FIRE ISLAND INLET TO MORICHES INLET, NY

STABILIZATION PROJECT

TECHNICAL SUPPORT DOCUMENT

EVALUATION OF AN PLAN FOR COASTAL STORM RISK MANAGEMENT

BACK-UP CALCULATIONS

U.S. Army Corps of Engineers

New York District

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1.0 INTRODUCTION

This appendix provides a summary of the methodology and calculations applied determine the quantities & costs of initial beachfill for the Fire Island Inlet to Moriches Inlet (FIMI) Stabilization Project. This appendix also includes back calculations for the renourishment quantities and costs differ for two beachfill alignments, Minimum Real Estate Impacts (MREI) and Medium Updated (MIDU). Updates to the estimated costs in the Breach Closure Plan (BCP) are also included.

2.0 POST-HURRICANE SANDY CONDITIONS

2.1 Observed Sub Aerial Changes from 2000 to 2012

Prior to Hurricane Sandy, beachfill quantity estimates for the TFSP were based on LIDAR data from 2000. Between 2000 and Dec 2012 the beach conditions along Fire Island have undergone considerable changes. In general, the dunes are narrower and lower and the beaches actually appear wider as of Dec 2012. Hurricane Sandy is primarily responsible for the observed erosion of the dunes. The generally wider beaches may be a consequence, at least partly, of local beachfill activities between 2000 and 2012. Dune losses and widespread berm lowering during Hurricane Sandy may have contributed to the apparent seaward shoreline movement in some areas.

2.1.1 Beachfill Projects

Two major beachfill projects occurred along Fire Island between 2000 and 2009. In 2003/2004 several communities in Fire Island placed approximately 1.28 MCY of sand in Western Fire Island and Fire Island Pines, and in 2009 1.82 MCY of sand was placed in eleven communities along Fire Island (CPE 2013). In addition to these two major beachfill projects, 172,000 CY and 21,000 CY of sand were placed at Smith County Park and Davis Park respectively in 2007 (CPE 2013). A summary of the placed beachfill volumes are presented in Table 1.

Table 1: Placed Beachfill Volumes (CY)

FIMP Design Reach	Name	2003/2004	2007	2009	Total
GSB-2A	Kismet to Lonelyville	717,728		520,743	1,238,471
GSB-2B	Town Beach to Corneille Est.			68,039	68,039
GSB-2C	Ocean Beach to Seaview			349,422	349,422
GSB-2D	OBP to POW			159,463	159,463
GSB-3C	Fire Island Pines	560,840		509,258	1,070,098
GSB-3G	Davis Park		21,000	292,804	313,804
MB-1B	SPCP		172,000		172,000
Total		**1,278,568**	**193,000**	**1,899,729**	**3,371,297**

Notes: Placed Beachfill Volumes from CPE (2013)

2.1.2 Observed Beach Changes at Fire Island Pines (LIDAR and Aerial Images)

Hurricane Sandy (October 29, 2012) produced record storm tides and wave heights in the New York Bight. As a result several breaches occurred and significant overwash and beach erosion was observed along Fire Island.

Aerial images and LIDAR data from 2000 to Nov. 4, 2012 are presented below for Fire Island Pines to illustrate the aforementioned beach changes (e.g. dune erosion, increased beach width) that are reflected in the initial beachfill volume estimates presented herein.

Aerial images of Fire Island Pines from March 2001, March 2012, and November 2012 are shown in Figure 1. The +2 NGVD contour derived from the LIDAR data is shown in red (2000) and cyan (2012 Post-Sandy).

LIDAR elevations from c. 2000, 2011 (Post-Irene), and 2012 (Post-Sandy) are shown in Figure 2. The +2 NGVD contour derived from the LIDAR data is shown in red (2000) and black (2012 Post-Sandy). The MREI baseline is shown in purple.

Representative cross-shore beach profiles cut from the 2000, 2011, and 2012 LIDAR are shown in Figure 3 and Figure 4. The design profiles for the TFSP (labeled as MREI-Medium) are also shown in Figure 3 and Figure 4.

The aerial images and LIDAR data tell the same story at Fire Island Pines: the beach width increased considerably from 2000 to 2011 and Hurricane Sandy caused significant dune erosion from 2011 to 2012. Some of the sediment eroded from the dune face and berm top during Hurricane Sandy appears to have been transported seaward and deposited along the seaward edge of the berm, resulting in a wider dry beach and shoreward migration of the +2 NGVD contour. The trends observed at Fire Island Pines are similar, although perhaps more exaggerated, to other communities along Fire Island.

2.1.3 Observed Beach Changes (USGS Measurements)

A recent study of coastal change from Hurricane Sandy at Fire Island was published by Cheryl J. Hapke et al. (2013). The study assessed the morpholgical impacts of Sandy to the beach and dune system at Fire Island. Profile surveys prior to landfall and in the months following Hurricane Sandy were used to capture the morphological evolution of the beach over the winter and spring.

As previously discussed the beaches and dunes on Fire Island were severely eroded during Hurricane Sandy, resulting overwash along approximately 45 percent of the island and breaches in three locations on the eastern segment of the island (Hapke et al., 2013). Enormous volumes of sand were carried from the beach and dunes to the central portion of the island, forming large overwash deposits. Figure 5 shows the alongshore patterns of overwash and upper beach (+ 10.5 feet NGVD) migration from Hurricane Sandy (Figure from Hapke et al., 2013). A majority of the dunes were either flattened or experienced severe erosion/scarping. In addition, the elevation of the beach was lowered leaving any surviving dunes vulnerable. Examples of pre- and post-Sandy survey profiles at three locations along Fire Island are presented in Figure 6 (Hapke et al., 2013) highlighting the changes in the beach and dune. Hapke et al. (2013) estimates that the upper portion of the profile lost on average 54.5 percent of its volume.

2.2 Existing Conditions for Economic Modeling

The existing beach conditions for the Economic Model are defined by the "equivalent" beach and are used as the starting conditions for the model. The equivalent beach width accounts for both the dune height and berm width, hence the term "equivalent". The post-Sandy equivalent beach width was determined for locations along Fire Island based on 2012 LIDAR; profiles spaced every 200 feet along the shoreline were extracted from the LIDAR and compared to 2000 LIDAR. Further west at Sedge Island, Tiana Beach, and West of Shinnecock Inlet (WOSI) the data source for the analysis was pre- and post-Hurricane Sandy aerials as well as qualitative estimates of damages. Table 2 presents the starting conditions representative of the conditions post-Hurricane Sandy that will applied in the Economics Modeling.

Table 2: Starting Conditions for Economic Modeling

Design Reach	Location	Simulated FVC Min Dune Height (ft NGVD)	2012 Minimum Dune Height (ft NGVD)	2013 Conditions	Equivalent Beach Width (ft)
GSB	FI Lighthouse	8	8	FVC	50
GSB	Kismet/Corneille	8	8	FVC	50
GSB	Talisman/Blue Pt.	10	12.5	BLC[1]	150
GSB	Davis Park	10	12	BLC/FVC[2]	150
GSB	Old Inlet W	8	OPEN	BOC	
GSB	Old Inlet E	8	5	FVC[3]	50
MOR	SPCP	8	5	FVC[3]	50
SHN	Sedge I.	10	NA	FVC	50
SHN	Tiana	8	NA	FVC	50
SHN	WOSI	10	NA	FVC	50

Notes:

[1] Similar dune height but in 2012 it has less beach width. It starts with 150 ft, narrow beach, perhaps it BLC is representative.

[2] This interpolation is between BLC-2000 with dune height of 15 ft and FVC 10 ft. The 13 ft templated had a 50% lower level of protection and beach width was 150 ft instead of 250 ft. I will suggest to use 150 ft as the best approximation.

[3]The condition is much worse than FVC.

3.0 ALTERNATIVE PLANS

Recent storm events, such as Hurricane Sandy and Hurricane Irene, have the left the dune and berm system along the south shore of Fire Island vulnerable, increasing the potential for overwash and breaching during future storm events. Two alternatives, MREI-Medium and MIDU-Medium, have been developed to reinforce the existing dune and berm system along the island. Both alternatives include beachfill at Robert Moses State Park, Fire Island Lighthouse Tract, all of the communities outside of Federal Tracts, and Smith Point County Park. Beachfill is not included in any Major Federal Tracts, except Fire Island Lighthouse which was requested by the National Park Service to protect the Lighthouse. The design sections (beachfill design templates) are the same for both alternatives and the extent of beachfill placement is also the same. The only difference between the two alternatives is the alignment. The MIDU alignment is located farther landward, requiring less initial fill and lower renourishment volumes. The MIDU alignment is tentatively selected plan for FIMI Stabilization Project (TSP).

3.1.1 Design Section

The Berm Only, Small, and Medium design templates are used in the two alternatives. The Small and Medium design templates have a dune with a crest width of 25 ft and dune elevations of +13 and +15 ft NGVD, respectively. All three design templates have a berm width of 90 ft at elevation +9.5 ft NGVD. The proposed design (not construction) foreshore slope (from +9.5 to +2 ft NGVD) is roughly 12.1 on 1. Below MHW (roughly +2 ft NGVD) the submerged morphological profile, representative of each specific reach, is translated and used as the design profile. Figure 8 shows a typical design section for the Medium template.

The Berm Only template is applicable to areas in which the existing condition dune elevation and width reduce the risk of breaching but have eroded beach berm conditions. The 90 ft design berm provides protection to the existing dunes and ensure vehicular access during emergency response and evacuation. The Berm Only template is applied to Robert Moses State Park (GSB-1A) and Smith Point Count Park-TWA (MB-1A). At Smith Point County Park the design provides protection to the existing park facilities and TWA memorial.

The Small template is sufficient to reduce the risk of breaching but does not prevent a significant portion of the damages to oceanfront structures. Therefore, the Small template is applied to areas with limited oceanfront structures: Robert Moses State Park (GSB-1A), Fire Island Lighthouse Tract (GSB-1B), and the eastern section of Smith Point County Park (MB-1B, and MB-2A).

The Medium template was identified as having the highest net benefits and provides for approximately a 44-yr level of protection. The Medium template is applied to the areas with the greatest potential for damages to oceanfront structures: Kismet to Lonelyville (GSB-2A), Town Beach to Corneille Estates (GSB-2B), Ocean Beach to Seaview (GSB-2C), Ocean Bay Park to Point O' Woods (GSB-2D), Cherry Grove (GSB-3A), Fire Island Pines (GSB-3C), Water Island (GSB-3E), Davis Park (GSB-3G), and the western section of Smith Point County Park (MB-1A).

The alternatives do not include beachfill in any Major Federal Tracts except Fire Island Lighthouse Tact, which suffered significant beach and dune erosion during Hurricane Sandy. The Major Federal Tracts are: Sailors Haven (GSB-2E), Carrington Tract (GSB-3B), Talisman to

Water Island (GSB-3D), Water Island to Davis Park (GSB-3F), Watch Hill (GSB-3H), Bellport Beach (GSB-4A), and Old Inlet (GSB-4B).

Table 3 provides an overview of the reach length, extents of dune and berm fill, and the dune heights for the MREI-Medium and MIDU-Medium alternatives.

Table 3: Overview of MREI-Medium and MIDU-Medium Alternatives

Design Reach	Location	Reach Length (ft)	Dune Fill Length (ft)	Berm Fill Length (ft)	Dune Height (ft NGVD)
GSB-1A	RMSP	23,200	1,000	16,562	-
GSB-1B	FILT	5,461	5,461	5,461	13
GSB-2A	Kismet to Lonelyville	8,918	8,918	8,918	15
GSB-2B	Town Beach to Corneille Estates	4,529	4,529	4,529	15
GSB-2C	Ocean Beach to Seaview	3,752	3,752	3,752	15
GSB-2D	OBP to POW	7,228	6,400	7,228	15
GSB-3A	Cherry Grove	2,950	0	2,950	15
GSB-3C	Fire Island Pines	6,457	6,000	6,457	15
GSB-3E	Water Island	2,000	2,000	2,000	15
GSB-3G	Davis Park	4,167	4,167	4,167	15
MB-1A	SPCP-TWA	6,342	800	6,342	-
MB-1B	SPCP	13,095	13,095	13,095	13
MB-2A	MB-2A	7,800	4,461	4,461	13

3.1.2 Alignment

The beachfill alignment or baseline defines the cross-shore location of design section. The design sections are oriented to the baseline by setting the centerline of the design dune coincident with the baseline. In the absence of oceanfront real estate, the most cost effective alignment is one that ties into the existing dune line and extends seaward from the existing shoreline only the distance necessary to achieve the required level of protection. The beachfill alignment also affects renourishment costs, as beachfill losses caused by “spreading out” or diffusion of beachfill will be greater the farther seaward an alignment is located.

The Updated Middle Alignment (MIDU), preserves as much as possible the existing (Post-Hurricane Sandy) dune alignment while balancing the cost of acquiring or relocating oceanfront structures versus increased renourishment needs. Lifecycle cost estimates for the MIDU and Minimum Real Estate Alignment (MREI) indicate that cost savings from the reduced initial fill volumes and renourishment volumes exceed the expense of the real estate acquisitions and relocations.

4.0 REPRESENTATIVE EROSION RATES

The advance fill berm width and renourishment volumes are determined based on the representative erosion rates for each design reach. The representative erosion rate accounts for:

1. "Spreading out" or diffusion of sand resulting from the shoreline anomaly or "bump" created by the beachfill;

2. Background shoreline erosion due to ongoing processes before the project was constructed.

Beachfill diffusion is a function of the longshore length of the beachfill, cross-shore width of the beachfill, and longshore diffusivity. The rate of beachfill diffusion is particularly sensitive to longshore length of the beachfill project. Shorter projects (e.g. Fire Island Pines) will generally experience a much higher rate of diffusion than longer projects (e.g. Western Fire Island). Analytical solutions to the diffusion equation (i.e. Pelnard Considere, 1956) are applied in Section 4.4 to determine the rate of beachfill diffusion along Fire Island.

Generally it is assumed that the background shoreline erosion will continue at the same rate as before project. Background erosion rates were determined from the FIMP sediment budget and Most Vulnerable Conditions Report.

4.1 Previous Work (c. 2008)

Representative erosion rates applied in the earlier estimates of renourishment volumes, Table 4, were based on the FIMP sediment budget, Most Vulnerable Conditions Report, and the performance of historical beachfill projects. The representative erosion rates essentially accounted for both the historical background erosion rate and beachfill diffusivity. However, a specific beachfill diffusion analysis was not performed and the relative contribution of the two processes was not identified. It was also assumed that the representative erosion rates were the same for all three project baselines (Minimum Real Estate, Middle, and Unconstrained).

Table 4: Previous (c. 2008) Representative Erosion Rates

Design Reach	Name	Representative Erosion Rate (ft/yr)
GSB-1A	RMSP	5
GSB-1B	FILT	5
GSB-2A	Kismet to Lonelyville	5
GSB-2B	Town Beach to Corneille Estates	5
GSB-2C	Ocean Beach to Seaview	5
GSB-2D	OBP to POW	5
GSB-3A	Cherry Grove	0
GSB-3C	Fire Island Pines	10
GSB-3E	Water Island	1
GSB-3G	Davis Park	1
MB-1A	SPCP-TWA	2

MB-1B	SPCP	2
MB-2A	MB-2A	2

Notes: [1]Distances are approximate (rounded to 200 ft)

4.2 Volumetric Erosion Rates (1998-2012)

Volumetric erosion rates were determined from 1998 to 2012 with profile data sets from USACE survey monuments (F-Monuments) supplemented with profiles form the communities' surveys (SFD, CFI, FIP, and DP-monuments) conducted in the same years (e.g. 1998 and 2012). A depth of closure of -27 ft NGVD was used to calculate the volumetric changes. The volumetric changes were modified based on the fill placed in 2003-2004 and 2009 to determine the net erosion rate. To illustrate the change in volumetric rate alongshore, unit volumetric rates (cy/yr/ft) were calculated at each monument location and the plotted with a three point moving average (Figure 7). A summary of the volumetric erosion rates tabulated by design reach is presented in Table 5 for 1998 to 2012.

Table 5: Volumetric Erosion Rates from 1998-2012

Design Reach	Location	1998-2012 Erosion Rate (ft/yr)
GSB-1A	RMSP	-1.0
GSB-1B	FILT	-1.1
GSB-2A	Kismet to Lonelyville	-5.0
GSB-2B	Town Beach to Corneille Estates	+1.3
GSB-2C	Ocean Beach to Seaview	-1.8
GSB-2D	OBP to POW	+1.7
GSB-3A	Cherry Grove	-2.0
GSB-3C	Fire Island Pines	-9.6
GSB-3E	Water Island	-1.8
GSB-3G	Davis Park	-3.4
MB-1A	SPCP-TWA	-1.0
MB-1B	SPCP	-6.5
MB-2A	MB-2A	n/a

The analysis of volumetric losses from 1998 to 2012 is a very valuable data source and provides insight in to past performance of beachfill projects and the required advance fill volumes. However, the performance the Tentatively Selected Plan (TSP) may differ due to the larger extent of the beachfill in the TSP, inclusion of beachfill tapers in Federal Tracts, and higher frequency of renourishment (4 years). At some of the communities beachfill has only been placed twice since the mid 1990's (mid 1990's and 2009) or once about every 9 years. Therefore, losses to beachfill diffusion are expected to be higher within some of these communities (e.g. Davis Park) than the 1998 to 2012 time period.

A more detailed analysis of the historical erosion rates by community indicates that erosion rates may vary considerably within design reaches and deviate from the net erosion rate shown in

Table 5. Special treatment of historical hot spots could be included in the final design, based on this detailed erosion rate analysis.

4.3 Recently Measured Erosion Rates (2009-2012)

From January to April of 2009 a total of 1.9 MCY of sand was placed in eleven communities along Fire Island (CPE, 2013). The 2009 project consisted of four continuous sections of beachfill placement: Western Fire Island, Central Fire Island, Fire Island Pines, and Davis Park. An overview of the 2009 beachfill project is provided in Figure 9. The performance of the beachfill project has been monitored by collecting beach profile surveys in May 2009, March 2011, and Dec 2012. These beach profile surveys were used by Coastal Planning & Engineering to determine the volumetric changes along the 2009 project extents. Volumetric losses were converted for this study to erosion rates by dividing the total volumetric loss over each project reach by the length of the project reach, and by the active beach height (36.5 feet, depth of closure plus berm elevation). Table 6 presents the volumetric losses and erosion rates for Western Fire Island, Central Fire Island, Fire Island Pines, and Davis Park in the 3.6 years following the 2009 beachfill project.

Table 6: Summary of 2009 Beachfill Project Performance

Project	Length (ft)	Placed Volume (cy)	May 2009 to Dec 2012 (cy)	Erosion Rate (ft/yr)
Western Fire Island	9,351	520,743	-462,446	-10.2
Central Fire Island	8,115	594,398	-733,873	-18.7
Fire Island Pines	6,785	491,784	-671,791	-20.4
Davis Park	4,125	291,352	-257,218	-12.9

The observed erosion rates from 2009 to 2012 are generally higher than from 1998-2012. The higher erosion rates from 2009 to 2012 may be attributed to more energetic wave conditions and beachfill diffusion following the 2009 beach nourishment project.

The 2009 to 2012 erosion rates for Western and Central Fire Island are significantly greater than the previously applied representative erosion rates for these design reaches (5 ft/yr). One possible explanation for the relatively high erosion rates is that the alongshore beachfill lengths in the 2009 project were significantly shorter (9,351 and 8,115) than in the Federal plan (41,800 ft). It will be shown later in Section 4.4 that the rate of beachfill diffusion is very sensitive to the alongshore length of the beachfill project. Another possible explanation is that the rate of background erosion and beachfill diffusion were above average from 2009 to 2013 due to the occurrence of several extreme storm events including several nor'easters, Hurricane Irene, and Hurricane Sandy.

As noted earlier, the rate of beachfill diffusion is a function of the cross-shore width of the beachfill project (e.g. how far the shoreline "sticks out" from adjacent shorelines). Therefore, it important to compare the width of the 2009 beachfill project to the proposed Federal alignments. The location of the design (TSP) or adjusted (CPE 2009) seaward berm crest is used here to represent the relative cross-shore width of the beachfill projects. Figure 10 to Figure 13 show the location of the design berm for the 2009 beachfill project and TSP at Western Fire Island, Central Fire Island, Fire Island Pines, and Davis Park. Visual analysis of Figure 10 to Figure 13 indicate that the cross-shore width of the 2009 beachfill projects are similar to the MREI alignment except at Davis Park where the cross-shore width of the 2009 beachfill is similar to the MIDU alignment. This simple analysis indicates that the measured erosion rates in the 3.6 years following the 2009 beachfill project may be representative of the erosion rates for the MREI alignment at Fire Island Pines and the MIDU alignment at Davis Park.

4.4 Beachfill Diffusion

A beach nourishment project constructed on a long beach represents a perturbation, which under wave action will spread out along the shoreline[1]. If the wave action is small, than the rate at which the anomaly resulting from the beach nourishment is spread out from the placement area will likewise be small[1]. It important to remember that beachfill diffusion is a separate process from background shoreline erosion, which is generally caused by gradients in the net longshore sediment transport.

4.4.1 Theoretical Background

The one-dimensional diffusion equation or Pelnard-Considere equation for planform evolution may be derived from combining the conservation of sediment equation with the total longshore sediment transport equation.

The conservation of sediment equation:

$$\frac{\partial Q}{\partial x} + \left(h_* + B\right)\frac{\partial y}{\partial t} = 0$$

Where Q is the total longshore sediment transport, y is the shoreline, and h_* and B are the depth of closure and berm height respectively.

The total longshore sediment transport, Q, equation or CERC formula is given by:

$$Q = C' H_b^{5/2} \sin 2\theta_b$$

$$C' = \frac{K\sqrt{g/\delta_b}}{8\left(S-1\right)\left(1-p\right)}$$

Where H_b is the breaking wave height, θ_b is breaking wave angle relative to shore normal, K sediment transport coefficient, g is acceleration of gravity, δ_b breaking wave index, S specific gravity of sand, and p is the porosity of sand.

For an undulating shoreline, with small values of $\partial y / \partial x$ the sediment transport equation may be re-written as follows

[1] Dean, R. G., 2005. "Beach Nourishment Theory and Practice," World Scientific Publishing Co., Hackensak, NJ.

$$Q = C' H_b^{5/2} \sin 2\theta_b - G(h_* + B)\frac{\partial y}{\partial x}$$

The first term above represents the background sediment transport rate for shoreline parallel to the x-axis, and the second term represents the transport induced by the shoreline undulations ($\partial y / \partial x$). Parameter G is the longshore diffusivity and is equal to

$$G = \frac{2C' H_b^{5/2} \cos 2\theta_b}{(h_* + B)}$$

Taking the derivative of the sediment transport equation (assuming $\partial y / \partial x << 1$) and combing with the conservation of sediment equation yields the final form of the Pelnard-Considere equation

$$\frac{\partial y}{\partial t} \cong G \frac{\partial^2 y}{\partial x^2}$$

There are many solutions to the equation, of interest here are the solutions for a rectangular and trapezoidal beachfill (e.g. with tapers) on a long straight beach. Consideration was given to solutions to the Pelnard-Considere equation for a barrier island with inlets; however, the distance between the inlets and limits of beachfill are sufficiently large to result in very small differences.

<u>Rectangular Beachfill</u>

The solution to the Pelnard-Considere equation for a rectangular beachfill project on a long straight beach is shown in panel "a" of Figure 14. The non-dimensional results for a rectangular beachfill project with alongshore length *l*, cross-shore width *Y*, and time *t* are shown in Figure 15 illustrating that the planform location after some time "*t*" is proportional to $1/l^2$. As a result, the performance of the beachfill is very sensitive to the alongshore length.

Figure 16 further demonstrates the sensitivity of the performance of a beachfill project to the alongshore length by plotting the fraction of volume remaining, M(t), versus non-dimensional time, $\sqrt{Gt}/l$. The solid black line shows the solution to the Pelnard-Considere equation, the dashed black line presents the results for exponential decay, and the four markers present the volume remaining after 4 years for beachfill projects at Western Fire Island (41,800 feet), Fire Island Pines (6,400 feet), Davis Park (4,200), and Easter Fire Island (19,400 feet). It is important to note, that the results in Figure 16 are in the absence of background erosion. The implications of Figure 16 are clear, shorter beachfill projects will experience a much higher rate of diffusion. Therefore, it is expected that the representative erosion rates at Fire Island Pines and Davis Park will be much higher than at Western and Eastern Fire Island because the alongshore length of the beachfill project is significantly smaller.

Trapezoidal Beachfill

The solution to the Pelnard-Considere equation for a trapezoidal beachfill project on a long straight beach is shown in panel "b" of Figure 14. The results for a trapezoidal beachfill project a similar to the results for a rectangular beachfill project except that end losses are slightly lower due to the tapers. The trapezoidal beach solution is applied here since tapers are expected to be considered in the final design. As in previous efforts, a six (6) degree taper was assumed for this study.

Incorporating Background Erosion

The combined effect of diffusion and background erosion, $\partial E / \partial t$, can be accounted for by adding an additional term to solutions for a rectangular or trapezoidal beachfill:

$$y(x,t) = ... - \frac{\partial E}{\partial t}$$

4.4.2 Application to FIMI

Federal Tracts along Fire Island prevent the construction of a continuous beachfill project. Instead the FIMI Project consists of several individual segments of beachfill that are sandwiched between Federal Tracts. The alongshore length of the individual segments varies from 1,200 feet at Water Island to 41,800 feet at Western Fire Island. For the simple analytical approach applied here, each beachfill segment is treated as a stand-alone project. In practice, the individual beachfill project may have positive impacts on each other. However, a more sophisticated shoreline modeling approach (e.g. GENESIS) would be required to simulate the combined performance of all the beachfill projects. The simple analytical approach taken here is conservative and believed to be suitable for determining the relative differences in the representative erosion rates between the MREI and MIDU alignments.

Table 7 presents the six individual beachfill projects, the design reaches they encompass, their respective length, and associated background erosion rate. It is assumed that the background erosion rates will continue at the same rate as before the project. Background erosion rates were determined from the FIMP sediment budget and Most Vulnerable Conditions Report.

Table 7: Individual Beachfill Segments

Location	Design Reaches	Length (ft)	Background Erosion Rate (ft/yr)
Western Fire Island	GSB-1A, GSB-1B, GSB-2A, GSB-2B, GSB-2C, GSB-2C	41,800	3
Cherry Grove	GSB-3A	3,000	0
Fire Island Pines	GSB-3C	6,400	0
Water Island	GSB-3E	1,200	0
Davis Park	GSB-3G	4,200	0
Eastern Fire Island	MB-1A, MB-1B	19,400	1

4.4.3 Alongshore Diffusivity

The alongshore diffusivity, G, controls the rate at which "spreading" or diffusion of the beachfill project occurs. The alongshore diffusivity is proportional to the breaking wave height raised to the 5/2 power. Since the wave conditions at a site vary over time, so too does the alongshore diffusivity. Therefore, the alongshore diffusivity can be determined by integrating G over time or by determining an effective wave breaking height.

If the gross sediment transport rate at a site is known, than it is possible to back-calculate the effective breaking wave height, H_b, from the CERC sediment transport formula and use H_b to determine the alongshore diffusivity, G. It is important to use the gross sediment transport rates because it reflects the true diffusivity of project site. For example, if a study area had a very high gross sediment transport potential but virtually zero net sediment transport, one would still expect the alongshore diffusivity to be high.

Based on a gross sediment transport rate 2.25 million m^3/yr (2.94 MCY), along Fire Island (Gravens et al, 1999), an effective breaking wave height of 3.65 feet (1.10 m), and alongshore diffusivity of 0.15 ft^2/s. The alongshore diffusivity was reduced by 60% to account for stabilizing effect of wave refraction around the beachfill project (Dean, 2005). Backup calculations for the alongshore diffusivity are provided at the end of this appnedix.

4.4.4 Approach to MREI and MIDU Baselines

In order to apply the beachfill diffusion analysis the cross-shore width, Y, of the beachfill project must be known. In this application, the cross-shore width represents the distance that the design berm (plus advance nourishment) protrudes from the adjacent shoreline where no beachfill placement is planned. It is not a straightforward task to determine this cross-shore width. The cross-shore width, Y, can be further broken down into three components:

$$Y = Y_o + Y_{baseline} + Y_a$$

Where Y_o is the initial cross-shore distance that the design MIDU shoreline protrudes from the adjacent shoreline, Y_a is the advance nourishment width, and $Y_{baseline}$ is equal to:

$$Y_{baseline} = 0 \qquad \text{for the MIDU Plan;}$$

$$Y_{baseline} = \overline{MREI_{baseline} - MIDU_{baseline}} \qquad \text{for the MREI Plan.}$$

Y_o is the same for both baselines, but Y_a will differ for two baselines since it is a function of the representative erosion rate and renourishment interval.

The approach adopted here to determine the representative erosion rates is as follows:

1. Assume the representative erosion rates in Table 4 (c. 2008) are valid for the MIDU plan except at Davis Park where recent monitoring data indicates that the erosion rate is closer to 12 ft/yr.

2. Iteratively run the diffusion analysis for MIDU plan to determine the value of Y_o which produces the desired representative erosion rates.

3. Iteratively run the diffusion analysis for the MREI plan to determine the required value of Y_a.

The representative erosion rate in the diffusion analysis is measured as the average shoreline position over the initial beachfill extents. In all cases the background erosion rates was included in the beachfill diffusion analysis.

A closer examination of the 2012 LIDAR profiles at Cherry Grove and Water Island indicate that both the MIDU and MREI baseline are set back far enough that beachfill design does not extend the width of the existing beach. Therefore, the representative erosion rates from Table 4 (c. 2008) are applied to both the MIDU and MREI plan.

Diffusion Results for MIDU Baseline

The results of the diffusion analysis for the MIDU baseline are presented in Table 8. The theoretical evolution at Western Fire Island and Fire Island Pines is presented in Figure 17 and Figure 18.

Table 8: Diffusion Results for MIDU Baseline

Location	Length (ft)	Y_o (ft)	$Y_{baseline}$ (ft)	Y_a (ft)	Y (ft)	Background Erosion (ft/yr)	Diffusive Erosion (ft/yr)	Representative Erosion (ft/yr)
Western Fire Island	41,800	50.5	0.0	20.0	70.5	3	2.0	5.0
Fire Island Pines	6,400	28.2	0.0	40.0	68.2	0	10.0	10.0
Davis Park	4,200	20.4	0.0	48.0	68.4	0	12.0	12.0
Eastern Fire Island	19,400	6.8	0.0	8.0	14.8	1	1.0	2.0

Diffusion Results for MREI Baseline

The results of the diffusion analysis for the MIDU baseline are presented in Table 9. The theoretical evolution at Western Fire Island and Fire Island Pines is presented in Figure 19 and Figure 20. It is worth noting the CP&E measured erosion rates of approximately 20 ft/yr at Fire Island Pines in the 3.5 years following the 2009 beachfill project so numbers in Table 9 seem reasonable. The results in Table 9 highlight the sensitivity of the beachfill diffusion to the alongshore length. The MREI representative erosion rate at Fire Island Pines increases by 100% whereas the MREI representative erosion rate at Western Fire Island increases by about 20% even though the baseline offset is nearly the same (34 feet). A significant increase in the representative erosion rate at Davis Park is predicted because the alongshore length is relatively short (4,200 feet) and the difference in the MREI and MIDU baseline is 72 feet, nearly twice as much as at Fire Island Pines.

Table 9: Diffusion Results for MREI Baseline

Location	Length (ft)	Y_o (ft)	$Y_{baseline}$ (ft)	Y_a (ft)	Y (ft)	Background Erosion (ft/yr)	Diffusive Erosion (ft/yr)	Representative Erosion (ft/yr)
Western Fire Island	41,800	50.5	34.8	24.3	109.6	3	3.1	6.1
Fire Island Pines	6,400	28.2	34.4	77.1	139.8	0	19.3	19.3
Davis Park	4,200	20.4	72.6	145.7	238.7	0	36.4	36.4
Eastern Fire Island	19,400	6.8	0.0	7.9	14.6	1	1.0	2.0

The results from the beachfill diffusion analysis have been rounded off and adjusted based on engineering judgment to determine the final representative erosion rates, Table 10, to be used in the renourishment volume estimates.

Table 10: Individual Beachfill Segments

Location	Design Reaches	Length (ft)	MIDU Representative Erosion Rate (ft/yr)	MREI Representative Erosion Rate (ft/yr)
Western Fire Island	GSB-1A, GSB-1B, GSB-2A, GSB-2B, GSB-2C, GSB-2C	41,800	5	6
Fire Island Pines	GSB-3C	6,400	10	20
Davis Park	GSB-3G	4,200	12	25
Eastern Fire Island	MB-1A, MB-1B	19,400	2	2

4.5 Summary of Applied Representative Erosion Rates

Review of volumetric losses from 1998 to 2012 and sediment budgets / historical shoreline erosion rates detailed in Gravens et al. (1999)[2] and Moffatt & Nichol (2005)[3], and beachfill diffusion analysis have been used to predict the effective erosion rates for advance fill and renourishment volumes. The beachfill diffusion analysis provides an analytical technique to quantify the relative increase in the renourishment volumes bewtweem the MIDU and MREI alignments. The analysis indicates that representative erosion rates at Fire Island Pines and Davis Park will double. At many of the locations, Kismet to Lonelyville, Cherry Grove, Fire Island Pines, and Water Island the observed erosion rates from 1998-2012 are in line with the recommended erosion rates from the beachfill diffusion analysis. In locations where the observed erosion rates from 1998 to 2012 differ from the recommended erosion rates are detailed below. An overview of the predicted erosion rates is provided in Table 11.

[2] Gravens, M. B., Rosati, J. D., and Wise, R. A., 1999. "Fire Island Inlet to Montauk Point reformulation study (FIMP): Historical and existing condition coastal processes assessment," prepared for the U.S. Army Engineer District, New York.
[3] Moffatt & Nichol, 2005. "Task 4.1 Define Future Barrier Island Conditions", prepared for the U.S. Army Corps of Engineers, New York Distric.

Table 11: Predicted Effective Erosion Rates

Design Reach	Location	MIDU Erosion Rate (ft/yr)	MREI Erosion Rate (ft/yr)
GSB-1A	RMSP	-5	-5
GSB-1B	FILT	-5	-6
GSB-2A	Kismet to Lonelyville	-5	-6
GSB-2B	Town Beach to Corneille Estates	-5	-6
GSB-2C	Ocean Beach to Seaview	-5	-6
GSB-2D	OBP to POW	-5	-6
GSB-3A	Cherry Grove	-2	-2
GSB-3C	Fire Island Pines	-10	-20
GSB-3E	Water Island	-2	-2
GSB-3G	Davis Park	-12	-25
MB-1A	SPCP-TWA	-2	-2
MB-1B	SPCP	-2	-2
MB-2A	MB-2A	-2	-2

RMSP

The Existing Conditions (c. 2001) sediment budget indicates that approximately 81,200 cy/yr of beachfill has been placed along Robert Moses State Park from backpassing of sediment at Fire Island Inlet. The backpassed sediment is generally placed over approximately 12,000 feet, resulting in average shoreline adjustment of +5 ft/yr. Despite the backpassing, shoreline erosion rates from 1979 to 2001 indicate and average shoreline erosion rate of approximately 2 ft/yr (Figure 22). It is anticipated that the construction of the TFSP will result in increased sediment supply to this reach. Therefore, it is recommended that historical backpassing volumes be used as an estimate of the renourishment/advance fill needs: 5 ft/yr over 12,000 ft.

Western Fire Island

At Fire Island Lighthouse Tract and the communities along western Fire Island (GSB-2A to GSB-2D) it is believed that an effective erosion rate of 5 ft/yr captures the historical shoreline trends from 1979-2001 and potential for losses from diffusion (Figure 23). It is noted that the observed volumetric losses from 1998-2012 are higher than 5 ft/yr at few locations, Dunewood and middle of Saltaire, and lower at others. However, the total volume of advance fill within these reaches will larger if 5 ft/yr is used. As discussed above, the expected erosion rates after implementation of the TFPS may differ from the observed erosion rates from 1998-2012. The eventual modification of the Ocean Beach groins (and filling in with nourishment) should result in increased bypassing downdrift to Lonelyville, Dunewood and Saltaire. Eventual modification of the groins may also result in greater erosion rates at Ocean Beach, Seaview, OBP, and Point O' Woods. Therefore, it is preferable to use a more uniform erosion rate along these communities, 5 ft/yr. As noted previously, special consideration of historic hotspots may be included during final design.

Davis Park

At Davis Park, the higher observed erosion rate[4] from 2009 to 2012 is believed to be more representative of the erosion rate in the 4 years following the initial construction of the TFSP. The period from 1998 to 2012 only included major beach nourishment in 2012 and is therefore not believed to capture the potential for significant erosion due to beachfill diffusion (e.g. 2009 to 2012). It is believed that erosion rates at Davis Park will be similar to Fire Island as fill at both communities will "stick out" from the adjacent shoreline.

Eastern Fire Island (Smith Point County Park)

At Smith Point County Park, historical shoreline rates from 1933-1979 were considerably higher than from 1979-2001 (Figure 24). The reduction in shoreline erosion rates in recent years in attributed to increased bypassing at Moriches Inlet. This increase in bypassing is probably related to several factors, including an apparently stable ebb shoal volume, relatively infrequent channel and deposition basin maintenance, and a significant input of sediment updrift of the inlet as a result of the Westhampton Interim project. Therefore, effective erosion rates for the TFPS are expected to be closer to 2 ft/yr. However, engineering judgment must be applied to Davis Park as the predicted increase in representative erosion rates seems excessively high.

[4] Coastal Planning & Engineering of NY, PC, 2013. "2009 Fire Island Beach Renourishment Project Post-Sandy Storm Report", prepared for Sponsoring Communities on Fire Island, New York.

5.0 INITIAL CONSTRUCTION BEACHFILL VOLUMES

The initial construction beachfill volumes are calculated based on profile surveys collected by CPE in the middle of December, 2012. These beachfill volumes supercede the preliminary beachfill volumes calculated based on LIDAR data collected on November 5th 2012.

There are pro's and con's to calculating the beachfill volumes with the LIDAR data versus profile survey data. The primary advantage of using LIDAR data is that a very high density of profiles (every 100 ft) may be used to estimate the beachfill quantities. The density of profile surveys is generally much lower, typically about 300 feet in the communities and between 500 and 1,000 feet in RMSP, FILT, and SPCP.

In both instances, profile translation below the design MHW contour (+2 NGVD) was used to estimate the subaqueous fill volume. A comparison of the LIDAR measurements and surveyed profiles revealed that differences between the dune elevations and berm elevations were very small. However, it was apparent that location of MHW was significantly farther landward in the surveyed profiles. As a result the design fill volumes (and advance fill volumes) were significantly higher when determined with the surveyed profiles. A 45% increase (2.76 MCY vs. 4.0 MCY) in the design fill volume estimates (excluding overfill, contingency, beachfill tapers, and advance fill) occurred when the beachfill quantities were calculated based on the Dec 2012 survey data.

As noted above, beachfill volumes assume the submerged profile is translated seaward of MHW. Therefore, the volume required for every additional 1 foot the design MHW is proportional to the active profile height and is equal to 1.35 cy/ft. An analysis of the sensitivity of the volume estimates to the location of MHW was performed based on the Nov. 5th 2012 LIDAR data (Table 12). The design berm width was adjusted to mimic a landward shift in MHW. A 30 feet change in MHW results in 4.17 million cy of design fill.

Table 12: Sensitivity of Design Volumes to Position MHW Contour

berm width (ft)	change in MHW (ft)	design fill volume (million cy)	change (million cy)
90	0	2.77	
100	10	3.16	0.39
110	20	3.62	0.46
120	**30**	**4.17**	**0.55**
130	40	4.83	0.66

Note: change in beach fill volume increases non-linearly as number of profiles with subaqueous fill increases.

A recently published paper by Hapke et al. (2013) describing the observed morphological changes along Fire Island during and in the months following Hurricane Sandy indicates that there was significant profile adjustment in the weeks after Hurricane Sandy (Figure 25). Several winter storm events occurred between the data of the LIDAR surveys and profile surveys resulting in additional subaerial beach erosion. Short profile surveys from the USGS and a 15 to 25 m (50 to 80 ft) landward shift in MHW was fairly consistent in their profiles from Nov 4, 2012 to Dec 12, 2012. These dates are nearly identical to the LIDAR (Nov 5, 2012) and CPE's surveys (Dec 9 – 20, 2012). These profile changes suggest that a shift of 30 feet in the MHW contour between the LIDAR and survey data is reasonable. The USSG profiles do show some recover in April they are still generally equal to or landward of the Dec 12 profiles. This analysis underscores the uncertainty and temporal nature of beachfill volume estimates.

5.1 Methodology to Determine Beachfill Volumes

The beachfill volumes were calculated with average end area method based on the available profiles within the beachfill plan. In general the average spacing between profiles is about 300 feet within the communities and between 500 and 1,000 feet outside the communities (RMSP, FILT, SPCP).

The following steps are performed:

1. Construct and center the design beachfill template at the baseline. Note that below +2 NGVD the submerged portion of the surveyed profile is used as part of the design beachfill template.

2. Calculate the volume of dune fill and berm fill required at each profile (CY/feet) down to the depth of closure (-27 feet NGVD). Negative beach fill volumes are not included in the calculations. In other words, the "cut" portion of the "cut and fill" volume is not considered, so the volumes will always be greater than or equal to zero.

3. Calculate the distance along the baseline between survey locations.

4. Apply the average end area method to determine the volumes over each design reach.

5. Advance fill volumes are computed based on modified fill template which includes the advance fill berm width. The advance fill berm width is equal to the representative erosion rate times the renourishment interval (e.g. 5 feet/year x 4 year = 20 feet).

Detailed tables showing the volume calculations for each profile are provided in Attachment B. It is reiterated that below MHW, both the beach profile and design profile are set to the submerged surveyed profile. As a result, the berm fill volumes below MHW are proportional to the offset in the design and existing MHW contour. In general, the berm fill volumes are dominated by the subaquoues fill volume, which is directly related to the difference between the MHW contour in the design profile and LIDAR data. Therefore, the beach fill volumes are very sensitive to the location of MHW.

5.2 FIMI Beachfill Volumes

Table 13 presents the lengths in which dune and berm fill was considered for the MIDU-Medium alternative, the design volumes, advance fill volumes, and total initial fill volumes. The total initial fill volumes include a 15% contingency and 10% overfill. The design beachfill and total initial beachfill volumes are 3.99 MYC and 6.99 MYC respectively.

Table 13: Total Initial Beach Fill Volume – MIDU Medium Design Template

Reach	Profile Lines	Distance (ft)	Design Fill Volume (c.y.)	Reserve Volume (c.y.)	Advance Fill Volume (c.y.)	10% Overfill Factor (c.y.)	Subtotal (c.y.)	15% Contingency (c.y.)	Total Fill (c.y.)
GSB-1A	Robert Moses State Park	16,562	458,164	785,601	110,942	56,911	635,238	95,286	730,524
GSB-1B	Fire Island Lighthouse Tract	5,461	253,025	217,266	98,301	35,133	386,459	57,969	444,428
GSB-2A	Kismet to Lonelyville	8,918	200,098	284,793	109,770	30,987	340,855	51,128	391,983
GSB-2B	Atlantique Park to Cornielle Estates	4,529	313,822	59,815	92,548	40,637	447,008	67,051	514,059
GSB-2C	Summer Club to Seaview Brookhaven	3,752	147,569	31,034	75,401	22,297	245,267	36,790	282,057
GSB-2D	Seaview Brookhaven to Point O' Woods	7,228	250,258	470,795	97,956	34,821	384,077	57,612	441,689
GSB-3A	Cherry Grove	2,950	10,278	78,164	0	1,028	14,041	2,106	16,147
GSB-3C	Fire Island Pines	6,457	549,255	3,069	346,159	89,541	1,029,435	154,415	1,183,850
GSB-3E	Water Island	1,196	30,676	11,845	9,127	3,980	59,670	8,951	68,621
GSB-3G	Davis Park	4,167	305,013	72,650	215,297	52,031	639,880	95,982	735,862
MB-1A	Smith Point County Park	6,342	265,725	254,738	13,872	27,960	373,830	56,075	429,905
MB-1B	Smith Point County Park	13,095	681,702	575,098	96,696	77,840	856,239	128,436	984,675
MB-2A	Smith Point County Park	4,461	525,019	0	43,725	56,874	668,126	100,219	768,345
	Total	85,118	3,990,604	2,844,868	1,309,794	530,040	6,080,125	912,020	6,992,145

Note: Taper volumes and lengths were included within the provided reaches under the subtotal tab.

6.0 RENOURISHMENT VOLUMES

Future renourishment volumes over the project life (50 years) are calculated based on the representative erosion rates determined in Section 4.0. Similarly to the advance berm width, the renourishment volumes is equal to the representative erosion rate multiplied by the renourishment interval (e.g. 5 feet/year x 4 years = 20 feet). At this time all the design reaches in the Fire Island Project assume a renourishment interval of 4 years. The relatively large representative erosion rates at Fire Island Pines and Davis Park under the MREI may warrant consideration of shorter renourishment interval in the future. The renourishment extents are the same as the initial construction extents presented in Table 3 with the exception of Robert Moses State Park (12,000 ft), which is based on the historical extent of back-passing operations at Fire Island Inlet.

Renourishment volumes for a single renourishment cycle and over the project life are presented in Table 14 and Table 15 for the MREI and MIDU plans respectively.

Table 14: Total Renourishment Fill Volumes Over Project Life – MREI Alignment

Reach Name	Subreach	Renourishment Length	Effective Erosion Rate	Advance Fill Berm Extension	Renourishment Design Fill	10% Overfill	Subtotal	15% Contigency	Renourishment Volume Per Cycle	Total Renourishment Volume
		(ft)	(ft/yr)	(ft)	(cy)	(cy)	(cy)	(cy)	(cy)	(cy)
RMSP	GSB-1A	12,000	5	20	1,620,000	162,000	1,782,000	267,300	2,049,300	24,591,600
FILT	GSB-1B	5,400	6	20	874,800	87,480	962,280	144,342	1,106,622	13,279,464
Kismet to Lonelyville	GSB-2A	9,000	6	20	1,458,000	145,800	1,603,800	240,570	1,844,370	22,132,440
Tow n Beach to Corneille Estates	GSB-2B	4,400	6	20	712,800	71,280	784,080	117,612	901,692	10,820,304
Ocean Beach to Seaview	GSB-2C	3,800	6	20	615,600	61,560	677,160	101,574	778,734	9,344,808
OBP to POW	GSB-2D	7,200	6	20	1,166,400	116,640	1,283,040	192,456	1,475,496	17,705,952
Sailors Haven	GSB-2E	0	0	0	0	0	0	0	0	0
Cherry Grove	GSB-3A	3,000	2	8	64,800	6,480	71,280	10,692	81,972	983,664
Carrington Tract	GSB-3B	0	0	0	0	0	0	0	0	0
Fire Island Pines	GSB-3C	6,400	20	40	6,912,000	691,200	7,603,200	1,140,480	8,743,680	104,924,160
Talisman to Water Island	GSB-3D	0	0	0	0	0	0	0	0	0
Water Island	GSB-3E	2,000	2	8	43,200	4,320	47,520	7,128	54,648	655,776
Water Island to Davis Park	GSB-3F	0	0	0	0	0	0	0	0	0
Davis Park	GSB-3G	4,200	25	48	6,804,000	680,400	7,484,400	1,122,660	8,607,060	103,284,720
Watch Hill	GSB-3H	0	0	0	0	0	0	0	0	0
Bellport Beach	GSB-4A	0	0	0	0	0	0	0	0	0
Old Inlet	GSB-4B	0	0	0	0	0	0	0	0	0
SPCP-TWA	MB-1A	6,400	2	8	138,240	13,824	152,064	22,810	174,874	2,098,483
SPCP	MB-1B	13,000	2	8	280,800	28,080	308,880	46,332	355,212	4,262,544
MB-2A	MB-2A	4,600	2	8	99,360	9,936	109,296	16,394	125,690	1,508,285
MB-2B	MB-2B	0	0	0	0	0	0	0	0	0
	Total	**81,400**			**20,790,000**	**2,079,000**	**22,869,000**	**3,430,350**	**26,299,350**	**315,592,200**

Table 15: Total Renourishment Fill Volumes Over Project Life – MIDU Alignment

Reach Name	Subreach	Renourishment Length	Effective Erosion Rate	Advance Fill Berm Extension	Renourishment Design Fill	10% Overfill	Subtotal	15% Contigency	Renourishment Volume Per Cycle	Total Renourishment Volume
		(ft)	(ft/yr)	(ft)	(cy)	(cy)	(cy)	(cy)	(cy)	(cy)
RMSP	GSB-1A	12,000	5	20	1,620,000	162,000	1,782,000	267,300	2,049,300	24,591,600
FILT	GSB-1B	5,400	5	20	729,000	72,900	801,900	120,285	922,185	11,066,220
Kismet to Lonelyville	GSB-2A	9,000	5	20	1,215,000	121,500	1,336,500	200,475	1,536,975	18,443,700
Tow n Beach to Corneille Estates	GSB-2B	4,400	5	20	594,000	59,400	653,400	98,010	751,410	9,016,920
Ocean Beach to Seaview	GSB-2C	3,800	5	20	513,000	51,300	564,300	84,645	648,945	7,787,340
OBP to POW	GSB-2D	7,200	5	20	972,000	97,200	1,069,200	160,380	1,229,580	14,754,960
Sailors Haven	GSB-2E	0	0	0	0	0	0	0	0	0
Cherry Grove	GSB-3A	3,000	2	8	64,800	6,480	71,280	10,692	81,972	983,664
Carrington Tract	GSB-3B	0	0	0	0	0	0	0	0	0
Fire Island Pines	GSB-3C	6,400	10	40	3,456,000	345,600	3,801,600	570,240	4,371,840	52,462,080
Talisman to Water Island	GSB-3D	0	0	0	0	0	0	0	0	0
Water Island	GSB-3E	2,000	2	8	43,200	4,320	47,520	7,128	54,648	655,776
Water Island to Davis Park	GSB-3F	0	5	0	0	0	0	0	0	0
Davis Park	GSB-3G	4,200	12	48	3,265,920	326,592	3,592,512	538,877	4,131,389	49,576,666
Watch Hill	GSB-3H	0	0	0	0	0	0	0	0	0
Bellport Beach	GSB-4A	0	0	0	0	0	0	0	0	0
Old Inlet	GSB-4B	0	0	0	0	0	0	0	0	0
SPCP-TWA	MB-1A	6,400	2	8	138,240	13,824	152,064	22,810	174,874	2,098,483
SPCP	MB-1B	13,000	2	8	280,800	28,080	308,880	46,332	355,212	4,262,544
MB-2A	MB-2A	4,600	2	8	99,360	9,936	109,296	16,394	125,690	1,508,285
MB-2B	MB-2B	0	0	0	0	0	0	0	0	0
	Total	**81,400**			**12,991,320**	**1,299,132**	**14,290,452**	**2,143,568**	**16,434,020**	**197,208,238**

7.0 BREACH CLOSURE PLAN

7.1 Overview

The Breach Closure Plan (BCP, 1995) allows for the rapid closure of barrier island breaches by quickly mobilizing federal, state, and municipal resources. The BCP is one component of the long-term solution for storm damage for the Fire Island Inlet to Montauk Point (FIMP) study area. The purpose of this memorandum is to update the BCP cost estimate to 2013 price levels for the FIMI Stabilization Project. Breach closures following Hurricane Sandy at Cupsogue Park and Smith County Park indicate that the cost of breach closures are significantly greater than previous estimates.

In addition, cross-sectional area measurements following the Hurricane Sandy breach at Old Inlet are used to update breach growth rates for Great South Bay. The methodology for cost estimating are the same as those presented in the memorandum "BCP Costs - Updated to Oct 2007 Price Levels".

7.2 BCP Locations

Although the BCP can be implemented at any location along the barrier islands fronting Great South Bay, Moriches Bay, and Shinnecock Bay, a few specific areas where breaching risk is greater according to model results were selected to serve as the basis for development of the BCP. These selected areas are those where a breach or partial breach was observed in the baseline and future vulnerable conditions storm surge modeling simulations. Table 16 lists the 10 specific locations (by design subreach) where a breach would be more likely.

Table 16: More likely Breach Locations

Location	Bay	Reach
FI Lighthouse Tract	Great South Bay	GSB-1B
Town Beach to Corneille States	Great South Bay	GSB-2B
Talisman to Water Island	Great South Bay	GSB-3D
Davis Park	Great South Bay	GSB-3G
Old Inlet	Great South Bay	GSB-4B
Old Inlet	Great South Bay	GSB-4B
Smith Point CP - East	Moriches Bay	MB-1B
Sedge Island	Shinnecock Bay	SB-1B
Tiana Beach	Shinnecock Bay	SB-1C
WOSI	Shinnecock Bay	SB-2B

7.3 Breach Growth

As in the 1995 BCP document, it is assumed that the along-shore cross sectional area of the breach will grow according to the exponential breach growth equation:

$$A(t) = A_0\left(1 - e^{-kt}\right)$$

The maximum breach cross sectional area is given by A_0 and the breach growth coefficient is given by k. These parameters vary depending on the bay and were previously obtained as part of the breach inlet stability analysis (USACE-NAN, 1995). Recent cross sectional area measurements following the breach at Old Inlet provide new information regarding breach growth dynamics at Great South Bay. The measurements from C. Flagg (No. 9) include data thru May 30, 2013 and show a fairly stable cross section since the end of February of approximately 4,300 ft^2. In the previous BCP analysis for Great South Bay, a maximum breach cross section of 36,200 was assumed.

In order to reflect the recent observations at Old Inlet an additional cost estimate was developed at all Great South Bay breach locations for a smaller breach with a maximum breach cross sectional area, A_0, of 6,500 ft^2. A uniform distribution of A_0 between 6,500 ft^2 and 36,200 ft^2 will be applied in the updated economic analysis. The cost estimates at Great South Bay are based on a constant growth coefficient of 0.2 $month^{-1}$. The lowest breach size (6,500 ft^2) combined with a k of 0.2 $month^{-1}$ yields and area of 4,850 ft^2 at 7 months, which is consistent with observations at Old Inlet.

A_0 and k are summarized for Great South Bay, Moriches Bay, and Shinnecock Bay in Table 17.

Table 17: Breach Growth Coefficients

Location	A_0 (ft^2)	k $(month)^{-1}$
Great South Bay – Small Breach Size	6,500	0.2
Great South Bay – Large Breach Size	36,200	0.2
Moriches Bay	16,000	0.3
Shinnecock bay	17,750	0.3

7.4 2007 Price Levels

Previous BCP cost estimates were based on an assumed daily revenue and calculated production rate. The production rate varies at each location based on the distance to the disposal site, assumed work day efficiency and weather efficiency. In the past, the same daily revenue was assumed at all BCP locations:

- $126,527 per day for 30" Cutter Head Dredge;
- $89,623 per day for 6,500 CY Hopper Dredge;
- $52,720 per day for 3,500 CY Hopper Dredge.

The cost estimate also depends on the “effective” production rate, which accounts for washout losses before the breach is choked. Washout losses have typically been assumed to about 60% before choking and 5% after the breach is choked.

As an example, the daily production rate at Sedge Island, 1.4 nautical miles from borrow site, was determined to be 35,280 CY/day for the 30” Cutter Head Dredge. The unit price for “cut” was $3.60 per CY. However, due to washout losses, the “effective” production rate was much lower and the unit price for “placed” was $8.05 per CY.

7.5 2013 Price Levels

Breach closures following Hurricane Sandy and recent CEDEP unit cost estimates of indicate that the 2007 price levels need to be escalated. The unit price for “cut” quoted by Great Lakes Dock and Dredge was $17.93 per CY for Cupsogue Park, which is significantly higher than the 2007 unit cost estimates at similar locations.

Recent CEDEP unit costs of beachfill were converted to a daily revenue cost estimate to evaluate the differences with the 2007 price levels. The CEDEP unit prices are based on a 3,800 CY Hopper Dredge and correspond to a daily revenue between $78,000 and $89,000 per day. The majority of the CEDEP daily revenue rates are $79,000 which represents a 50% increase from the 2007 price levels ($52,720 per day).

Based on this information it is recommended that all three of the dredging daily revenues be increased by 50%, resulting in daily revenues of:

- $190,000 per day for 30" Cutter Head Dredge;
- $134,500 per day for 6,500 CY Hopper Dredge;
- $79,000 per day for 3,500 CY Hopper Dredge.

The cost of mobilization and demobilization for the 30” Cutter Head Dredge and 6,5000 Hopper Dredge is increased from $2.5 million to $4.0 million based on the recent estimates provided by CENEN. The cost of mobilization and demobilization for the 3,500 CY Hopper Dredge is $2.5 million, which is only used for BCP maintenance cost estimates.

The discount rate was updated to 3.75%, consistent with 2013 price levels. No changes have been made to washout losses, production rates, etc. Only the daily revenue, Mob/Demob costs, and discount rate were updated.

7.6 Updated BCP Costs

Table 18 presents the estimated cost of breach closure with and without a BCP for large breach sizes at Great South Bay. The without project BCP assumes a 9 month delay in construction. All the without BCP locations apply the “No Dune” template and all the with BCP locations, except WOSI, apply the “No Dune” template. For the with BCP at WOSI the “+13 ft dune” template is applied. Table 19 presents the estimated cost of breach closure with and without a BCP for Great South Bay and small breach size.

Table 20 presents the estimated cost of breach closure with and without BCP for Moriches Bay and Shinnecock Bay.

Table 18: GSB Breach Closure Cost by BCP Location (Large Breach)

Location	Construction Alternative Resulting in Lowest Total Cost	Without Project Closure Cost	BCP Closure Cost
FI Lighthouse Tract	Hopper Dredge	$38,003,144	$30,889,187
Town Beach to Corneille Estates	Cutterhead Dredge	$35,907,418	$18,142,427
Talisman to Water Island	Cutterhead Dredge	$27,985,258	$13,538,938
Davis Park	Cutterhead Dredge	$28,011,630	$13,548,514
Old Inlet West	Cutterhead Dredge	$30,674,660	$15,046,005
Old Inlet East	Cutterhead Dredge	$27,324,129	$13,776,437
Smith Point County Park	Hopper Dredge	$23,978,911	$17,748,379
Sedge Island	Cutterhead Dredge	$16,289,061	$9,996,032
Tiana Beach	Cutterhead Dredge	$15,785,951	$9,780,084
WOSI	Hopper Dredge	$18,675,831	$14,986,134

Table 19: GSB Breach Closure Cost by BCP Location (Small Breach)

Location	Construction Alternative Resulting in Lowest Total Cost	Without Project Closure Cost	BCP Closure Cost
FI Lighthouse Tract	Hopper Dredge	$10,643,657	$8,429,302
Town Beach to Corneille Estates	Cutterhead Dredge	$10,474,926	$7,155,493
Talisman to Water Island	Cutterhead Dredge	$9,104,355	$6,509,027
Davis Park	Cutterhead Dredge	$9,109,116	$6,510,758
Old Inlet West	Cutterhead Dredge	$9,612,294	$6,886,784
Old Inlet East	Cutterhead Dredge	$9,007,616	$6,657,433

Table 20: MB and SB Breach Closure Cost by BCP Location

Location	Construction Alternative Resulting in Lowest Total Cost	Without Project Closure Cost	BCP Closure Cost
Smith Point County Park	Hopper Dredge	$23,978,911	$17,748,379
Sedge Island	Cutterhead Dredge	$16,289,061	$9,996,032
Tiana Beach	Cutterhead Dredge	$15,785,951	$9,780,084
WOSI	Hopper Dredge	$18,675,831	$14,986,134

8.0 REFERENCES

Coastal Planning & Engineering of NY, PC, 2013. “2009 Fire Island Beach Renourishment Project Post-Sandy Storm Report”, prepared for Sponsoring Communities on Fire Island, New York.

Dean, R. G., 2005. “Beach Nourishment Theory and Practice,” World Scientific Publishing Co., Hackensak, NJ.

Gravens, M. B., Rosati, J. D., and Wise, R. A., 1999. “Fire Island Inlet to Montauk Point reformulation study (FIMP): Historical and existing condition coastal processes assessment,” prepared for the U.S. Army Engineer District, New York.

Hapke, C. J., Brenner, O., Hehre, R., Reyonlds, B. J., 2013. “Coastal Change from Hurricane Sandy and the 2012-13 Winter Storm Season: Fire Island, New York”, Open-File Report 2012-1231, U.S. Department of the Interior, U. S. Geological Survey.

Moffatt & Nichol, 2005. “Task 4.1 Define Future Barrier Island Conditions”, prepared for the U.S. Army Corps of Engineers, New York District.

Figure 1: Aerial Images from 2001, 2012 Pre-Sandy, 2012 Post-Sandy.
MHW contour from 2000 LIDAR shown in Red, MHW contour from 2012 LIDAR shown in Cyan.

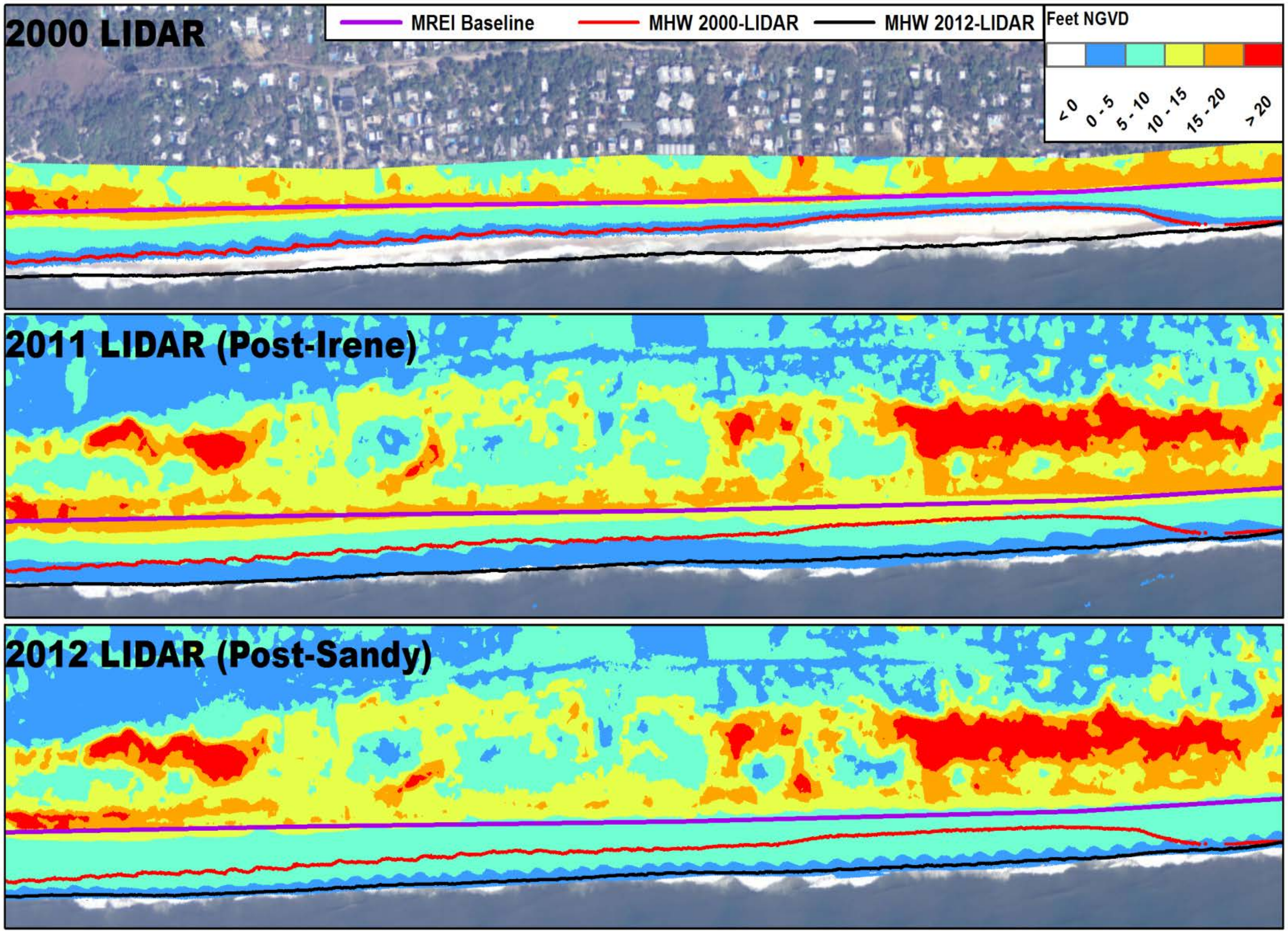


Figure 2: LIDAR Data from 2000, 2011, and 2010 (Fire Island Pines).

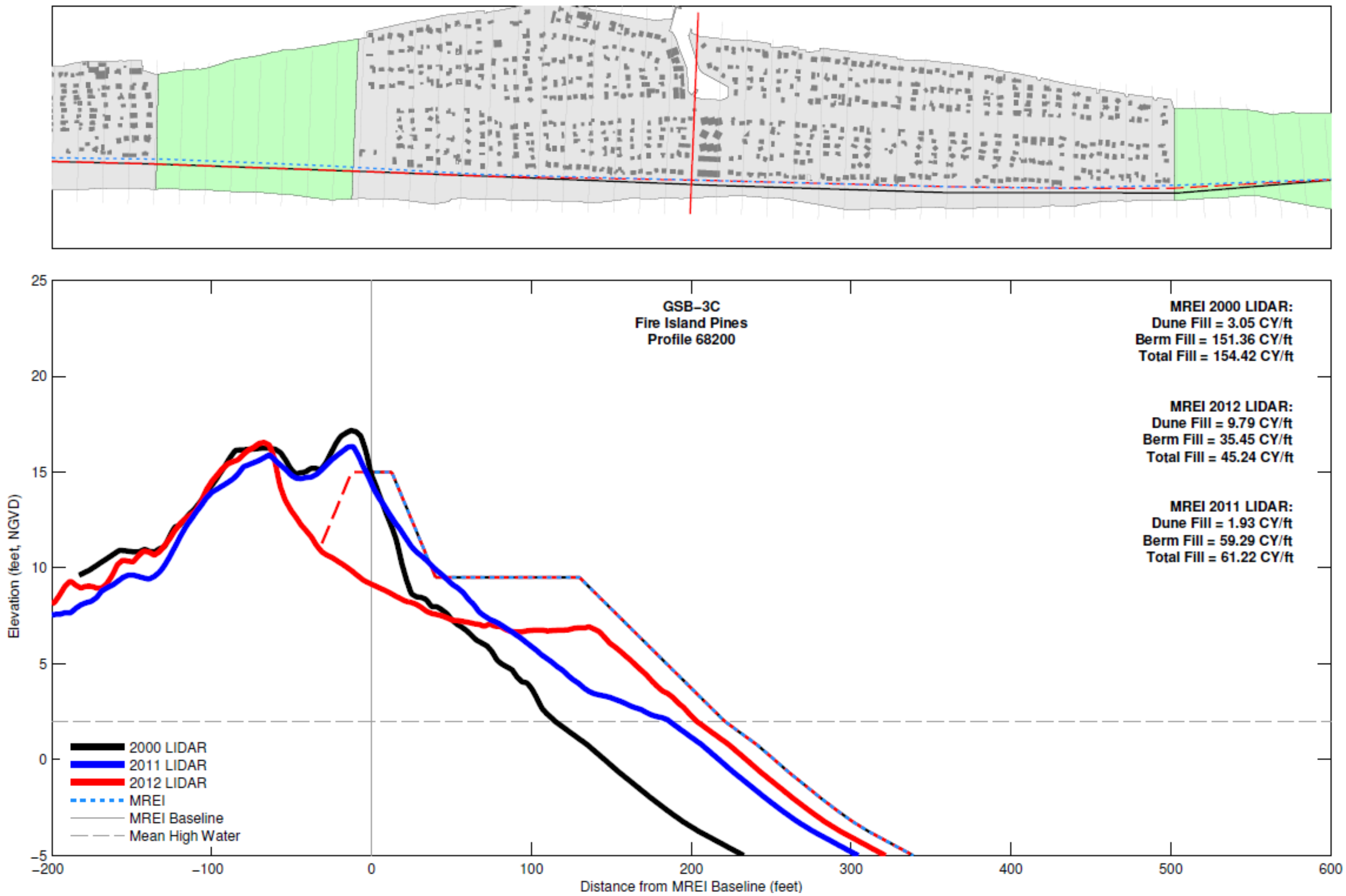


Figure 3: Comparison of Cut LIDAR Profiles at Fire Island Pines (Profile 68200)

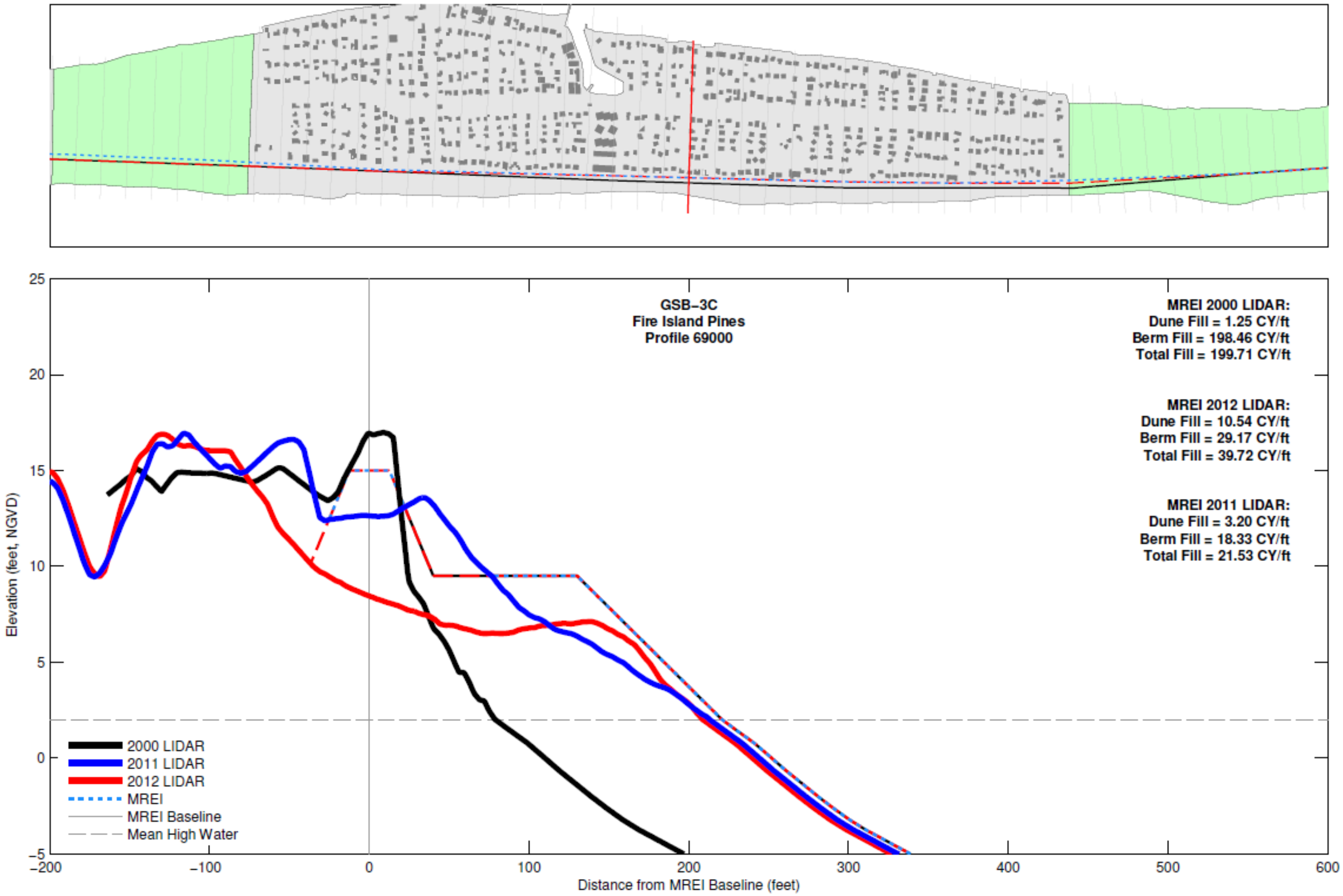


Figure 4: Comparison of Cut LIDAR Profiles at Fire Island Pines (Profile 69000)

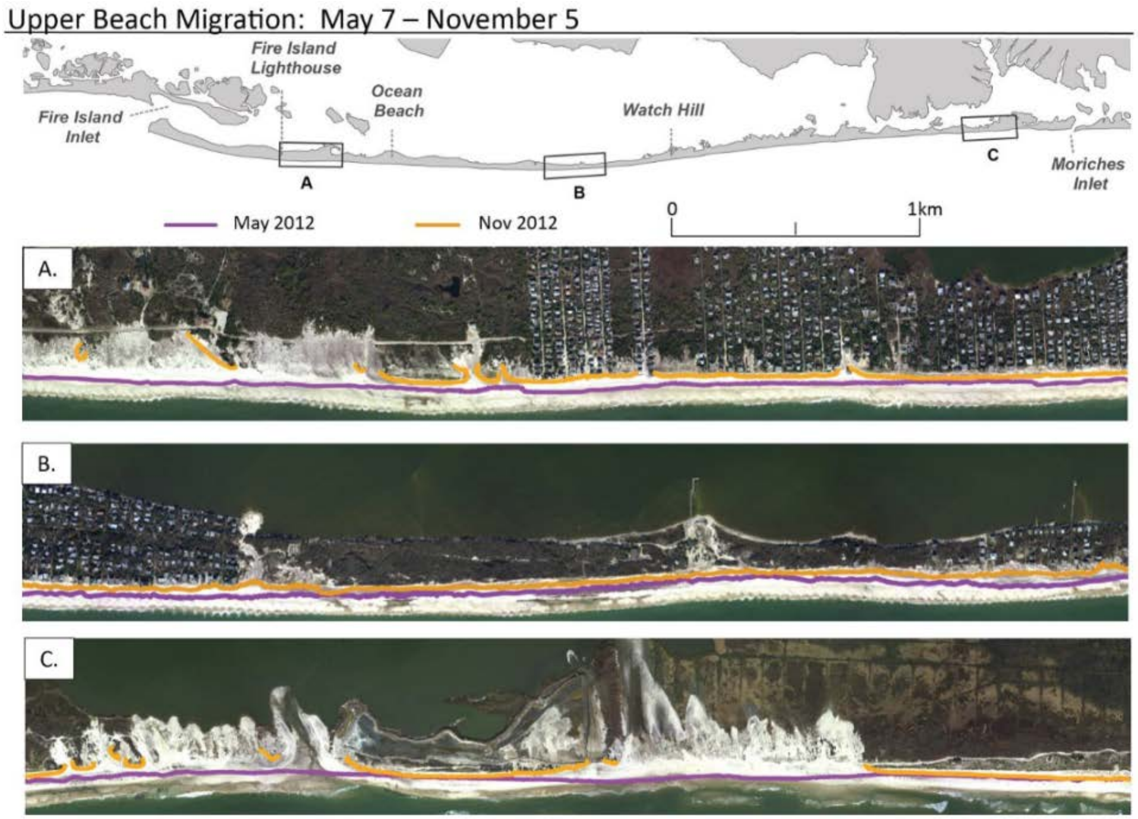


Figure 5: Post-Sandy Images Showing Overwash (Hapke et al. 2013)

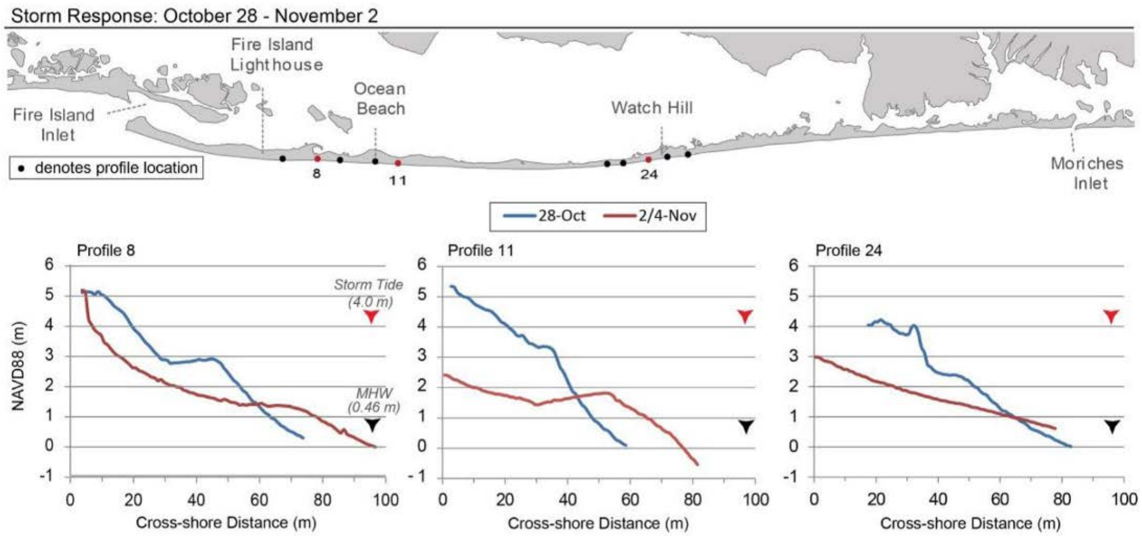


Figure 6: **Observed Beach and Dune Change on Fire Island (Hapke et al. 2013)**

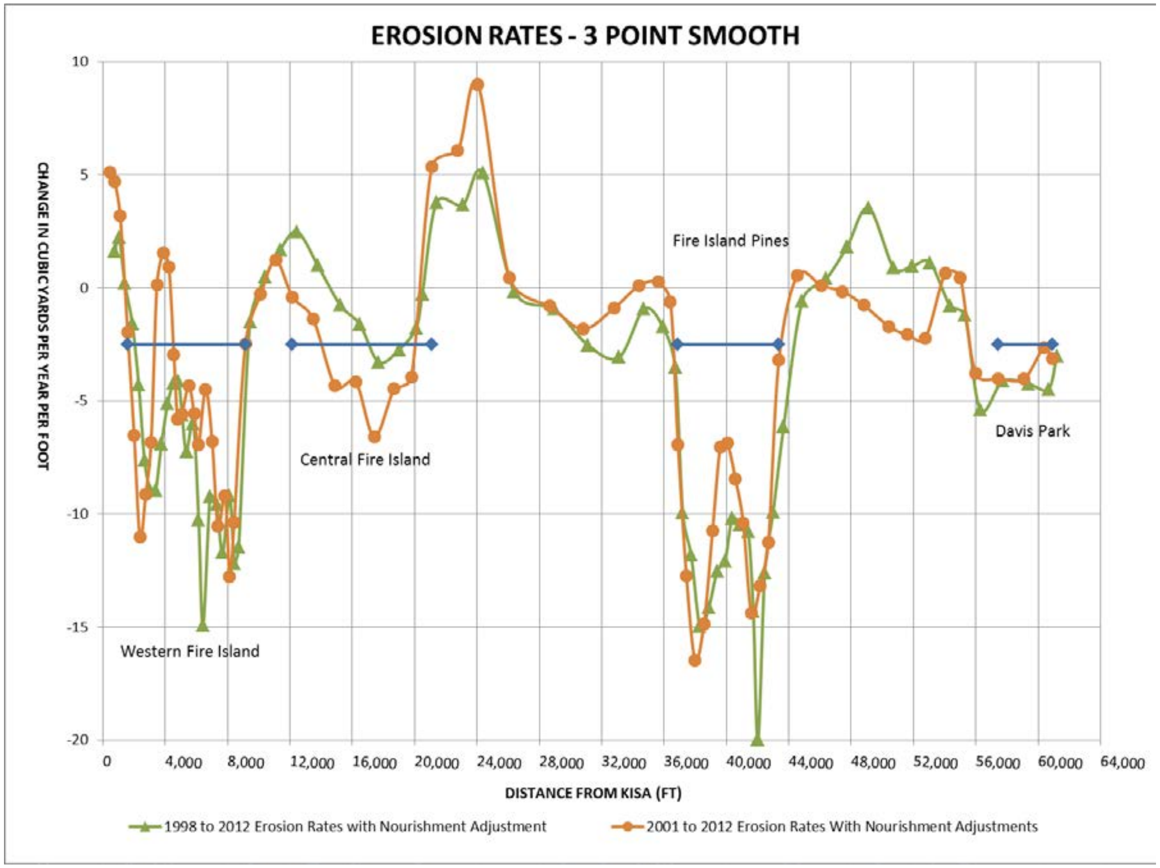


Figure 7: Volumetric Erosion Rates Derived from Profile Surveys

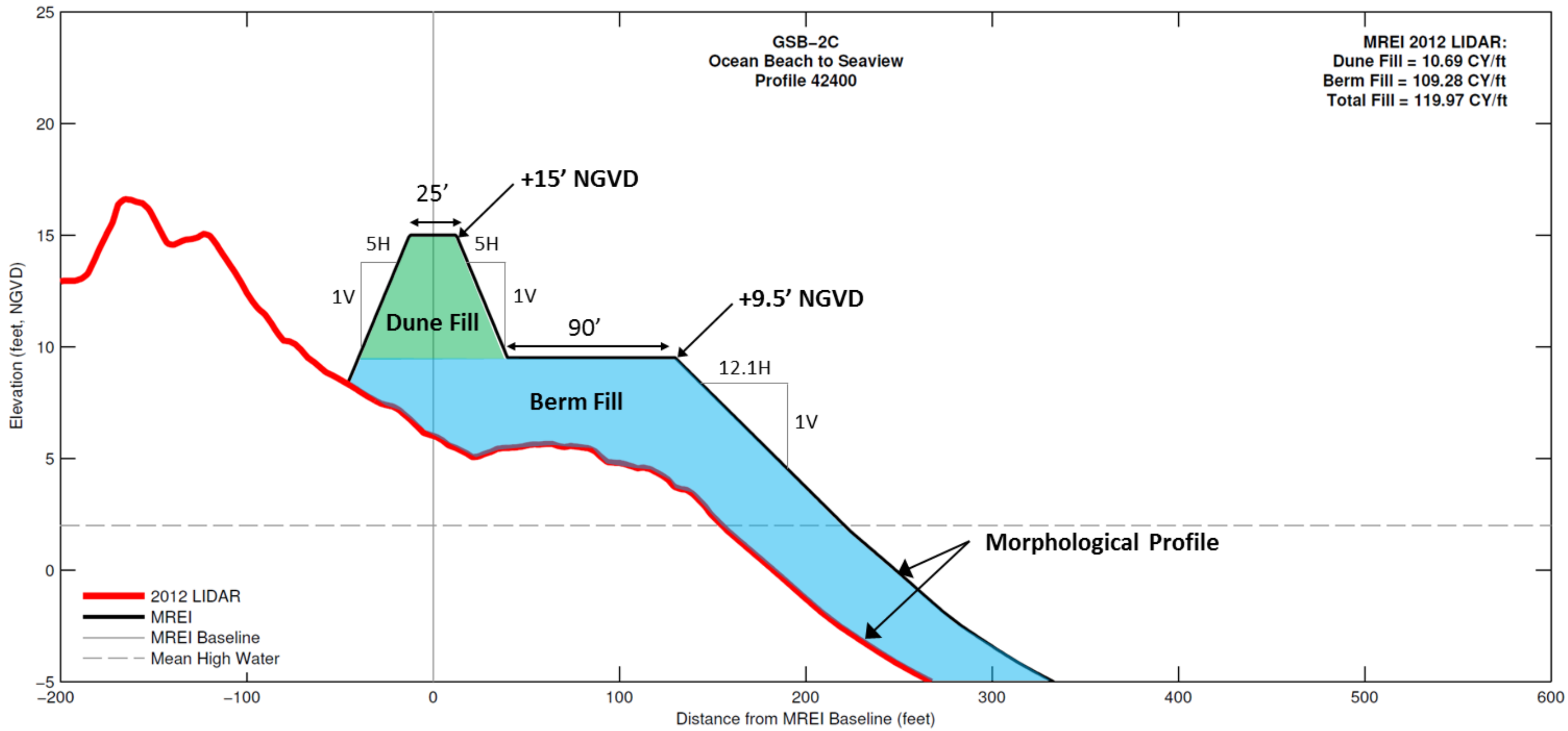


Figure 8: Typical Beachfill Section

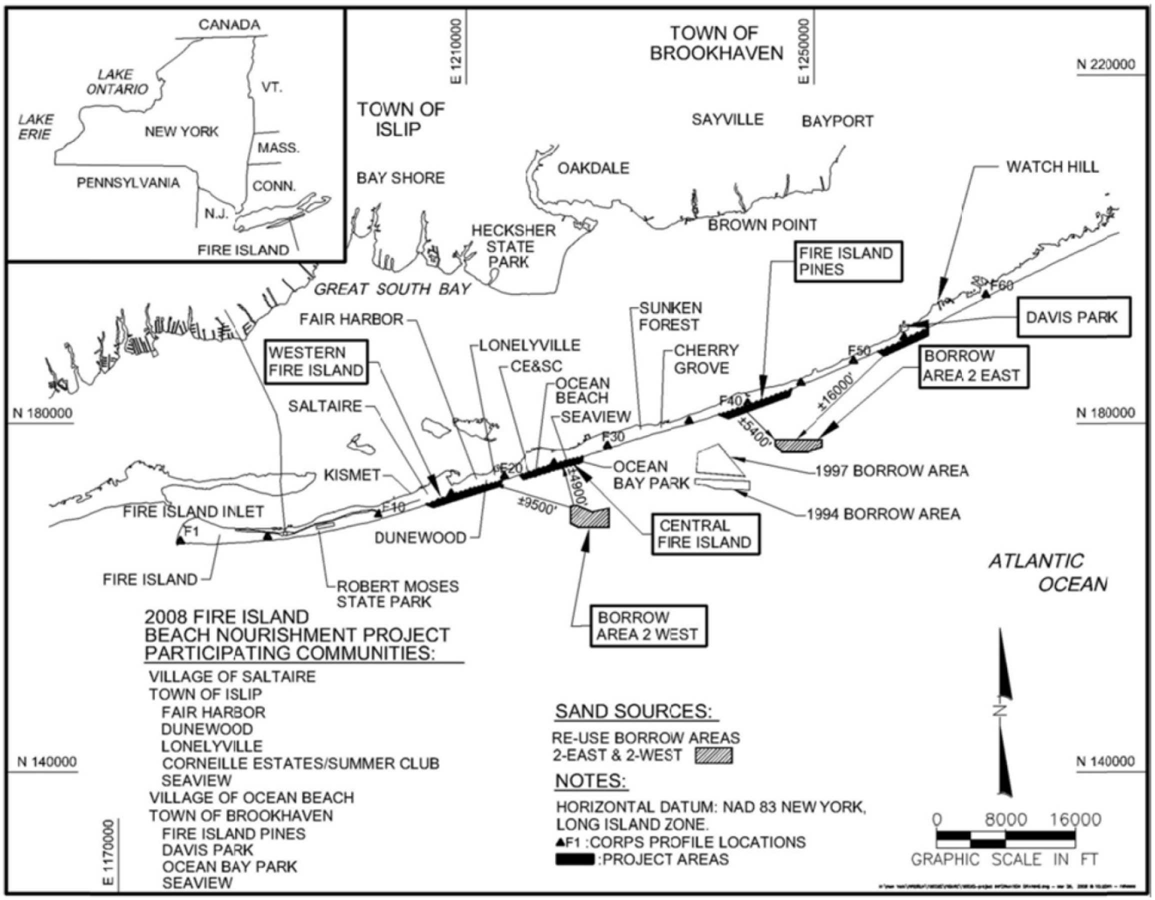


Figure 9: **2009 Beachfill Project Location Map (CPE, 2013)**

Figure 10: **2009 Design Berm at Western Fire Island**

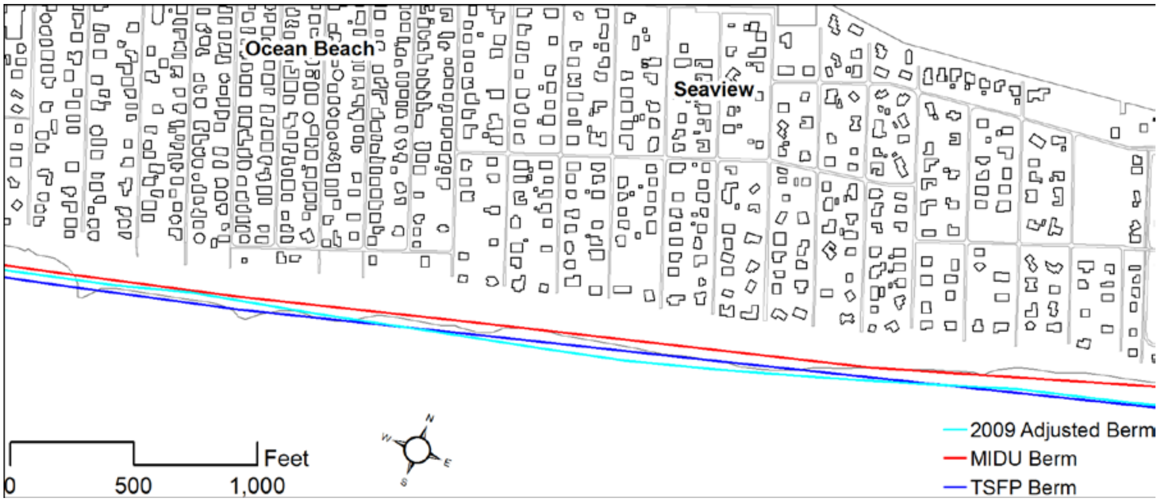


Figure 11: 2009 Design Berm at Central Fire Island

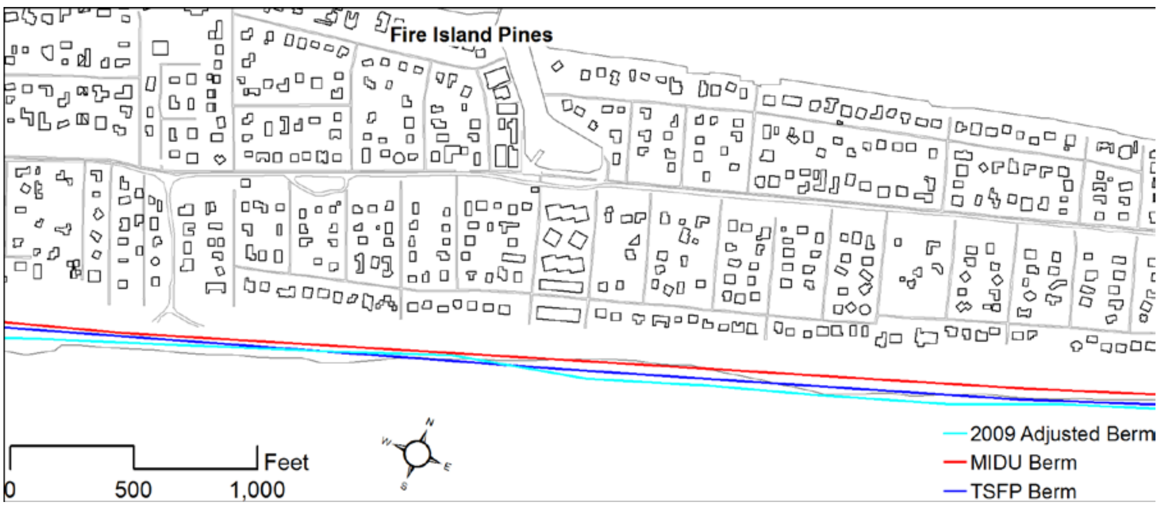


Figure 12: 2009 Design Berm at Fire Island Pines

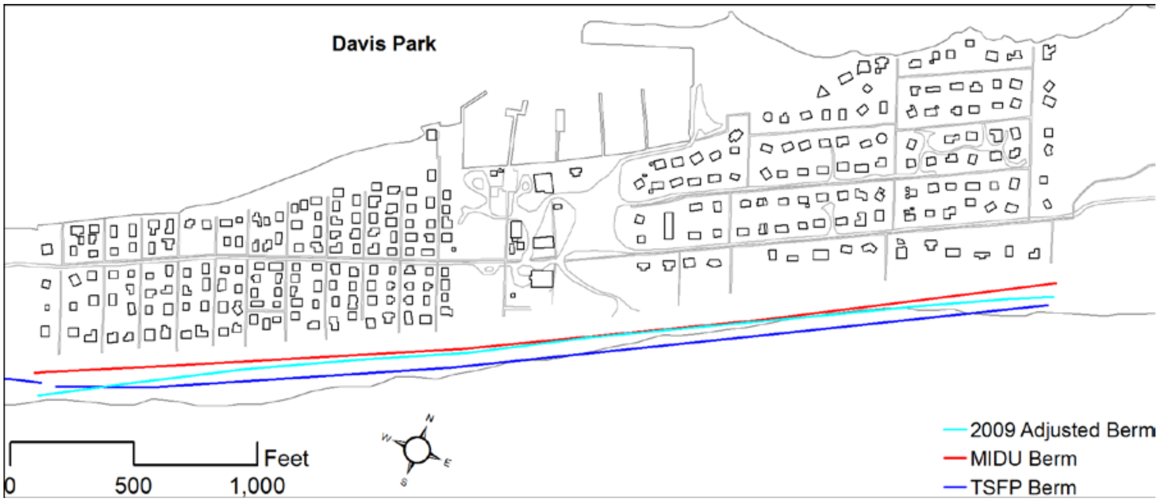
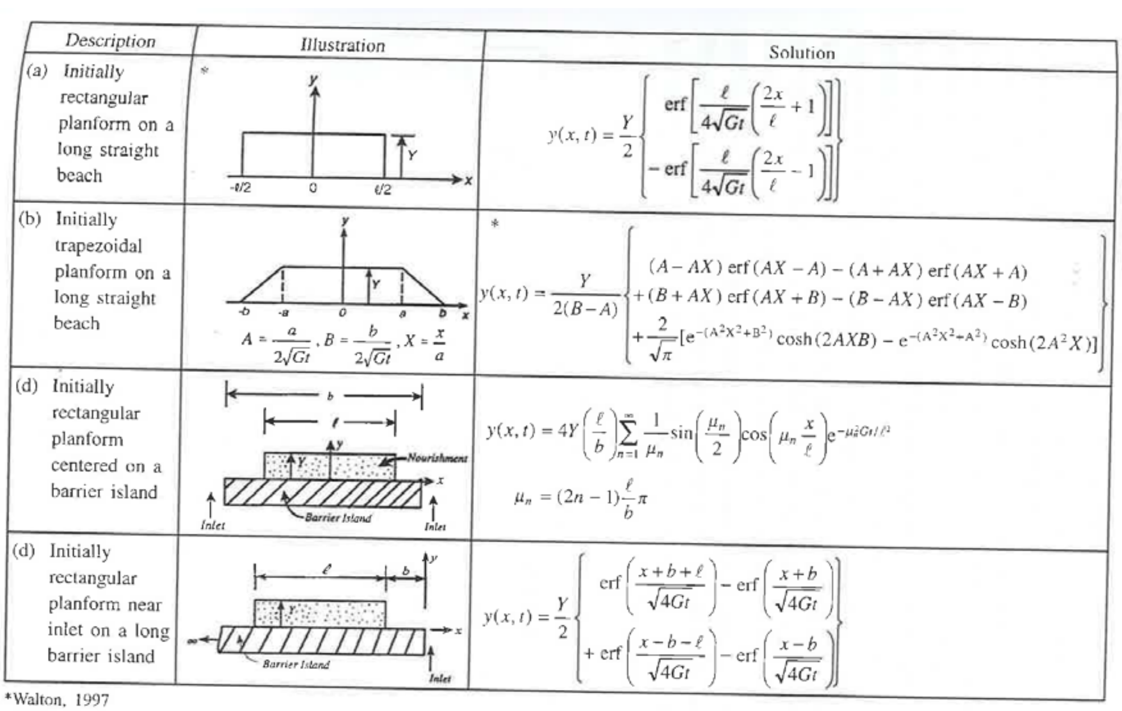


Figure 13: 2009 Design Berm at Davis Park



Description	Illustration	Solution
(a) Initially rectangular planform on a long straight beach	*	$y(x,t)=\frac{Y}{2}\left\{\operatorname{erf}\left[\frac{\ell}{4\sqrt{Gt}}\left(\frac{2x}{\ell}+1\right)\right]-\operatorname{erf}\left[\frac{\ell}{4\sqrt{Gt}}\left(\frac{2x}{\ell}-1\right)\right]\right\}$
(b) Initially trapezoidal planform on a long straight beach	$A=\frac{a}{2\sqrt{Gt}},\ B=\frac{b}{2\sqrt{Gt}},\ X=\frac{x}{a}$	* $y(x,t)=\frac{Y}{2(B-A)}\left\{(A-AX)\operatorname{erf}(AX-A)-(A+AX)\operatorname{erf}(AX+A)+(B+AX)\operatorname{erf}(AX+B)-(B-AX)\operatorname{erf}(AX-B)+\frac{2}{\sqrt{\pi}}\left[e^{-(A^2X^2+B^2)}\cosh(2AXB)-e^{-(A^2X^2+A^2)}\cosh(2A^2X)\right]\right\}$
(d) Initially rectangular planform centered on a barrier island	Nourishment; Barrier Island; Inlet; Inlet	$y(x,t)=4Y\left(\frac{\ell}{b}\right)\sum_{n=1}^{\infty}\frac{1}{\mu_n}\sin\left(\frac{\mu_n}{2}\right)\cos\left(\mu_n\frac{x}{\ell}\right)e^{-\mu_n^2Gt/\ell^2}$ $\mu_n=(2n-1)\frac{\ell}{b}\pi$
(d) Initially rectangular planform near inlet on a long barrier island	Barrier Island; Inlet	$y(x,t)=\frac{Y}{2}\left\{\operatorname{erf}\left(\frac{x+b+\ell}{\sqrt{4Gt}}\right)-\operatorname{erf}\left(\frac{x+b}{\sqrt{4Gt}}\right)+\operatorname{erf}\left(\frac{x-b-\ell}{\sqrt{4Gt}}\right)-\operatorname{erf}\left(\frac{x-b}{\sqrt{4Gt}}\right)\right\}$

*Walton, 1997

Figure 14: Solutions to Pelnard-Considere Equation[5]

[5] Dean, R. G., 2005. “Beach Nourishment Theory and Practice,” World Scientific Publishing Co., Hackensak, NJ.

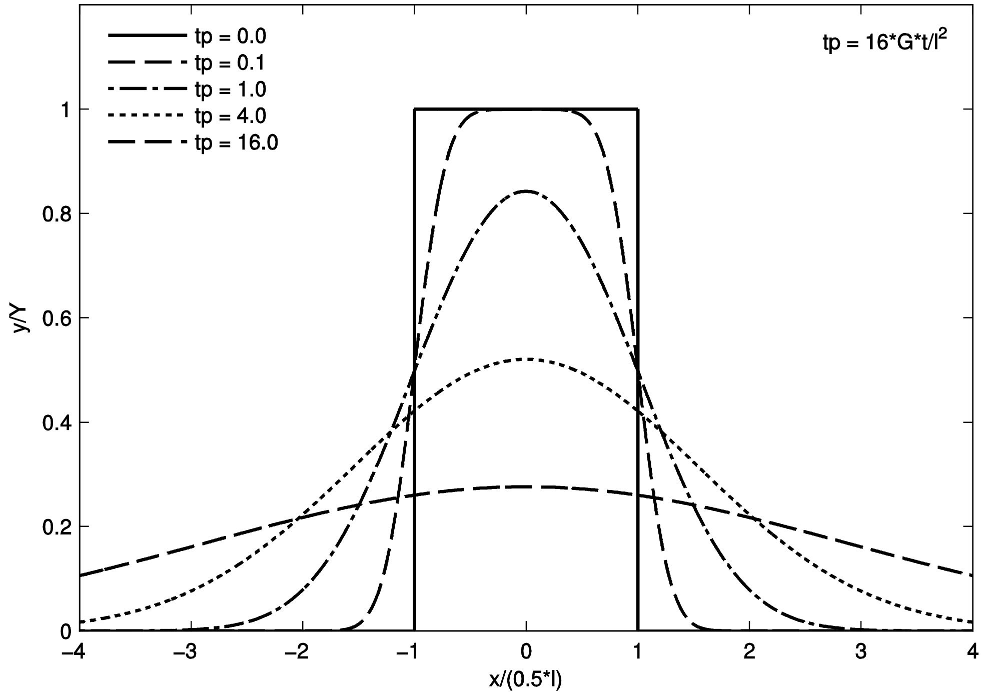


Figure 15: Nondimensional Beachfill Evolution Based on Diffusion Equation

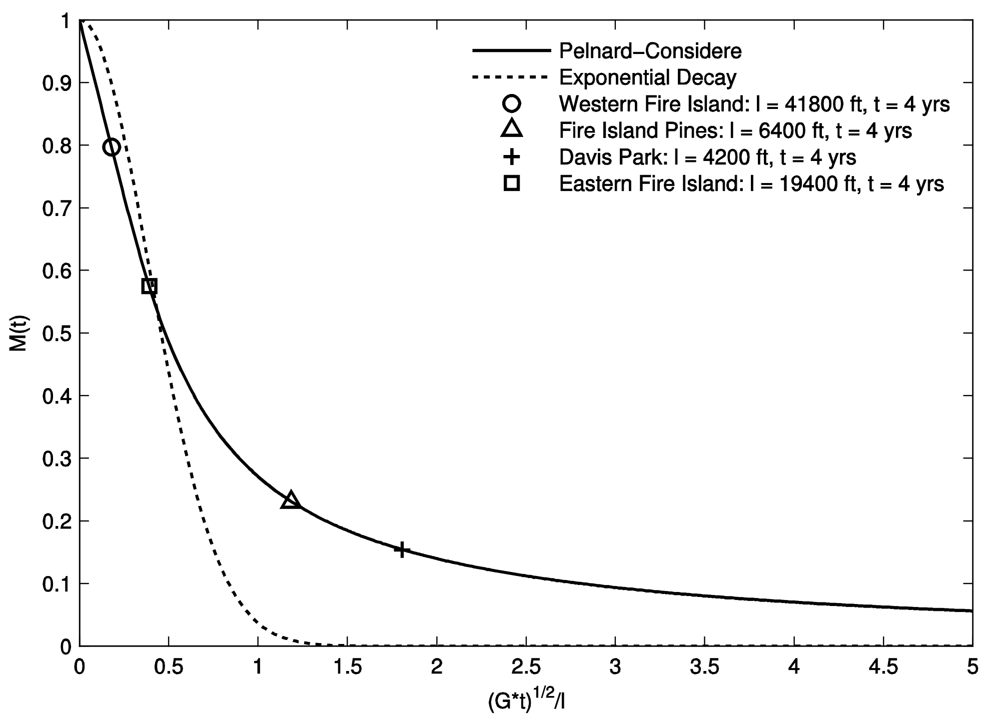


Figure 16: Theoretical Longevity of Beachfill (Excluding Background Erosion)

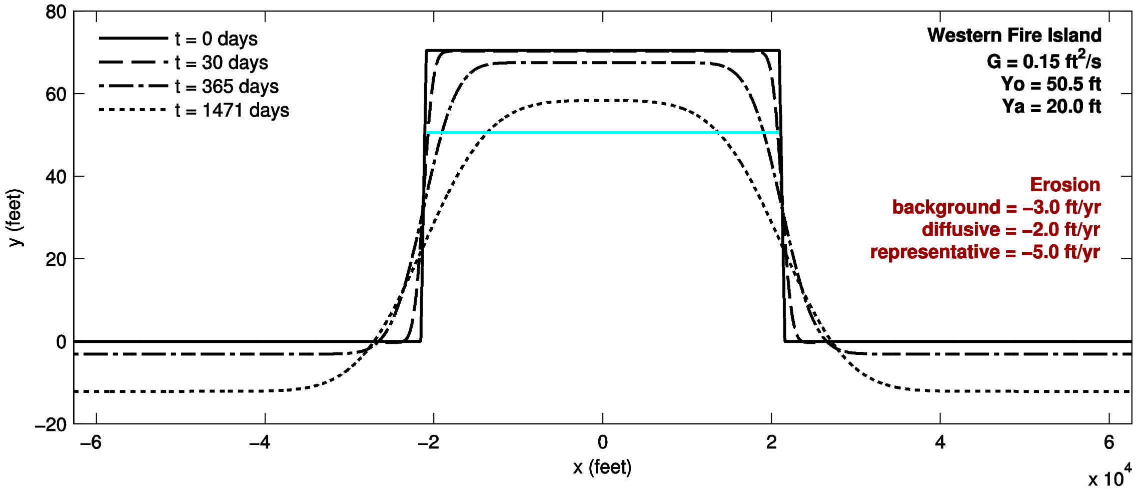


Figure 17: Beachfill Evolution at Western Fire Island (MIDU)

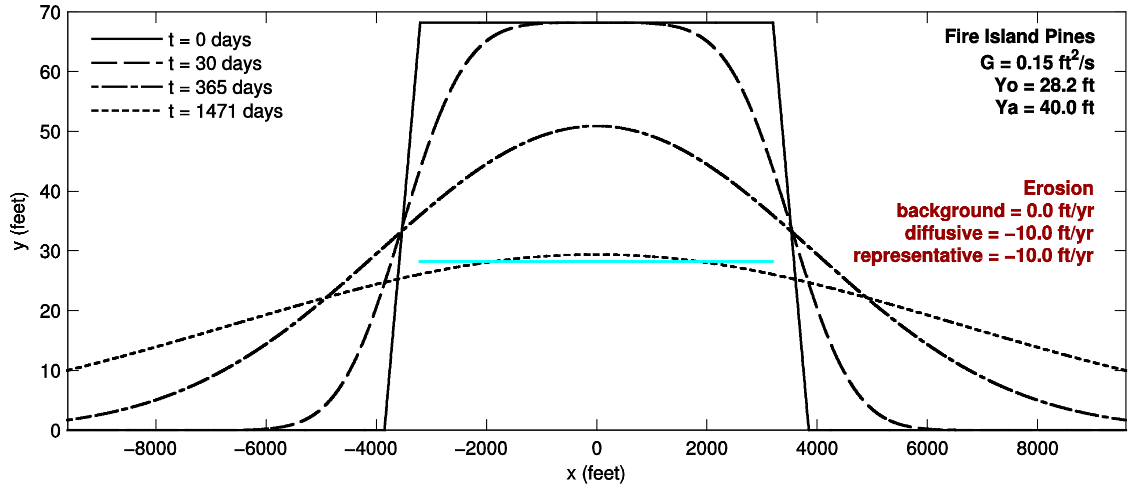


Figure 18: Beachfill Evolution at Fire Island Pines (MIDU)

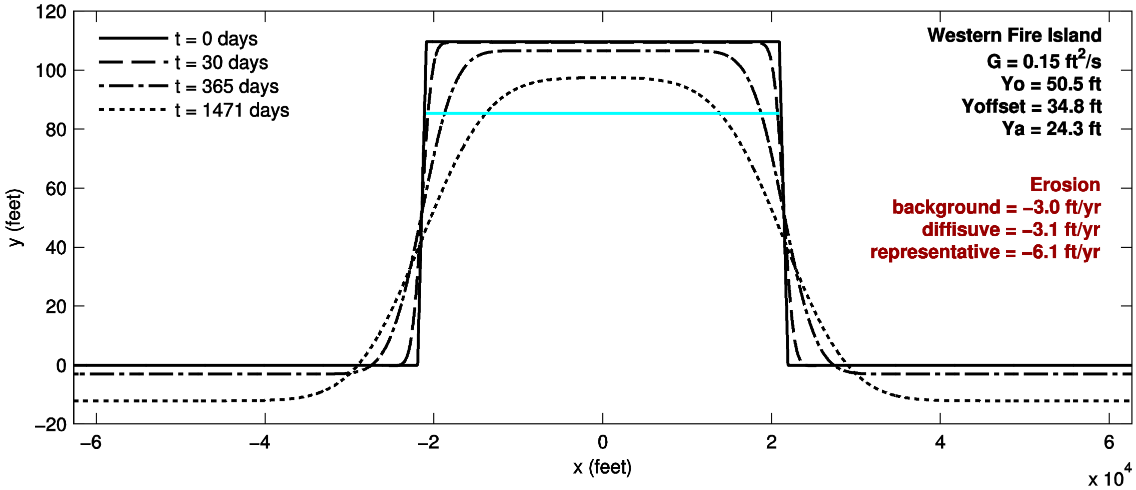


Figure 19: Beachfill Evolution at Western Fire Island (MREI)

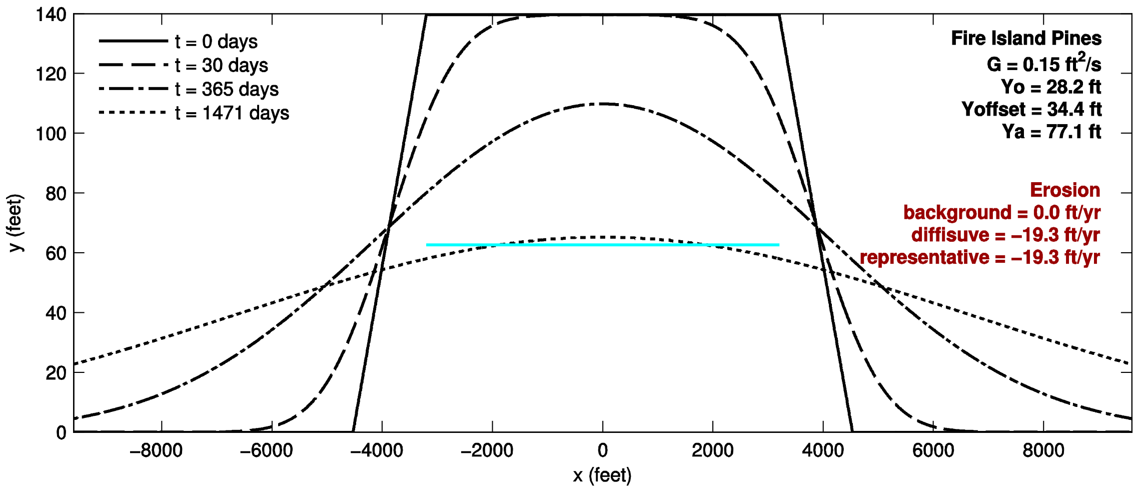


Figure 20: Beachfill Evolution at Fire Island Pines (MREI)

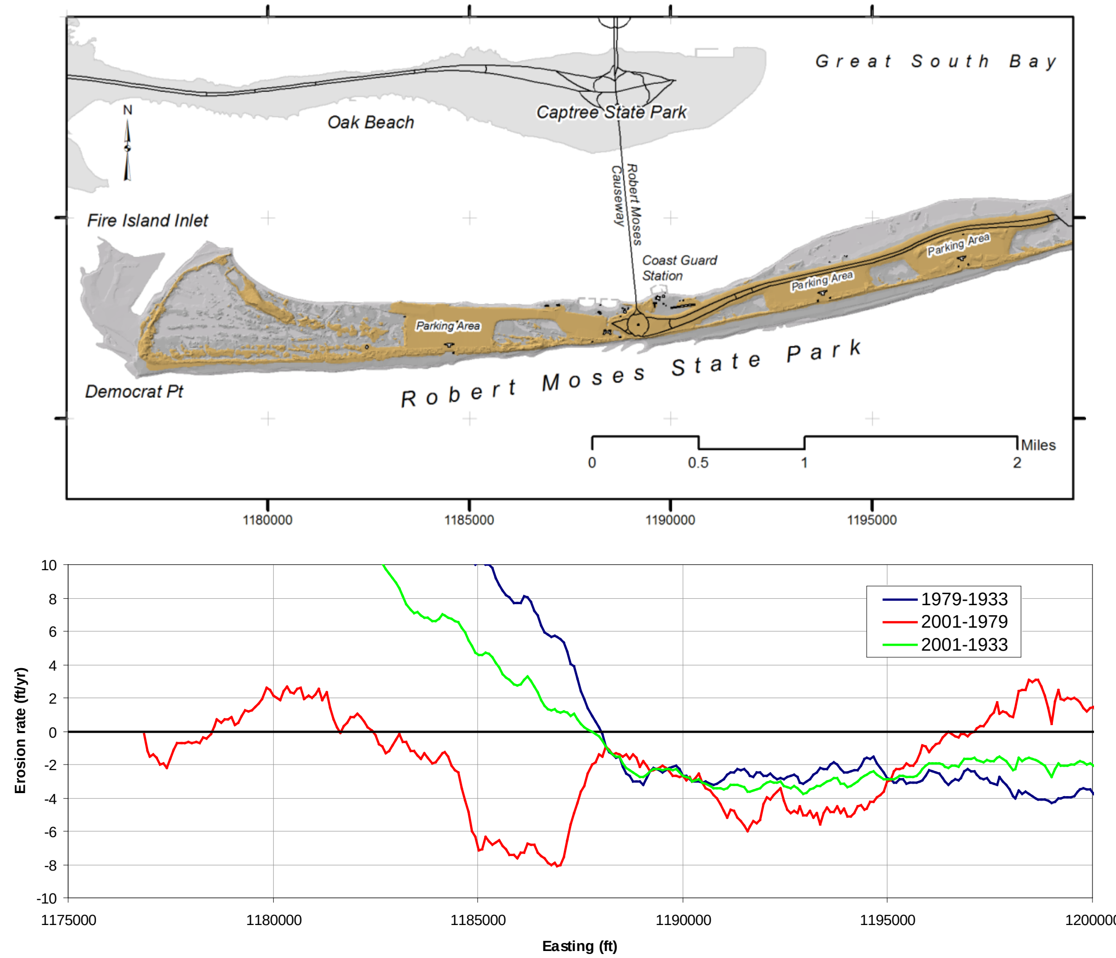


Figure 21: Historic Shoreline Erosion Rates at RMSP

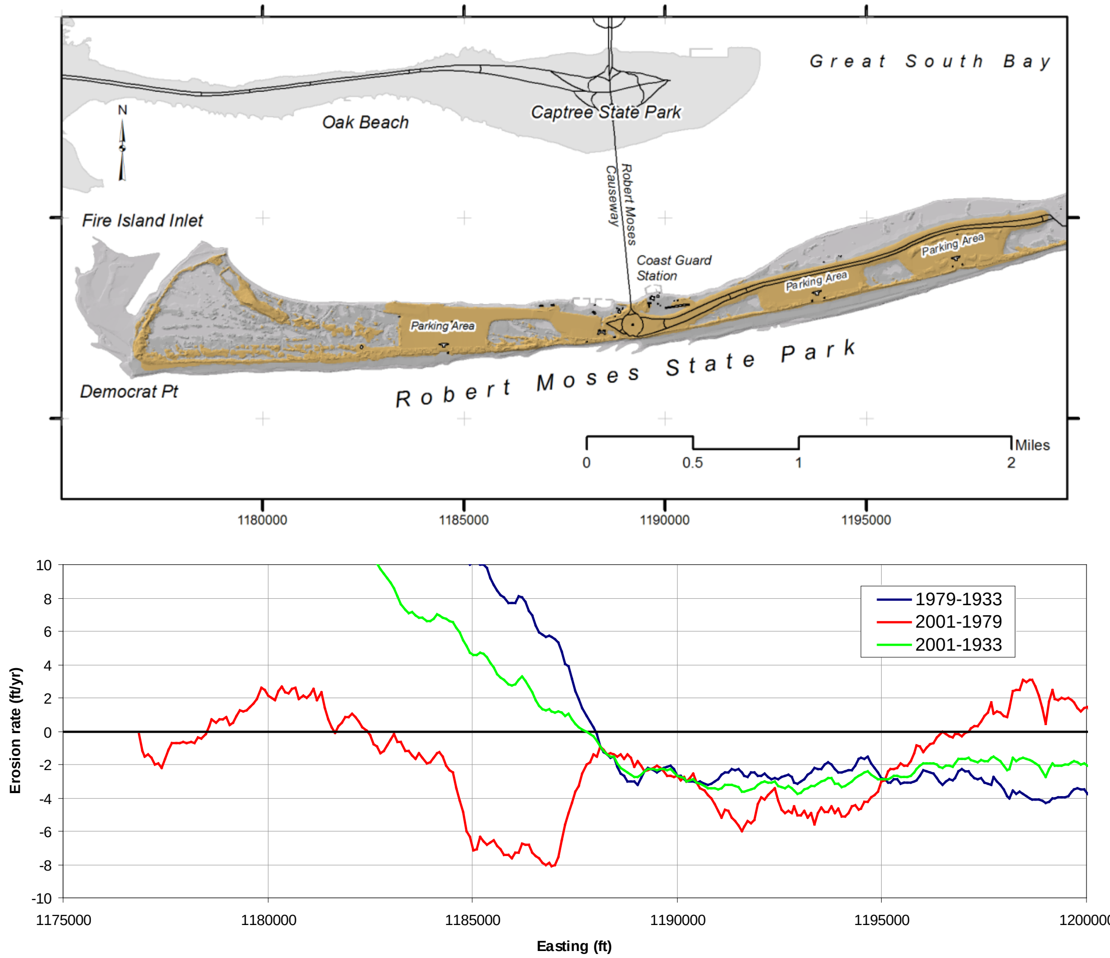


Figure 22: Historic Shoreline Erosion Rates at RMSP

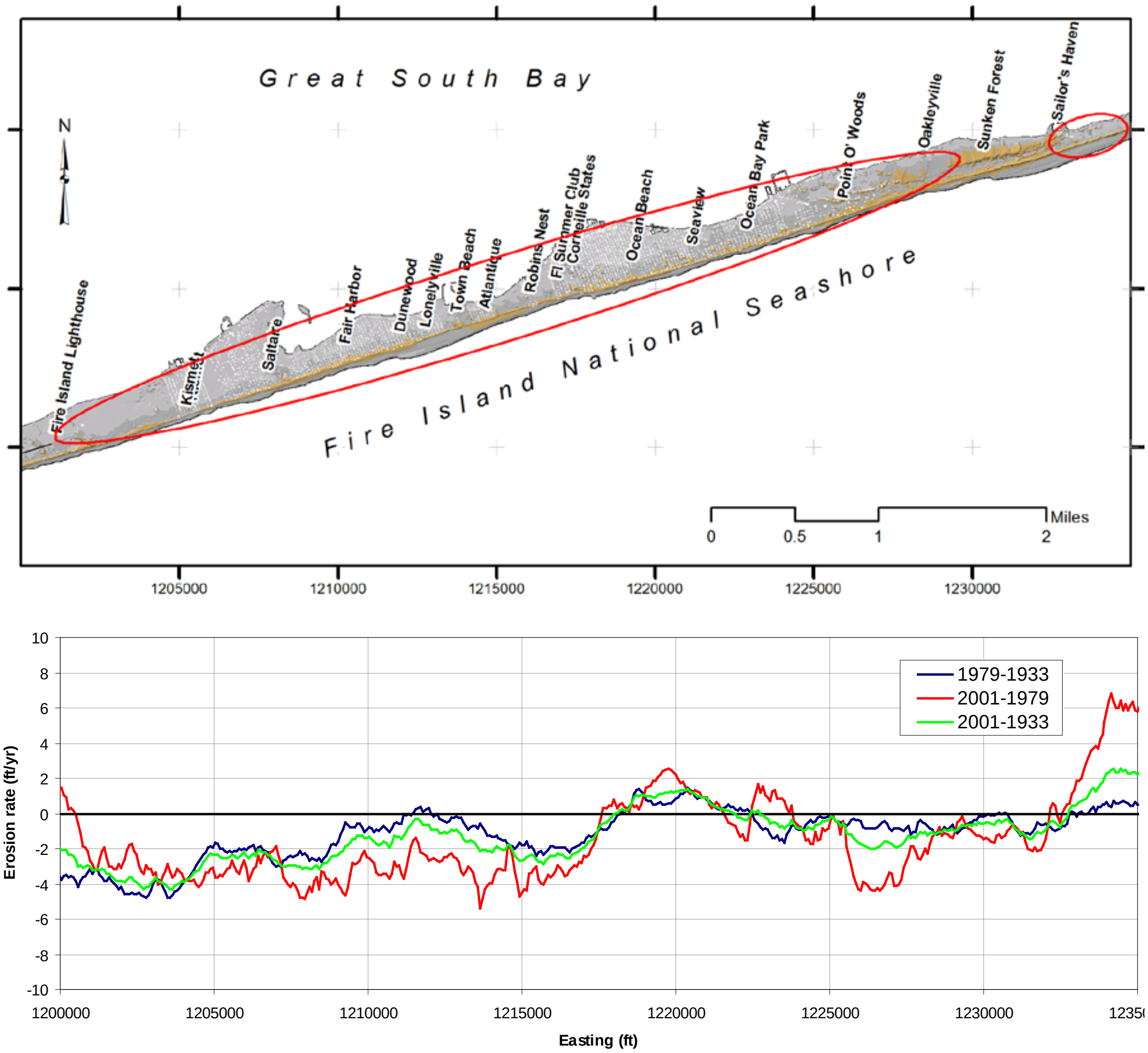
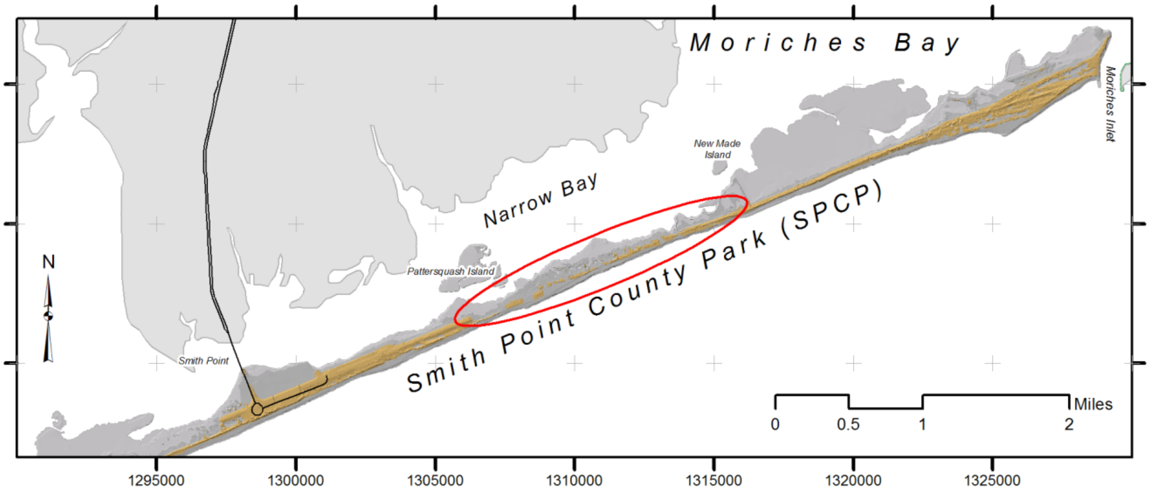


Figure 23: Historic Shoreline Erosion Rates at Western Fire Island



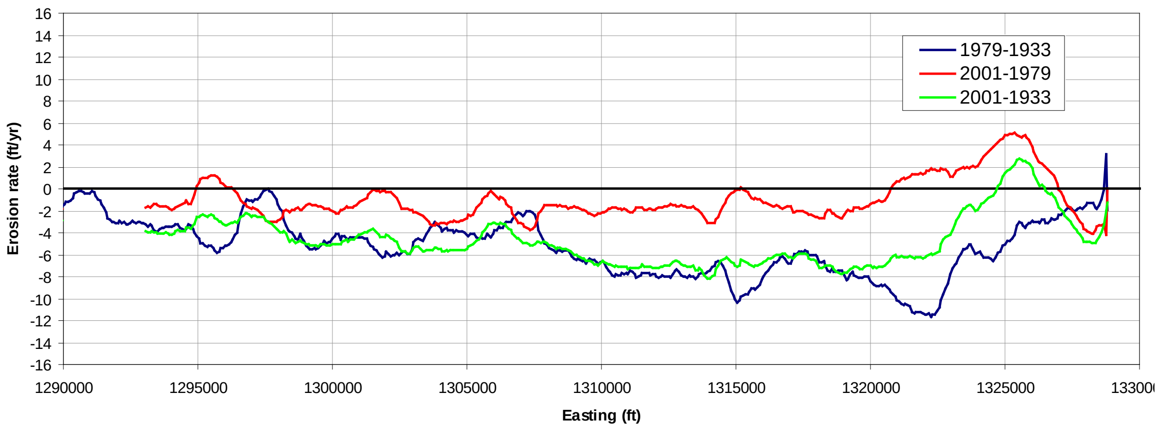


Figure 24: Historic Shoreline Erosion Rates at Smith Point County Park

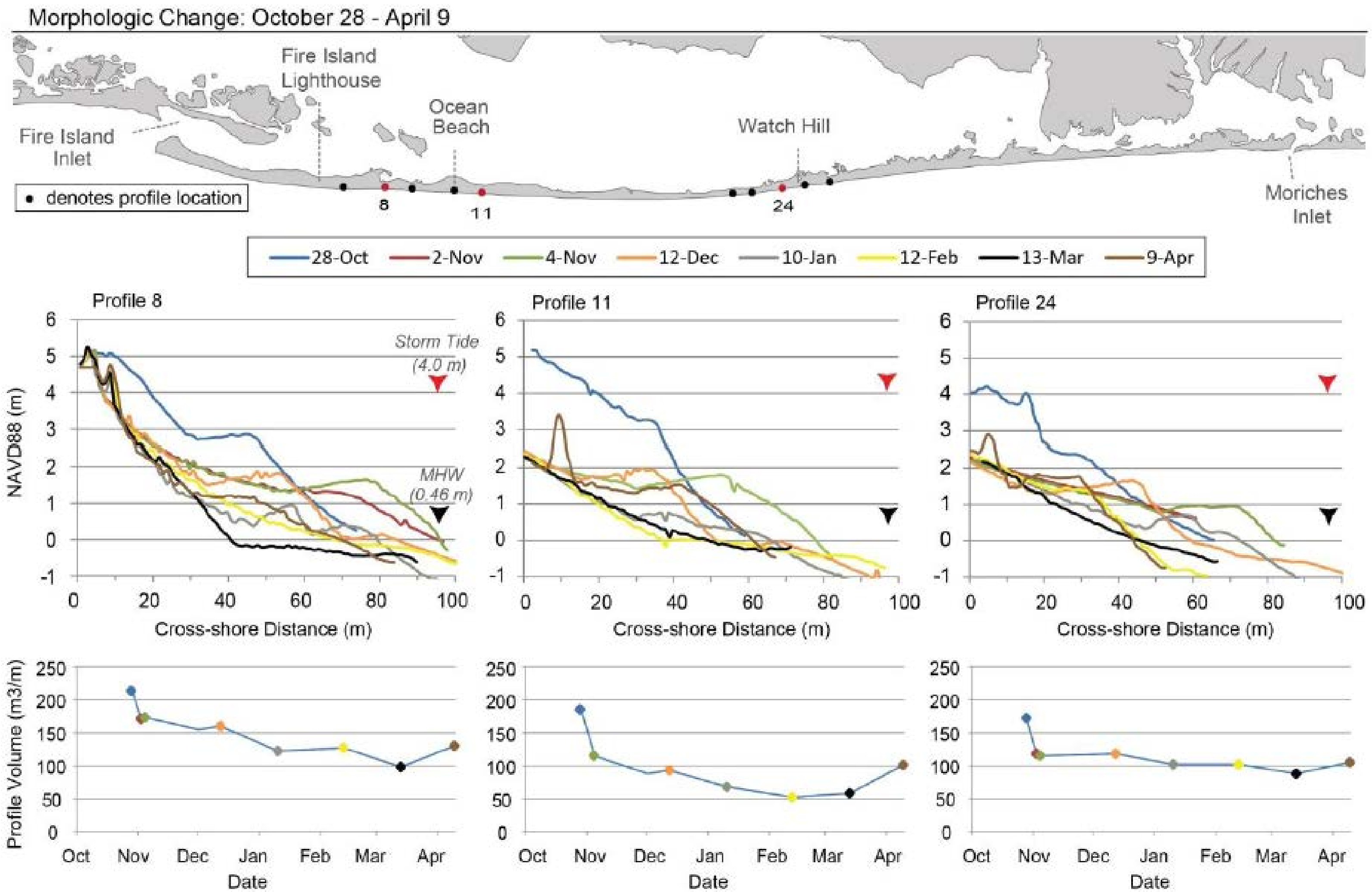


Figure 25: **Evolution of Subaerial Beach Following Hurricane Sandy (Hapke et al., 2013)**

ATTACHMENT A

BEACHFILL DIFFUSION CALCULATIONS

ATTACHMENT B

BACKUP VOLUME CALCULATIONS