

SAND BYPASSING RESTORES NATURAL PROCESSES TO ASSATEAGUE ISLAND, MARYLAND

Courtney A. Schupp[1], Gregory P. Bass [2], William G. Grosskopf [3]

1. Assateague Island National Seashore, 7206 National Seashore Lane, Berlin, MD 21811, USA. Courtney_Schupp@nps.gov
2. US Army Engineer District, Baltimore, P.O. Box 1715, Baltimore, MD 21203-1715, USA. Gregory.P.Bass@nab02.usace.army.mil
3. Offshore Coastal Technologies, Inc., P.O. Box 1368, Chadds Ford, PA 19317, USA. wgrosskopf@offshorecoastal.com

Abstract: The North End Restoration Project uses a regional sediment management approach to address jetty-induced sediment deprivation and accelerated erosion on Assateague Island, Maryland. The biannual sand bypassing project dredges sand from the ebb and flood tidal deltas and places it in the nearshore area of the project site rather than on the upper shoreface, thereby replicating natural sediment transport processes and minimizing adverse impacts to subaerial habitats. Calm weather has prevailed since sand bypassing began, and accretion occurred at all depths within the placement area and at shallow depths to the north and south. Erosion occurred at lower depths and north of the ebb tidal delta attachment bar, which may block sand transport to the northernmost shoreface and where and where wave refraction over the ebb tidal delta and unique tidal circulation patterns contribute to upper shoreface erosion.

INTRODUCTION

Since its construction in 1935, a jetty system at Ocean City Inlet has caused unnatural sediment deprivation on northern Assateague Island, Maryland, thereby accelerating the natural erosion rate and causing associated habitat degradation. Assateague Island was later established as a National Seashore, and because the National Park Service (NPS) is required to reestablish natural functions and processes, NPS partnered with the U.S. Army Corps of Engineers (USACE) to address the ongoing and future effects of the jetties. The North End Restoration Project uses a regional sediment management approach to re-establish an historic, pre-inlet sediment transport to the northern 13.2 km of the island.

The method chosen to restore natural sediment transport processes at Assateague Island is known as sand bypassing, the hydraulic or mechanical movement of sand from an area of accretion to a downdrift area of erosion, across a barrier to natural sand transport such as large-scale jetty structures. Most sand bypassing projects around the world build permanent pumps to move sand across inlets and onto beaches (see Boswood and Murray, 2001 for an extensive list). A less common approach, and the one chosen for Assateague Island, is to use dredge boats to bypass sand to the nearshore or surf zone rather than onto the beach. This method has been successful at several locations including Tweed River, Australia, and Mount Maunganui, New Zealand, where placed sand remained in the nearshore and beach system at least one year later (Foster et al., 1994; Dyson et al., 2002).

The North End Restoration Project at Assateague Island will develop information concerning the effectiveness of restoring natural barrier island processes through the systematic nearshore placement of bypass sand and regular topographic and shoreline surveys over a 25-year period. For the purposes of this study, “surf zone” is defined as the area of breaking waves, and “nearshore” is defined as the subaqueous region extending offshore from the mean high water (MHW) line out to the depths at which waves begin to be significantly altered by the shoaling bathymetry, an area which encompasses the survey depth limit of -10 m (North American Vertical Datum, NAVD88). The biannual sand bypassing project, which began in January 2004, dredges sand from the ebb and flood tidal deltas and places it in the nearshore area of the project site rather than on the upper shoreface, thereby minimizing adverse impacts to subaerial habitats. An additional advantage of this method is a reduction in dredging needed to maintain the inlet navigation channel.

REGIONAL SETTING

Assateague Island is a barrier island that extends 58 km along the coast of Maryland and Virginia (Figure 1). Island width ranges from 300 m to 1200 m, and elevations are generally around 2 m (NAVD88), though dunes may rise up to 10 m high. Its northern end is bounded by Ocean City Inlet, which has an associated flood tidal delta and a large ebb tidal delta that extends both north and south of the inlet, curving to form a 300-meter wide attachment bar that currently meets the shoreline between 650-950 m south of the inlet (Figure 1). The growth of the ebb tidal delta since inlet formation, and its shoreline attachment by 1980, are well documented (Dean and Perlin, 1977; Leatherman, 1984; Underwood and Hiland, 1995; Rosati and Ebersole, 1996; Stauble, 1997; Kraus, 2000). This attachment bar is a significant bathymetric feature in the nearshore, rising 3.5 m above the surrounding seafloor, and steeper on its south flank (1:46 slope) than its north flank (1:180 slope).

The coast is classified as wave-dominated (average height of 1 m) and microtidal (0-2 m tide range) with spring tides fluctuating from -1 m to 3 m relative to mean low water (MLW) (Field 1979). Winter storms and high wave energy create a low, flat beach with sand stored in a nearshore sand bar; summer beach profiles are steeper. Depth of closure, defined as the depth beyond which sediment transport of engineering significance does not occur (Hallermeier, 1981), is estimated to be -6.2 m NAVD88

(Stauble, 1994) and is typically found about 275 to 400 m from the high tide line. Net alongshore sediment transport is southward due to strong winter northeasters; in the summer, waves from the southeast drive sand transport less vigorously northward. As a result, the net annual alongshore transport is estimated to be between 115,000 and 214,000 m³/yr toward the south (Underwood and Hiland, 1995).

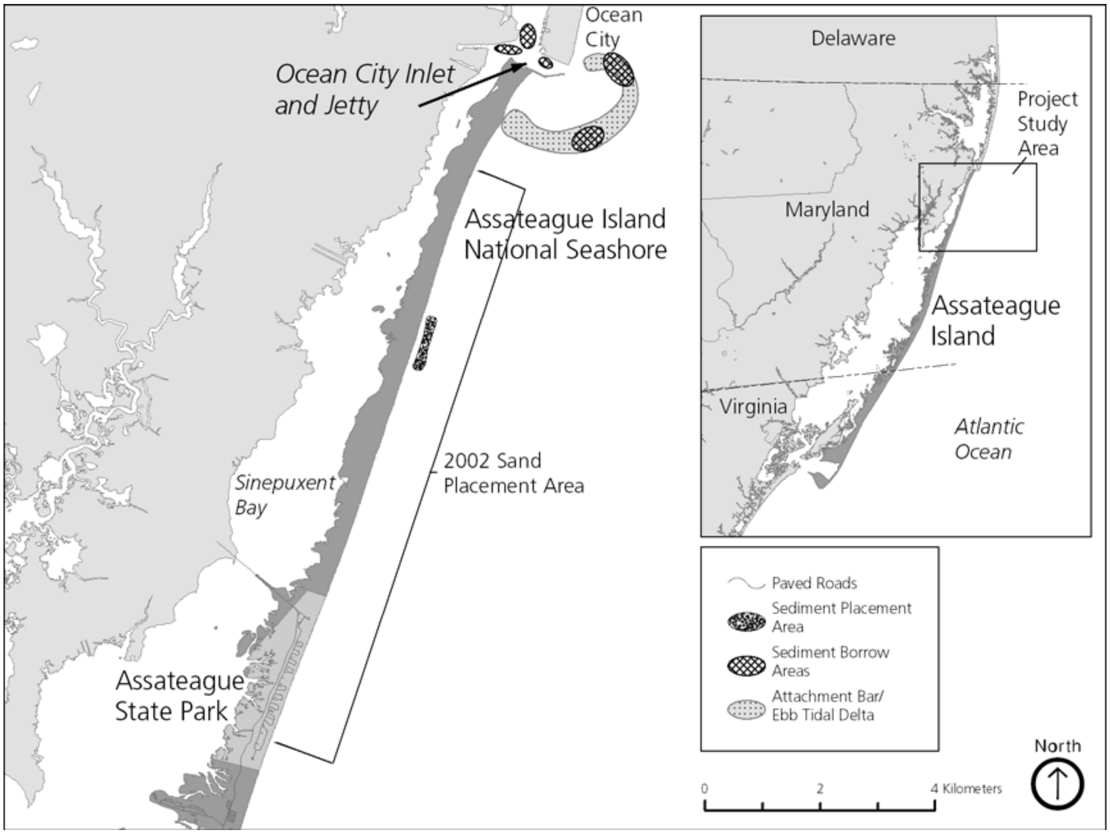

Figure 1. Location of project study area and major sediment features.

The majority of the island is managed as a National Seashore and has little infrastructure along its length, with the exception of the section 10-13.2 km south of the inlet. In that section, a state park constructed high dunes to protect extensive park infrastructure, and maintenance sometimes involves scraping the beach and importing clay to stabilize beach access over the dunes.

North of the state park, most of the northern 10 km of Assateague Island is a dynamic environment composed of a beach and low berm on the ocean side of the island, with a low elevation, sparsely vegetated back barrier flat and a narrow fringing salt marsh with overwash fans along an estuary. This dynamic area is prime habitat for state- and federally-listed endangered species and protects the mainland directly to the west from storm tides and waves.

The northern end of Assateague Island is classified by the U.S. Geological Survey as having 'very high vulnerability' because of its low elevation, frequent overwashing, and high rates of shoreline erosion (Pendleton et al., 2004). This vulnerability is thought to be caused primarily by an interruption in alongshore sediment transport by the jetties built around the Ocean City Inlet in 1935 (Rosati and Ebersole 1996). Along the northern 13.2 km of the island, the shoreline erosion rate more than doubled when the inlet was stabilized, from a pre-inlet rate (1850-1933) of -1.5 m/yr to a post-inlet rate (1942-1997) of -3.70 m/yr.

This increase in shoreline erosion is associated with a volume loss in the active profile (from the beach berm offshore to the depth of closure) that increased after the inlet was stabilized from an estimated 150,000 m^3/yr to 370,000 m^3/yr. Because detailed historical bathymetric data do not exist for this project site, this volumetric loss rate was approximated using a method established by Hanson and Kraus (1989) that integrates the active profile depth, the pre- and post-inlet shoreline change rates, and the assumption that shoreline change is represented as a horizontal and uniform translation of the profile. This assumption and the resulting volume calculations do not include the area north of the attachment bar, where the depth of closure and active berm are quite different from the shoreline directly southward.

North End Restoration Project

USACE predicted that without mitigation, the north end of the island would destabilize and eventually breach during storms in the near future (USACE, 1998). Should this occur, it would have both a significant impact on the values and purpose of Assateague Island National Seashore and serious implications for the adjacent mainland communities, including infrastructure vulnerability, loss of estuarine habitats, and increased maintenance needs for Ocean City Inlet.

To mitigate the loss of natural sand transport processes, local and national government agencies created a comprehensive two-phase restoration plan. The first, short-term phase of the restoration program intended to replace some of the sediment lost since inlet stabilization, estimated to be 9.7 million m^3 in the northernmost 12 km of the island by 1996 (USACE, 1998). During this phase, 1.4 million m^3 of sand was placed just seaward of the mean high water line in September 2002 in an area extending from 2 to 12.5 km south of the inlet (Figure 1).

The second, long-term (25-year) sand management phase is intended to restore sand transport to northern Assateague Island at a pre-inlet rate. The intent of the project is neither to create a fixed-width beach nor to stop erosion, but rather to reduce the erosion rate to the pre-inlet conditions by restoring the sediment transport pathway. Beginning in January 2004, and recurring every early spring and fall, a hopper dredge takes approximately 72,000 m^3 of sand from the ebb and flood tidal deltas (borrow sites delineated in Figure 1) and deposits it just seaward of the surf zone on Assateague Island approximately 2.5 to 5 km south of the inlet (Table 1). Unlike a typical beachfill project in which the material is pumped high on the beach, the bypassed borrow material is deposited on the crest and just seaward of the nearshore bar, which has an approximate crest elevation of -1.45 m to -1.75 m NAVD88. The loaded hopper dredge, which drafts approximately 2.4 m, enters the placement area perpendicular to the shore until the bow makes contact with the bar. The hopper doors (approximately 30 m long and 7.6 m wide) are then slowly opened. As the material starts to exit the hopper and the load lightens, the vessel attempts to move shoreward to deposit the remaining material as close to shore as possible. The dredge deposits the majority of sand in depths of -1.5 to -5 m (NAVD88) and about 80-250 m from shore (Figure 1). Ideally, because the sediment is placed landward of the depth of closure, waves and alongshore transport processes then move this material onshore, shaping this sand into a natural configuration in the surf zone and on the beach.

Sand is not deposited along the northernmost 2.5 km of the island because USACE hydrodynamic models indicate that within that region, sediment has a localized net northward transport. The net northward transport is apparently caused by wave refraction and wave breaking on the ebb tidal delta and attachment bar (Buttolph et al., 2006).

Table 1. Sources and Volumes of Borrowed Sand Delivered to Assateague Island

Time Period	Borrowed from Inlet and Flood Tidal Delta (m^3)	Borrowed from Northern Ebb Tidal Delta (m^3)	Borrowed from Southern Ebb Tidal Delta (m^3)	Total delivered to Assateague Island (m^3)
Spring 2004 (1/30 – 4/1)	10964	45090	0	56054
Fall 2004 (10/1 – 11/26)	3280	0	66814	70094
Spring 2005 (3/29-4/28)	776	0	24332	25108
Fall 2005 (9/18-11/13)	12374	49386	0	53140*
Total	27394	94476	91146	204396

*8620 m^3 of the total borrowed volume was delivered to Ocean City.

Design studies performed prior to the short-term phase of the restoration project indicated that the native beach sediments in the active profile of the project area had a mean grain size of 0.25 mm and a standard deviation of 0.88 mm (moderately sorted sand), with finer sand seaward of the storm bar (USACE, 2001). Samples collected in 2004 and 2005 from the ebb and flood shoals indicate that the mean diameter of the sediments range from .17 mm to .65 mm, or fine to coarse sand and moderately well to well sorted.

Storm activity during the bypassing phase, from January 2004 through December 2005, was relatively minor, according to observations at the USACE wave and water level gauge located about 3 km north of the inlet in about 9 meters of water. It is not uncommon for the gauge to record wave heights in excess of 3 meters several times a year, with a maximum wave height of 4.2 meters being recorded during the January 1992 northeaster. In contrast, between January 2004 and December 2005, wave heights exceeded 3 m during only one event. It should be noted, however, that the gauge was inoperable during the first half of 2005.

METHODS

To monitor the effects of the restoration project and the sand permanence, nearshore bathymetric profiles are surveyed annually and shoreline position is mapped quarterly, as described below.

Volume Change

Nearshore bathymetry profiles were surveyed just after the second round of dredging each fall. The profiles extended in an offshore direction from the beach berm out to about -10 m NAVD88. Surveys relied on a towed survey sled and an optical total station and were tied to monuments established along the island. The towed sled surveys have been performed on an irregular time interval since 1986, usually in response to engineering activities or storm events, and have been surveyed annually since 2003 as a part of the North End Restoration Project. The surveys analyzed for this paper were collected November 14-16, 2003, November 7-9, 2004, and November 11-13, 2005. Each survey followed mild frontal passages with minor waves, tides and sediment transport activity, so that the surveys could be performed during the offshore winds and calmer surf zone activity that follow the fronts.

Due to the distance between each of the nearshore profiles, true volume changes cannot be calculated, and were instead approximated using the following method. The change in cross-sectional area at each transect during each year was calculated for four different depth categories:

1. the beach, from 2 m to 0.36 m NAVD88 (MHW);
2. the shallow water, from 0.36 m (MHW) to -3 m NAVD88 (active profile zone);
3. deep water, from -3 m NAVD88 down to the closure depth as observed in graphs of the three surveys at each transect line; and
4. the total area from 2 m NAVD88 down to observed closure depth (varies for each transect).

The observed closure depth varied between transects and did not always extend to the generalized depth of closure for two reasons: not all transect surveys were collected out to the documented depth of closure; and for each transect line, the three surveyed profiles closed (joined at depth with no change in bathymetry on the three survey dates) within the survey area and at a unique depth.

Next, to approximate volume change over the two year period, the average area change of adjacent transects was multiplied by the distance between the two transects to get the approximate volume change between each pair of transects. These approximated volumes were then summed for a total volume change estimate. This process was used for each depth category.

Shoreline Change

To calculate shoreline change rates, several sources of shoreline positions were used. The seven historic shoreline positions from 1850 to1980 came from various sources, including NOS T-sheets and aerial photographs. Recent high tide shoreline positions, collected from 1994 to the present, were surveyed quarterly at Assateague Island during near-average tidal ranges when the predicted high tides ran close to MHW. The high tide line, as evidenced by the wet/dry line or deposited wrack, was collected with a kinematic differential GPS receiver mounted on an ATV, and was post-processed.

The linear regression rates of shoreline change (LRR) were calculated using DSAS (Thieler et al., 2005), which cast shore-perpendicular transects at 50 m intervals between a user-defined baseline and each shoreline position. It then fit a least-squares regression line to all shoreline points for a particular transect and assigned the slope of the line as the change rate. Negative rates indicate erosion; positive rates indicate accretion. Although this method tends to underestimate the rate of change relative to other statistical methods, such as end point rate (Dolan et al., 1991), it offers the following benefits: all the data are used, regardless of changes in trend or accuracy; the method is purely computational and does not require any other analysis such as error measurements; and it is based on accepted statistical concepts (Thieler et al., 2005).

To examine the patterns in shoreline change related to the restoration project, several eras were selected. The long-term shoreline change rate was calculated for 1850-2005, and the shoreline change related to the long-term restoration phase was calculated from the positions surveyed between February 2004 and December 2005, which was a relatively calm weather period, with recorded wave heights exceeding 3 m (moderate intensity) during only one event. For comparison, shorelines from December 1994 through December 1997 were used to calculate the shoreline change rates for a pre-restoration period with similar weather. During that period, there was relatively little storm activity; wave heights at the gauge reached or just exceeded 3 m on only three occasions.

RESULTS

Nearshore Volume Change

As a whole, the study area experienced net accretion in the first year and erosion in the second year (when less sand was bypassed, Table 1), resulting in a net volume loss (Table 2). In the two-year period, net volume loss occurred at nearly all profile locations, with the exceptions of the attachment bar location, the sand placement location, and the state park (Figure 2A). After two years, the majority (63%) of volume increase lay in two places: within the placement area (96299 m^3) and on the attachment bar (32339 m^3).

Volume changes at each profile and in each depth category varied, with net accretion in the beach and shallow areas and net erosion in deeper areas (Table 2, Figure 2). Despite the large volume of sand deposited in the nearshore of Assateague Island, and despite a relatively calm period of weather, there was a net volume loss in the active profile of Assateague Island. Most of this loss was at depth.

Table 2. Volume Changes by Depth Category 2003-2005

Depth Category (NAVD88)	2003-2004 (m^3)	2004-2005 (m^3)	2003-2005 (m^3)
Beach (2 to 0.36 m)	135718	-25415	110303
Shallow (0.36 to -3 m)	507596	-127531	380065
Deep (-3 m to deepest)	-628462	-370623	-999085
Total Profile	14852	-523569	-508717

The beach (2 m to 0.36 m NAVD88) accreted some sand the first year and then lost 30% of that volume the second year, resulting in an overall accretion along the 13.2 km study area (Table 2). The majority of this accretion was measured within two sites: the 2.5 km region centered on the sand placement site, and the point at which the attachment bar meets the beach (Figure 2B).

The shallow region (0.36 m to -3 m NAVD88) experienced net accretion over the two years (Table 2, Figure 2C). During the first year of the project, sand accreted at every transect location with one exception: north of the attachment bars (Table 2, Figure 2). During the second year, the shallow region experienced a 30% net loss of this accreted sand along much of the study area. As a result, over two years, the net change at this depth was erosional north of the attachment bar but accretional along most of the shoreline, particularly in and north of the placement area and in the northern section of the state park, where a large bar moved shoreward into shallower water.

At depth (below -3 m NAVD88), sand eroded at every transect location every year, with three exceptions: within the placement area, which gained sand both years; where the attachment bar meets the beach; and at one location within the state park, where a large bar migrated landward, moving into the 'shallow' depth category (Figure 2D). Most (60%) of the sand loss occurred in the first year (Table 2).

The volume of sand bypassed to Assateague during the first year of the project accounts for only 20% of the net volume of sand accreted in the beach and shallow areas that year. Over the two-year study period, the volume gained in the beach and shallow regions accounts for only 41% of the combined volume of bypassed sand and sand lost from the deep water (1.2 million m^3, Tables 1 and 2). The active profile area north of the attachment bar, represented by the northernmost two transects, accounts for a net volume loss of -129891 m^3, or 34% of the net volume loss along the whole study area (11% of the combined bypassed and lost volume).

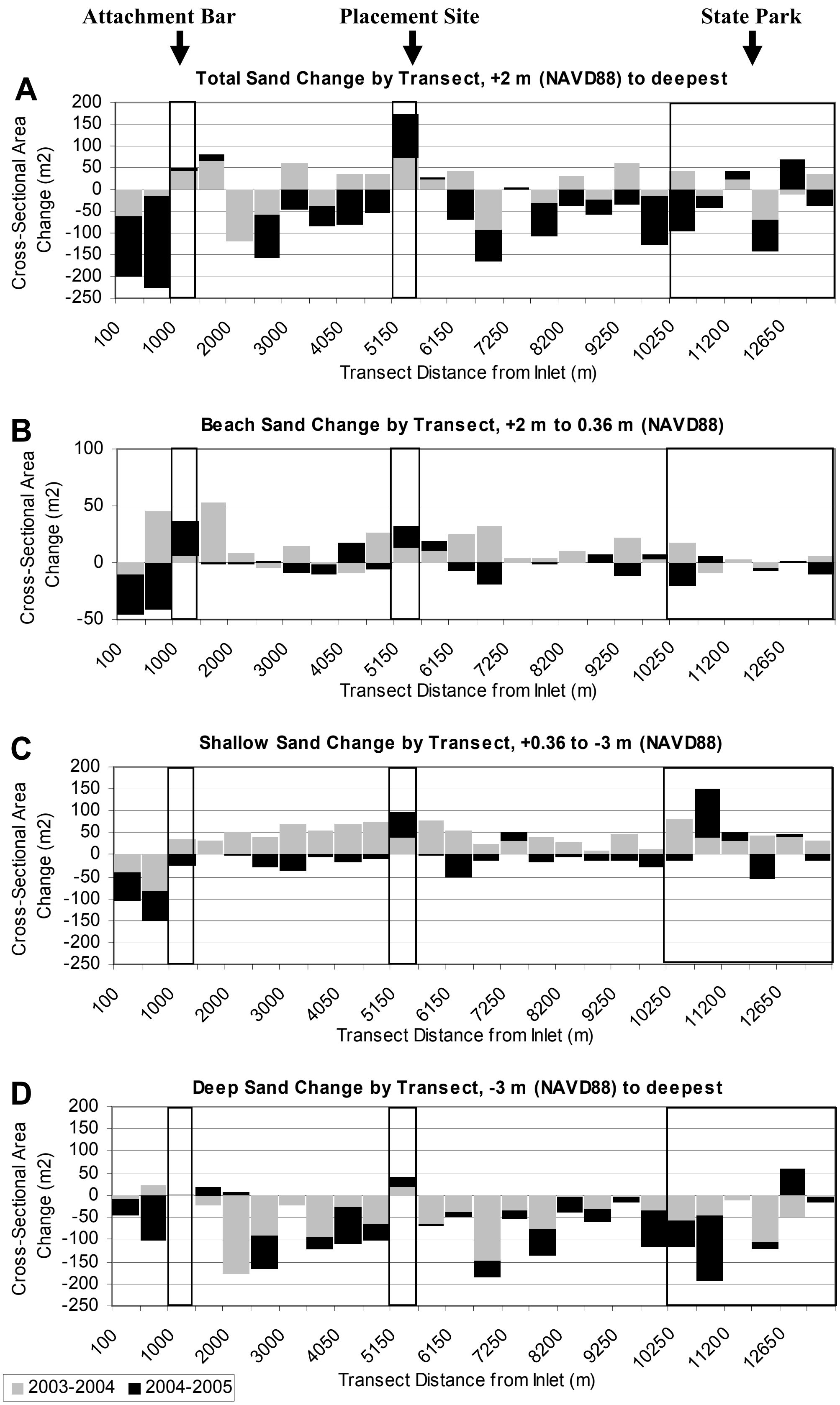

Figure 2 (A-D). Sand loss or gain for each depth category at each transect.

Shoreline Change Rates

The long-term (1850-2005) shoreline change rate in the 13.2 km study area averages -3.25 m/yr (erosion), with a slightly lower erosion rate in the area south of where the attachment bar developed (Table 3, Figure 3). Because the rate is calculated over a longer period of time with fewer shorelines, the standard deviation is lower than for the short-term rates (Table 3).

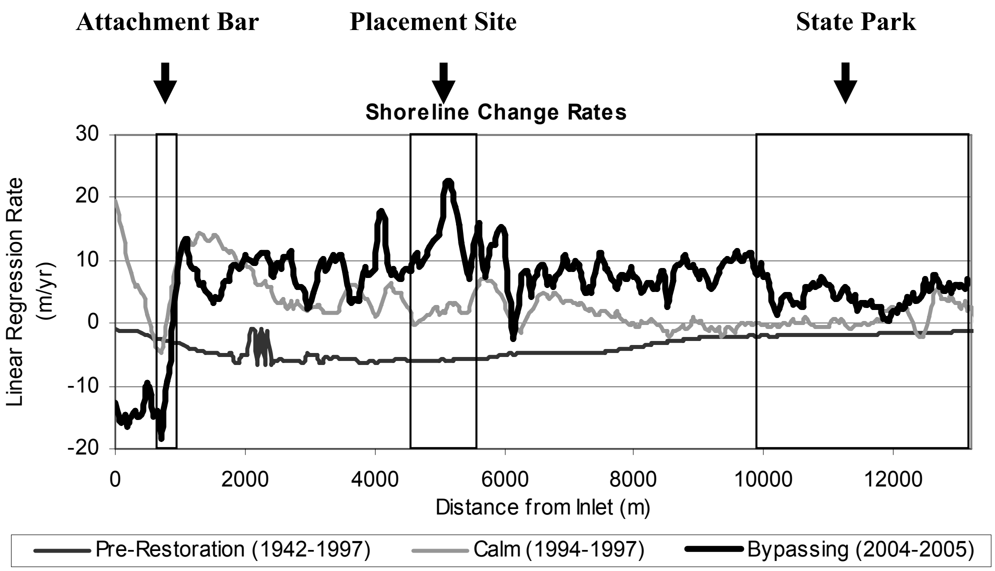

Figure 3. Linear regression rates of shoreline change before and during the long-term restoration project. Positive rates indicate accretion; negative rates indicate erosion.

Table 3. Linear Regression Rates of Shoreline Change by Era

Time Period	LRR (m/yr) in Study Area	Standard Deviation (m/yr)	LRR (m/yr) in Study Area, South of Attachment Bar	Standard Deviation (m/yr)
1850-2005	-3.25	1.96	-3.02	2.01
1994-1997 (calm weather, pre-restoration)	1.87	2.39	1.87	2.39
2004-2005 (calm weather, sand bypassing)	6.22	6.49	7.69	3.82

The tendency of the shoreline to accrete during calm years was evident during a calm-weather period (1994-1997) just before the restoration project began, when the shoreline in the northern 13.2 km study area was stable or accreting along its entire length, with the exception of the area north of the attachment bar, where the shoreline eroded (Figure 3). The two-year study period (February 2004 through December 2005) experienced a similar lack of major storms in addition to sand bypassing, and the accretion rate along the entire 13.2 km study area shoreline was even higher, although erosion quadrupled in the area north of the attachment bar (Figure 3). In the state park, the shoreline also accreted during the recent period, but at a lower rate (Figure 3).

DISCUSSION

Correlation of Shoreline Change and Volume Change

The alongshore trend of shoreline accretion and erosion over the two-year period reflects the alongshore pattern of sand gain and loss in all depth categories. The volume loss seen north of the attachment bar is reflected in the high shoreline erosion rate there, and the high shoreline accretion rate at the northern end of the placement site is also reflected in the volumetric gain in all depth categories. Appropriately, the shoreline change rate is tied more closely to the alongshore volume changes on the beach than to the changes in other depth categories. The large sand gains in the beach and shallow regions were associated with a high accretion rate along most of the shoreline, particularly in the sand placement area, which had a large net volume increase (96,300 m^3).

Sand Sources and Sinks

Although the processes driving the volumetric changes along Assateague Island are difficult to ascertain based on two years of monitoring data, the likely sources of sand transport are known.

The long-term natural processes of barrier island retreat, which have driven Assateague Island toward the west, likely have continued. These processes include recession of the entire active profile and would account for the continued loss of material seaward of the -3 m contour. The sediment that is lost from the active profiles is being transported in possibly all four directions, along with the bypassed sand that was placed in the nearshore. The lost material probably did not move seaward of what is assumed to be the maximum depth of the active profile. Because the period 2003-2005 lacked major storms, it is assumed that the wave energy was not sufficient to move sand from the beach and shallow areas and into deeper waters; instead, waves would tend to deposit sand onto the beach and shallow areas, a process described by Hoefel and Elgar (2003).

Some of the sand from below the -3 m contour, along with the large amount of sand bypassed to the nearshore, would have been transported onshore by long period waves. This process accounts for the significant gains of sand above the -3 m contour and the associated shoreline accretion. Much (45%) of the sand remained within the nearshore placement area, a tendency documented in a similar project site at Mount Maunganui, New Zealand, where all of the placed sand remained in the placement area one year later (Foster et al., 1994). The retention difference may be attributed in part to the reduced wave energy and larger placement area at the New Zealand site.

Although topographic volume changes were not quantified for this study, it can be assumed that some of the sand carried into the shallow areas may have been carried farther onto the island as overwash fans, which have been measured on Assateague as accreting by 20 to 90 cm in one year (Kochel and Dolan, 1986). Sand may also have blown inland from the lower beach; Leatherman (1976) found that deposition by aeolian sand transport could dominate even overwash processes, particularly in wide low areas such as the north end of Assateague Island. Likely, some of the bypassed sand was also transported southward from the placement area, along the island and out of the study area, as indicated by the effects in the shallow and beach areas diminishing with distance from the placement site, and by the absence of recognizable effects on the deeper areas (Figure 2). The muted accretion in the state park likely reflects the combination of increased sand supply from the north and the impacts of dune construction and maintenance; beach scraping can result in compaction, altered morphology (slope), and sediment transport (Conaway and Wells, 2005).

Northerly transport toward the inlet and into the ebb shoal complex due to tidal circulation occurs almost continuously and probably in large volumes. The assumption of northward transport is supported by the expectation of northward transport in the absence of storms, the shoreline accretion and volumetric gain on the attachment bar, and the trend of volume loss increasing with distance north of the placement site. The attachment bar appears to have blocked the northward transport of sand, as there was no sand accretion north of the attachment bar. The northward-moving sand likely welded to the bar both within the profile survey area and farther offshore as sand was shunted eastward around the curve and toward the inlet. Some natural accretion at the location where the attachment bar joins the shoreline is typical of tidal inlets (Fenster and Dolan, 1996), but the increased accretion can probably be attributed to the increased sand supply from the south.

The localized tidal circulation pattern contributes to the erosion of the island north of the ebb shoal attachment point. The expansion of the ebb tidal shoal and southward movement of the attachment bar has expanded the reach of erosive tidal currents north of the attachment bar, translating those profiles landward. This erosion was probably exacerbated by jetty tightening in 2002 and 2003, which in reducing jetty permeability also reduced sand transport to the areas adjacent to the jetty and shunts sand further offshore (Buttolph et al., 2006).

Future Work

The two-year period of data used in this paper helps to document sediment transport processes and the evolution of various features of the island. However, the period is far too short to examine long-term or weather-related trends, and is considered anomalously calm compared to typical conditions on Assateague Island. As more storminess occurs, other processes will become evident, such as overall beach erosion throughout the active profile, while other processes will become more pronounced, such as island overwash and both alongshore and cross-shore transport. Continued monitoring of bathymetry and shoreline position over the 25-year project period will shed great insight on the sand bypassing effects, including sand borrow and placement location, the feasibility of restoring natural sediment transport processes, and the effectiveness of restoring natural barrier island processes through nearshore sand placement. A fuller understanding of the project effects will be gained by statistically analyzing the correlation between changes in both shoreline position and sand volume; by including subaerial volumetric changes driven by wind and overwash; and by comparing the performance of the bypassed sand project to that of the traditional beachfill project at neighboring Ocean City, MD.

CONCLUSION

The reduced erosion of the shoreface in the project site and the increase in shoreline accretion indicate that the sand bypassing project is effective in delivering beach-quality sand to the surf zone and shoreline of the project site. When assessing the effects of nearshore sand bypassing, volumetric changes must be assessed not only along the total depth profile but also within various process-related depths. In the two-year study period, which lacked major storms, the sand spread both north and south of the project area, and accreted only on the beach and at shallow depths. Much of the sand lost at depth is believed to have accreted to the ebb tidal delta and upper shoreface, with significant volume also being transported alongshore and out of the study area.

ACKNOWLEDGEMENTS

Thanks to Andrew Roach for the location figure.

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