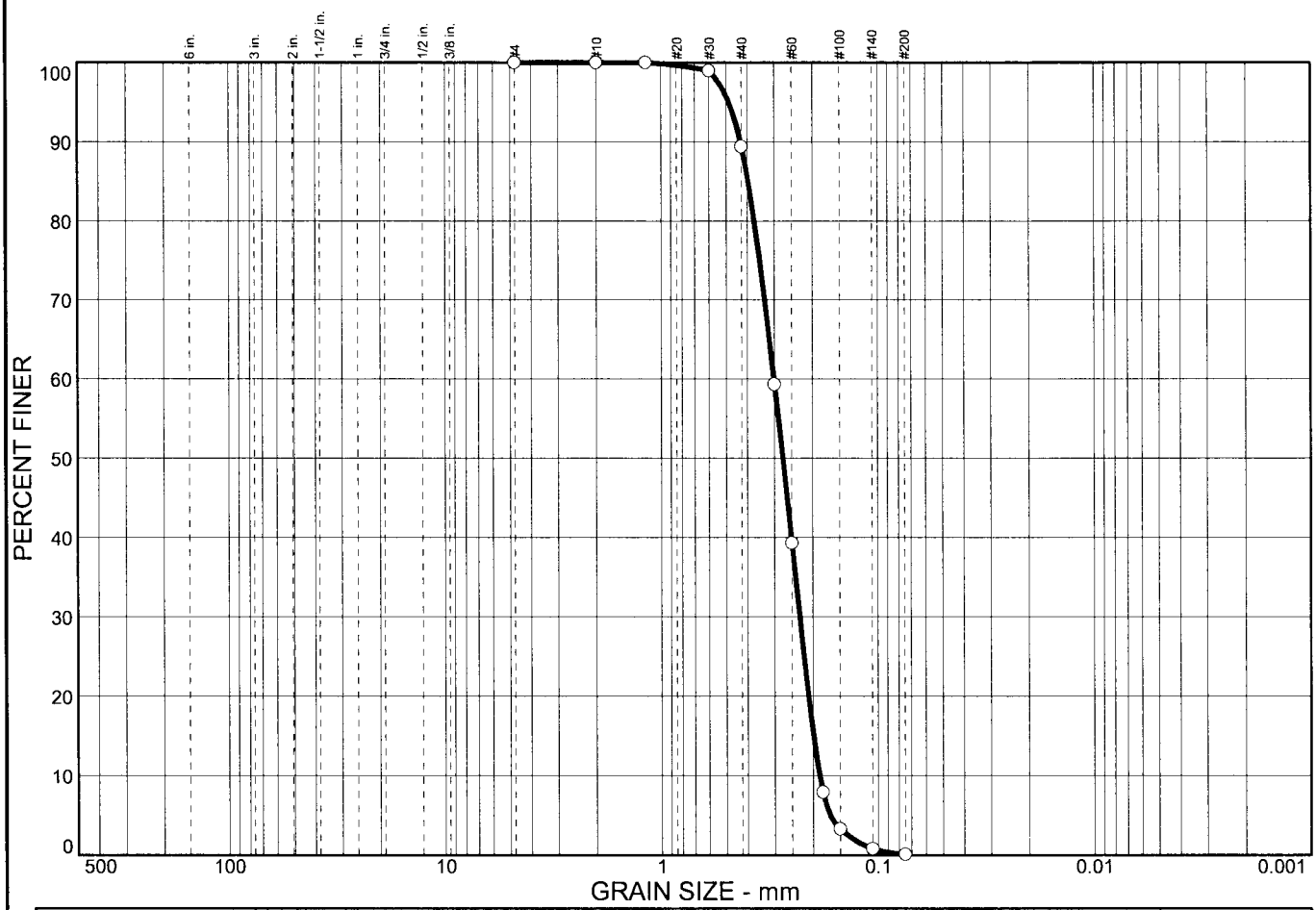
OV-34
Sample A

Sample No.: A **Source of Sample:** **Date:** 4/2/04
Location: OV-34 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 34A

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.9	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	100.0		
#30	99.0		
#40	89.4		
#50	59.3		
#60	39.3		
#80	7.9		
#100	3.3		
#140	0.8		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.397 D_{60}= 0.302 D_{50}= 0.275
D_{30}= 0.230 D_{15}= 0.199 D_{10}= 0.187
C_u= 1.62 C_c= 0.94

Classification

USCS= SP AASHTO= A-3

Remarks

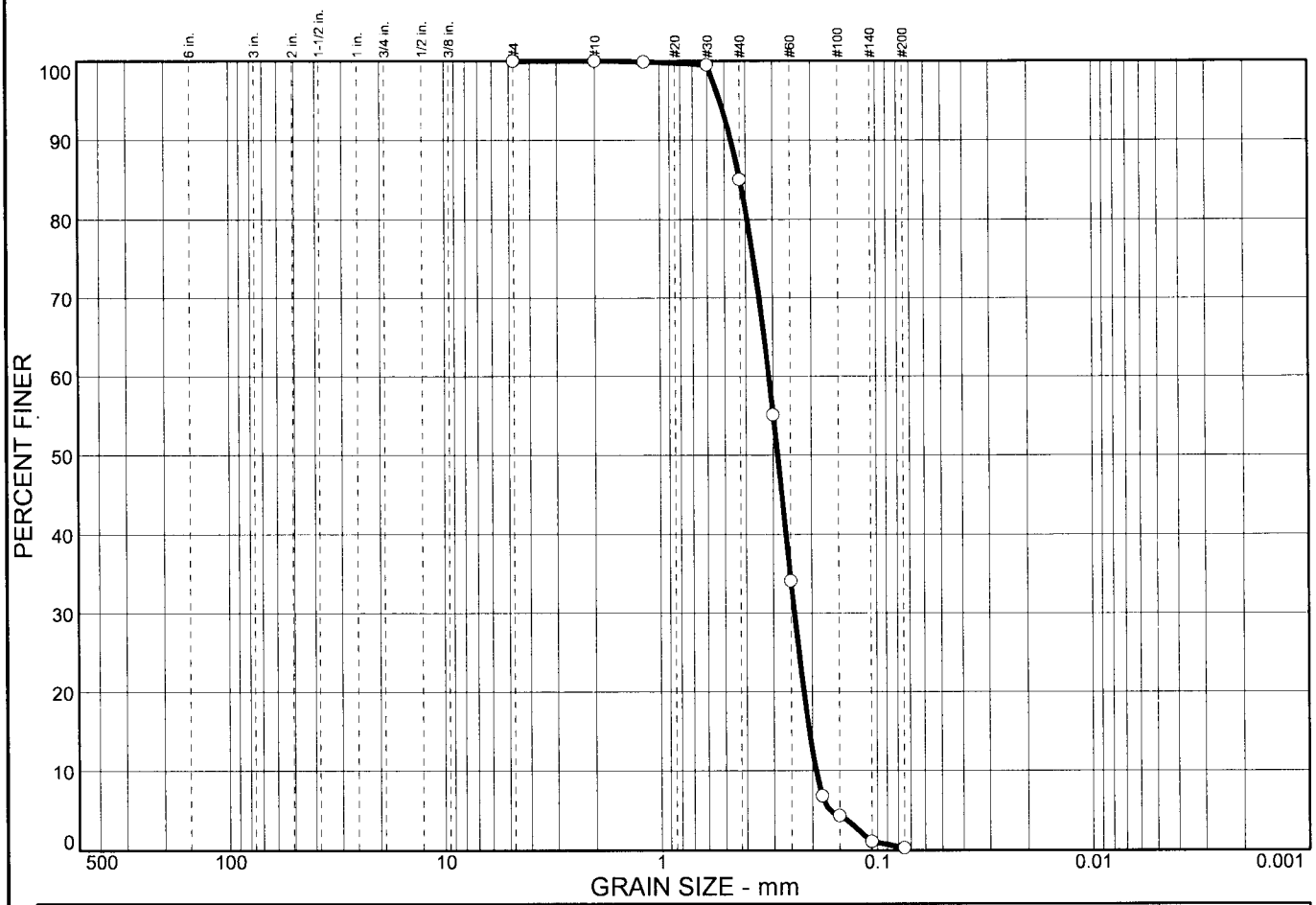
OV-34
Sample B

Sample No.: B **Source of Sample:** **Date:** 4/2/04
Location: OV-34 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 34B

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.7	0.3	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	99.9		
#30	99.5		
#40	85.1		
#50	55.1		
#60	34.1		
#80	6.8		
#100	4.3		
#140	1.1		
#200	0.3		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.424 D_{60}= 0.314 D_{50}= 0.287
D_{30}= 0.241 D_{15}= 0.207 D_{10}= 0.192
C_u= 1.63 C_c= 0.96

Classification

USCS= SP AASHTO= A-3

Remarks

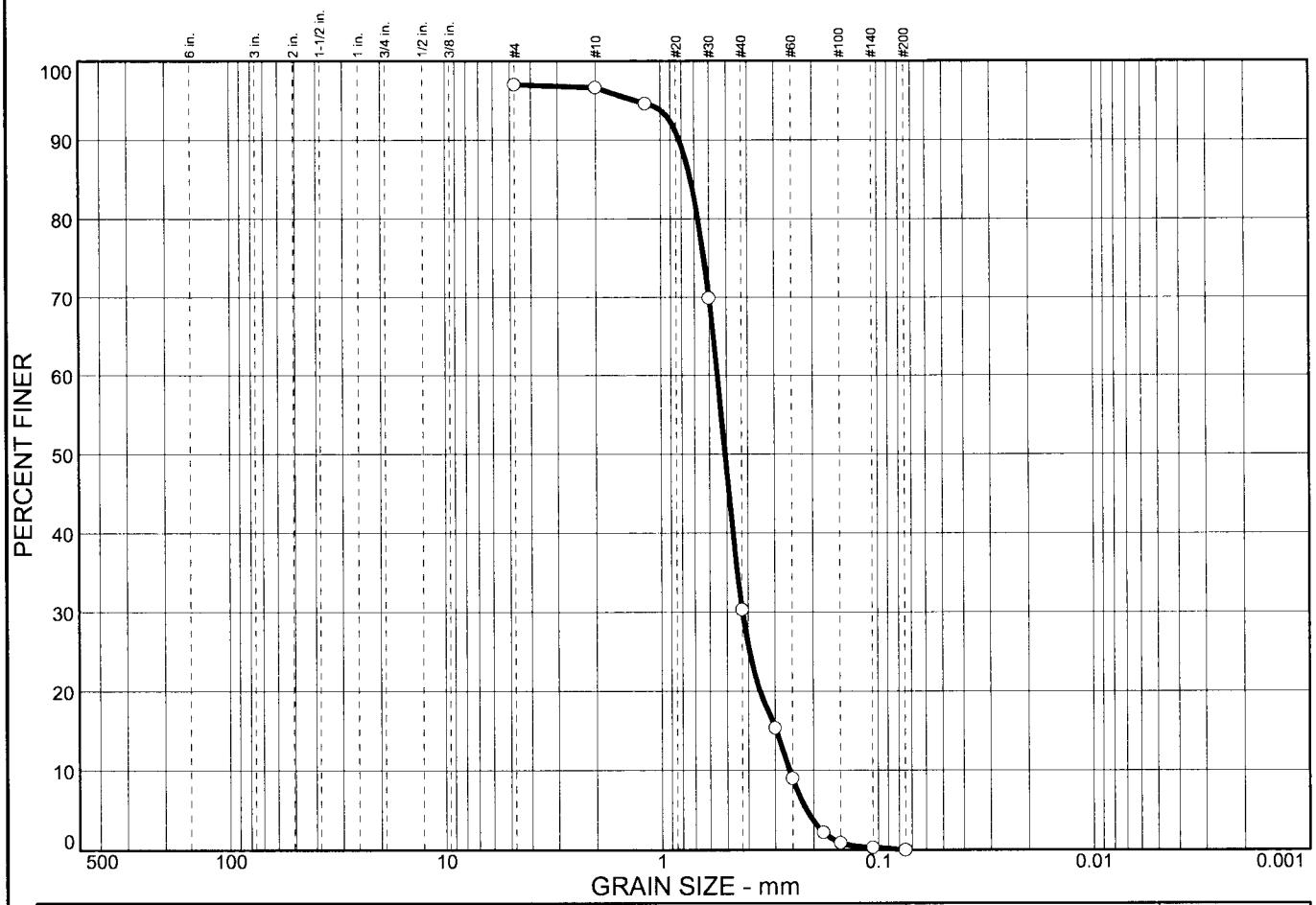
OV-34
Sample C

Sample No.: C **Source of Sample:** **Date:** 4/2/04
Location: OV-34 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 34C

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		97.0	0.0	0.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	97.0		
#10	96.6		
#16	94.6		
#30	69.9		
#40	30.3		
#50	15.3		
#60	9.0		
#80	2.2		
#100	0.9		
#140	0.3		
#200	0.0		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.729 D_{60}= 0.550 D_{50}= 0.508
D_{30}= 0.423 D_{15}= 0.297 D_{10}= 0.258
C_u= 2.14 C_c= 1.27

Classification

USCS= SP AASHTO= A-1-b

Remarks

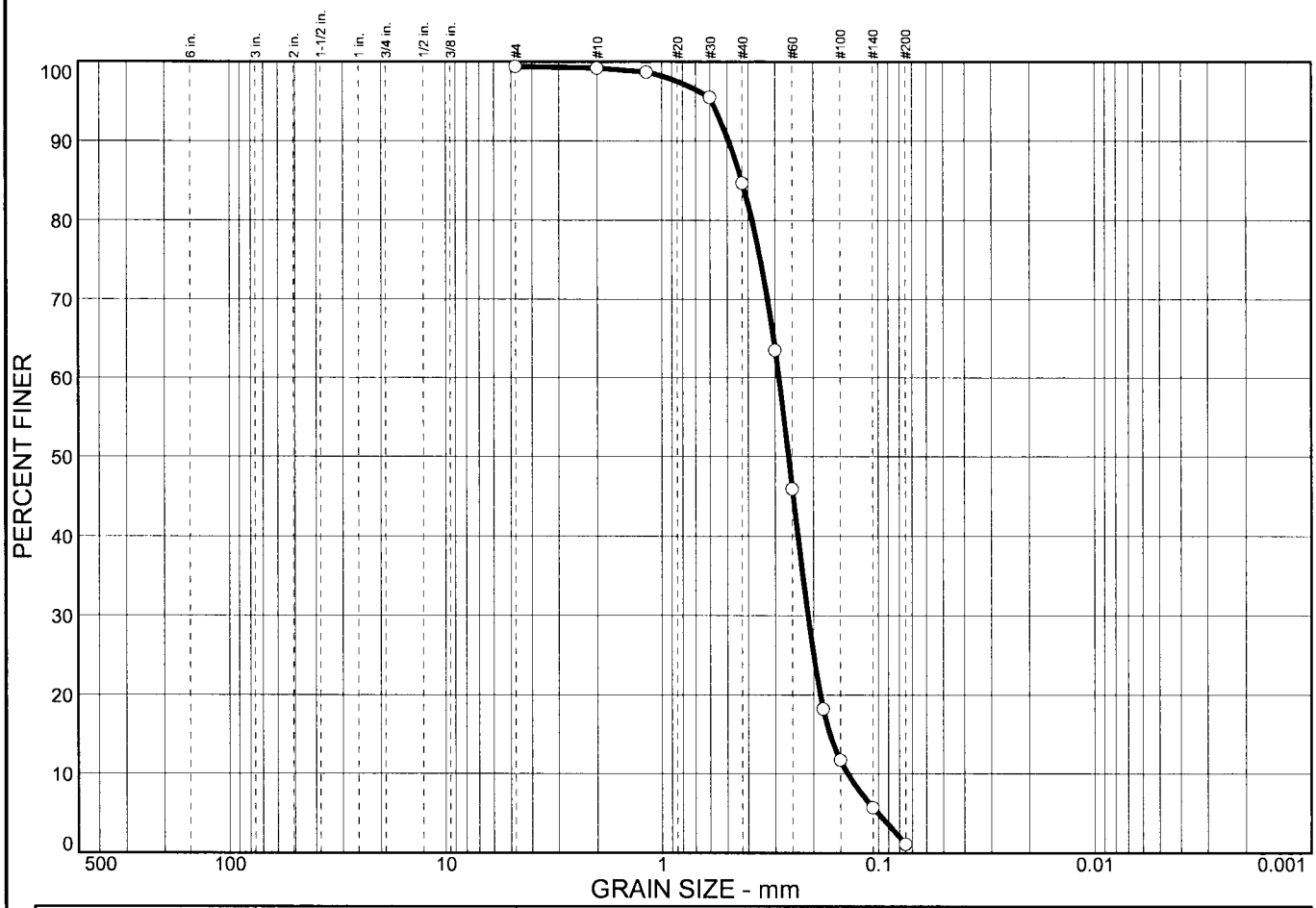
OV-34
Sample D

Sample No.: D **Source of Sample:** **Date:** 4/2/04
Location: OV-34 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 34D

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		98.3	1.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	99.4		
#10	99.2		
#16	98.7		
#30	95.5		
#40	84.7		
#50	63.5		
#60	45.9		
#80	18.2		
#100	11.7		
#140	5.7		
#200	1.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.428 D_{60}= 0.288 D_{50}= 0.260
D_{30}= 0.212 D_{15}= 0.168 D_{10}= 0.139
C_u= 2.08 C_c= 1.12

Classification

USCS= SP AASHTO= A-3

Remarks

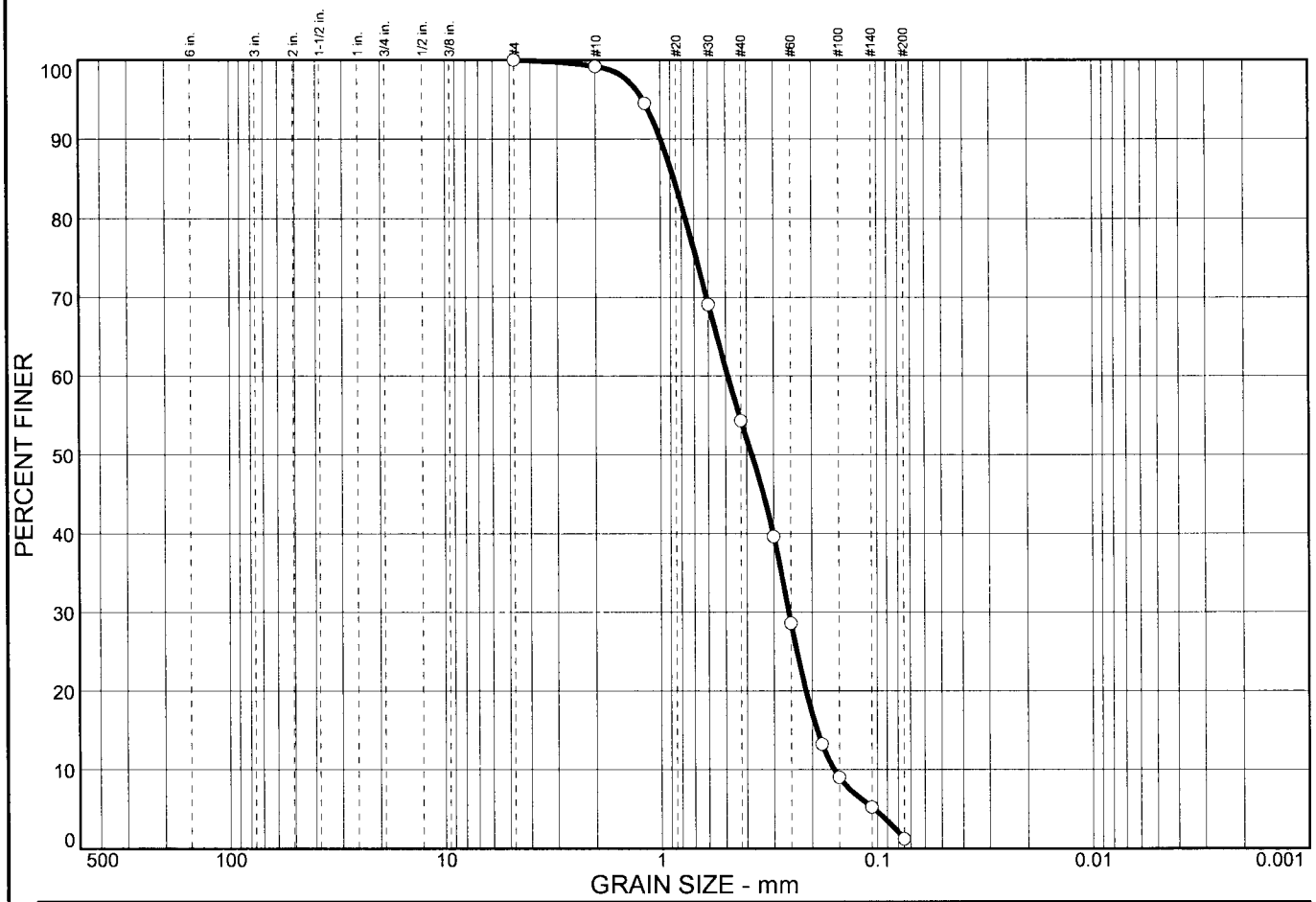
OV-35
Sample A

Sample No.: A **Source of Sample:** **Date:** 4/21/04
Location: OV-35 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 35A

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	98.8	1.2	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.2		
#16	94.5		
#30	69.1		
#40	54.3		
#50	39.6		
#60	28.6		
#80	13.2		
#100	9.0		
#140	5.2		
#200	1.2		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.868 D_{60}= 0.488 D_{50}= 0.379
D_{30}= 0.256 D_{15}= 0.190 D_{10}= 0.159
C_u= 3.08 C_c= 0.85

Classification

USCS= SP AASHTO= A-3

Remarks

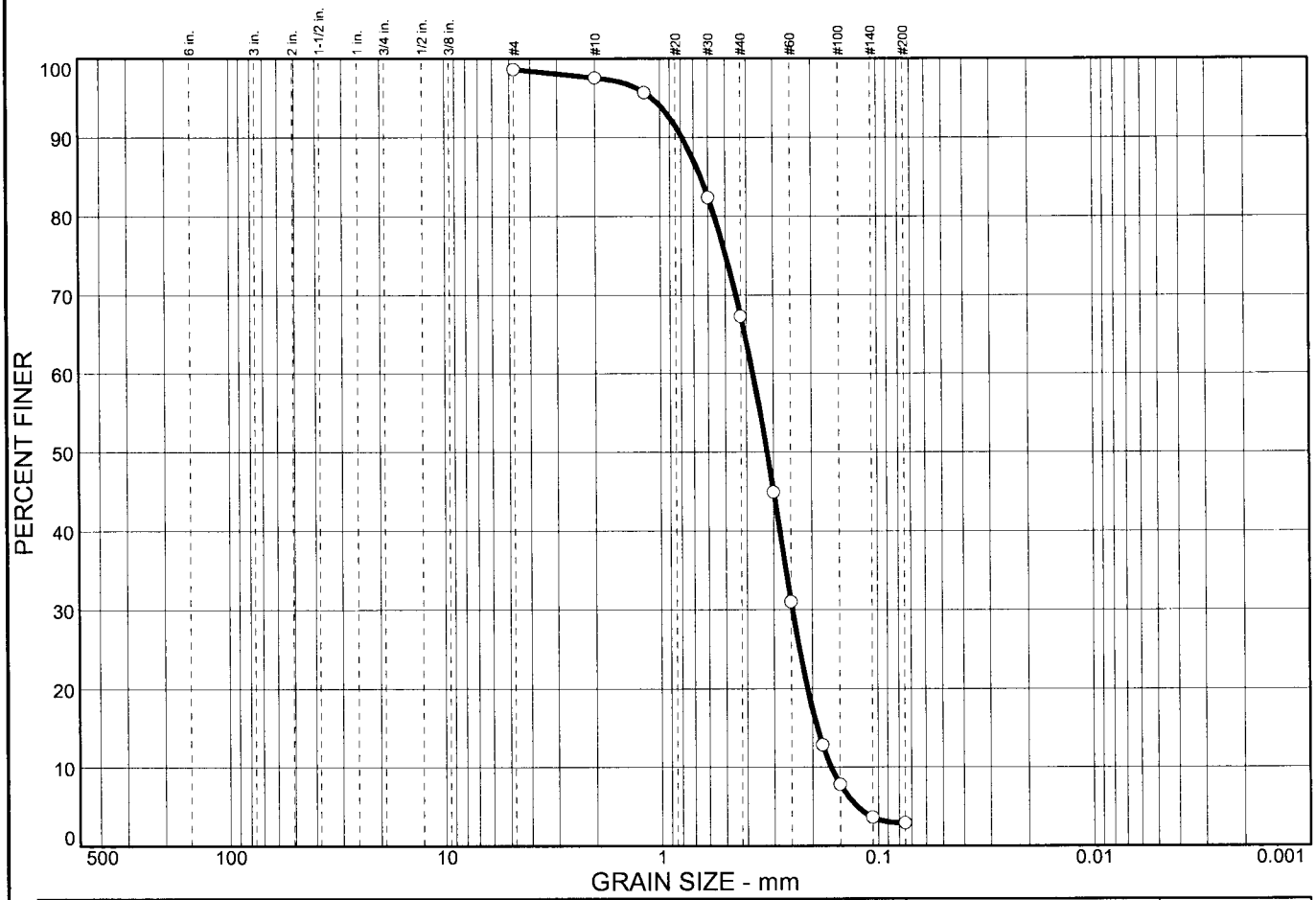
OV-35
Sample B

Sample No.: B **Source of Sample:** **Date:** 4/21/04
Location: OV-35 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 35B

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		95.7	2.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	98.6		
#10	97.5		
#16	95.6		
#30	82.4		
#40	67.3		
#50	44.9		
#60	31.0		
#80	12.8		
#100	7.8		
#140	3.6		
#200	2.9		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.651 D_{60}= 0.374 D_{50}= 0.322
D_{30}= 0.247 D_{15}= 0.190 D_{10}= 0.165
C_u= 2.27 C_c= 0.99

Classification

USCS= SP AASHTO= A-3

Remarks

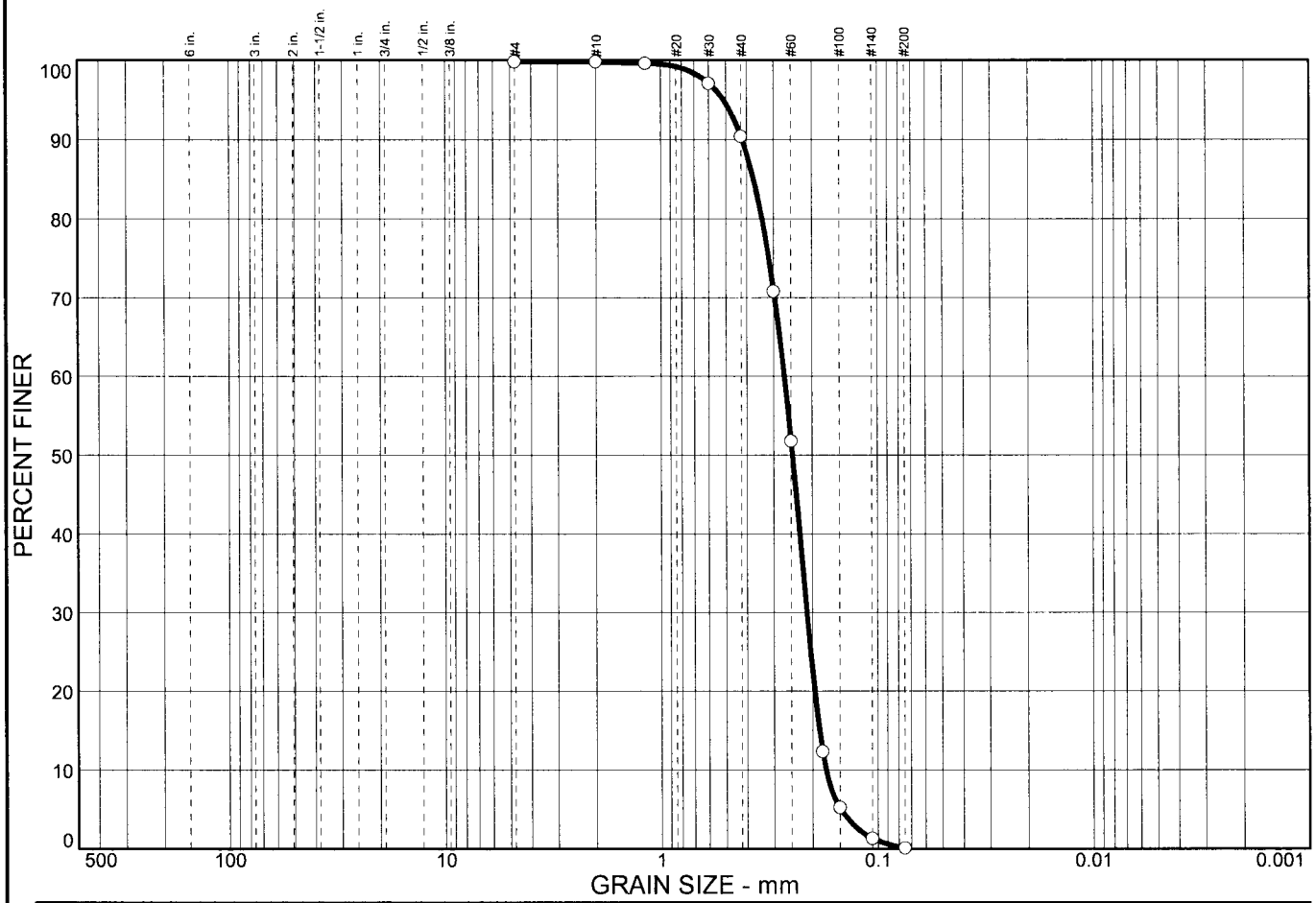
OV-35
Sample C

Sample No.: C **Source of Sample:** **Date:** 4/22/04
Location: OV-35 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 35C

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		99.7	0.3	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	99.8		
#10	99.8		
#16	99.6		
#30	97.1		
#40	90.4		
#50	70.8		
#60	51.8		
#80	12.3		
#100	5.2		
#140	1.3		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.372 D_{60}= 0.268 D_{50}= 0.246
D_{30}= 0.212 D_{15}= 0.186 D_{10}= 0.174
C_u= 1.54 C_c= 0.97

Classification

USCS= SP AASHTO= A-3

Remarks

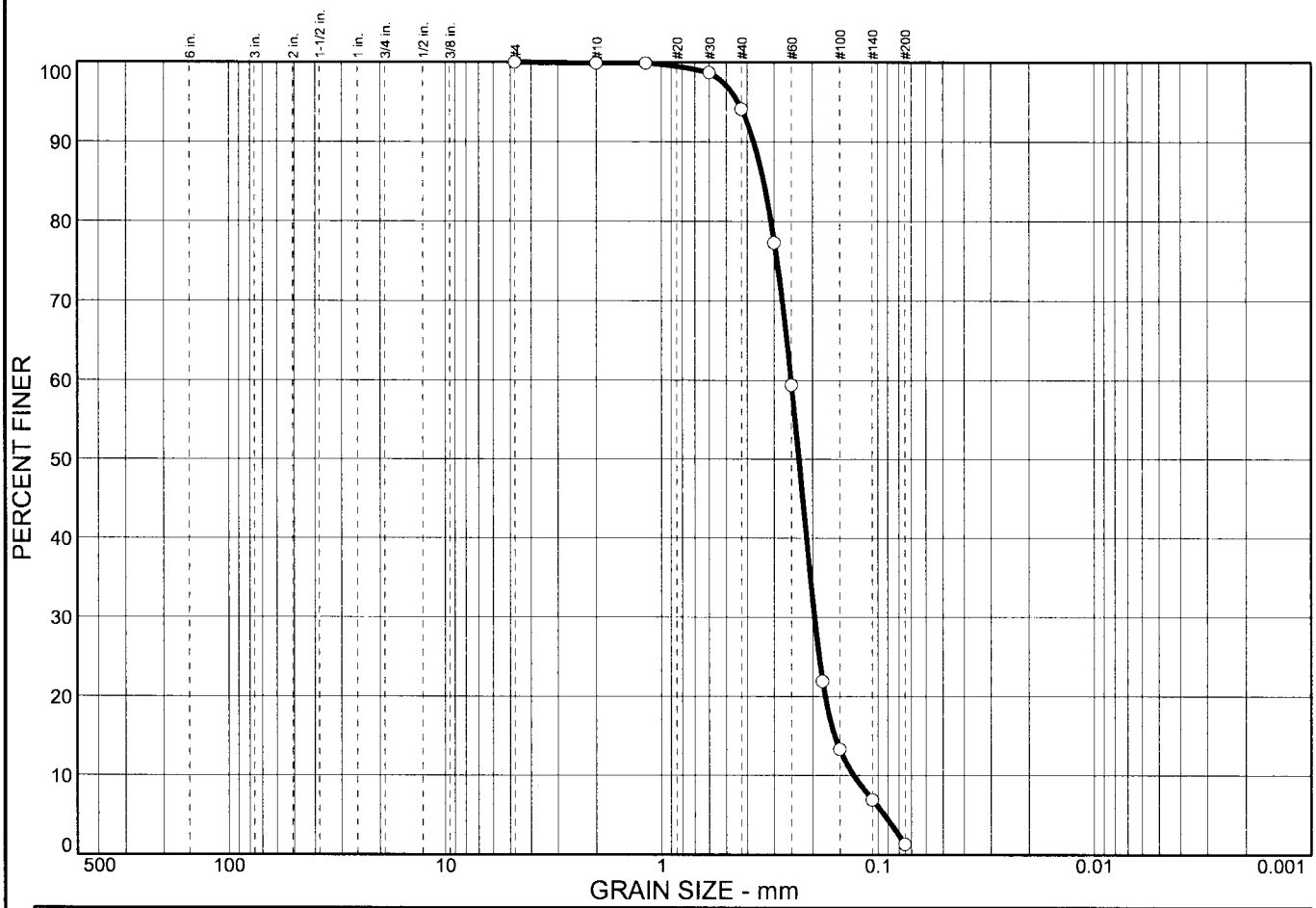
OV-35
Sample D

Sample No.: D **Source of Sample:** **Date:** 4/22/04
Location: OV-35 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 35D

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	98.7	1.3	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.9		
#16	99.9		
#30	98.7		
#40	94.1		
#50	77.3		
#60	59.4		
#80	21.9		
#100	13.3		
#140	6.9		
#200	1.3		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.336 D_{60}= 0.251 D_{50}= 0.232
D_{30}= 0.196 D_{15}= 0.158 D_{10}= 0.130
C_u= 1.94 C_c= 1.18

Classification

USCS= SP AASHTO= A-3

Remarks

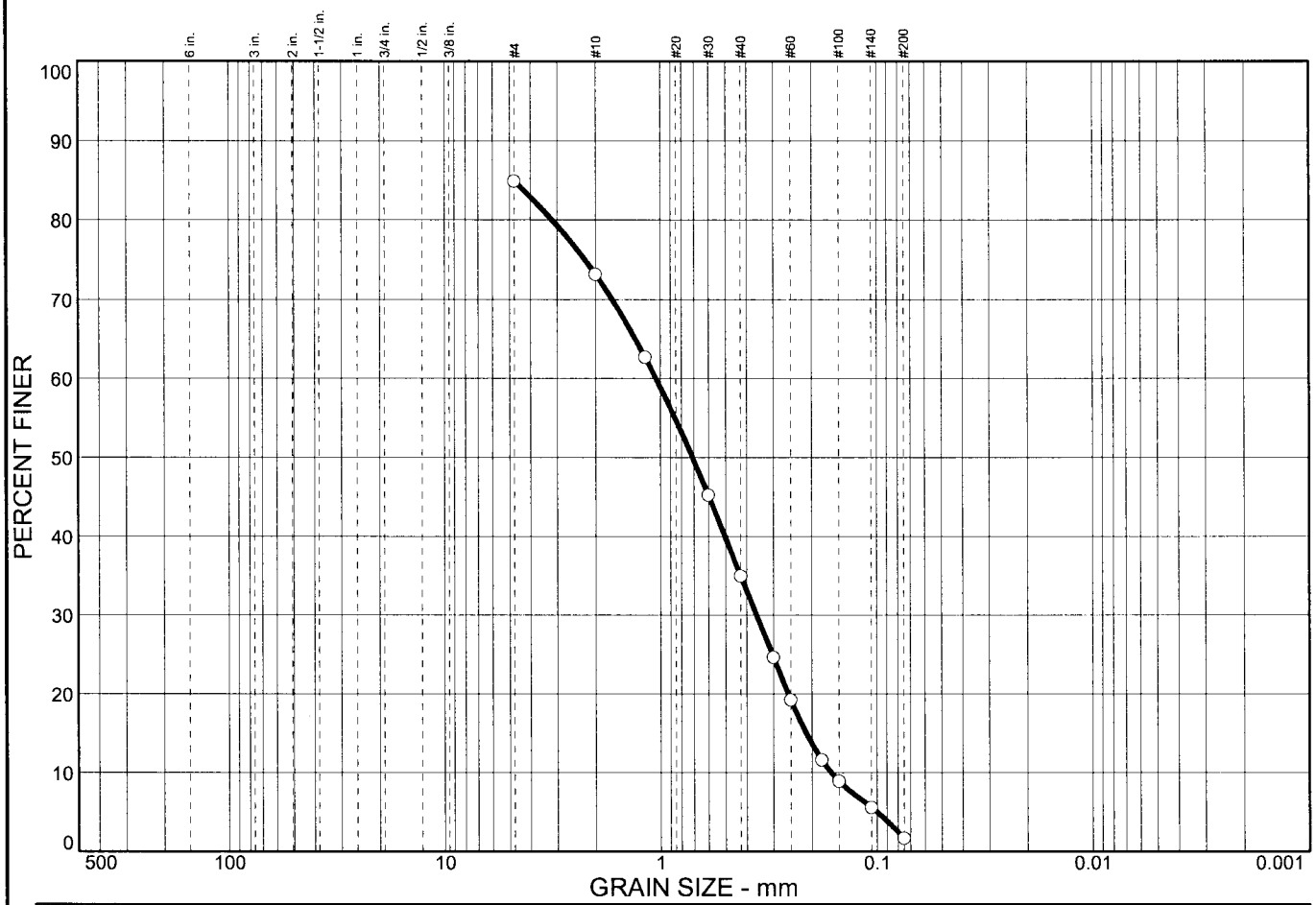
OV-36
Sample A

Sample No.: A **Source of Sample:** **Date:** 4/22/04
Location: OV-36 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 36A

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		83.2	1.7	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	84.9		
#10	73.2		
#16	62.7		
#30	45.2		
#40	34.9		
#50	24.6		
#60	19.2		
#80	11.6		
#100	8.9		
#140	5.6		
#200	1.7		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= D_{60}= 1.05 D_{50}= 0.711
D_{30}= 0.360 D_{15}= 0.212 D_{10}= 0.163
C_u= 6.44 C_c= 0.76

Classification

USCS= SP AASHTO= A-1-b

Remarks

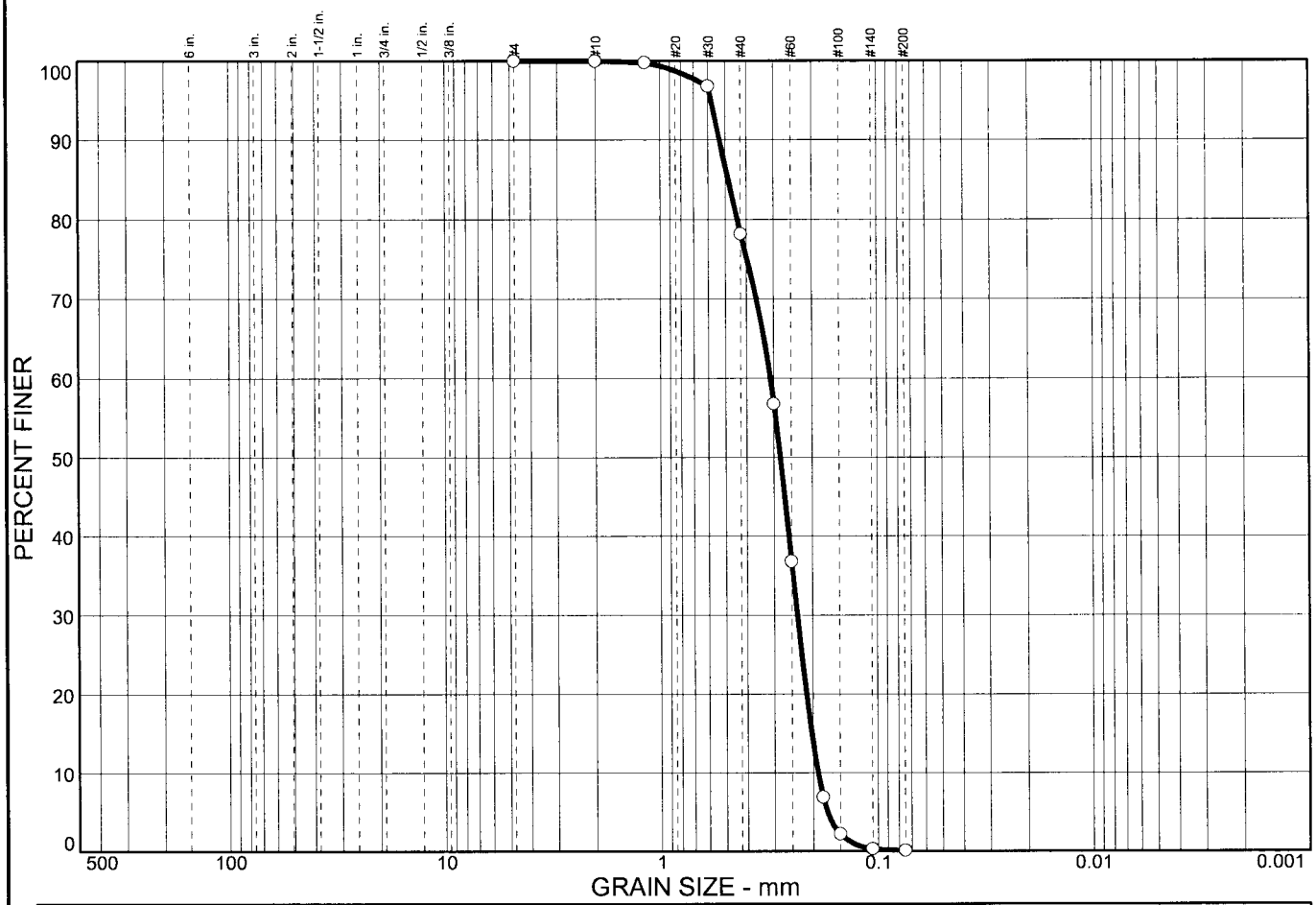
OV-36
Sample B

Sample No.: B **Source of Sample:** **Date:** 4/22/04
Location: OV-36 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 36B

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.9	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	99.8		
#30	96.8		
#40	78.2		
#50	56.8		
#60	36.8		
#80	6.9		
#100	2.2		
#140	0.3		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.485 D_{60}= 0.311 D_{50}= 0.281
D_{30}= 0.236 D_{15}= 0.203 D_{10}= 0.190
C_u= 1.64 C_c= 0.94

Classification

USCS= SP AASHTO= A-3

Remarks

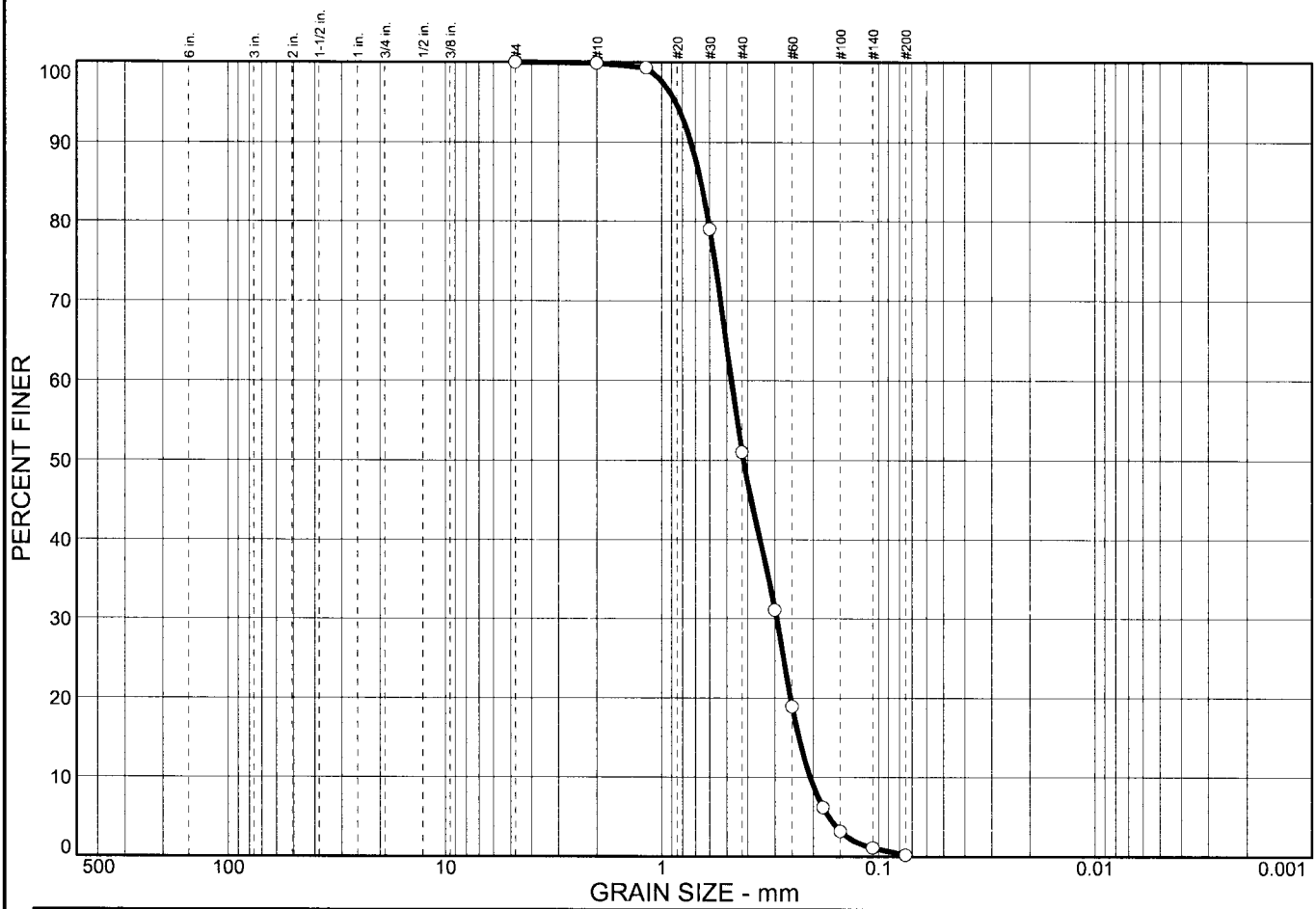
OV-36
Sample C

Sample No.: C **Source of Sample:** **Date:** 4/22/04
Location: OV-36 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 36C

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.8	0.2	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.9		
#16	99.3		
#30	79.0		
#40	51.0		
#50	31.1		
#60	18.9		
#80	6.2		
#100	3.2		
#140	1.1		
#200	0.2		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.660 D_{60}= 0.477 D_{50}= 0.419
D_{30}= 0.295 D_{15}= 0.233 D_{10}= 0.207
C_u= 2.31 C_c= 0.88

Classification

USCS= SP AASHTO= A-3

Remarks

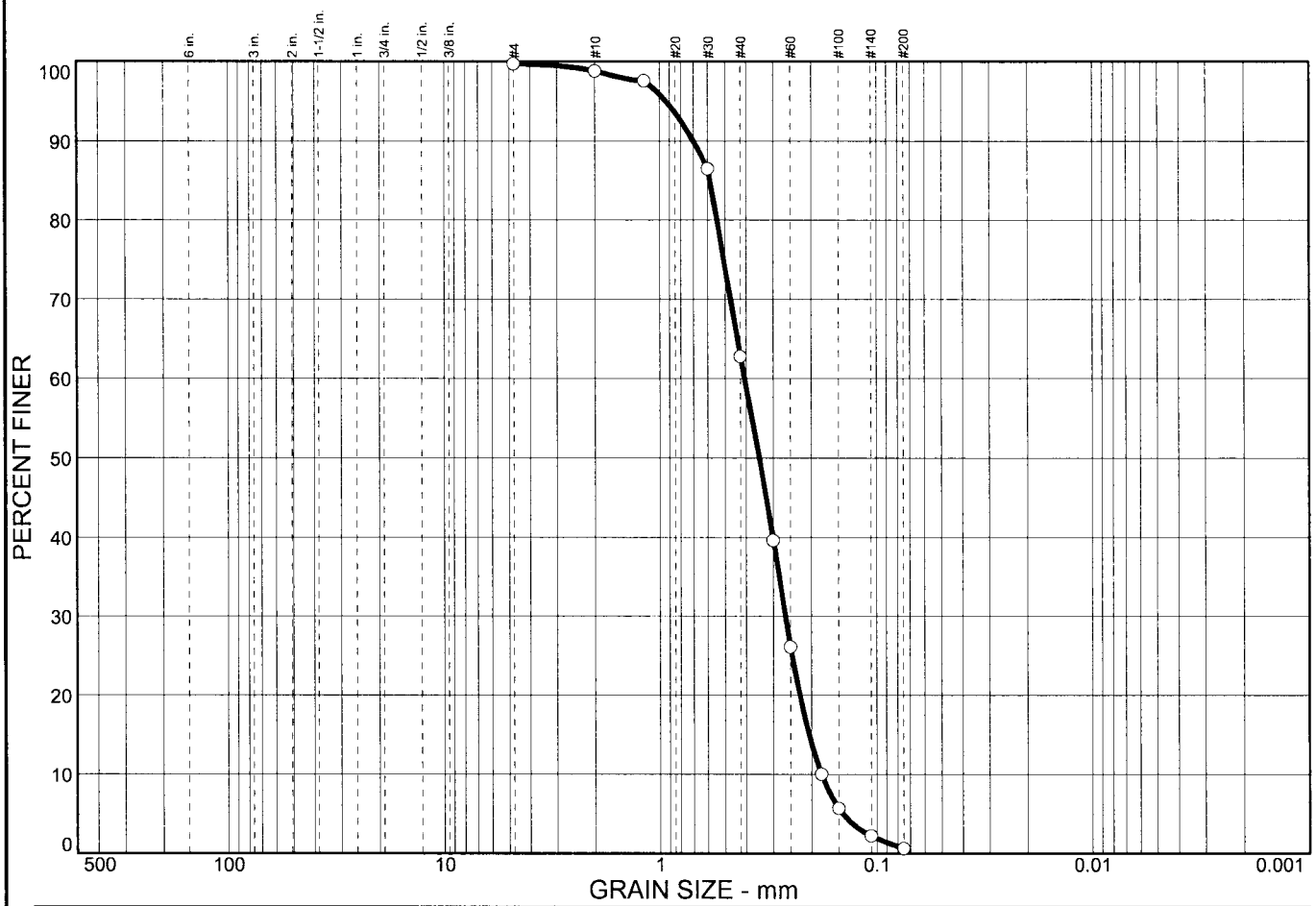
OV-37
Sample A

Sample No.: A **Source of Sample:** **Date:** 4/22/04
Location: OV-37 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 37A

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		99.1	0.6	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	99.7		
#10	98.8		
#16	97.6		
#30	86.5		
#40	62.8		
#50	39.6		
#60	26.1		
#80	10.0		
#100	5.7		
#140	2.2		
#200	0.6		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.587 D_{60}= 0.407 D_{50}= 0.349
D_{30}= 0.264 D_{15}= 0.205 D_{10}= 0.180
C_u= 2.26 C_c= 0.95

Classification

USCS= SP AASHTO= A-3

Remarks

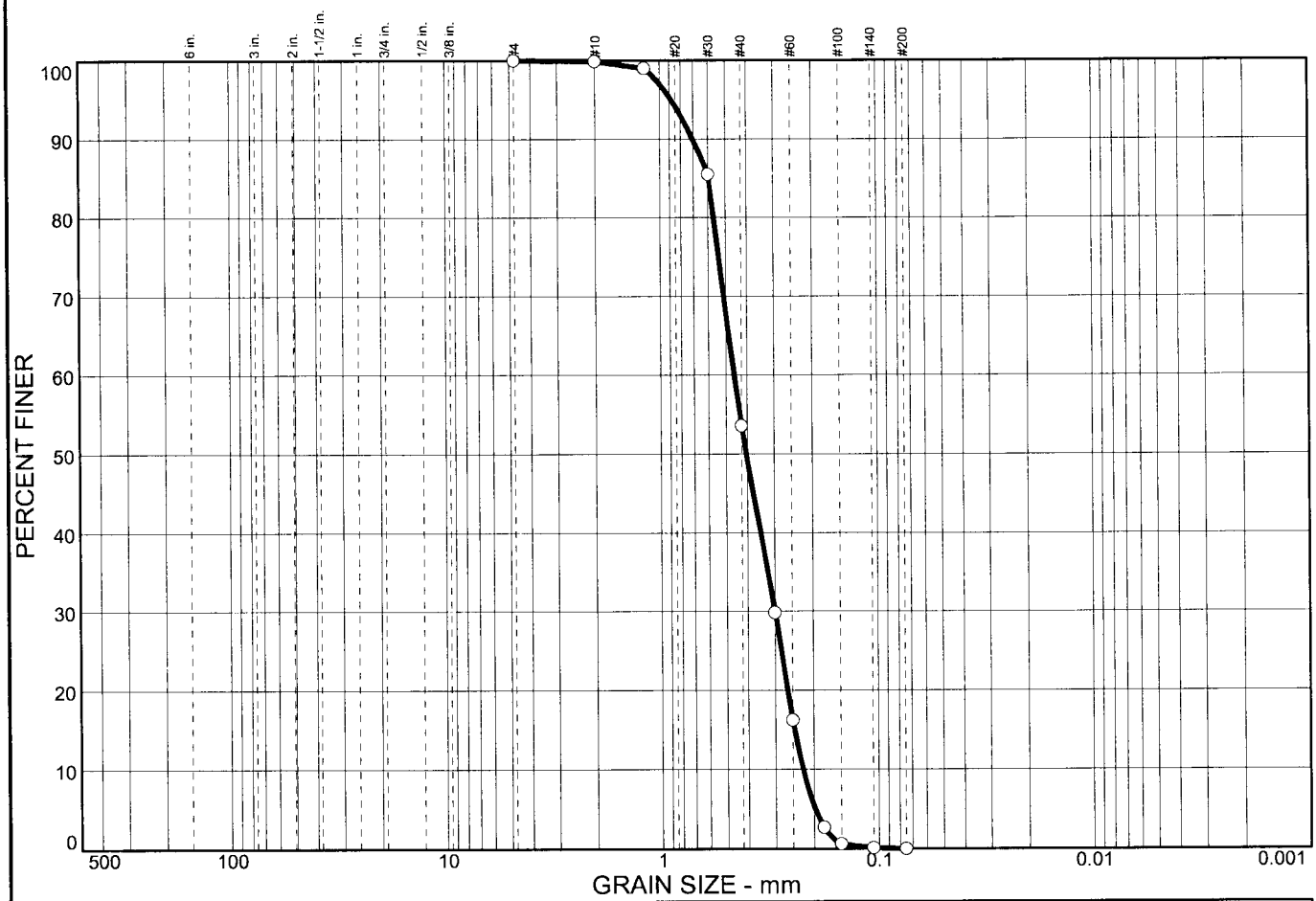
OV-37
Sample B

Sample No.: B **Source of Sample:** **Date:** 4/22/04
Location: OV-37 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 37B

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	100.0	0.0	0.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.9		
#16	99.0		
#30	85.5		
#40	53.6		
#50	29.8		
#60	16.2		
#80	2.7		
#100	0.6		
#140	0.1		
#200	0.0		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.597 D_{60}= 0.459 D_{50}= 0.405
D_{30}= 0.301 D_{15}= 0.245 D_{10}= 0.224
C_u= 2.04 C_c= 0.88

Classification

USCS= SP AASHTO= A-3

Remarks

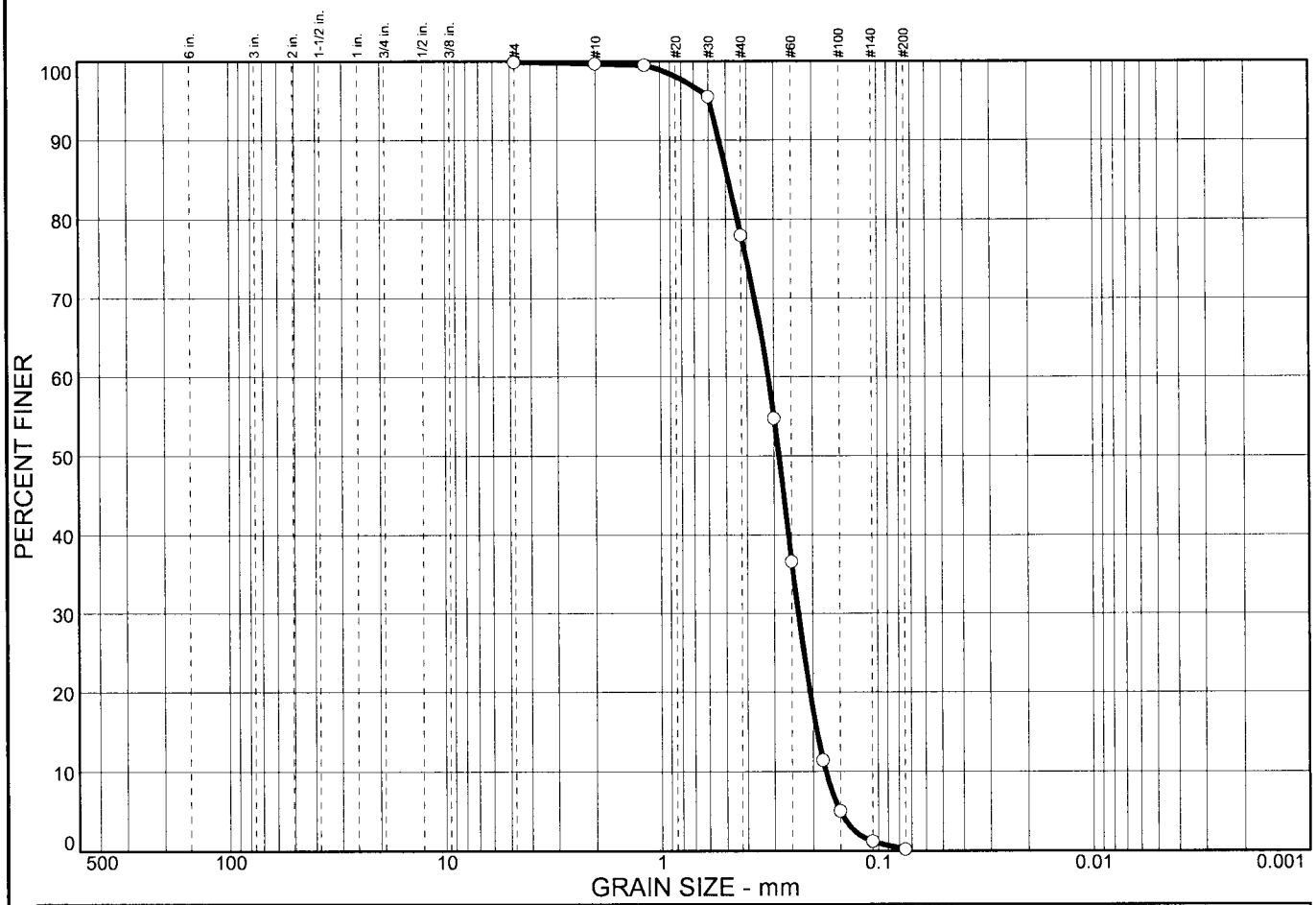
OV-37
Sample C

Sample No.: C **Source of Sample:** **Date:** 4/22/04
Location: OV-37 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 37C

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		99.7	0.3	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	99.9		
#10	99.7		
#16	99.5		
#30	95.5		
#40	78.0		
#50	54.7		
#60	36.6		
#80	11.4		
#100	5.0		
#140	1.2		
#200	0.2		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.486 D_{60}= 0.319 D_{50}= 0.285
D_{30}= 0.233 D_{15}= 0.192 D_{10}= 0.175
C_u= 1.83 C_c= 0.97

Classification

USCS= AASHTO= A-3

Remarks

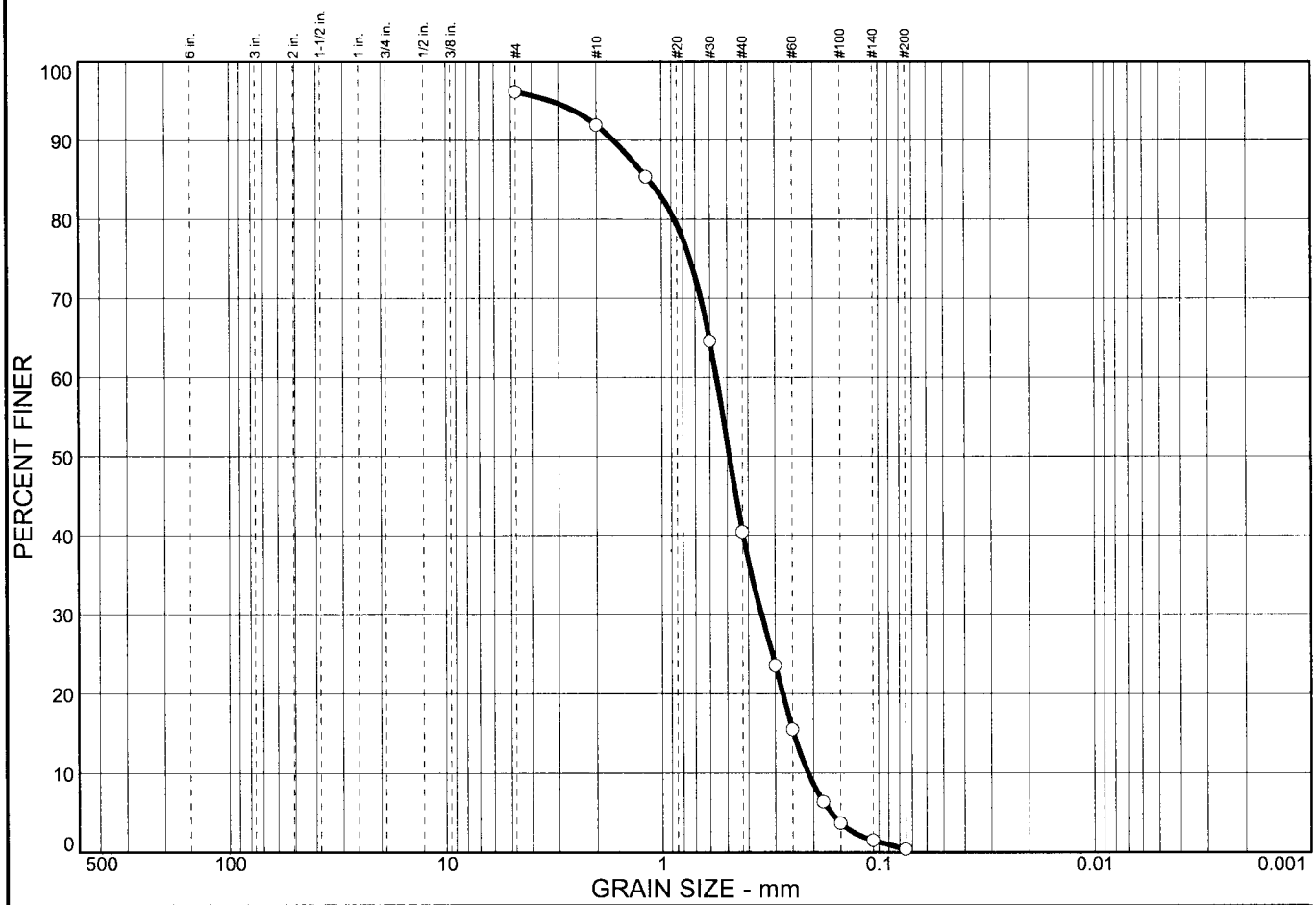
OV-38
Sample A

Sample No.: A **Source of Sample:** **Date:** 4/22/04
Location: OV-38 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 38A

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		95.7	0.4	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	96.1		
#10	91.9		
#16	85.4		
#30	64.6		
#40	40.4		
#50	23.5		
#60	15.5		
#80	6.4		
#100	3.7		
#140	1.5		
#200	0.4		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 1.15 D_{60}= 0.560 D_{50}= 0.488
D_{30}= 0.348 D_{15}= 0.247 D_{10}= 0.211
C_u= 2.65 C_c= 1.02

Classification

USCS= SP AASHTO= A-1-b

Remarks

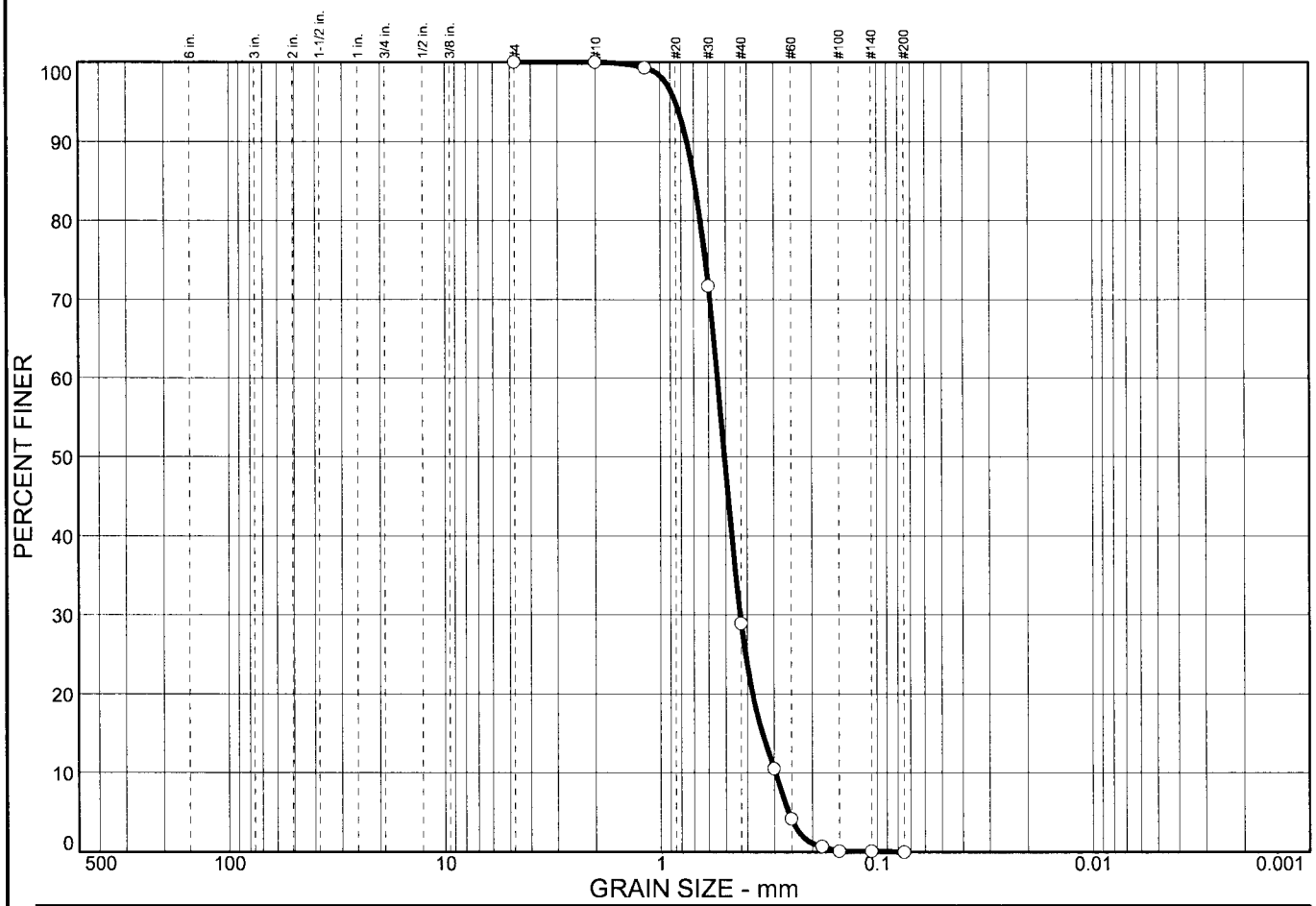
OV-38
Sample B

Sample No.: B **Source of Sample:** **Date:** 4/23/04
Location: OV-38 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 38B

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	100.0	0.0	0.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	99.3		
#30	71.7		
#40	28.9		
#50	10.5		
#60	4.2		
#80	0.7		
#100	0.1		
#140	0.1		
#200	0.0		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.695 D_{60}= 0.546 D_{50}= 0.506
D_{30}= 0.430 D_{15}= 0.340 D_{10}= 0.296
C_u= 1.84 C_c= 1.14

Classification

USCS= SP AASHTO= A-1-b

Remarks

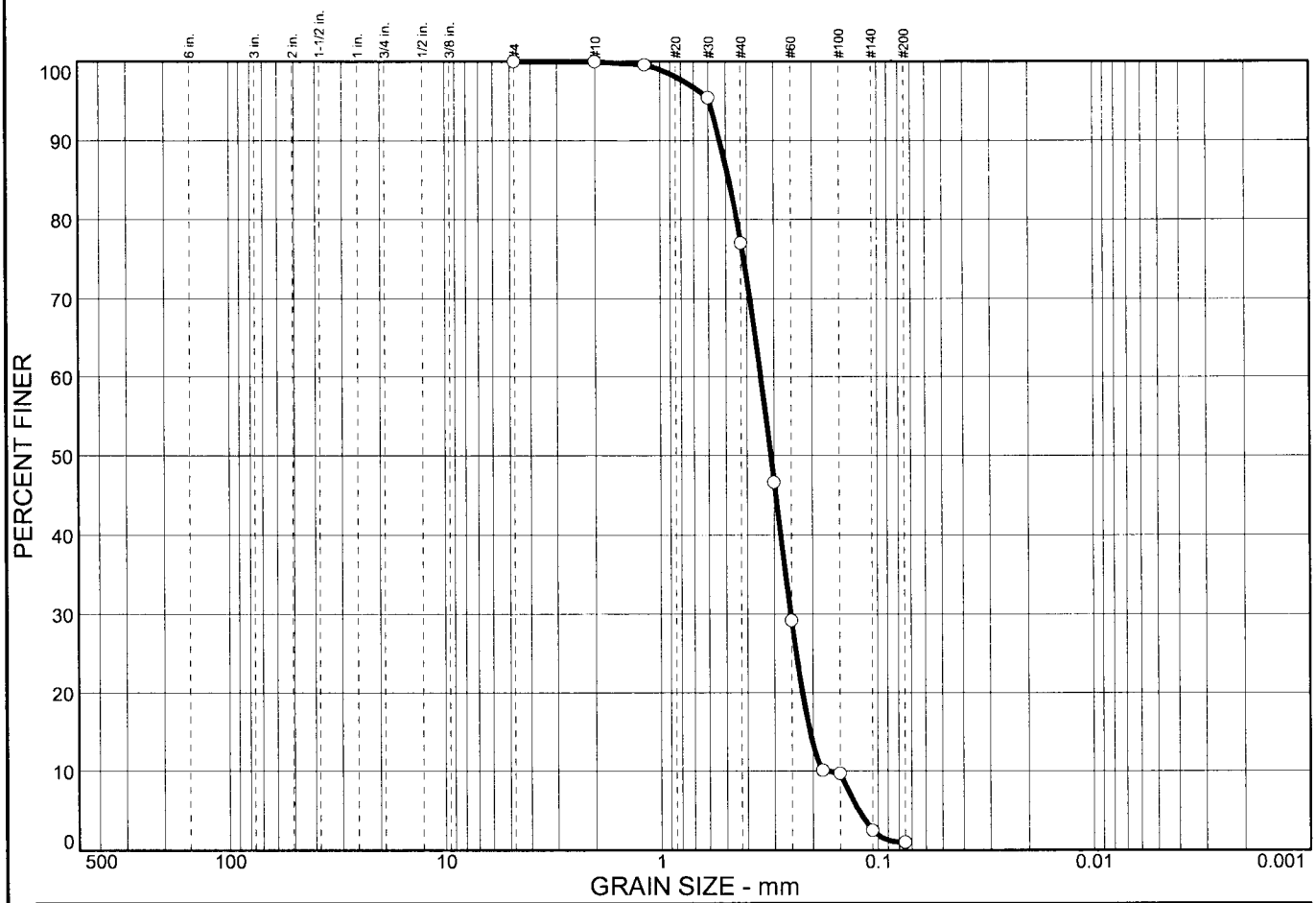
OV-38
Sample C

Sample No.: C **Source of Sample:** **Date:** 4/23/04
Location: OV-38 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 38C

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	0.0	99.0	1.0	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#16	99.6		
#30	95.4		
#40	77.0		
#50	46.6		
#60	29.2		
#80	10.1		
#100	9.7		
#140	2.5		
#200	1.0		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 0.484 D_{60}= 0.345 D_{50}= 0.311
D_{30}= 0.252 D_{15}= 0.206 D_{10}= 0.172
C_u= 2.01 C_c= 1.07

Classification

USCS= SP AASHTO= A-3

Remarks

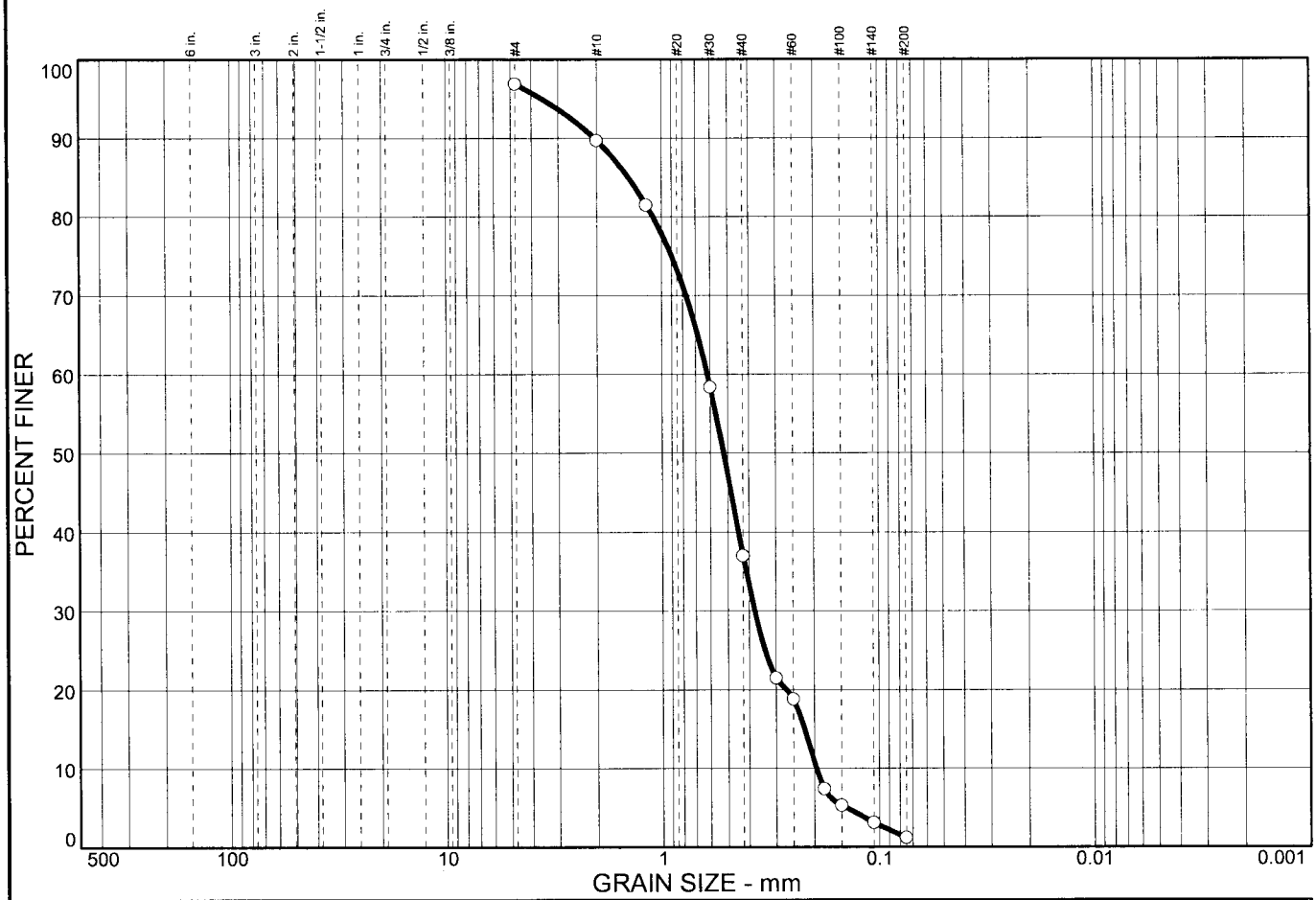
OV-39
Sample A

Sample No.: A **Source of Sample:** **Date:** 4/23/04
Location: OV-39 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 39A

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		95.7	1.2	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	96.9		
#10	89.7		
#16	81.5		
#30	58.4		
#40	37.0		
#50	21.5		
#60	18.8		
#80	7.4		
#100	5.3		
#140	3.1		
#200	1.2		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 1.43 D_{60}= 0.618 D_{50}= 0.521
D_{30}= 0.376 D_{15}= 0.222 D_{10}= 0.196
C_u= 3.16 C_c= 1.17

Classification

USCS= SP AASHTO= A-1-b

Remarks

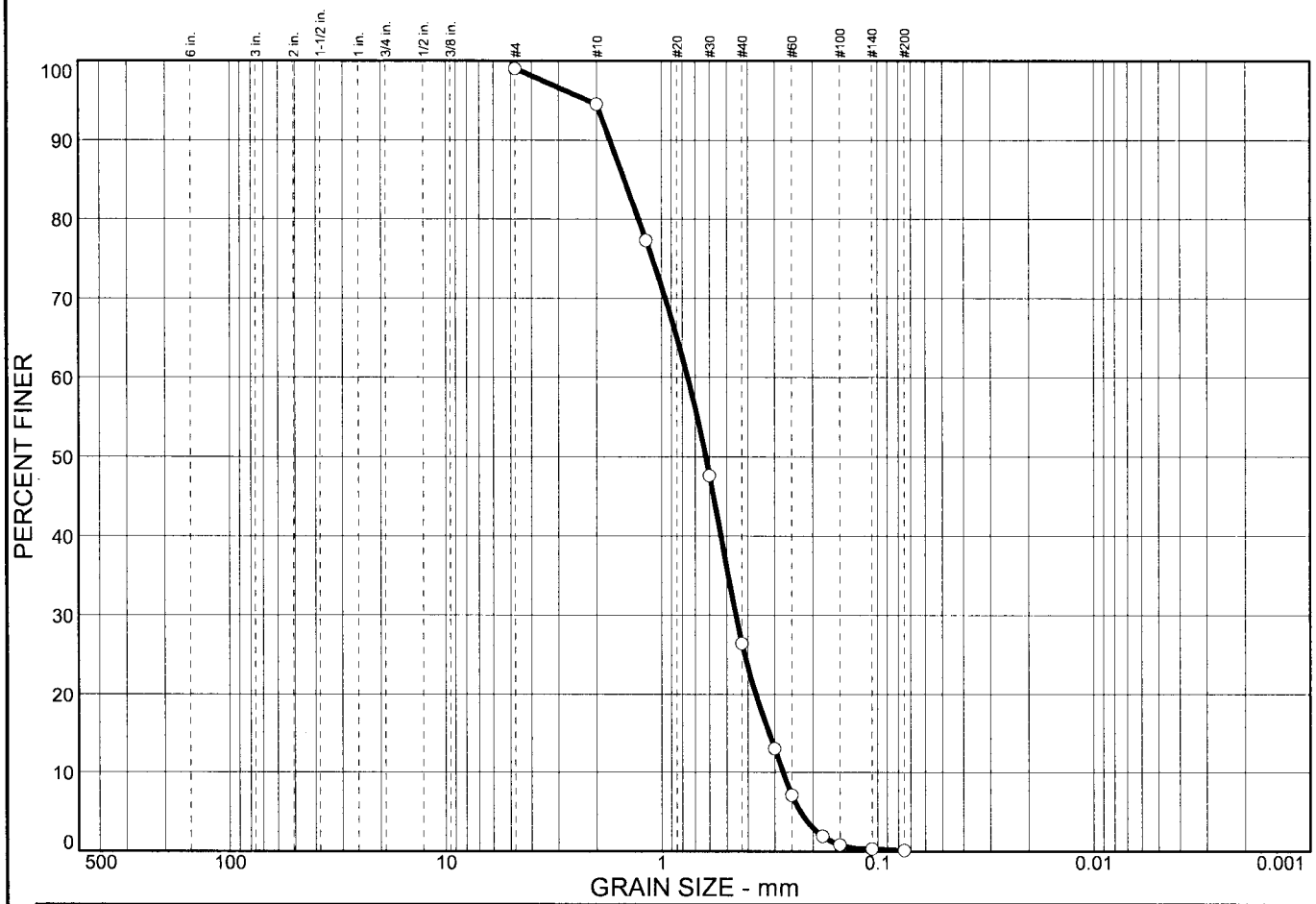
OV-39
Sample B

Sample No.: B **Source of Sample:** **Date:** 4/23/04
Location: OV-39 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 39B

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
		98.9	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	99.0		
#10	94.5		
#16	77.3		
#30	47.6		
#40	26.4		
#50	13.0		
#60	7.1		
#80	1.9		
#100	0.8		
#140	0.3		
#200	0.1		

* (no specification provided)

Soil Description

Tan, Poorly Graded SAND

Atterberg Limits

PL= NP LL= NP PI= NP

Coefficients

D_{85}= 1.49 D_{60}= 0.757 D_{50}= 0.625
D_{30}= 0.454 D_{15}= 0.318 D_{10}= 0.275
C_u= 2.76 C_c= 0.99

Classification

USCS= SP AASHTO= A-1-b

Remarks

OV-39
Sample C

Sample No.: C **Source of Sample:** **Date:** 4/23/04
Location: OV-39 **Elev./Depth:** NA

GET SOLUTIONS, INC.

Client: Waterway Surveys and Engineering, LTD
Project: Ocean View Sediment Analysis
Project No: VB04-131G **Figure** 39C

APPENDIX D

Engineering Activities Log

ENGINEERING ACTIVITIES LOG AND LOG OF SURVEYS FOR ENTIRE OCEAN VIEW SHORELINE

No	Date	Project Type	Location	Description	Vol (cy)	Extent (ft)	Unit Vol (cy/ft)	Sand Source
1	1920-1937	Groin Construction	Willoughby Spit Shoreline	62 groins built by private property owners				
2	Dec 1926-Jan 1928	Jetty Construction	Little Creek Inlet	East Jetty Construction				
3	Dec 1926-Nov 1928	Jetty Construction	Little Creek Inlet	West Jetty Construction				
4	1938	Groin Construction	Between Willoughby Spit and Chesapeake Blvd.	37 timber groins built by City of Norfolk				
5	1953	Beach Nourishment	18th Bay St to 27th Bay St (East Ocean View)	Beach Nourishment	1,260,000	3,000	420	
6	1953	Beach Nourishment	27th Bay St to West Jetty (East Ocean View)	Beach Nourishment	500,000	1,800	278	
7	1960	Beach Nourishment	East End Parking Lot to West Jetty (East Ocean View)	Beach Nourishment	159,000	900	177	
8	1962	Beach Nourishment	Terminal Groin to 9th View St (Willoughby Spit)	Beach Nourishment	176,000	6,900	25	
9	1981	Groin reconstruction	Willoughby Spit area	5 timber groins were reconstructed				
10	1982	Beach Nourishment	East Ocean View	Beach Nourishment	400,000			Pretty Lake
11	1983	Groin Removal	Ocean View Park area	3 groins removed				
12	1983	Groin Construction	Western end of Willoughby Spit	5 groins built by the City of Norfolk				
13	Jan-Apr 1984	Beach Nourishment	Terminal Groin to 5th View St (Willoughby Spit)	Beach Nourishment	537,500	11,000	49	Navy Piers
14	Aug-Nov 1984	Beach Nourishment	21st Bay St to East End Parking Lot (East Ocean View)	Beach Nourishment	400,000	3,000	133	Pretty Lake
15	1985	Beach Nourishment	6th View St to Sarah Constant Shrine Park	Beach Nourishment	50,000			Navy's Willoughby project site
16	1987	Beach Nourishment	5th View St to Mason Creek	Beach Nourishment	50,000	2,000	25	Truck Haul
17	1988	Beach Access Construction	Willoughby and Ocean View	19 pedestrian beach access ways constructed				
18	Spring 1988	Dune Repair	Willoughby Beach	used 10,000 cy of accretion from terminal groin				
19	June, 1989	Dune Repair	Willoughby Beach	used 25,000 cy of accretion from terminal groin				
20	1989	Beach Nourishment	21st Bay St to East End Parking Lot (East Ocean View)	Beach Nourishment	133,000	3,000	44	Cape Henry Channel
21	1990	Breakwater Construction	Western end of Willoughby Spit-Lea View Ave.	2 near shore breakwaters				
22	1990	Terminal Groin Reconstruction	Western end of Willoughby Spit-Lea View Ave.	Original wooden groin raised and extended using rock				
23	1990	Beach Nourishment	Willoughby Spit-Near Terminal Groin	Beach Nourishment	100,000			West of Terminal Groin
24	1990-1991	Dune Stabilization/repair	Various Locations	dune vegetation planting,sand fence construction, elevated public access way, cross-over structures, and timber roads for vehicles				
25	1995	Beach Nourishment	Willoughby Spit	Beach Nourishment	240,000			15th View
26	December, 1995	Beach Nourishment	13th View St to 12 View St (in 4 groin pockets)	Beach Nourishment	4,000			15th View
27	December, 1995	Beach Nourishment	Critical Area 1: 8th View St to 7th View St	Beach Nourishment	30,000	1,000	30	15th View
28	March, 1997	Terminal Groin (trunk) Elevated	Willoughby Spit	terminal groin (trunk) elevated +4 ft				
29	Jan 1997- April 1997	Breakwater Construction	Critical Area 1: Worth St to 8th View	nearshore breakwaters 1-4 constructed				
30	December 1997 - March 1998	Breakwater Construction	Critical Area 1: Worth St to 8th View	nearshore breakwaters 5-7 constructed				
31	***October 1998 City Survey***		***Entire Ocean View Shoreline***					
32	December, 1998	Beach Nourishment	Critical Area 1: East of 8th View St-near site of future groin spur	Beach Nourishment	500	175	3	
33	***October 1999 City Survey***		***Entire Ocean View Shoreline***					
34	1999	Breakwater Construction	Critical Area 2: Just east of Community Beach	4 nearshore breakwaters constructed				
35	November-December 1999	Groin Spur Construction	Critical Area 1: Worth St to 8th View	groin spur construction				
36	December, 1999	Beach Nourishment	Center of COV breakwaters	Beach Nourishment	4,000			
37	December, 1999	Beach Nourishment	Critical Area 1: East of 8th View St-leeward of newly constructed groin spur	Beach Nourishment	1,000	200	5	15th View
38	***July 2000 City Survey***		***From Approx. 9th View St to Little Creek Inlet***					
39	August, 2000	Breakwater Construction	Critical Area 3: 21st Bay to Little Creek Inlet	nearshore breakwaters 2,3,4 constructed				
40	***October 2000 City Survey***		***From Approx. 12th View St to Little Creek Inlet***					
41	July, 2001	Beach Nourishment	Critical Area 1: Worth St to 8th View	Beach Nourishment	500			Truck Haul
42	September, 2001	Beach Nourishment	Critical Area 1: East of 8th View St-between breakwater 7 and groin spur	Beach Nourishment	2,000	300	7	15th View
43	***October 2001 City Survey***		***Entire Ocean View Shoreline***					
44	November, 2001	Breakwater Construction	Critical Area 3: 21st Bay to Little Creek Inlet	nearshore breakwaters 1,5,6,7 constructed				
45	March - April, 2002	Breakwater Work	Critical Area 1: breakwater 7	work on toe extensions				
46	May, 2002	Beach Nourishment	Critical Area 1: East of 8th View St-between breakwater 7 and groin spur	Beach Nourishment	3,438	300	11	15th View
47	June, 2002	Groin Removal	Critical Area 1: Worth St to 8th View	Removal of timber groin channalward of rock spur				
48	***July 2002 City Survey***		***Entire Ocean View Shoreline - excluding approx. Sherwood Pl. to Warwick Ave.***					
49	***October 2002 City Survey***		***Entire Ocean View Shoreline - minimal survey data (no beach or bathymetric survey points)***					
50	***March 2003 City Survey***		***East Ocean View Shoreline (19th Bay to Little Creek Inlet)***					
51	***April 2003 City Survey***		***East Ocean View Shoreline (17th Bay to Little Creek Inlet)***					
52	***June 2003 Waterway Survey***		***East Ocean View Shoreline (17th Bay to Little Creek Inlet)***					
53	September, 2003	Beach Nourishment	Critical Area 1: West of 8th View St beach access	Beach Nourishment	1,100	350	3	15th View
54	***October 2003 Waterway Survey***		***Post-Isabel Survey - East Ocean View Shoreline (17th Bay to Little Creek Inlet)***					
55	October, 2003	Beach Nourishment	Critical Area 3: 19th Bay St	Beach Nourishment	6,000	545	11	upland sand trucked in
56	October, 2003	Beach Nourishment	Critical Area 3: East of 30th Bay St	Beach Nourishment	1,000	150	7	upland sand trucked in
57	December, 2003	Beach Nourishment	Critical Area 3: 17th Bay St to Little Creek Inlet	Beach Nourishment	359,000	5,280	68	Thimble Shoal Channel
58	December, 2003	Beach Nourishment	Critical Area 1: 9th View St to 7th View St (+400 ft)	Beach Nourishment	39,800	1,260	32	
59	***Nov-Dec 2003 Post-Fill Survey***		***East OceanView Shoreline (17th Bay to Little Inlet Creek)***					
60	***Feb-April, 2004 Waterway Survey***		***From Approx. Willoughby Spit to 17th Bay St***					
61	August, 2004	Beach Nourishment	13th View to 11th View, Behind Western 4 Breakwaters at 800 Block, 1200' East of dogleg	Beach Nourishment	37,000	4,950	7	Truck Haul
62	January-March, 2005	Dune Restoration	Willoughby Spit to Central Ocean View (14th View St to Warwick Ave)	Willoughby Spit to Central Ocean View Dune Restoration Project	504,329	18,300	28	Thimble Shoal Channel
63	***January-March 2005 Post-Fill Survey***		***Willoughby Spit to Warwick Ave.***					
64	***September 2005 McKim & Creed Periodic Survey***		***Entire Ocean View Shoreline***					
65	January-February, 2006	Groin Spur & Toe Extension Removal	Critical Area 1: East of 8th View	groin spur removal				
66	January-February, 2006	Breakwater Construction	Critical Area 1: East of 8th View	nearshore breakwater 8 constructed				
67	January-February, 2006	Breakwater Construction	Critical Area 3: 29th Bay to Little Creek Inlet	nearshore breakwaters 8, 9, & 10 constructed				
68	***March 2006 McKim & Creed Periodic Survey***		***Entire Ocean View Shoreline***					
69	***October 2006 McKim & Creed Periodic Survey***		***Entire Ocean View Shoreline***					

REFERENCE*
Critical area 1: Worth St to 8th View
Critical area 2: Chesapeake Blvd. to Atlans St.
Critical area 3: 21st Bay to Little Creek Inlet

*Critical areas of concern for erosional damage defined in
Andrews, Miller & Assoc., Inc. "Beach Management Plan, City of Norfolk Virginia", January, 1993.
*Highlighted Activties Impacted East Ocean View and the Bay Oaks Study Area

APPENDIX E

SBEACH Results

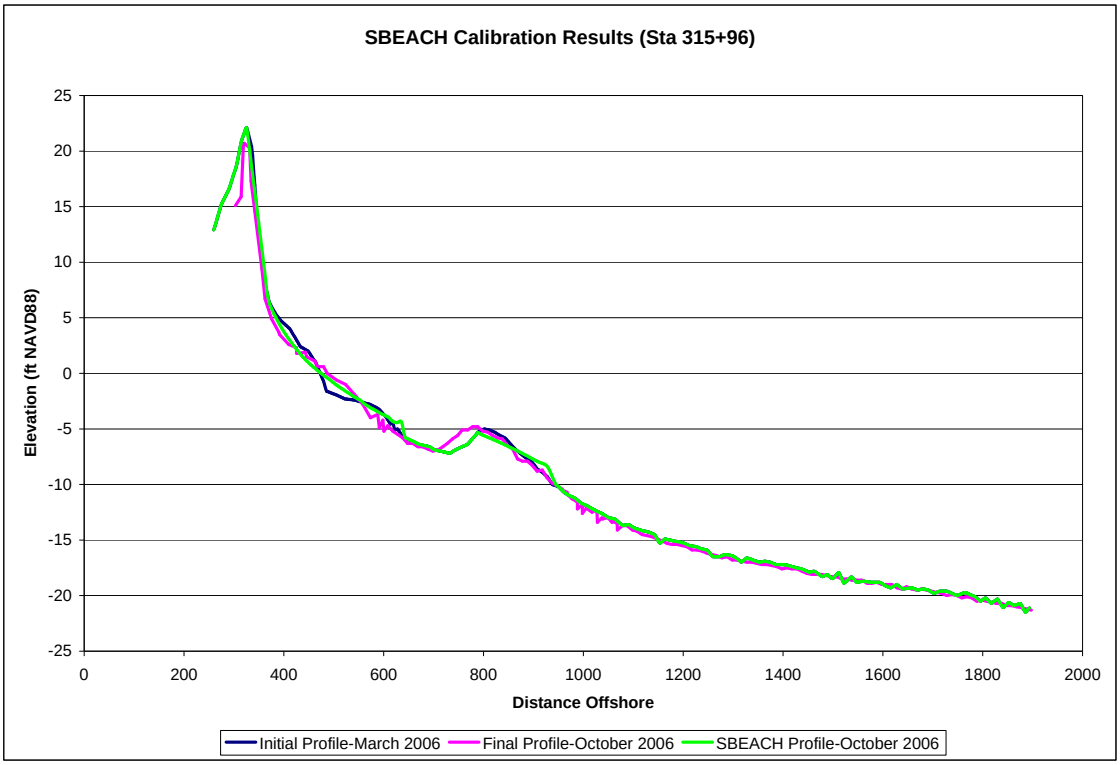


Figure E-1. SBEACH Calibration Results (Sta 315+96)

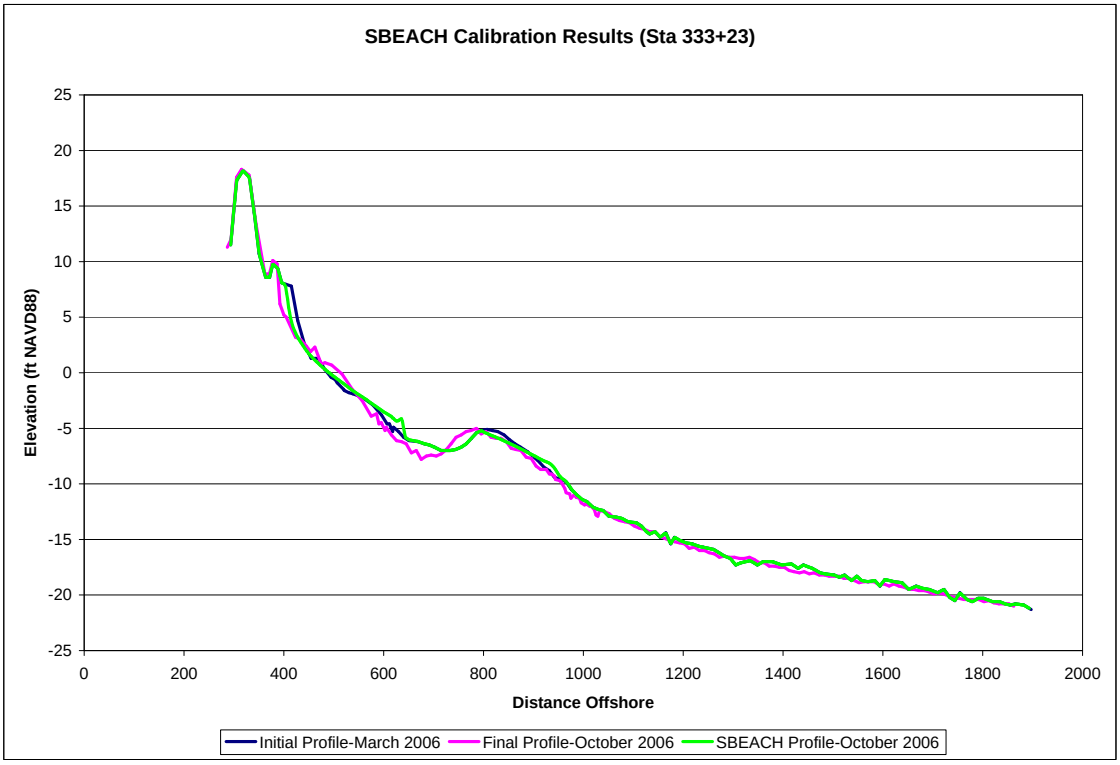


Figure E-2. SBEACH Calibration Results (Sta 333+23)

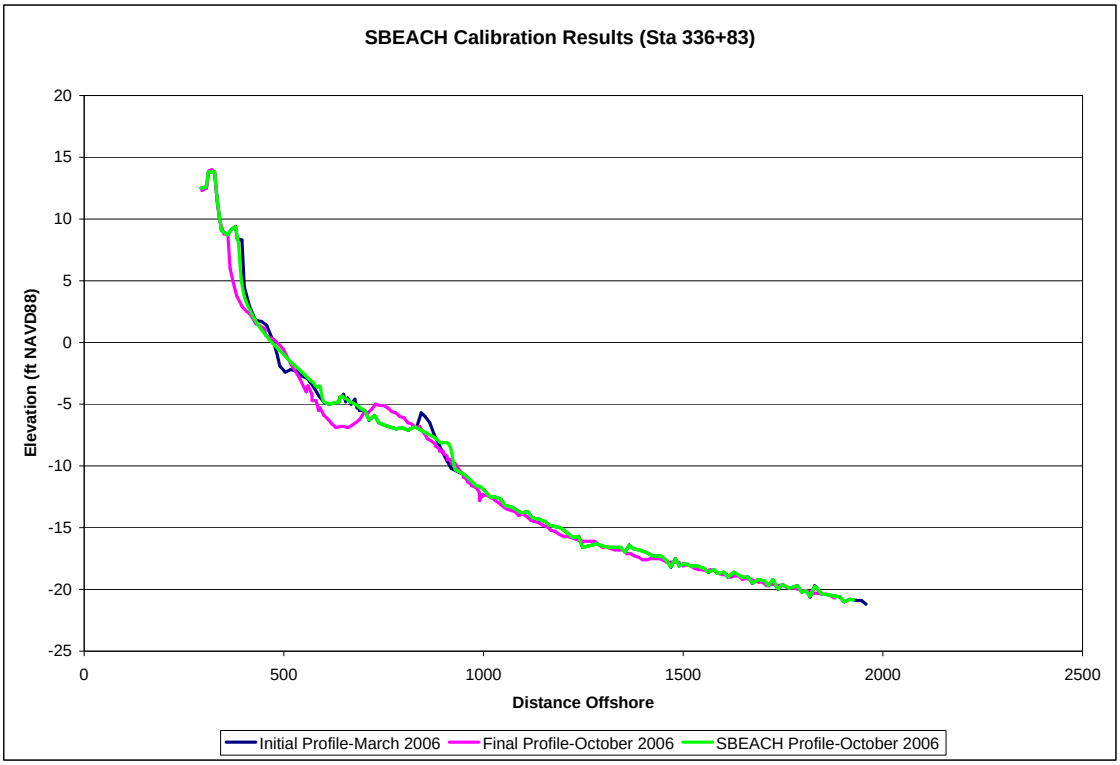


Figure E-3. SBEACH Calibration Results (Sta 336+83)

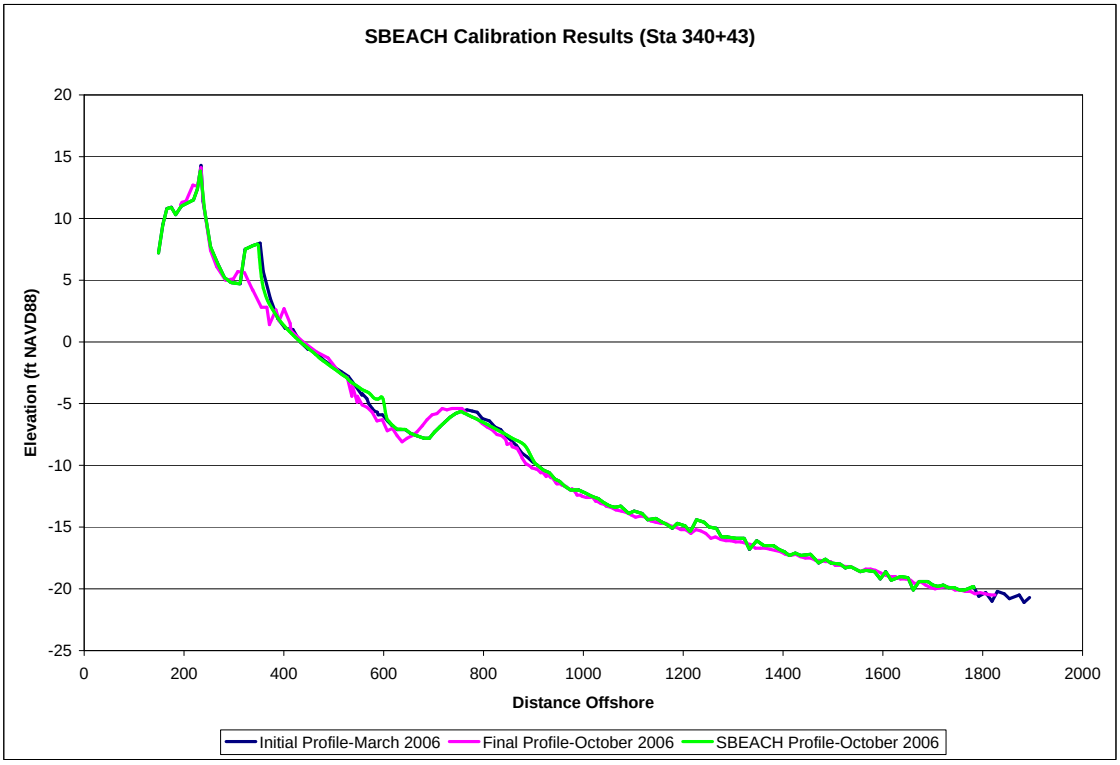


Figure E-4. SBEACH Calibration Results (Sta 340+43)

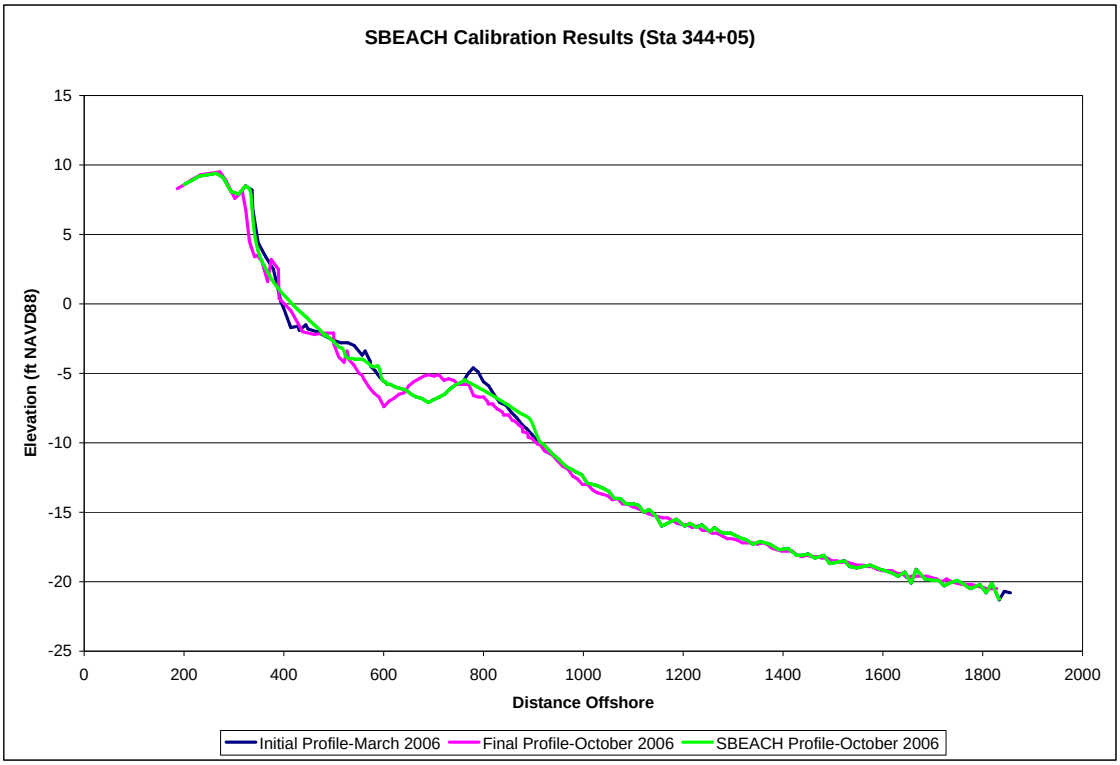


Figure E-5. SBEACH Calibration Results (Sta 344+05)

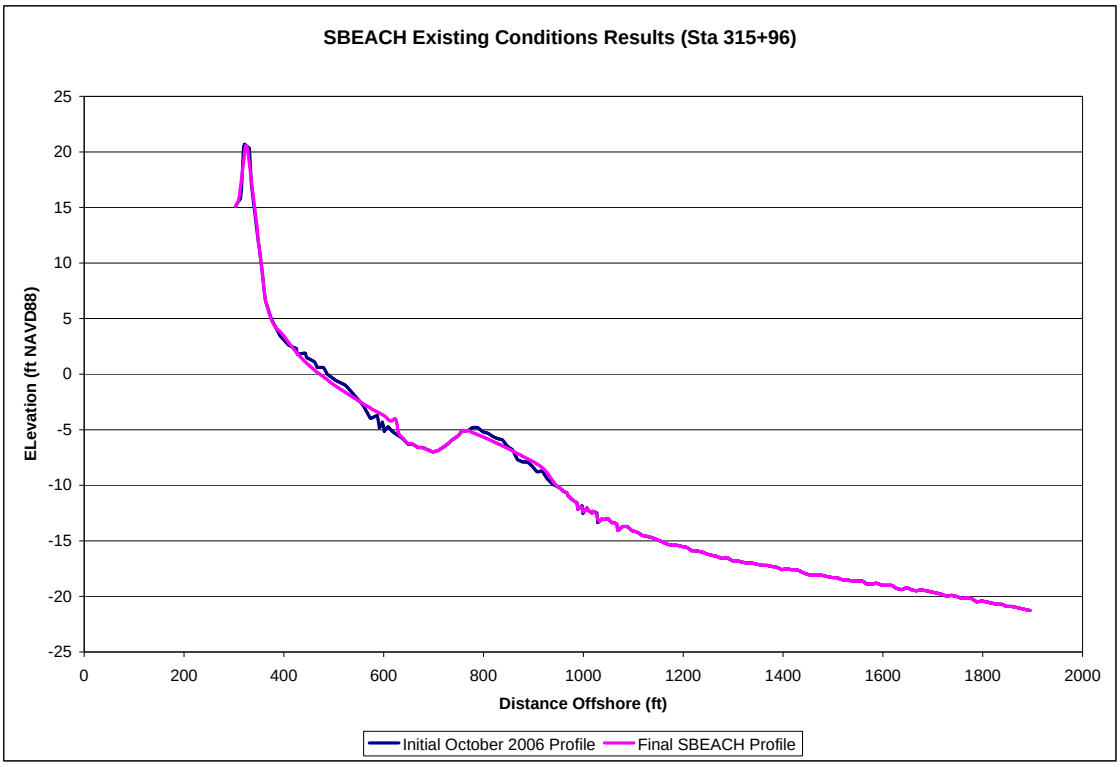


Figure E-6. SBEACH Existing Conditions Results (Sta 315+96)

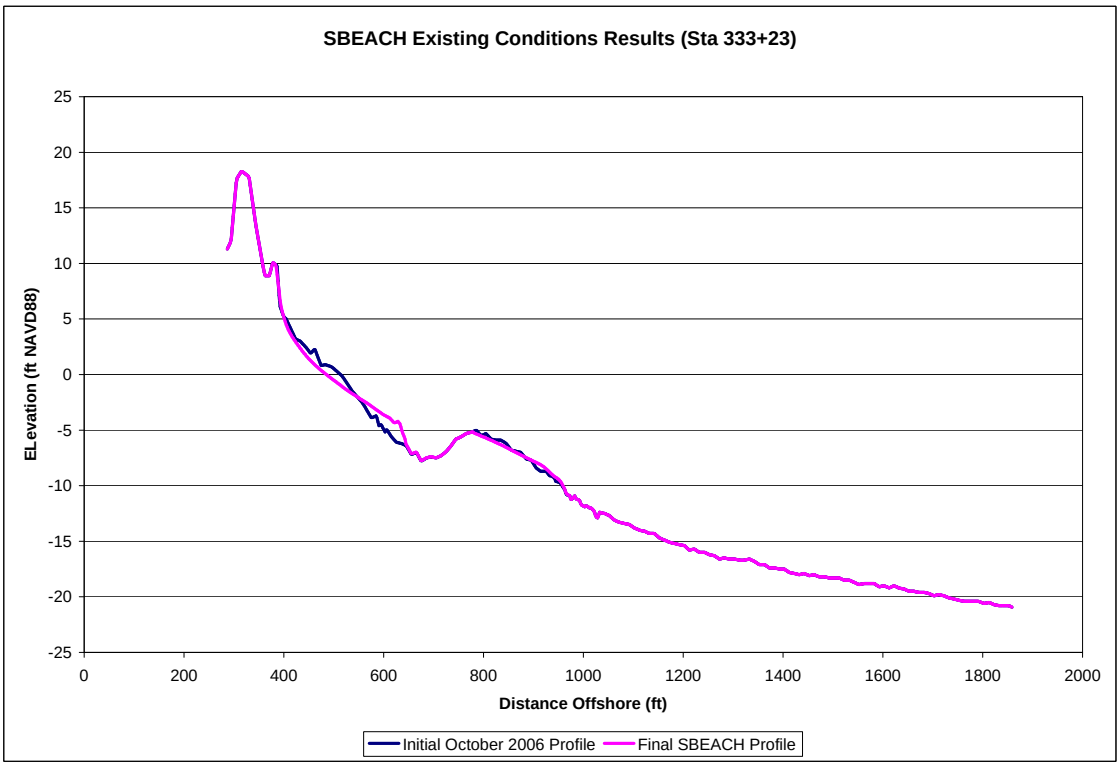


Figure E-7. SBEACH Existing Conditions Results (Sta 333+23)

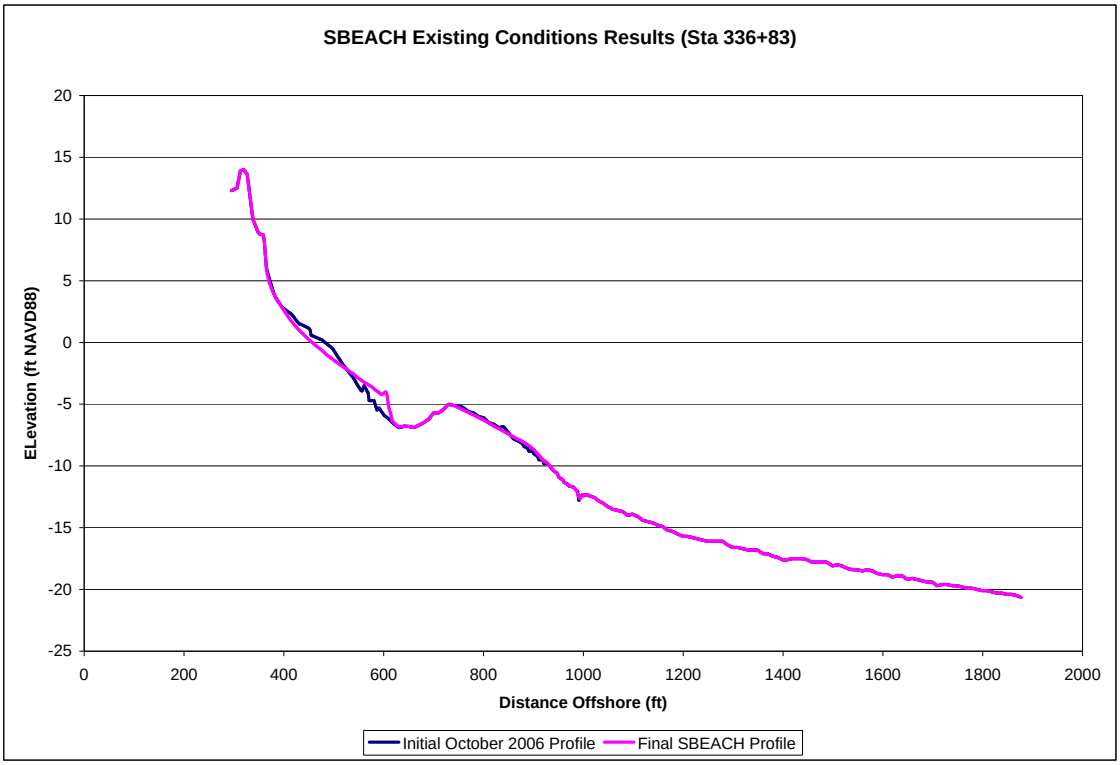


Figure E-8. SBEACH Existing Conditions Results (Sta 336+83)

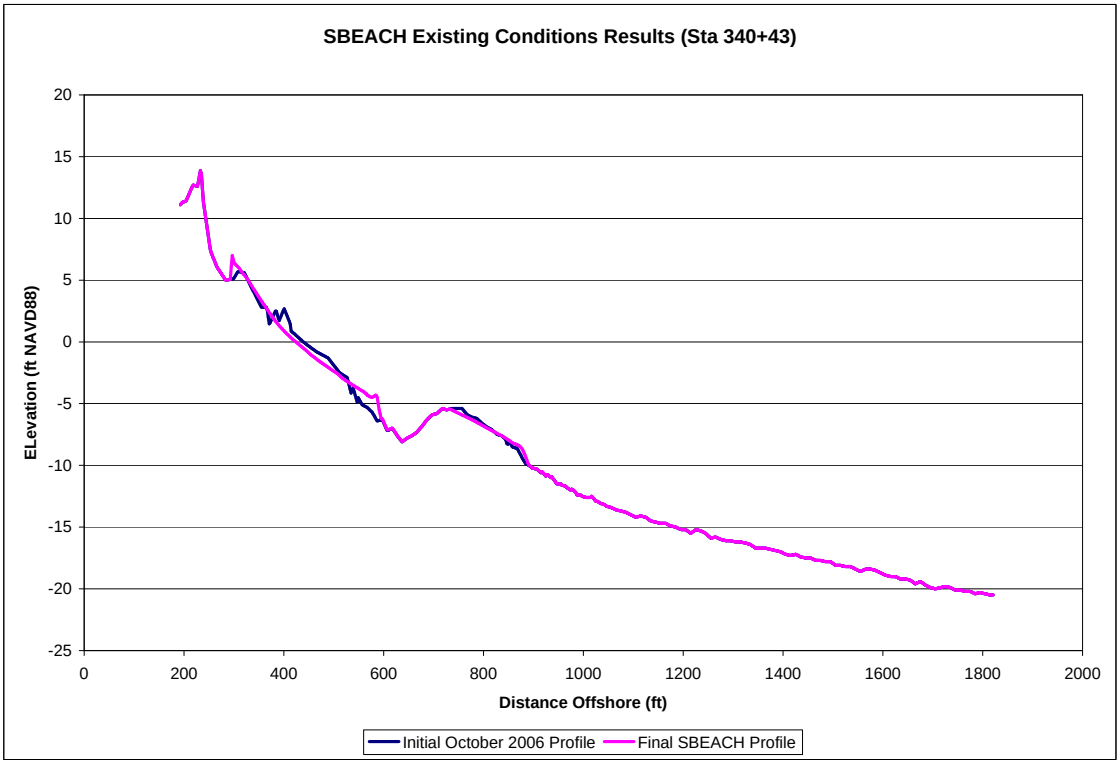


Figure E-9. SBEACH Existing Conditions Results (Sta 340+43)

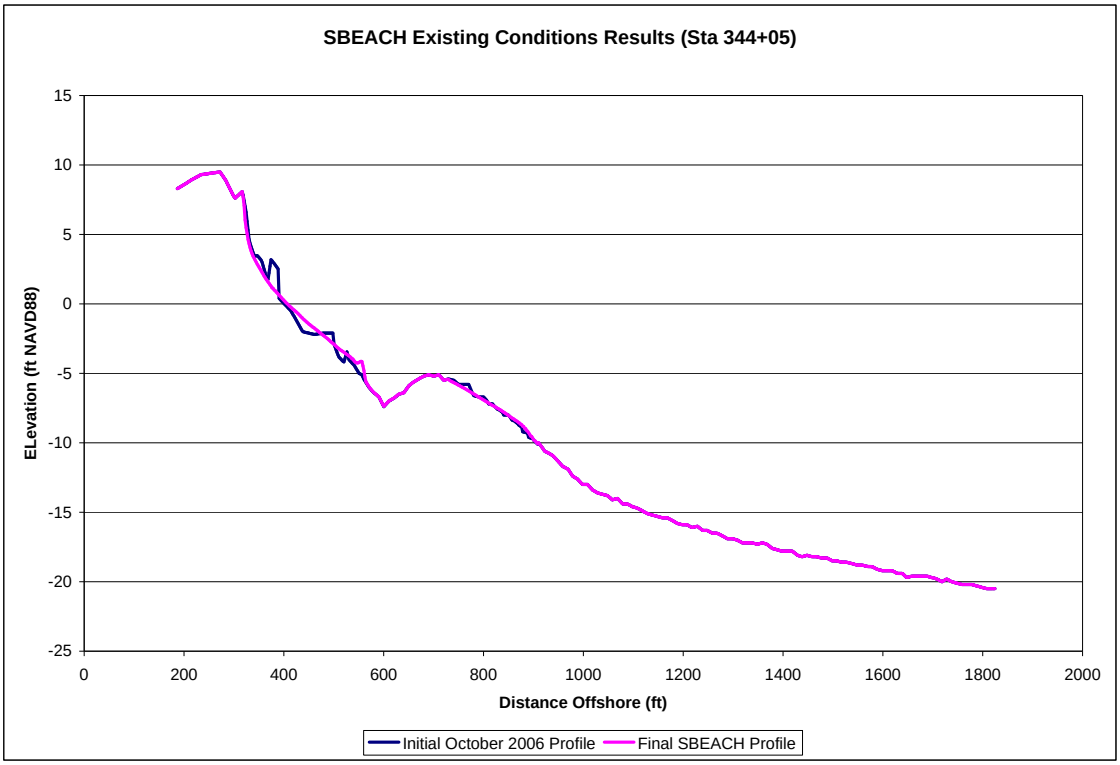


Figure E-10. SBEACH Existing Conditions Results (Sta 344+05)

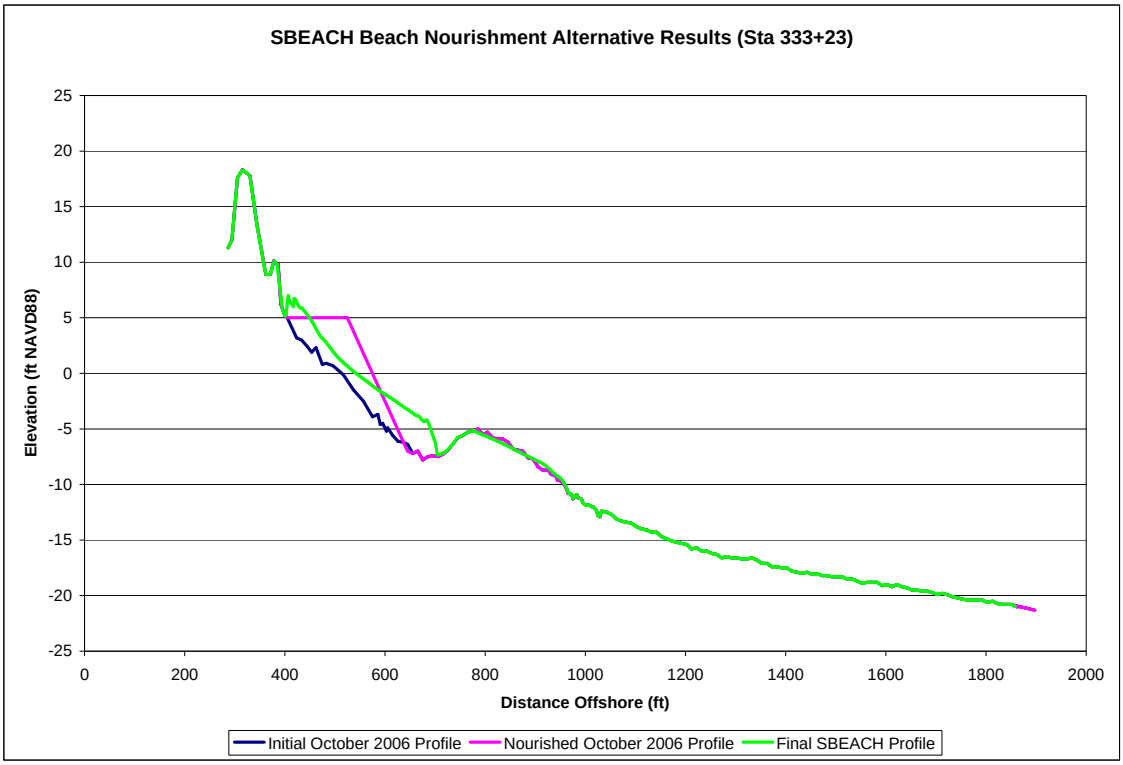


Figure E-11. SBEACH Beach Nourishment Alternative Results (Sta 333+23)

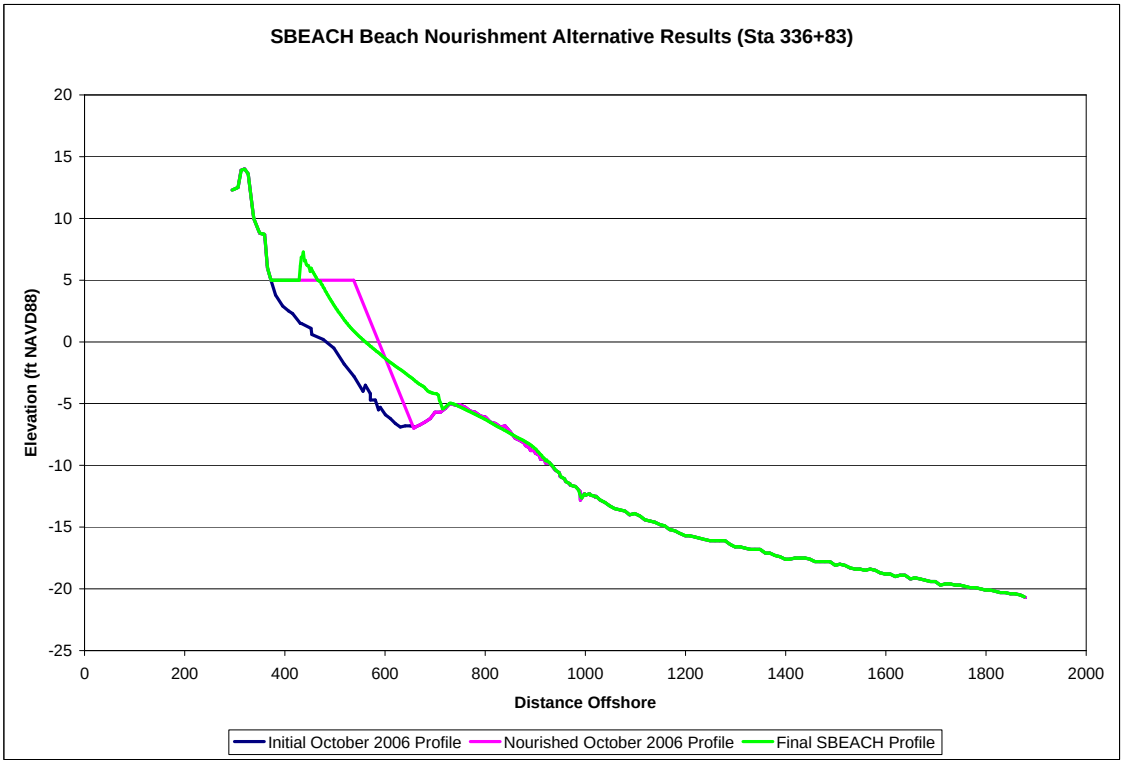


Figure E-12. SBEACH Beach Nourishment Alternative Results (Sta 336+83)

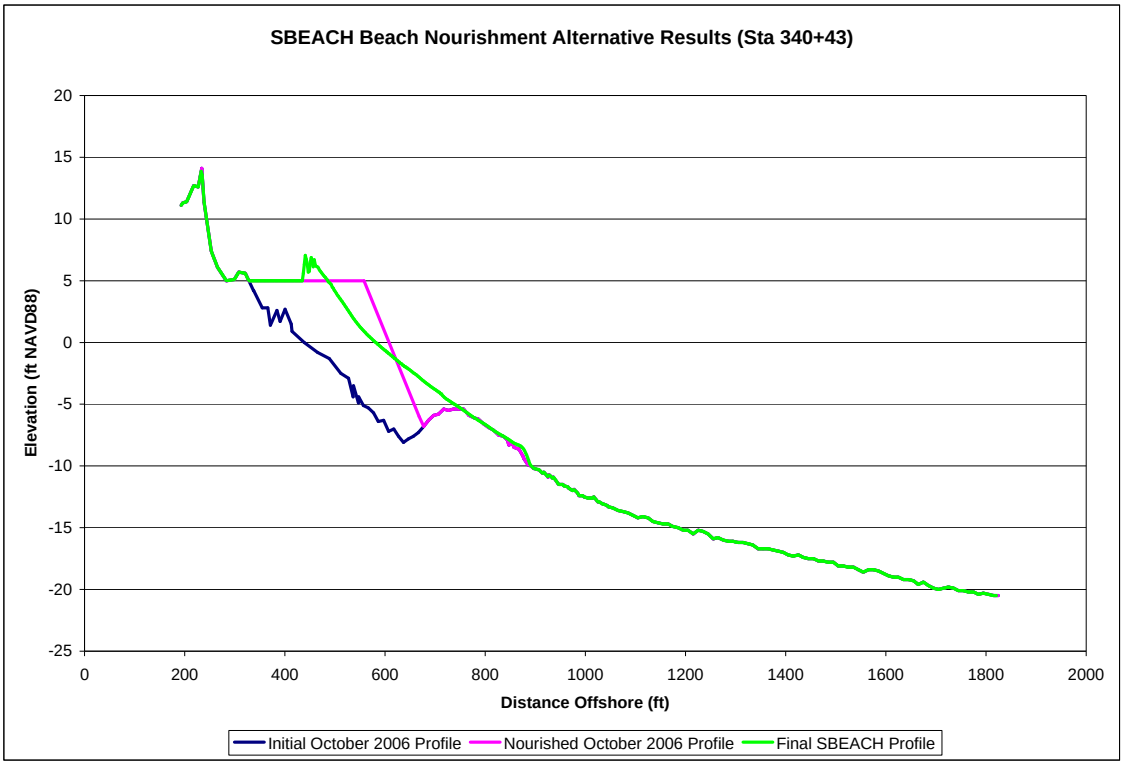


Figure E-13. SBEACH Beach Nourishment Alternative Results (Sta 340+43)

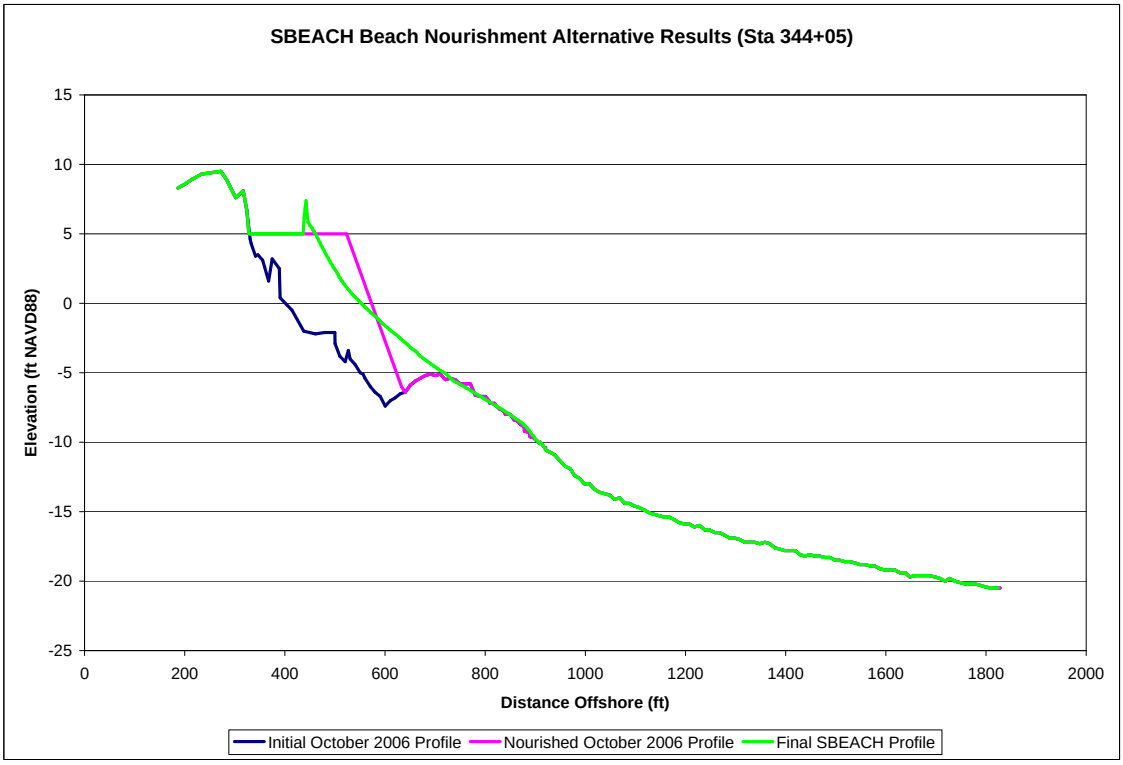


Figure E-14. SBEACH Beach Nourishment Alternative Results (Sta 344+05)

APPENDIX F

Opinion of Probable Cost

OPINION OF PROBABLE COST	DATE PREPARED 07/17/07	SHEET 1 OF 1
ACTIVITY AND LOCATION Bay Oaks Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE Bay Oaks Study - Alternative #1 Beach Nourishment	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Opinion of Probable Cost Alternative #1	JOB ORDER NUMBER 6086-02

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
BEACH NOURISHMENT								
Material	100,000	CY	$5.00	$500,000.00	$7.00	$700,000.00	$12.00	$1,200,000.00
BREAKWATER WORK								
Mob/Demob for Breakwater Work	0	EA	$30,000.00	$0.00	$20,000.00	$0.00	$50,000.00	$0.00
Breakwater #1								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #2								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #3								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #4								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #5								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #6								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
							SUBTOTAL	**$1,200,000.00**
PROJECT SUBTOTAL				**$500,000.00**		**$700,000.00**		**$1,200,000.00**
Contingency	20%							$240,000.00
Design/P&S/Construction Admin	12%							$144,000.00
							GRAND TOTAL	**$1,584,000.00**
							SAY	**$1,590,000**

OPINION OF PROBABLE COST	DATE PREPARED 07/17/07	SHEET 1 OF 1
ACTIVITY AND LOCATION Bay Oaks Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE Bay Oaks Study - Alternative #2 Add 1 190' Breakwater w/ Beach Nourishment	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Opinion of Probable Cost Alternative #2	JOB ORDER NUMBER 6086-02

ITEM DESCRIPTION	QUANTITY NUMBER	QUANTITY UNIT	MATERIAL COST UNIT COST	MATERIAL COST TOTAL	LABOR COST UNIT COST	LABOR COST TOTAL	ENGINEERING ESTIMATE UNIT COST	ENGINEERING ESTIMATE TOTAL
BEACH NOURISHMENT								
Material	100,000	CY	$5.00	$500,000.00	$7.00	$700,000.00	$12.00	$1,200,000.00
BREAKWATER WORK								
Mob/Demob for Breakwater Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
Breakwater #1								
Armor Stone	2335	ton	$40.00	$93,400.00	$40.00	$93,400.00	$80.00	$186,800.00
Bedding Stone	525	ton	$30.00	$15,750.00	$40.00	$21,000.00	$70.00	$36,750.00
Filter Fabric	950	SY	$4.00	$3,800.00	$2.00	$1,900.00	$6.00	$5,700.00
Breakwater #2								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #3								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #4								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #5								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #6								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
							SUBTOTAL	**$1,479,250.00**
PROJECT SUBTOTAL				**$642,950.00**		**$836,300.00**		**$1,479,250.00**
Contingency	20%							$295,850.00
Design/P&S/Construction Admin	12%							$177,510.00
							GRAND TOTAL	**$1,952,610.00**
							SAY	**$1,960,000**

OPINION OF PROBABLE COST	DATE PREPARED 07/17/07	SHEET 1 OF 1
ACTIVITY AND LOCATION Bay Oaks Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE Bay Oaks Study - Alternative #3 Add 5 120' Breakwaters w/ Beach Nourishment	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Opinion of Probable Cost Alternative #3	JOB ORDER NUMBER 6086-02

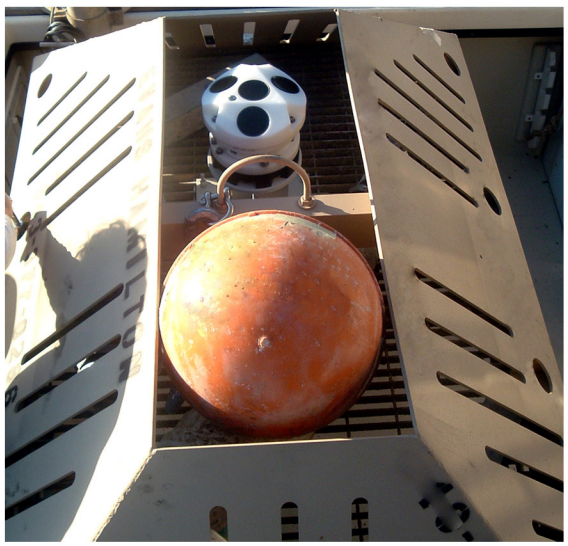
ITEM DESCRIPTION	QUANTITY NUMBER	QUANTITY UNIT	MATERIAL COST UNIT COST	MATERIAL COST TOTAL	LABOR COST UNIT COST	LABOR COST TOTAL	ENGINEERING ESTIMATE UNIT COST	ENGINEERING ESTIMATE TOTAL
BEACH NOURISHMENT								
Material	100,000	CY	$5.00	$500,000.00	$7.00	$700,000.00	$12.00	$1,200,000.00
BREAKWATER WORK								
Mob/Demob for Breakwater Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
Breakwater #1								
Armor Stone	1560	ton	$40.00	$62,400.00	$40.00	$62,400.00	$80.00	$124,800.00
Bedding Stone	360	ton	$30.00	$10,800.00	$40.00	$14,400.00	$70.00	$25,200.00
Filter Fabric	650	SY	$4.00	$2,600.00	$2.00	$1,300.00	$6.00	$3,900.00
Breakwater #2								
Armor Stone	1560	ton	$40.00	$62,400.00	$40.00	$62,400.00	$80.00	$124,800.00
Bedding Stone	360	ton	$30.00	$10,800.00	$40.00	$14,400.00	$70.00	$25,200.00
Filter Fabric	650	SY	$4.00	$2,600.00	$2.00	$1,300.00	$6.00	$3,900.00
Breakwater #3								
Armor Stone	1560	ton	$40.00	$62,400.00	$40.00	$62,400.00	$80.00	$124,800.00
Bedding Stone	360	ton	$30.00	$10,800.00	$40.00	$14,400.00	$70.00	$25,200.00
Filter Fabric	650	SY	$4.00	$2,600.00	$2.00	$1,300.00	$6.00	$3,900.00
Breakwater #4								
Armor Stone	1560	ton	$40.00	$62,400.00	$40.00	$62,400.00	$80.00	$124,800.00
Bedding Stone	360	ton	$30.00	$10,800.00	$40.00	$14,400.00	$70.00	$25,200.00
Filter Fabric	650	SY	$4.00	$2,600.00	$2.00	$1,300.00	$6.00	$3,900.00
Breakwater #5								
Armor Stone	1560	ton	$40.00	$62,400.00	$40.00	$62,400.00	$80.00	$124,800.00
Bedding Stone	360	ton	$30.00	$10,800.00	$40.00	$14,400.00	$70.00	$25,200.00
Filter Fabric	650	SY	$4.00	$2,600.00	$2.00	$1,300.00	$6.00	$3,900.00
Breakwater #6								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
							SUBTOTAL	**$2,019,500.00**
PROJECT SUBTOTAL				**$909,000.00**		**$1,110,500.00**		**$2,019,500.00**
Contingency	20%							$403,900.00
Design/P&S/Construction Admin	12%							$242,340.00
							GRAND TOTAL	**$2,665,740.00**
							SAY	**$2,670,000**

OPINION OF PROBABLE COST	DATE PREPARED 07/17/07	SHEET 1 OF 1
ACTIVITY AND LOCATION Bay Oaks Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE Bay Oaks Study - Alternative #4 Add 5 Breakwaters (4 @ 120', 1 @ 150' Angled) w/ Beach Nourishment	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Opinion of Probable Cost Alternative #4	JOB ORDER NUMBER 6086-02

ITEM DESCRIPTION	QUANTITY NUMBER	QUANTITY UNIT	MATERIAL COST UNIT COST	MATERIAL COST TOTAL	LABOR COST UNIT COST	LABOR COST TOTAL	ENGINEERING ESTIMATE UNIT COST	ENGINEERING ESTIMATE TOTAL
BEACH NOURISHMENT								
Material	100,000	CY	$5.00	$500,000.00	$7.00	$700,000.00	$12.00	$1,200,000.00
BREAKWATER WORK								
Mob/Demob for Breakwater Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
Breakwater #1								
Armor Stone	1560	ton	$40.00	$62,400.00	$40.00	$62,400.00	$80.00	$124,800.00
Bedding Stone	360	ton	$30.00	$10,800.00	$40.00	$14,400.00	$70.00	$25,200.00
Filter Fabric	650	SY	$4.00	$2,600.00	$2.00	$1,300.00	$6.00	$3,900.00
Breakwater #2								
Armor Stone	1560	ton	$40.00	$62,400.00	$40.00	$62,400.00	$80.00	$124,800.00
Bedding Stone	360	ton	$30.00	$10,800.00	$40.00	$14,400.00	$70.00	$25,200.00
Filter Fabric	650	SY	$4.00	$2,600.00	$2.00	$1,300.00	$6.00	$3,900.00
Breakwater #3								
Armor Stone	1560	ton	$40.00	$62,400.00	$40.00	$62,400.00	$80.00	$124,800.00
Bedding Stone	360	ton	$30.00	$10,800.00	$40.00	$14,400.00	$70.00	$25,200.00
Filter Fabric	650	SY	$4.00	$2,600.00	$2.00	$1,300.00	$6.00	$3,900.00
Breakwater #4								
Armor Stone	1560	ton	$40.00	$62,400.00	$40.00	$62,400.00	$80.00	$124,800.00
Bedding Stone	360	ton	$30.00	$10,800.00	$40.00	$14,400.00	$70.00	$25,200.00
Filter Fabric	650	SY	$4.00	$2,600.00	$2.00	$1,300.00	$6.00	$3,900.00
Breakwater #5								
Armor Stone	1895	ton	$40.00	$75,800.00	$40.00	$75,800.00	$80.00	$151,600.00
Bedding Stone	430	ton	$30.00	$12,900.00	$40.00	$17,200.00	$70.00	$30,100.00
Filter Fabric	775	SY	$4.00	$3,100.00	$2.00	$1,550.00	$6.00	$4,650.00
Breakwater #6								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
							SUBTOTAL	**$2,051,950.00**
PROJECT SUBTOTAL				**$925,000.00**		**$1,126,950.00**		**$2,051,950.00**
Contingency	20%							$410,390.00
Design/P&S/Construction Admin	12%							$246,234.00
							GRAND TOTAL	**$2,708,574.00**
							SAY	**$2,710,000**

OPINION OF PROBABLE COST	DATE PREPARED 07/17/07	SHEET 1 OF 1
ACTIVITY AND LOCATION Bay Oaks Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE Bay Oaks Study - Alternative #5 Add 6 Breakwaters (3 @ 230', 1 @ 200', 1 @ 170', 1 @ 140') w/ Beach Nourishment	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Opinion of Probable Cost Alternative #5	JOB ORDER NUMBER 6086-02

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
BEACH NOURISHMENT								
Material	100,000	CY	$5.00	$500,000.00	$7.00	$700,000.00	$12.00	$1,200,000.00
BREAKWATER WORK								
Mob/Demob for Breakwater Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
Breakwater #1								
Armor Stone	2780	ton	$40.00	$111,200.00	$40.00	$111,200.00	$80.00	$222,400.00
Bedding Stone	620	ton	$30.00	$18,600.00	$40.00	$24,800.00	$70.00	$43,400.00
Filter Fabric	1095	SY	$4.00	$4,380.00	$2.00	$2,190.00	$6.00	$6,570.00
Breakwater #2								
Armor Stone	2780	ton	$40.00	$111,200.00	$40.00	$111,200.00	$80.00	$222,400.00
Bedding Stone	620	ton	$30.00	$18,600.00	$40.00	$24,800.00	$70.00	$43,400.00
Filter Fabric	1095	SY	$4.00	$4,380.00	$2.00	$2,190.00	$6.00	$6,570.00
Breakwater #3								
Armor Stone	2780	ton	$40.00	$111,200.00	$40.00	$111,200.00	$80.00	$222,400.00
Bedding Stone	620	ton	$30.00	$18,600.00	$40.00	$24,800.00	$70.00	$43,400.00
Filter Fabric	1095	SY	$4.00	$4,380.00	$2.00	$2,190.00	$6.00	$6,570.00
Breakwater #4								
Armor Stone	2445	ton	$40.00	$97,800.00	$40.00	$97,800.00	$80.00	$195,600.00
Bedding Stone	550	ton	$30.00	$16,500.00	$40.00	$22,000.00	$70.00	$38,500.00
Filter Fabric	970	SY	$4.00	$3,880.00	$2.00	$1,940.00	$6.00	$5,820.00
Breakwater #5								
Armor Stone	2115	ton	$40.00	$84,600.00	$40.00	$84,600.00	$80.00	$169,200.00
Bedding Stone	475	ton	$30.00	$14,250.00	$40.00	$19,000.00	$70.00	$33,250.00
Filter Fabric	840	SY	$4.00	$3,360.00	$2.00	$1,680.00	$6.00	$5,040.00
Breakwater #6								
Armor Stone	1780	ton	$40.00	$71,200.00	$40.00	$71,200.00	$80.00	$142,400.00
Bedding Stone	405	ton	$30.00	$12,150.00	$40.00	$16,200.00	$70.00	$28,350.00
Filter Fabric	715	SY	$4.00	$2,860.00	$2.00	$1,430.00	$6.00	$4,290.00
							SUBTOTAL	**$2,689,560.00**
PROJECT SUBTOTAL				**$1,239,140.00**		**$1,450,420.00**		**$2,689,560.00**
Contingency	20%							$537,912.00
Design/P&S/Construction Admin	12%							$322,747.20
							GRAND TOTAL	**$3,550,219.20**
							SAY	**$3,560,000**

MOFFATT & NICHOL

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