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Performance Monitoring of a Nearshore Berm at Ft. Myers Beach, Florida: Final Report

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Final report

Abstract

This report documents the placement and monitoring of an active nearshore berm at Ft. Myers Beach, Florida. From May to July 2009, mixed sand and finer sediment dredged from a nearby inlet were placed in the active littoral zone in the form of a bar-shaped nearshore berm. Six sets of beach-nearshore profile surveys and two periods of sediment sampling along profiles were collected. The Ft. Myers Beach nearshore berm migrated onshore roughly 300 ft during the first 2 years. The elevation of the berm crest increased up to 2 ft. Nearly half of the onshore migration occurred during the first 9 months post-construction. Greater distances of onshore migration were measured during the more energetic winter seasons than during calmer summer seasons. No offshore migration was measured during the entire 2-year study period. The shape of the nearshore berm evolved from a roughly symmetrical bell-shaped bar to a highly asymmetrical shape with a steep landward slope, typical of a landward migrating bar. At the end of the 2-year period, the berm migrated to roughly 150 to 200 ft from mean sea level shoreline. The dry beach landward of the berm and along the adjacent beaches remained stable over the 2-year period.

A primary concern of this project was the dispersion of fine sediment following placement. Results of sediment sampling indicated that some of the fine material initially migrated into the nearshore trough and was then dispersed further offshore after several months. Onshore-directed transport and deposition of coarser sand fractions and offshore-directed transport and deposition of fine fractions were observed. The nearshore berm had negligible influence on the characteristics of the dry beach sediment, which remained to be well-sorted, fine sand.

The constructed berm showed considerable longshore variation in morphology, including several gaps/depressions. These gaps were maintained over the 2-year period, although longshore and cross-shore migrations were measured. Future studies should include continued monitoring to document potential attachment of the nearshore berm to the dry beach.

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Preface

This study was performed by the Coastal Inlets Research Program (CIRP) and the Regional Sediment Management (RSM) Program, both funded by Headquarters, US Army Corps of Engineers (HQUSACE) in collaboration with the University of South Florida (USF), and the US Army Engineer District, Jacksonville (hereafter, the Jacksonville District). The CIRP and RSM Programs are administered for Headquarters at the US Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL) under the Navigation Program of the US Army Corps of Engineers. At the time of this study, James E. Walker was the HQUSACE Navigation Business Line Manager overseeing CIRP and RSM. Jeff Lillycrop, CHL, is the ERDC Technical Director of Civil Works and the Navigation Program. Dr. Julie Rosati and Linda Lillycrop are the CIRP and RSM Program Managers, respectively.

This report documents the placement and 2-year monitoring of an active nearshore berm at Ft. Myers Beach, Florida. The monitoring effort consisted of topographic and bathymetric profiling and surface and subsurface sediment sampling. The 2 years of monitoring began in July 2009 and concluded in July 2011. The morphologic and sedimentologic evolution of the nearshore berm is detailed herein.

This report was prepared by Dr. Ping Wang and Katherine E. Brutsche, USF; James W. LaGrone, Jacksonville District; Tanya M. Beck, Coastal Engineering Branch (CEB), Navigation Division (ND), Coastal and Hydraulics Laboratory (CHL); Dr. Julie D. Rosati, Flood and Coastal Division, Coastal Processes Branch, CHL; and Linda S. Lillycrop, CEB, ND, CHL, Vicksburg, MS. The work described in the report was performed under the general administrative supervision of Dr. Jeffrey Waters, Chief of Coastal Engineering Branch, and Dr. Rose M. Kress, Chief of Navigation Division. Tony L. Tullos, ERDC Editor, Information Technology Laboratory, reviewed and edited the report. Jose Sanchez and Dr. William D. Martin were Deputy Director and Director of CHL, respectively, during the study and preparation of the report.

COL Jeffrey R. Eckstein was ERDC Commander. Dr. Jeffery Holland was ERDC Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards (cy)	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
knots	0.5144444	meters per second
miles (nautical)	1,852	meters
miles (US statute)	1,609.347	meters
miles per hour	0.44704	meters per second
pounds (force)	4.448222	newtons
pounds (force) per foot	14.59390	newtons per meter
pounds (force) per square foot	47.88026	pascals
square feet	0.09290304	square meters
square miles	2.589998 E+06	square meters
tons (force)	8,896.443	newtons
tons (force) per square foot	95.76052	kilopascals
yards	0.9144	meters

1 Introduction

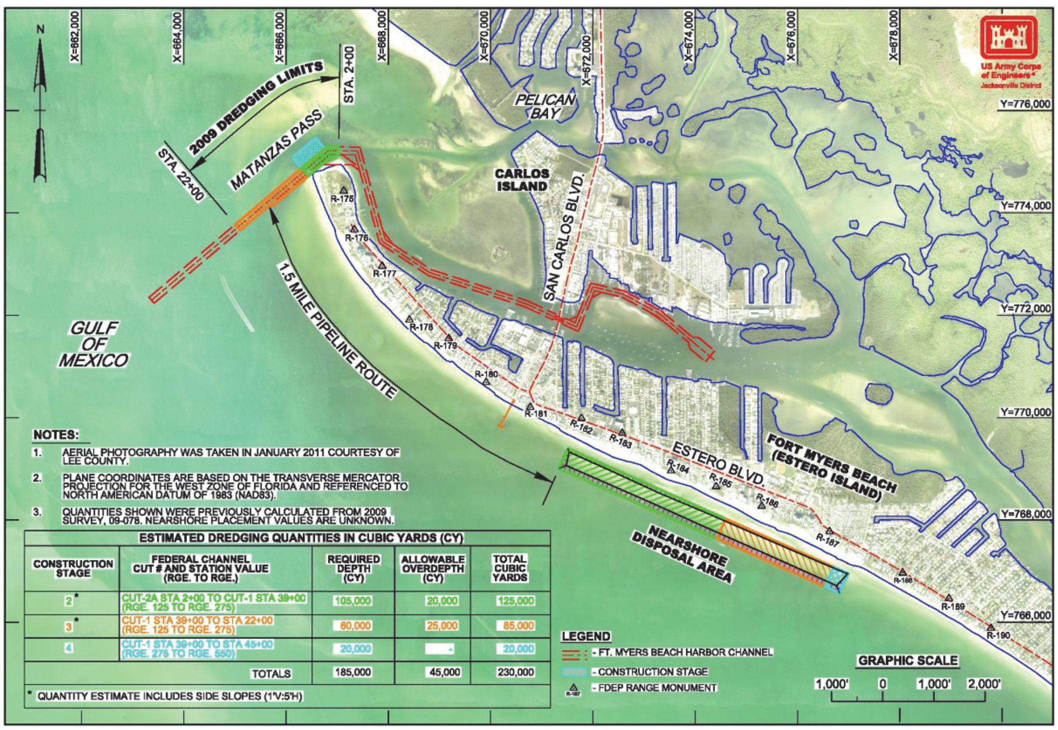
This report documents a 2-year monitoring study conducted by the Coastal Inlets Research Program (CIRP) and Regional Sediment Management (RSM) Program, two US Army Corps of Engineers (USACE) Research Programs, in collaboration with the US Army Corps of Engineers Jacksonville District (SAJ) and the Coastal Research Laboratory at the University of South Florida (USF-CRL) to evaluate the performance of a nearshore berm project. Placement of nearshore berms as a beneficial use of dredged material is becoming an increasingly applied practice for Operations & Management (O&M) within the USACE. These placements are typically less costly to construct and do not have strict environmental restrictions as compared to beach placement.

Historically, there have not been many extensive studies on the performance of various types of nearshore placements. Our present knowledge is not adequate to justify the many ways a nearshore berm may be beneficial to local and regional stakeholders. To address this, the CIRP and RSM Programs collaborated with SAJ and USF-CRL to monitor and analyze the performance of a nearshore berm in Ft. Myers Beach, Florida.

In the summer of 2009, SAJ dredged Matanzas Pass, located along the southwest coast of Florida, and placed the dredged material as a nearshore berm at Ft. Myers Beach (Figure 1). The artificial berm was constructed in the form of a nearshore bar largely within the zone of wave breaking, with the goal of replicating the morphodynamics of a natural nearshore bar. Pre- and post-construction surveys and subsequent semi-annual surveys were conducted by SAJ and USF to collaboratively monitor the morphologic evolution of the berm. USF-CRL collected and analyzed extensive surface and subsurface sediment samples. This report documents the detailed morphologic evolution, sediment properties, and temporal variations of the nearshore berm, in comparison with the characteristics of the control sites extending from both ends of the nearshore berm.

The objectives of the 2-year monitoring study were to 1) quantify the morphologic and sedimentologic evolution of the nearshore berm, 2) investigate the interactions between the nearshore placement and the adjacent beaches in terms of both morphology and sediment characteristics, and 3) determine the corresponding physical processes and controlling factors of the berm evolution. Understanding the physical processes and controlling parameters can help engineers to improve confidence in the selection of placement sites and design configuration under specific temporal and spatial guidelines, prevent rehandling of proximally placed sediment from being transported into the navigation channel. By monitoring project performance, guidelines can be further refined for determining project success, of which the prediction of potential sediment exchange between the beaches and the placement is critical. This is the third and final report (following Brutsche and Wang 2011; Beck et al. 2011) detailing the findings of the 2-year monitoring study.

Figure 1. Study area map including local R-Monument locations for Ft. Myers Beach, Estero Island, Florida.



This report is organized into nine chapters. Following the introduction in Chapter 1, Chapter 2 briefly reviews existing knowledge on artificial nearshore berms. Chapter 3 provides details on the project construction. A review of processes in the region is given in Chapter 4, and Chapter 5 details the monitoring of the berm project. Chapters 6 and 7 discuss analyses and findings from the monitoring program for morphologic and sedimentologic evolution, respectively. Findings of the study are discussed in Chapter 8, followed by a summary in Chapter 9.

2 Review of General Guidelines for Nearshore Berm Design and Performance

One of the alternatives of placing sediments from dredging navigation channels has been nearshore placement in the form of a berm. Nearshore berm placements are becoming an increasingly preferred option for the placing of clean (non-contaminated) dredged material with a relatively high percentage of sand sized particles. Compared to often-preferred beach nourishment, nearshore berm placements can be desirable for several reasons, e.g., less costly, easily constructed, and fewer environmental restrictions; however, various site-specific issues associated with berm nourishments need to be carefully addressed. Key issues include whether and how the nearshore berm will move onshore or offshore, the processes that are associated with the berm movement, and how the coarser and finer fractions of the placed sediment will redistribute.

For mixed sediment with mostly sand but some fine fractions that are not considered beach quality, nearshore berms offer a placement option that can keep sand in the littoral zone, with the potential to reduce waves in the lee of the berm and allow the sand fraction to move onshore while fines disperse offshore. Depending upon the site and placement type, berms can offer recreational benefits such as surfable waves and shallower nearshore areas for beach-goers. However, there may be aesthetic detriments to the recreational benefits of nearshore berms, such as stagnant water if the berm migrates onshore and becomes intertidal, temporary deposition of fine materials in the trough, and the navigation impediments of a shallow bar.

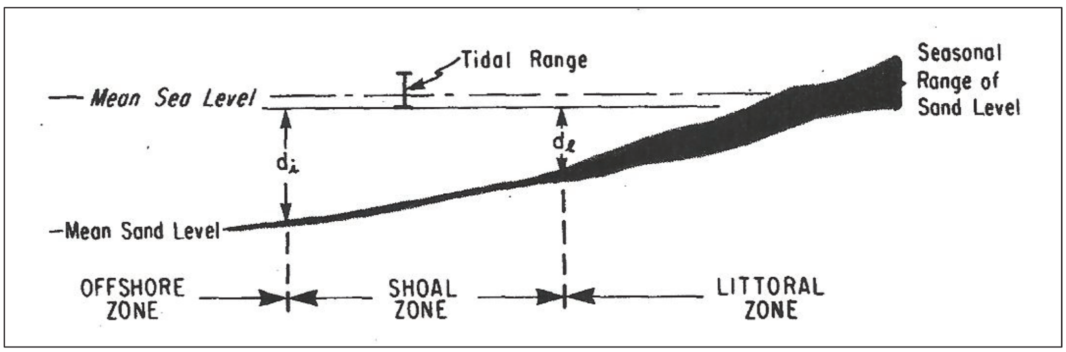
Systematic studies on design considerations for nearshore berm placement were primarily conducted in the late-1980s to mid-1990s, with several studies (e.g., Hands and Bradley 1990; Hands and Deloach 1984; Hands and Allison 1991; Scheffner 1991; Allison and Pollock 1993; McLellan and Kraus 1991; McLellan 1990) funded by the USACE Dredging Research Program (DRP). These studies resulted in guidance for evaluating the general stability of a nearshore berm. Recognizing the significant control of site-specific conditions on berm performance, nearly all of the studies recommended detailed field monitoring. The developments of the berm performance criteria and design guidelines were strongly based on the findings of Hallermeier's (1981a and 1981b) study on profile zonation and

Larson and Kraus' (1992 and 1994) studies on natural bar morphodynamics.

After an extensive review of existing data and theory, Hallermeier (1978, 1981a, 1981b, and 1983) defined three active profile zones based on the intensity of forcing conditions for sediment transport and subsequent morphology change (Figure 2). The boundaries of the zones were empirically derived and are calculated using local sediment characteristics and summary statistics of annual wave climate. Hallermeier (1981b) related the mean annual significant wave height, H_s, and the associated standard deviation, σ_{Hs}, to define the landward boundary of shoaling zone (d_l), modified here to the inner limit of active transport, D_{inner}. This nearshore depth D_{inner} defines the seaward boundary of Hallermeier's littoral zone where wave breaking occurs under normal conditions:

$$D_{inner} = d_l = 2H_s + 11\sigma_{Hs} \quad (1)$$

Figure 2. Shore perpendicular profile zonations (Hallermeier 1981).



By including the mean significant wave period, T_s, and the typical median sand diameter (at $1.5d_l$), D, the seaward boundary of shoaling zone (d_i), modified here as the outer limit (D_{outer}), can be calculated as follows:

$$D_{outer} = d_i = \left(H_s - 0.3\sigma_{Hs}\right)T_s\sqrt{\frac{g}{5000D}} \quad (2)$$

It is worth noting that the modified notations, D_{inner} and D_{outer}, are introduced here to avoid possible confusion of original d_l and d_i. Also, in this version of the Hallermeier (1981b) equations, the annual mean significant wave height is used. A similar approach was used by Houston (1995). Several other closure depth equations, e.g., Hallermeier (1978) and

Birkemeier (1985), used extreme wave conditions, such as extreme significant wave height exceeded 12 hours per year.

The *littoral zone* (Figure 2) is dominated by active, breaking-wave induced sediment transport and morphologic change. The *shoal zone* is dominated by shoaling waves, especially high and long-period waves, with active sediment transport and measureable morphologic change occurring under storm conditions. The *offshore zone* is located beyond the influence of surface water waves. Negligible wave-induced morphologic change should occur under the typical wave climatology in this zone. Therefore, it is reasonable to hypothesize that berms placed in the offshore zone with berm crest deeper than D_{outer} should remain stable, and it should not significantly affect wave propagation patterns. Berms placed in the shoal and littoral zones should experience active sediment transport and therefore be mobile and influence wave propagation patterns.

Assuming that bar-shaped artificial berms placed in the nearshore should behave similarly to natural bars, Larson and Kraus (1992, 1994) investigated the morphodynamics of the longshore bars at the USACE Field Research Facility (FRF) in Duck, North Carolina. They hypothesized that findings on nearshore bar morphodynamics should be directly applicable to understanding and predicting artificial berm behavior. The beach at Duck, surveyed bi-weekly, is characteristic of a 2-bar system: an inner bar approximately 300 ft from the shoreline and an outer bar roughly 1000 ft offshore. Due to the highly dynamic nature of nearshore bars, their morphology tends to be smoothed when averaged over space and time. An average monotonic profile is often used to represent an equilibrium shape (Bruun 1954; Dean 1977 1991; Bodge 1992; Wang and Davis 1998, 1999). Based on averaged profiles derived from the FRF data, and the Dean (1977) equilibrium profile concept, Larson and Kraus (1992, 1994) developed a modified equilibrium profile as follows:

$$h = A_* \left[x + \frac{1}{\lambda} \left(\frac{D_0}{D_\infty} - 1 \right) \left(1 - e^{-\lambda x} \right) \right]^{2/3} \tag{3}$$

where:

h = water depth
A_* = shape parameter based on median grain size

x = distance offshore measured from the MSL (Mean Sea Level) shoreline
D_o = equilibrium wave energy dissipation per unit volume in the inshore
D_∞ = equilibrium wave energy dissipation per unit volume in the offshore
λ = characteristic decay length describing the rate at which D_o reaches D_∞. Based on Larson and Kraus (1992), λ is determined empirically.

In order to quantify bar morphology and to predict bar movements, Larson and Kraus (1994) developed various parameters and examined their relationships. They documented strong correlations between bar volume and bar height, bar volume and bar length, depth of bar crest and distance to its center of mass. Furthermore, Larson and Kraus (1994) examined relationships between bar properties and incident wave conditions. Correlations were identified between certain wave properties and bar properties, including $h_c/(H_o)_{max}$ and $(H_o/L_o)_{mean}$, and $\Delta V_b/H_o^2$ and $(H_o/wT)_{mean}$. The notations here are as follows: h_c=water depth at the bar crest; $(H_o)_{max}$=maximum deep wave height; $(H_o)_{mean}$=mean deep water wave height; $(L_o)_{mean}$=mean deep water wave length; ΔV_b=change in bar volume; H_o=deep water wave height; w=sediment settling velocity; and T_{mean}=mean wave period.

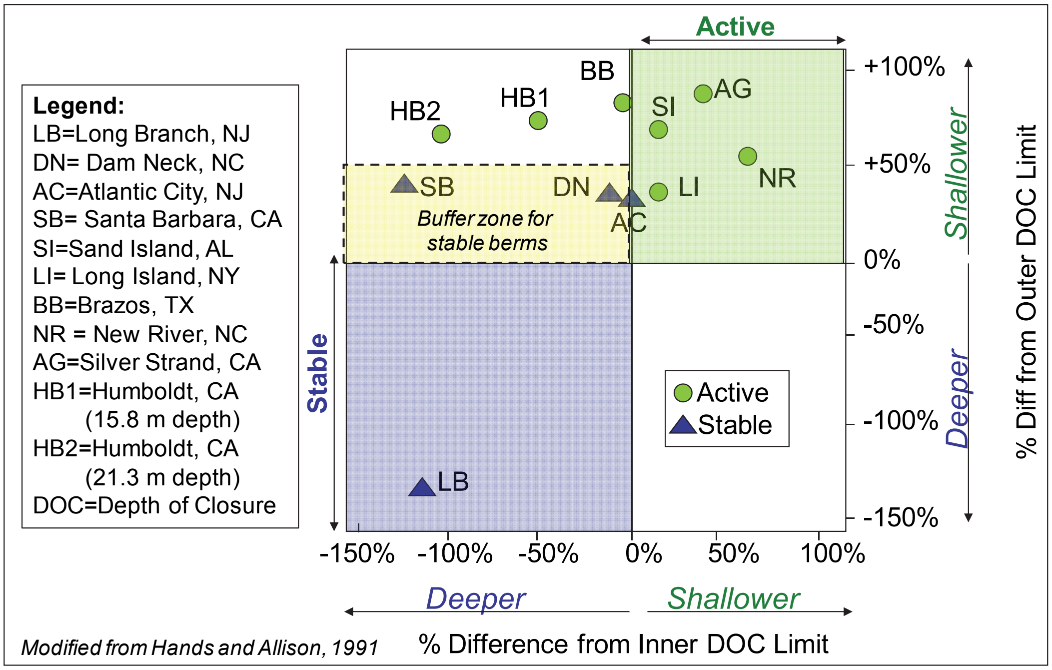
The criteria developed based on the FRF field data were applied to successfully predict the trend of movement of an artificial berm at Silver Strand, California. It was therefore concluded that the geometric bar property correlations derived from the US east coast field research facility at Duck North Carolina may apply to other coasts and to the morphodynamics of artificial berms. Furthermore, the above parameters may be used in the design of artificial berms.

Nearshore berms can be designed to be active or stable as determined by sedimentologic, morphologic, and hydrodynamic conditions. Hands and Allison (1991) defined active berms as those that show significant movement within the first few months, while stable berms retain most of their original volume and remain at the placement site for years. Adopting a similar approach, McLellan and Kraus (1991) classified artificial berms into two types: feeder berms and stable berms. A feeder berm is placed in sufficiently shallow water and with relatively high relief. A linear and shore-parallel feeder berm induces wave breaking, especially during storm conditions, therefore significantly reducing the wave energy arriving at the shoreline. A feeder berm also tends to migrate onshore under accretionary wave conditions. A stable berm is designed to remain largely stationary. It may attenuate larger storm waves. Generally, feeder berms should be composed of beach quality sand. If a stable berm consists of beach quality sand, it can serve as a stockpile for future beach nourishments. Based on McLellan and Kraus' (1991) classification, the Ft. Myers Beach nearshore berm is a linear shore-parallel feeder berm. Based on Hands and Allison's (1991) criteria, the Ft. Myers Beach berm is considered active.

McLellan and Kraus (1991) proposed comprehensive design guidance for nearshore berm construction. They recommended several steps for determining the potential success of a nearshore berm constructed with sediment dredged from an adjacent navigation channel. These steps included assessing the quantity and quality of material, availability of equipment, local wave conditions, and economics of berm construction and alternatives. McLellan and Kraus (1991) suggested that artificial berm design should consider the following factors: a) placement proximity to navigation channel, b) timing of placement (which could be seasonally dependent), c) depth of placement, and d), for a berm to reduce wave forcing, the overall dimensions of the constructed berm. They recommended that a feeder berm be placed downdrift of the inlet channel and away from the direct hydrodynamic effects of the tidal inlet. They also suggested that timing of placement should consider the annual beach cycle. For a beach with a typical winter-summer cycle in the northern hemisphere, the early- to mid-summer time frame should be optimal for accretionary wave conditions. McLelland and Kraus (1991) also provided various design guidelines on the dimensions of a nearshore berm.

Hands and Allison (1991) investigated the evolution of 11 artificial berms, focusing on whether overall onshore migration occurred. They found that stability of the berm can be related to the depth of placement. The 11 cases were categorized into active and stable. Hands and Allison (1991) developed a nearshore berm stability graph, which is reproduced in Figure 3 (Beck et al. 2012). This graph illustrates the stability of artificial berms based on the percent shallower or deeper of the berm base as compared to the D_{inner} and D_{outer} limits (Equations 1 and 2) of the project area.

Figure 3. Nearshore berm stability graph illustrating the difference between active and stable berms in deep or shallow water (modified from Hands and Allison 1991).



The Hands and Allison (1991) criteria have been broadly and successfully used to evaluate berm stability. They have also been applied to evaluate the behavior of different portions of a nearshore berm. Bodge (1994) applied the criteria to predict the behavior of the 1993 Port Canaveral berm and concluded that the Hands and Allison (1991) model successfully predicted, as confirmed by field data, the shallow portion of the berm as being active and deeper portion as stable. However, Dean and Dalrymple (2002) pointed out that the well documented Perdido Key berm (discussed in more detail in the following section) was predicted to be active according to the Hands and Allison model, contrary to field results. The Perdido Key berm is not included in the Hands and Allison (1991) analyses (Figure 3).

Several studies have documented a characteristic morphological evolution of active nearshore berms, or, as used in other terminology, *mounds* (Bodge 1994; Mesa 1996; Andrassy 1991). Here, the term mound is used qualitatively to represent a largely 3D disposal feature in comparison to elongate shore parallel berm features. As the mounds migrated onshore, the heights of the mounds decreased over time. All of the above studies found that the mound dispersion is mostly directed onshore with little to no longshore and offshore directed dispersion.

Scheffner (1991) proposed a systematic approach to analyze placement site stability, which includes numerical modeling of wave field, storm surge, tidally driven currents, and magnitude of sediment transport. Scheffner (1991) emphasized the importance of realistic and accurate site-specific measurement data. Although beyond the scope of this report, it is worth noting that various models have been applied to evaluate the design and anticipated performance of nearshore berms. Allison and Pollack (1993) used the Regional Coastal Processes WAVE (RCP WAVE) model (Ebersole, et al. 1986) and the Numerical Model of Longshore Current (NMLONG) (Kraus and Larson, 1991) to evaluate several berm design options including crest length and end slopes. Douglass (1995, 1996) developed an analytical model to calculate onshore berm migration rate. The recent developments in numerical modeling (Lin et al. 2012; Reed et al. 2011; Lin et al. 2011; Hanson and Kraus 2011) should provide valuable tools for improved design and evaluation of artificial nearshore berms.

Table 1 summarizes basic morphological information on existing berms. Site-specific annual average wave conditions, measured or from hindcast database, are not included in Table 1 for the convenience of fitting to one page. As summarized in Table 1, construction of submerged berms appears to have begun in the mid-1930s in Santa Barbara, California (Hall 1953). Interest in this type of nourishment and shore protection has increased in recent years.

Table 1. Summary of existing artificial berms/mounds. A portion of this table was obtained from Otay (1994).

Location	Year	Placed volume × 10^3 (yd^3)	Place-ment water depth (ft)	Berm height (ft)	Sediment grain size (mm)	Stable or active	Reference
Santa Barbara, CA	1935	201	20	5.0	0.18	stable	Hall and Herron (1950)
Atlantic City, NJ	1942	3,531	15-25	-	0.32	stable	Hall and Herron (1950)
Long Beach, NJ	1948	602	28	7.0	0.34	stable	Hall and Herron (1950)
Durban, South Africa	1970	3,270	23-52	0-27		both	Zwamborn et al. (1970)
Copacabana Beach, Brazil	1970	2,616	13-20	-	0.4-0.5	Active	Vera-Cruz (1972)
Long Island Sound, CT	1974	1,530	60	30	silt	stable	Bokuniewicz et al. (1977)
Lake Erie, OH	1975	24	56	1.2	silt	stable	Danek et al. (1978)

Location	Year	Placed volume × 10^3 (yd^3)	Place-ment water depth (ft)	Berm height (ft)	Sediment grain size (mm)	Stable or active	Reference
New River Inlet, NJ	1976	35	6-13	Up to 6 m	0.49	active	Schwartz and Musialowski (1977)
Tauranga Bay, New Zealand	1976	2,616	36-56	30	Fine to coarse sand	stable	Healy et al. (1991)
Dam Neck, VA	1982	850	33-36	11	0.08	stable	Hands and Deloach (1984)
Sand Island, AL	1987	350	19	6-7	0.22	active	Hands and Bradley (1990)
Fire Island, NY	1987	458	16	6			McLellan (1990)
Jones Inlet, NY	1987	392	16	6			McLellan (1990)
Mobile, AL (outer mound)	1988	18,704	35-45	22	fine	stable	McLellan (1990)
Coos Bay, OR	1988	5,232	66-85	15-25	0.25-0.3	dispersed	Hartman et al. (1991)
Silver Strand, CA	1988	148	15-18	7	0.2	active	Andrassy (1991)
Kira Beach, Australia	1988	1,962	23-33	6.6	--	active	Smith and Jackson (1990)
South Padre Island, TX	1989	438	26	2-4.6		active	Aidala et al., (1996)
Mt. Maunganui, New Zealand	1990	105	13-23	6.6	--	active	Foster et al. (1994)
Perdido Key, FL	1992	4,000	16-20	5.7	0.3	stable	Otay (1994)
Port Canaveral, FL	1992	130	17-22	5.4		active	Bodge (1994)
Port Canaveral, FL	1993	200	22 to >26	--		Both stable and active	Bodge (1994)
New Port Beach, CA	1992	1,670	5-30	Up to 16	0.09-0.22	Both stable and active	Mesa (1996)
Terschelling, the Netherlands	1993	2,616	16-23	--	--	active	Kroon et al. (1994)
Egmond, the Netherlands	1999	1,177	25	2	0.2	active	Van Duin et al. (2004)
Ocean Beach, CA	2005	902	30-46		0.18	active	Barnard et al. (2009)
Ft. Myers Beach, FL	2009	229	5-8	Up to 6	0.17	active	Brutsche and Wang (2012)

Andrassy (1991) and Junhke, Mitchell and Piszker (1990) monitored the placement of a nearshore berm at Silver Strand State Park located near San Diego Harbor, California. This was a small project in terms of volume placed. It was designed to be an active berm, expected to move onshore and nourish the littoral zone. The berm was approximately 1200 ft long, 600 ft wide, had an average relief of 7 ft, and was placed between the 15- and 28-ft depth contours, or above the depth of closure of 33 ft for this area. During the first 2 years after the berm placement, Andrassy (1991) documented onshore migration of the berm and nourishment of littoral zone. Of all the cases reviewed here, this is the only one that documented considerable subaerial sand accumulation within and above the intertidal zone, which lies between zero and 10 ft above Mean Lower Low Water (MLLW) at the site. The accumulation was interpreted as the direct result of onshore migration of the berm, in addition to the hydraulic effects (modification to wave propagation pattern) of the berm. The Silver Strand case was used by several key modeling studies including Hands and Allison (1991) and Larson and Kraus (1992).

One of the largest nearshore berm projects in terms of volume placed was the Perdido Key, Florida, project constructed in 1989. The Perdido Key berm was probably one of the most comprehensively studied projects, monitored over an 8-year period encompassing proximal passages of several hurricanes (Otay 1995; Work and Otay 1996; Browder and Dean 2000). Otay (1995) analyzed the berm nourishment based on topographic and bathymetric surveys, wave and current measurements, sediment sampling, meteorological data analysis, and analysis of oblique aerial photography. It was concluded that the berm remained largely stable with no significant volumetric changes except some degree of bathymetry smoothing (Otay 1995). Wave modeling indicated that the berm provided some protection to the landward beach. Browder and Dean (2000) analyzed additional longer-term survey data and concluded that 8 years after the construction, the berm remained largely stable, confirming the earlier findings of Otay (1995). Based on the findings of Otay (1995) and Browder and Dean (2000), the Perdido Key berm behaved differently from most of the berms listed in Table 1. The Hands and Allison (1991) model would predict this berm to be an active one, whereas the long-term field monitoring suggested otherwise. No specific reasons were given by Otay (1995) and Browder and Dean (2000) for the contrary behavior of the Perdido Key berm as would be predicted by the Hands and Allison (1991) model.

Mesa (1996) applied the Hands and Allison (1991) criteria to the Newport Beach nearshore berm in California (constructed in 1992) and concluded that the berm could be considered both stable and active. Based on near-bed velocities, it should be categorized as stable; however, based on the Hallermeier depth limits, the berm falls into the *buffer zone* in the Hands and Allison (1991) classification (Figure 3). Mesa (1996) suggested that the berm seemed to have improved the surfing conditions in the area, providing a positive public perception to local stakeholders.

Two recent shoreface nourishment projects in the Netherlands were constructed along coasts characteristic of a dynamic 2-bar system, referred to here as the inner and outer bar. The Terschelling shoreface nourishment was placed in the trough between the 2 bars at a depth of 16 to 23 ft below mean sea level (Kroon et al. 1994). The Egmond shoreface nourishment was placed directly seaward of the outer bar at a water depth of approximately 25 ft (van Duin et al. 2004). The shoreface nourishment had substantial influence on the morphodynamics of the 2 bars at both projects. A common response observed at both sites was the rapid re-establishment of both bars following the placement, despite the different placement locations. This led to their conclusion that the nearshore profile has the ability to restore its equilibrium shape against perturbations (van Duin et al. 2004; Kroon et al. 1994; Hoeskstra et al. 1996; Gruunet et al. 2004). Onshore migration of the artificial berm was measured at both sites. In addition, the shoreface nourishment induced onshore migration of both the inner and outer bars. In both cases, modeling of higher waves indicated that the function of the nearshore berms acting as submerged breakwaters contributed partially to the shoreline accretion. Attachment of the berm onto the shoreline was not observed.

In summary, various degrees of initial onshore migration, especially directly following placement, have been measured for most of the active nearshore berms. The function of the shallow artificial berms as submerged breakwaters is also well documented through numerical wave modeling. Existing empirical models (e.g., Hands and Allison 1991; Larson and Kraus 1992) are capable of predicting the status of the berm as being active or stable under most circumstances, and, therefore, providing valuable design guidance. A major goal of the feeder (or active) berm is to provide beach quality sand to the littoral zone and ultimately to the subaerial beach. However, limited information is available on exactly how an active berm would supply sand to the beach environment, especially the dry beach and upper intertidal zone.

There is a need to address several critical questions that detail the morphologic benefit of nearshore berms:

1. Is there a landward limit of onshore migration of a berm in both space and time?
2. What conditions would favor shoreline accretion or shoreline attachment of a nearshore berm?
3. How does a nearshore berm affect the morphology of adjacent beaches?

In addition to trend of morphologic changes, another key issue for nearshore placement is the relationship between the sediment characteristics and its evolution over time and space. As discussed earlier, a common reason for nearshore placement instead of beach fill is a higher-than-permissible fraction of fine sediment. Information and knowledge on how the sediments redistribute through selective transport are essential to design, placement operation, and prediction of berm behavior. Several crucial questions exist:

1. What is the trend of transport for the fine fractions in the sediment? (A desirable trend would be offshore transport.)
2. What is the temporal scale for the offshore-directed transport of fine fractions?
3. Is there a temporal scale for nearshore-directed transport of fine material before long-term effects redistribute them to quiescent areas?
4. What fraction of the sediment remains within the zone of placement? (Limited study has been conducted to investigate long-term selective transport associated with nearshore berm placement.)

3 Overview of Ft. Myers Beach Nearshore Berm Project

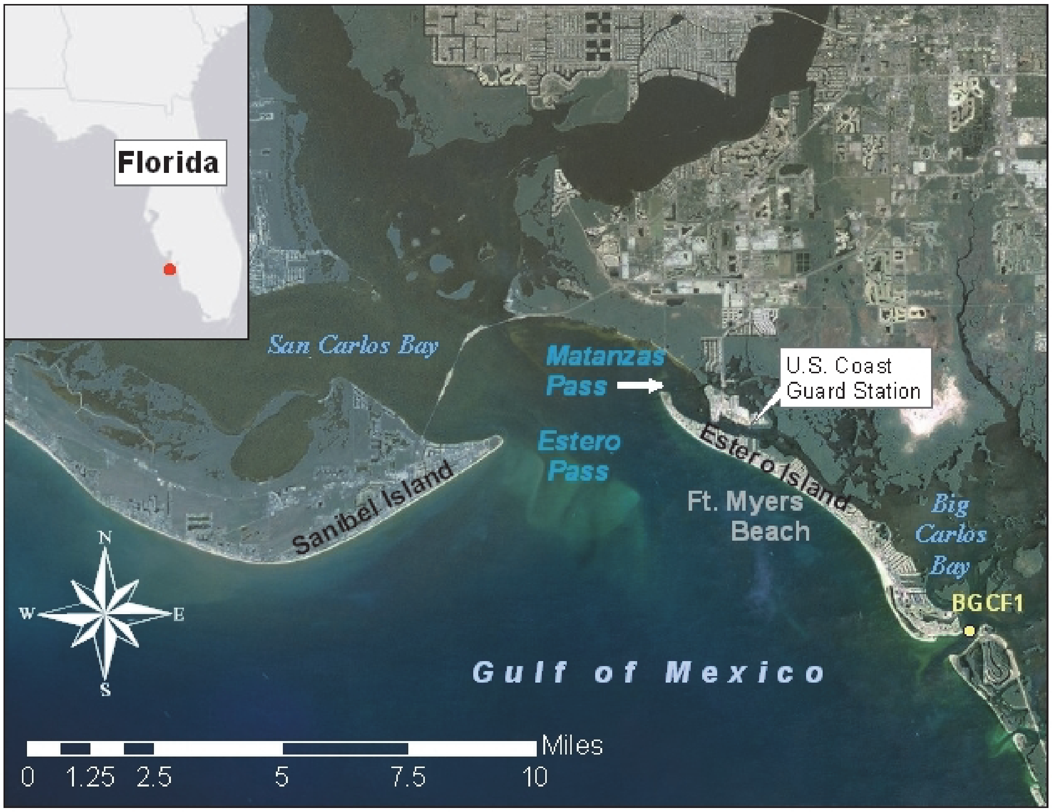
Project Location and History

Ft. Myers Beach is located in southwest Florida on a low-lying barrier island, Estero Island, fronting the Gulf of Mexico (Figure 4). Estero Island is crescent shaped and bordered to the north by San Carlos Bay and Big Carlos Bay to the south. The back-barrier environment is comprised of numerous mangrove islands, bays, and inlets. Estero Island is sheltered from northwest-approaching waves by Sanibel Island protruding into the Gulf of Mexico (Balsillie and Clark 1992). This sheltering and the expansiveness of San Carlos Bay facilitate the natural channel at the end of the barrier island that is Federally maintained for harboring the local fishing community, pleasure craft, and the United States Coast Guard (USCG).

The Federally-maintained channel is a segment of waterway between Estero Island and various islands to the east. The channel is locally known as Matanzas Pass and extends north of Estero Island into the bay towards San Carlos Island to the east (Figure 1). Near the San Carlos Boulevard Bridge, the channel becomes Estero Pass. The Federally-maintained channel was originally constructed in 1961. Maintenance dredging of the channel occurred in 1986, 1998, and 2001. In 2001, the dredged material was placed subaerially along the northern reach of Estero Island between Range Monuments (R-Monuments) R178 to R184 (Figure 1). In 2009, dredging of the entrance channel was necessary as navigation around the island had become increasingly hazardous, limiting the USCG's Search and Rescue Operation capabilities. The Federal Channel shoaled to such a degree that upland vegetation was established.

After the 2001 project, the Florida Department of Environmental Protection (FDEP) recalled the permit that allowed subaerial beach placement of dredged sediments (the preferred method of placement at the site) due to issues associated with relatively high percentages of fines. The nearshore berm placement and location were chosen by a local coastal engineering firm and state officials to be downdrift of the local nodal point on the island, yet still far enough away from the channel to lessen the potential of shoaling by the sediment in the berm. Furthermore, the placement was permitted to be close to the shoreline so that sand would, with reasonable certainly, migrate to the shoreline and possibly nourish the beach.

Figure 4. Location of project showing water bodies and sheltering by Sanibel Island.



Project Operations

The 2009 project consisted of maintenance dredging of Cut-1 (Sta. 24+00 to 45+28.32)[note: Figure 5 shows Sta 22+00 to Sta 45+00], Cut-2A (Stations 0+00 to 2+00), and advance maintenance (an allowable increase in dredging depth) area of the Ft. Myers Beach Harbor Channel to a 12-ft required depth (Figure 5). The total quantity of material to be dredged was estimated to be 225,000 cu yd with placement in a designated nearshore area about one quarter mile east from Ft. Myers Beach Pier, between R-182 and R-187A. The dredging work included removal of roughly 1.6 acres of upland beach, which accumulated into the Federal Navigation Channel due to northerly longshore sediment transport near the tip of the barrier island. The material was cleared, grubbed, and hauled away. The dredging operation also included turbidity monitoring. The project was awarded on April 29, 2009, and commenced on May 25, 2009, and was completed on July 15. An 18-inch cutter suction dredge called *The Wilko* (Figure 6) was fixed with a booster pump and used on the lee side of the island (Figure 5). The contractor, Southwind, routed a pipeline from the dredge over the island and to the nearshore placement site.

Figure 5. Dredging location and stationing (top) for the project (from SAJ).

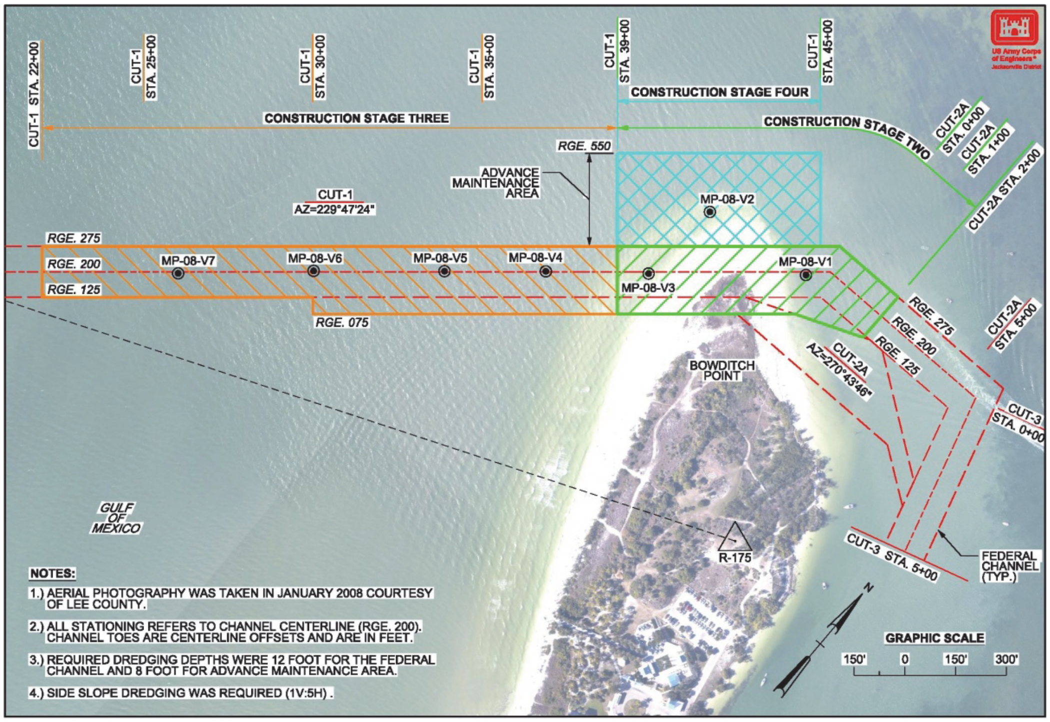
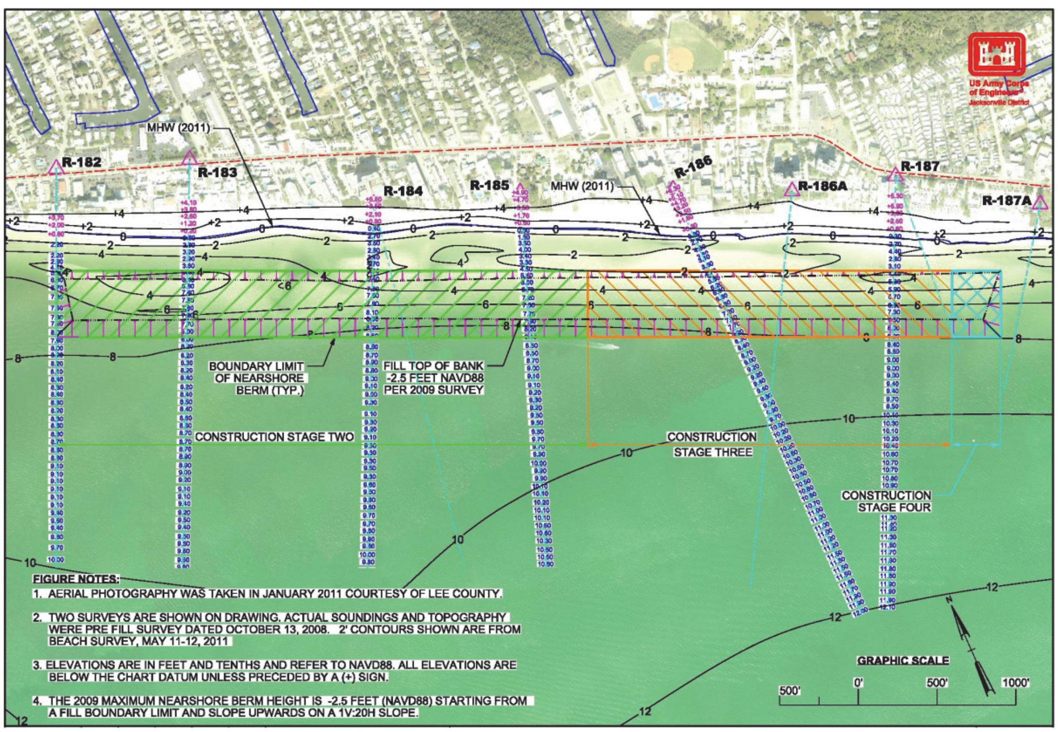


Figure 6. Contractor's dredge, *The Wilko*, an 18-in cutter suction dredge; note the fixed booster pump on the back end, which was piped to the disposal area (from SAJ).

Southwind's construction operation was broken into four stages. Stage One marked the mobilization of the dredge and supporting equipment, and clearing, grubbing and hauling of upland vegetated material and debris before dredging could commence. During Stage Two, dredging operations began at Station 2+00 (Cut-2a) and continued to Station 29+00 (Cut-1). Stage Two sediment was used to construct the northern terminus of the nearshore berm at R-182 to R-187A (Figure 7). Stage Three began after the contractor finished dredging the emergent island and began open channel dredging between Stations 39+00 and 22+00 (Figure 5). Stage Four was advanced-maintenance dredging outside the channel limits from Stations 39+00 to 45+00, where the shoal had migrated over the channel. It is worthy of note that the coarsest material was excavated during Stages Two and Four. During Stage Three, the percent of fines increased to greater than 10 percent as the dredge moved offshore in Cut-1. Stages 3 and 4 placement occurred respectively at the southeastern portions of the nearshore berm (Figure 7).

Figure 7. Placement locations by dredging stages, with R-Monument locations (from SAJ).



Dredging progressed rather quickly during Stage Two, with Stages Three and Four slow in comparison. The speed difference between the stages was attributed to a more adapted and controlled nearshore placement method. During Stage Two, the contractor's initial nearshore placement operation was a pipeline between two pontoons on a cradle, with lines to two tender vessels. The pipeline, barge and tender technique enabled the contractor to work quickly during Stage Two but created a narrower berm width with less than 50-ft fill gaps and undulating berm heights up to 1.5 ft above design elevation. Due to the shallow water on the landward side of the berm, tender vessels could only work from the seaward side; therefore, narrower fill was placed seaward of the designed berm.

Shortly after the Contractor began dredging Stage Three (June 2009), the area experienced high seas associated with a summer storm, and the dredging halted. The pause in dredging operations allowed the contractor and the Federal Government's Quality Assurance Representative (QAR) to reanalyze the quantity of placement and sediment remaining to be dredged. The analysis found that the design template was more than halfway filled; however, there was still a substantial amount of sediment left to dredge. Evaluation of construction-stage nearshore surveys indicated the berm-fill technique failed to occupy the entire designed nearshore berm width. A more effective method for hydraulically filling using a barge with a mounted excavator was developed (Figure 8). The change in offloading technique occurred at Cut-1 Station 28+50, with the fill location at the nearshore berm near R-185 (Figures 5 and 6). The revised technique created the desired nearshore berm width and uniform fill. Stage Four began when the contractor began dredging the advance maintenance area on July 5, 2009. After the contractor knocked down overfilled nearshore berm at the south end, the project was certified complete on July 16, 2009.

Controlled by the placement method and construction stages as discussed above, some gaps or depressions were left in the artificial nearshore berm. Because of the change in construction method discussed above, considerable longshore variations existed in the constructed berm.

Figure 8. A barge with a mounted excavator for disposal in shallow water (from SAJ).

4 Regional Setting

Nearshore waves in the greater study area are typically low and generated by local winds, except during extreme events such as tropical storms. Table 2 summarizes the post-construction wind conditions during the study period from May 2009 until September 2011, including only onshore directed winds. The measurement station (USF-National Oceanic and Atmospheric Administration partnership gauge BGCF1) is located in the inlet at the south end of Estero Island, (Figure 4). Onshore wind, averaging slightly above 13 ft/s, occurs 37 percent of the time. The relatively stronger winds approach from the south-southwest (176-220 degrees) and from the west (221-265 degrees). These winds are considerably oblique relative to the shoreline orientation (130-310 degree strike). The westerly wind is the most frequently occurring onshore wind. No major tropical storm occurred during the first 2 years after construction.

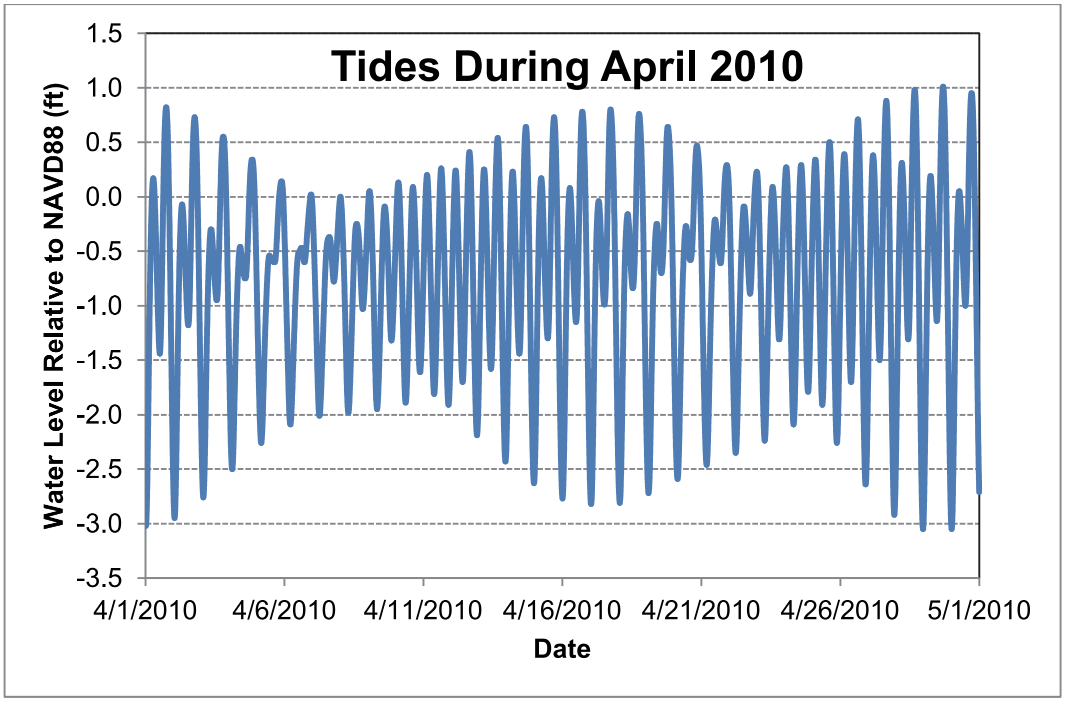
Table 2. Statistical wind conditions during the first 28 months after the berm construction*.

	Wind Direction			
	Southeast 130-175 deg.	South-Southwest 176-220 deg.	West 221-265 deg.	Northwest 266-310 deg.
Wind Speed	Percentage of Occurrence			
< 13 ft/s	58.3	38.0	46.6	61.1
13-23 ft/s	32.3	48.7	49.1	35.5
23-33 ft/s	8.7	12.8	3.9	3.4
> 33 ft/s	0.7	0.5	0.4	0.0
Avg. Speed (ft/s)	12.6	15.4	13.7	11.6
% of Total Wind	6.3	7.8	15.1	7.4

*May 2009 to September 2011 (From BGCF1).

The study area is influenced by a mixed-tide regime. Spring tides tend to be diurnal with a range of nearly 4 ft, while neap tides are semi-diurnal ranging approximately 2.0 to 2.5 ft (Figure 9). In Figure 9, the water level is referred to NAVD88 in ft. Several other water levels are used in this report for the convenience of discussion. Mean Higher High Water (MHHW), which is 0.58 ft above NAVD88, is used to separate the *dry beach* from the rest of the profile. Mean Sea Level (MSL) is 0.64 ft below NAVD88. Mean Low Water (MLW), which is used here as the seaward boundary of intertidal zone for profile-volume calculation, is 1.68 ft below NAVD88. Mean Lower Low Water (MLLW) is 2.29 ft below NAVD88.

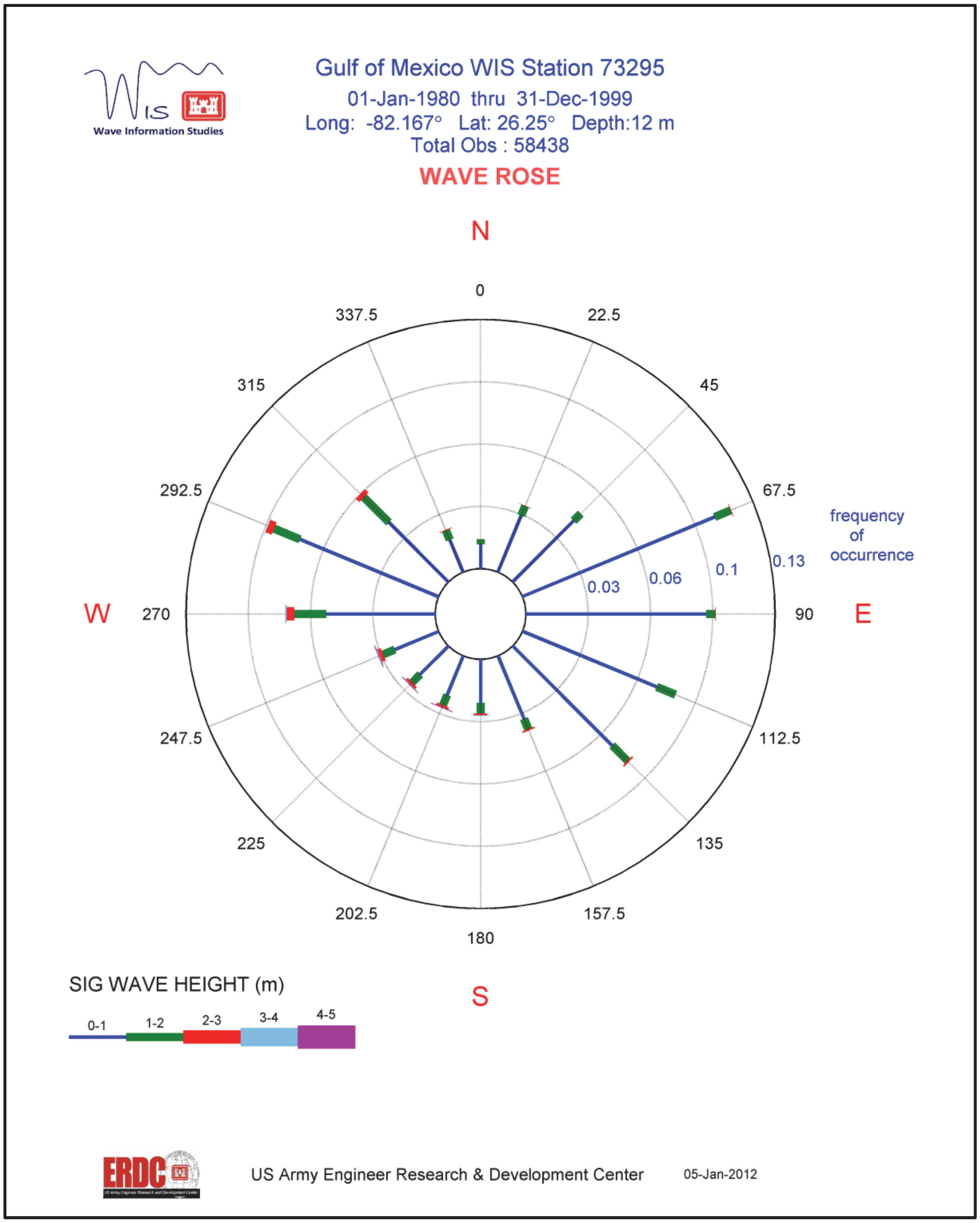
Figure 9. An example of tides measured at NOAA Naples Station (8725110), approximately 20 miles south of the study area.



The average hindcast significant wave height from 1980 to 1999 at Station 73295 was 2.2 ft (Wave Information Study (WIS) 2012). This WIS station is approximately 18 miles southwest of the study area and is used here to provide general regional scale wave conditions. It is worth noting that the offshore waves can be significantly different from the nearshore waves which relate closely to local wind conditions. Figure 10 shows the composite wave rose for the 20-year period. The incident wave angle that is relevant for the project area ranges from 130 (southeast) to 310 (northwest) degrees, i.e., onshore approaching waves. This represents approximately 40 percent occurrence which is consistent with the percent occurrence of measured onshore winds (Table 2).

The protruding Sanibel Island shelters the north-northwest and west-northwest approaching waves to a certain extent. The Sanibel Island headland is about 12 km west-northwest of the project area, and its effect on locally wind-generated waves, e.g., by summer afternoon sea breeze, are somewhat limited. Wave heights in the greater study area, as obtained from the WIS station, very rarely exceed 6 to 9 ft. It is worth noting that the average wave height of 2.2 ft was obtained from waves approaching from all directions. Given the fact that the project area is sheltered by Sanibel Island to the north and northwest in addition to only 40 percent of the waves being

Figure 10. General wave conditions computed by WIS at station 73295, approximately 18 miles southwest of the project area; note significant wave heights are in meters. WIS wave directions use meteorological convention. A direction of 0° corresponds to a wind that is blowing from True North or a wave arriving from True North.



directed onshore, wave conditions at the study area should be considerably lower than an annual average of 2.2 ft. No measured nearshore wave data are available in the study area. Various previous studies have used WIS data. Based on the above discussion, direct application of WIS wave data to the study area is difficult and can induce considerable uncertainties.

Numerical wave modeling incorporating nearshore wind conditions is necessary to obtain nearshore wave conditions. Detailed wave modeling is beyond the scope of this report and will be included in future reports.

The morphodynamics of the generally low-wave energy, west-central Florida barrier islands are strongly influenced by the frequent, approximately every 10 to 14 days, passage of winter cold fronts that occur from October to April (Wang et al. 2011a). The prolonged northerly winds associated with cold front passages tend to generate relatively high northerly approaching waves, which are responsible for the regional, net southward longshore sediment transport. The morphology of many west-central Florida tidal inlets reflects this net southward longshore transport (Beck and Wang 2009; Wang and Beck 2012). Coastal processes along the Ft. Myers Beach project area are somewhat different than at the WIS station. The protruding Sanibel Island shelters Ft. Myers Beach from northerly waves, creating a local reversal in the net longshore sediment transport along the northern tip of Estero Island. The artificial berm project is over 2 km from the inlet. Tide-driven flow in the vicinity of the inlet should not have significant influence to the beach morphodynamics.

The study area has not been directly impacted by a tropical storm in the last 7 years. Charley, a category 4 hurricane, made landfall near Cayo Costa barrier island on 13 August 2004, about 20 miles north of the study area. Based on the FDEP's post-Charley beach conditions and impact report[1], significant shoaling in the Federal Channel occurred due to the transport of sand off the northern tip of Estero Island, called Bowditch Point. Severe beach and dune erosion was sustained, generally decreasing in severity to the south, farther away from the hurricane eye.

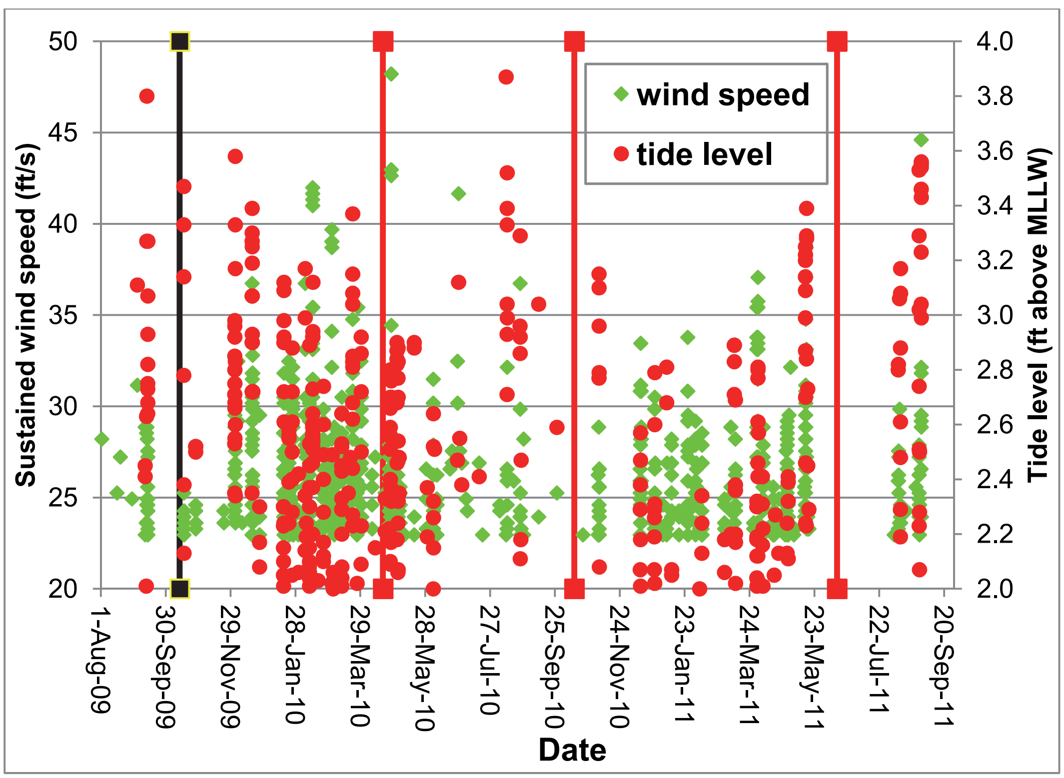
Wilma, a large category 3 hurricane, made landfall in Cape Romano on 24 October 2005, about 50 miles south of the project area. Based on the FDEP's post-Wilma beach conditions and coastal impact report[2], the damage along the Lee County coast, which includes Ft. Myers Beach, was minor. Because the project area is located north of the storm passage, the area was largely affected with offshore-directed wind forcing from Wilma.

[1] http://www.dep.state.fl.us/beaches/publications/pdf/charley.pdf

[2] http://www.dep.state.fl.us/reports/wilma/wilma.pdf

No significant tropical storms passed through the greater study area during the 28-month study period. Changes in morphology are mainly induced by relatively high-wave energy conditions associated with stronger local winds. For changes along the dry beach, the occurrence of elevated water levels coupled with high waves plays an essential role. Figure 11 compiles the events with onshore-directed wind speeds exceeding 23 ft/s with tidal water levels exceeding 2 ft above MLLW. Since MHHW is 2.87 ft above MLLW, water levels above 3 ft likely represent occurrences of surges driven by prolonged onshore winds. It is hypothesized that these are the energetic conditions that may induce substantial changes to the nearshore berm and beach. Seasonal variations during the study period can be identified from the data (Figure 11), with more energetic events occurring in the winter (defined here as mid-October through mid-April) than in the summer (mid-April to mid-October).

Figure 11. Summary of winds exceeding 20 ft/s and associated water levels from August 2010 through September 2011; the black vertical line indicates the time of post-construction survey; red lines indicate times of USF surveys.



5 Study Procedure

The morphologic changes and sediment characteristics of the Ft. Myers Beach nearshore berm during the first 26 months post construction were characterized based on time series beach profile surveys, shoreline surveys, and surface and subsurface sediment sampling. The study area was divided into three sections: the control area northwest of the berm, the berm project area, and the control area southeast of the berm. In the following, *study area* refers to the berm area and the two control areas; *project area* refers to the area where the berm was placed. This section describes the methodology applied in morphology and sediment analyses.

Monitoring of Beach and Nearshore Morphology

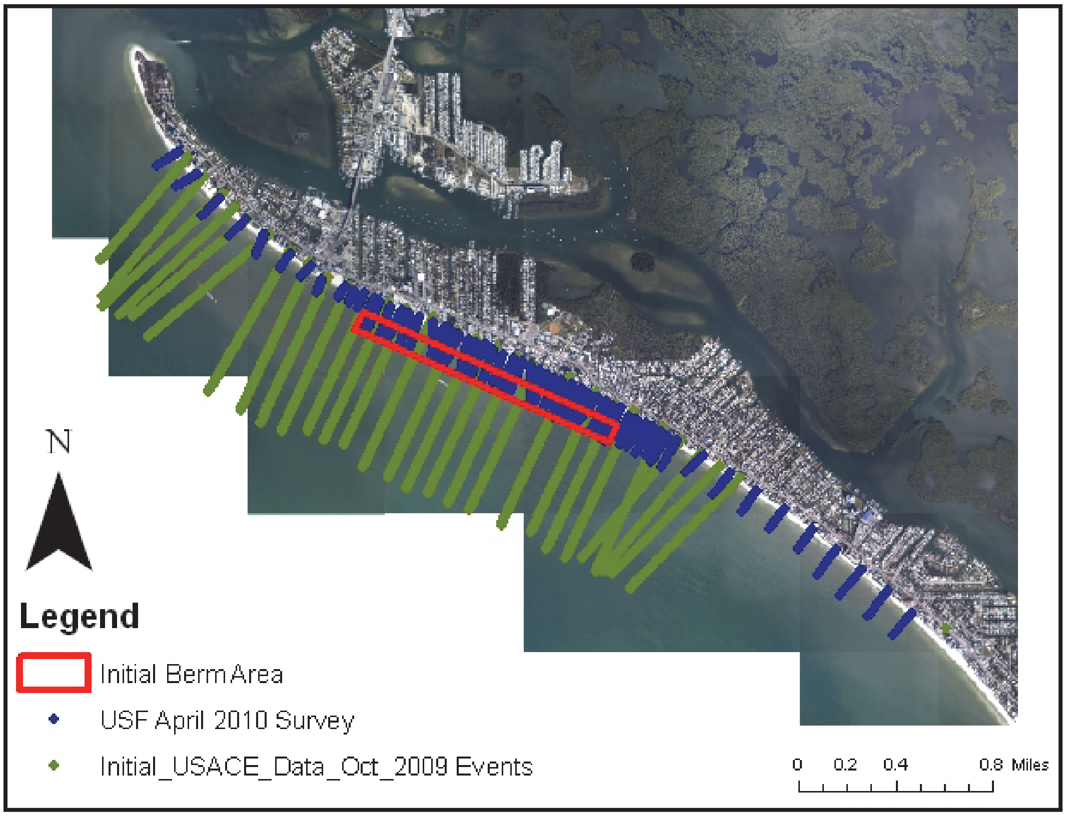
A pre-construction survey of the area was conducted by SAJ in May 2009. An initial post-construction survey was also conducted by SAJ in October 2009. Both surveys included hydrographic and beach-profile data collection. Based on surveyor reports, hydrographic survey data were collected using an Odom transducer and fathometer. Horizontal positioning was obtained using a Real-Time Kinematic Global Positioning System (RTK GPS) with real-time tide corrections. Horizontal and tide values were checked daily with a tide staff at the boat launch. Topographic surveys were completed using RTK GPS with automated data collection.

Because the post-construction survey was conducted nearly 3 months after the completion of the placement in July 2009, inspection of wind data was necessary to assess the potential of significant morphologic changes during that time. Based on the wind measurements at the BGCF1 station, these 3 months (from July 16 to October 15, 2009) were very calm with a total of only 13.5 hours when the onshore wind exceeded 23 ft/s. This compares with 152 hours during the following winter season (defined here from 15 October 2009 through 14 April 2010). The 23 ft/s, or 16 mph, wind was chosen here arbitrarily to represent strong wind conditions. Therefore, morphology changes during the 3-month period between construction completion and the post-construction survey should be small.

Beginning in April 2010, beach and nearshore profile surveys were conducted by the USF-CRL (Figure 12). Four surveys were conducted by USF-CRL in April 2010, October 2010, June 2011, and September 2011.

Including the pre- and post-construction surveys conducted by USACE, a total of six time series surveys spanning a 2-year period were used to quantify evolution of the nearshore berm.

Figure 12. Ft. Myers Beach Nearshore Berm reach (red) overlain with SAJ (green) and USF-CRL (blue) survey lines; note increased spatial resolution within the berm project area.



Both SAJ and USF-CRL profiles were numbered from the southeast end, increasing toward the northwest (Figures 12 and 13). The USF-CRL beach profiles were established by creating temporary benchmarks using RTK GPS (Figure 14). In most cases, two stakes were placed, one as the monument and one as the survey instrument location, and their coordinates recorded in order for the same line to be reoccupied and surveyed repeatedly. The temporary survey benchmarks were typically established in the stable vegetated sections of the beach or over a seawall. Survey lines in the control area were spaced in approximately 650-ft intervals, while lines over the berm and immediate adjacent areas were placed roughly 150 ft apart to allow for more dense coverage in that area. In total, 57 profiles were established and surveyed using an electronic total station and prism following standard level and transit procedures beginning at the benchmark and extending to about -8 ft NAVD88.

Figure 13. Locations of SAJ (USACE) profiles.

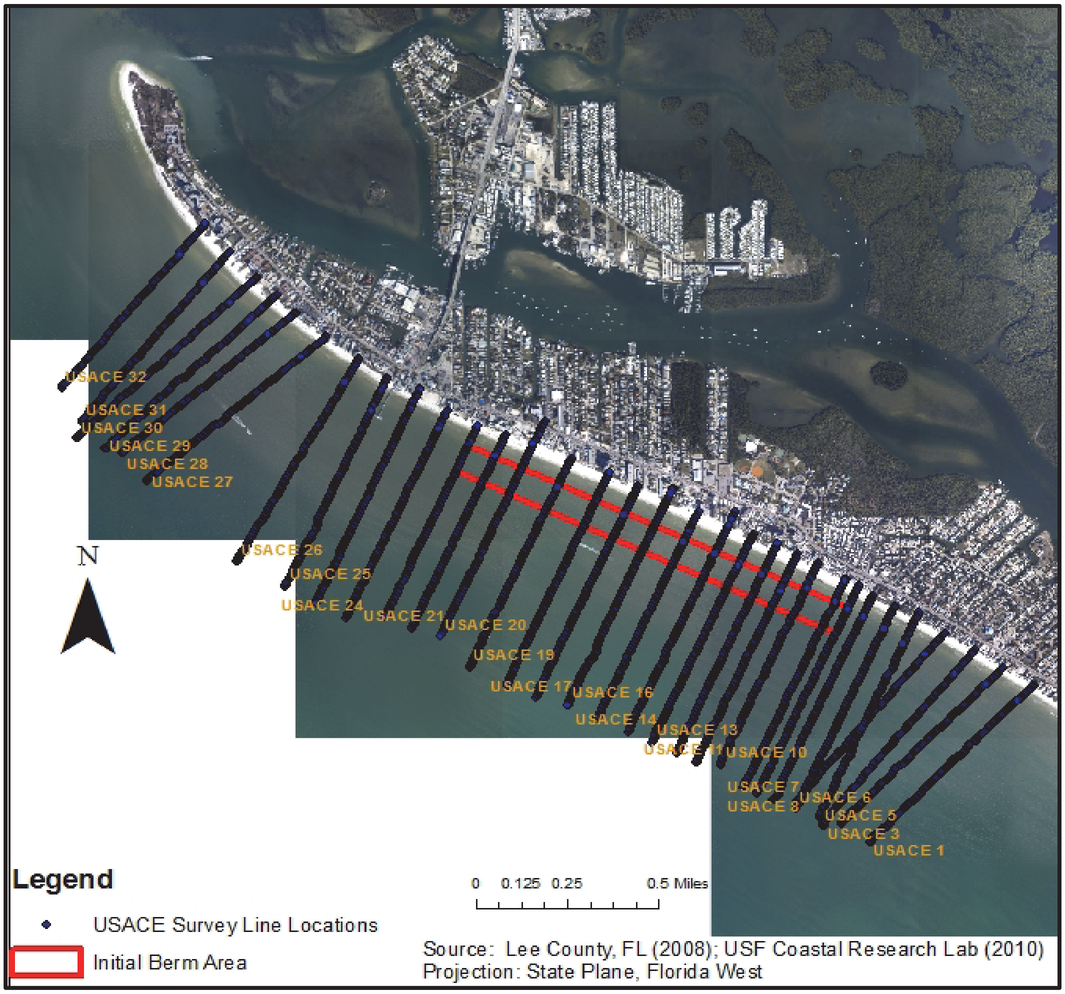


Figure 14. Establishing a temporary benchmark.

Visually estimated vegetation/toe-of-dune line, MHHW line (identified based on the debris line), berm crest, and MLLW line were surveyed using RTK GPS. A four-wheel all-terrain vehicle was used to tow a small cart carrying the RTK GPS to reduce inaccurate elevation data due to suspension on the vehicle (Figure 15). These shore-parallel survey lines extended about 1 mile northwest and southeast of the berm project area. The goal of the contour line surveys was to document shoreline curvatures, if any, that may have been associated with the nearshore berm.

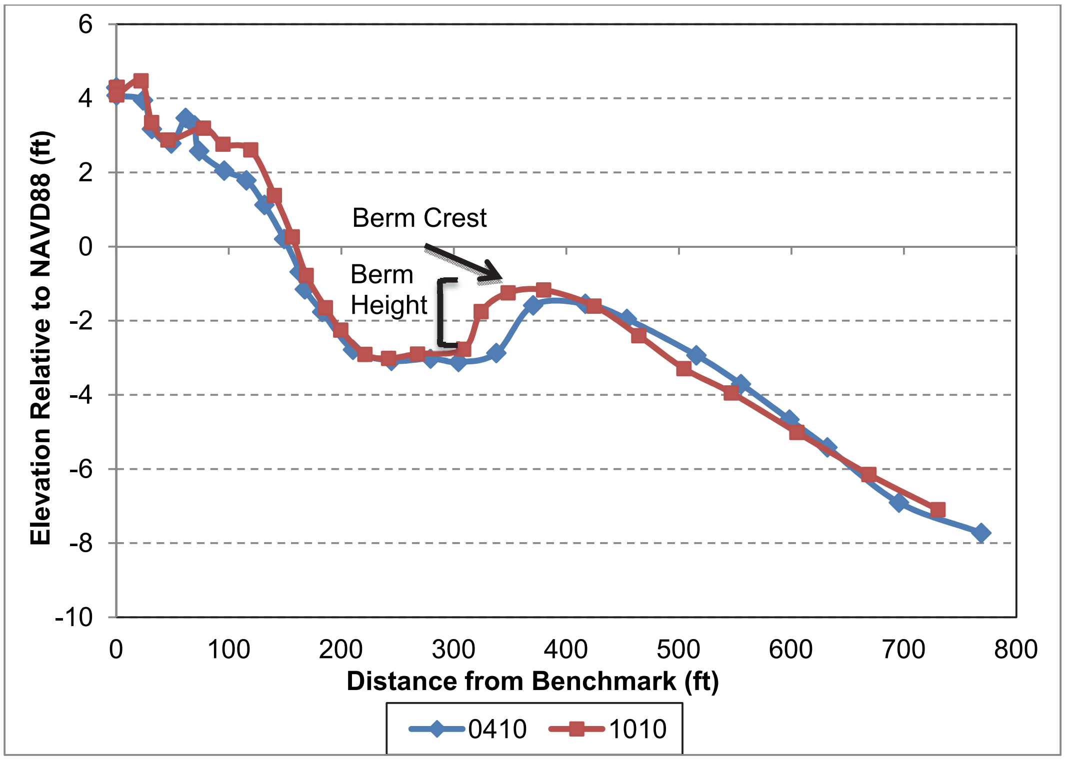
Figure 15. All-terrain vehicle and cart used to conduct contour line surveys.

Beach profile data were analyzed using the Regional Morphology and Analysis Package (RMAP) designed by the USACE, Coastal and Hydraulics Laboratory. Beach profiles were examined to find location of berm crest, elevation of berm crest, berm height, and rate and direction of bar migration. The nearshore berm crest was defined as the highest survey point on the berm. Berm height is defined as the difference between the berm crest elevation and the landward trough elevation (Figure 16). For each survey within the berm project area, rate and direction of berm migration was calculated by finding the difference between the distances from shoreline to the berm crest between subsequent surveys.

Sedimentologic Analsysis

Both surface and subsurface sediment samples were collected and analyzed. The time series surface sampling was aimed at obtaining information on selective transport of sediments, i.e., if segments of the profile were becoming finer or coarser over time. Sediment characteristics within the berm project area were also compared with those in the control areas northwest and southeast of the nearshore berm.

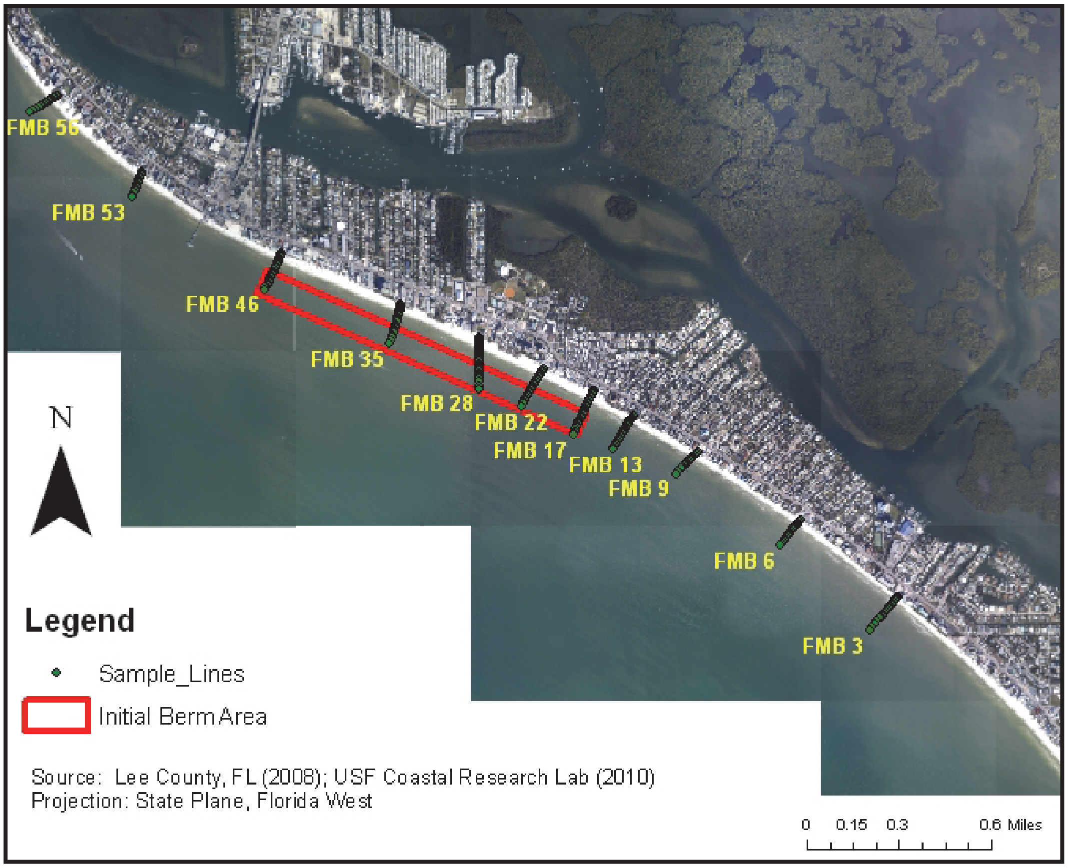
Figure 16. Time series beach profile, FMB 25, illustrating the definitions of berm crest and berm height.



One of the main goals of this study is to document the sediment properties of the artificial nearshore berm in comparison to the native sediment and the potential temporal changes in sediment grain size. Seven vibracores were extracted by SAJ in the dredged area. Two to four sediment samples were collected from each core. In addition, five surface sediment samples, including one from the dredged area and four from the target beach along Estero Island, were collected.

A large amount of surface sediment samples was collected by USF-CRL across selected beach profile transects (Figure 17) during two sampling events. The first sampling event was in April 2010, after the first winter season post-construction. The second sampling event was a year later in June 2011 to quantify temporal variation of sediment properties. Surface sediment samples were taken across 11 beach profile transects (Figure 17): 2 northwest of the berm, 5 across the berm, and 4 southeast of the berm.

Figure 17. Locations of sediment sampling transects showing USF-CRL profile ID.



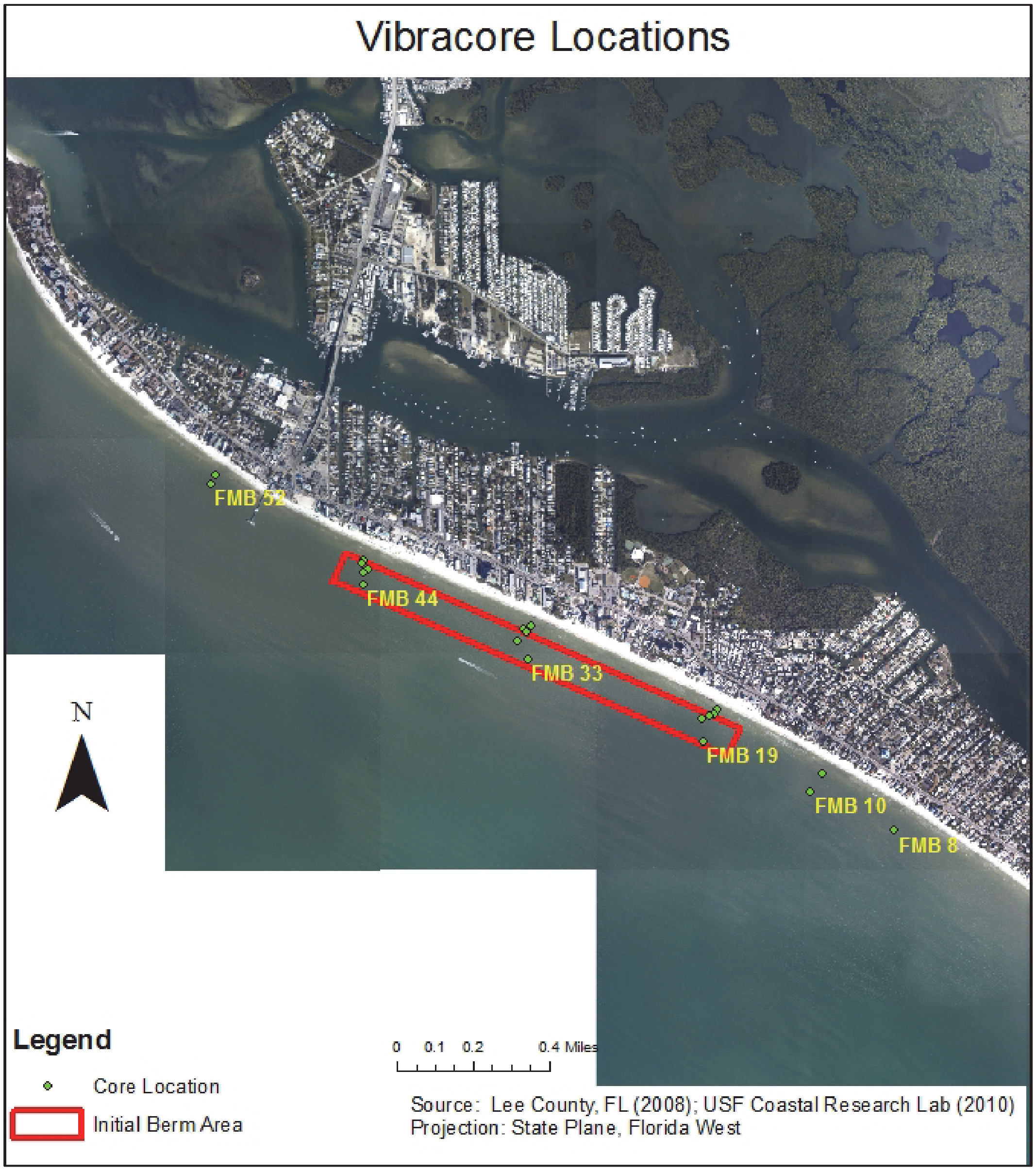
Typically, 9 samples per beach profile were collected in the control areas, and 11 samples per profile were collected in the berm area. In the control areas, surface sediment samples were taken at the toe of the dune (where present), backbeach, high tide line, mean sea level, low tide line, and then at approximately 2-ft, 4-ft, 6-ft, and 8-ft water depths. In the berm area, surface sediment samples were taken at the toe of the dune (where present), backbeach, high tide line, mean sea level, low tide line, in between the berm and the shoreline, landward toe of the berm, midway up the landward slope of the berm, top of the berm, and seaward approximately every 100 ft until about 8-ft water depth. A total of 104 samples were collected in April 2010, and 108 samples were collected in June 2011.

Sediment samples were analyzed using standard sieves. Wet sieving was conducted to separate mud-sized sediment from coarser sediment using a +4 phi (0.063 mm) sieve. In the following discussion, the term *mud* refers to the combined fractions of silt and clay. The coarser fraction was then dried and sieved using a sieve shaker. The mud fraction was dried and weighed for weight percent content; no further sediment grain size analyses were conducted for the mud fraction. Both wet and dry color descriptions were recorded using the Munsell color chart. Dry color was recorded for coarse fraction only. Grain size and sorting of each sample was calculated using the moment method (Krumbein and Sloss 1938), which yields a mean grain size and a standard deviation that relates to the sorting of the sample. The sand and gravel fractions were then mixed with hydrochloric acid to dissolve the carbonate fraction. The remainder of the sample was then dried and weighed to obtain the concentration of carbonate grains in each of the samples. The carbonate grains were mostly shell debris. Sediment analysis tables for each sample are given in Appendix A.

A total of twenty vibracores were extracted by USF-CRL along six profiles (Figure 18). Five vibracores per profile were collected within the berm project area, including one in the trough, one on the landward slope of the berm, one on the berm crest, one on the seaward slope of the berm, and one at or seaward of the toe of the berm. Typically, two cores per profile were taken in the control areas, including one in the nearshore zone and one offshore. The sediment cores are used to document the overall sediment properties of the artificial berm and to compare with native sediment in the control site.

The wet color of the sediment in the cores was described based on the Munsell color chart. Sediment layers were identified based on visually distinguishable sediment properties, such as grain size, sedimentary structures, and color. A sediment sample was collected in each layer or within 1.5-ft intervals, whichever was shorter. Sediment analyses followed the same procedure as discussed for surface sediments.

Figure 18. USF-CRL vibracore locations.



6 Beach and Nearshore Morphologic Evolution

Morphologic evolution of the artificial berm was quantified using the time series survey data. Analyses discussed in this chapter were aimed at answering the following questions:

1. Is the berm migrating onshore or offshore during the first 2 years post construction?
2. Is the shape of the berm and berm crest elevation changing?
3. Is the berm spreading alongshore?
4. Is the berm influencing the morphology of the beach landward and adjacent to the project area?
5. Is the distance of the berm to MHHW uniform alongshore?
6. Is the berm crest elevation uniform alongshore?
7. Is the berm shape uniform alongshore?
8. Are the location and elevation of the trough uniform alongshore?
9. Is the overall berm morphology evolving towards an alongshore uniformity?

The following section discusses the pre-construction morphology, berm morphology after placement, and cross-shore and longshore morphologic evolution of the artificial berm, in comparison with the control areas.

The Constructed Berm

Pre-construction Morphology

Pre-construction morphology of Ft. Myers Beach included a small natural bar that was about 1 ft high and approximately 100 to 200 ft offshore of the MHHW line (0.58 ft NAVD88). The beach width was approximately 100 to 200 ft with a gentle slope. Figure 19 shows a representative profile surveyed in May 2009, before the construction of the nearshore berm.

Profile averaging similar to that performed by Larson and Kraus (1992) was conducted. The average profiles were obtained to provide an equilibrium profile. Therefore, by comparing individual profiles with the average profile, information on berm morphology could be obtained (Larson and Kraus 1992). Spatially averaged profiles were calculated from the pre-construction surveys. The profiles were first interpolated at every 10 feet for the averaging. Figure 20 illustrates the average of all pre-construction beach and offshore profiles. The standard deviation was also calculated and used to create a profile envelope representative of each of the three sections in the study area.

Figure 19. Beach Profile USACE 3.

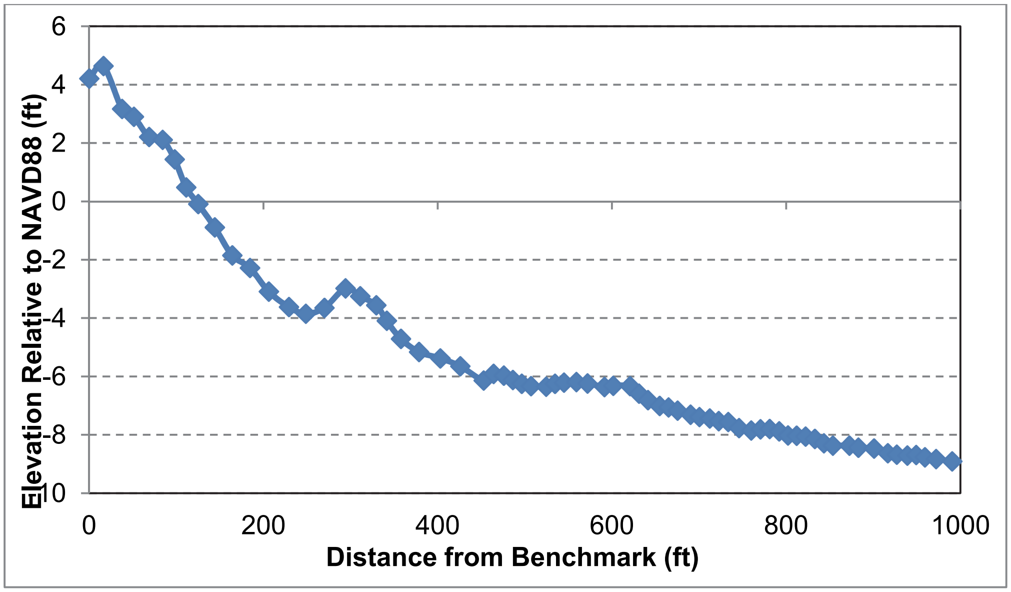
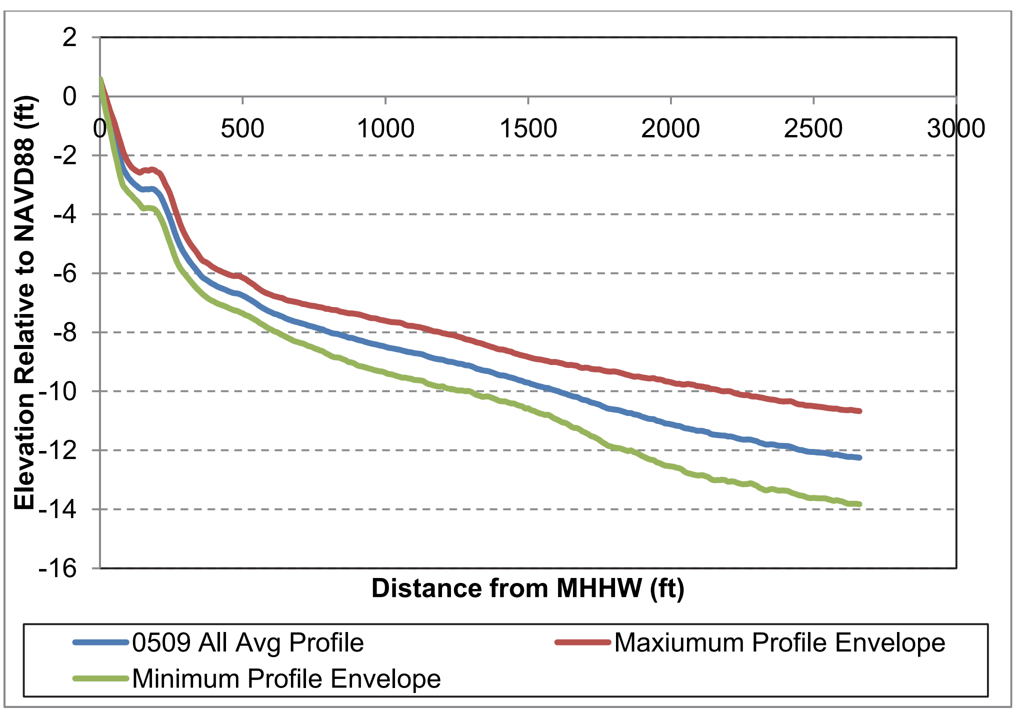


Figure 20. Spatially averaged profile from the May 2009 surveys.



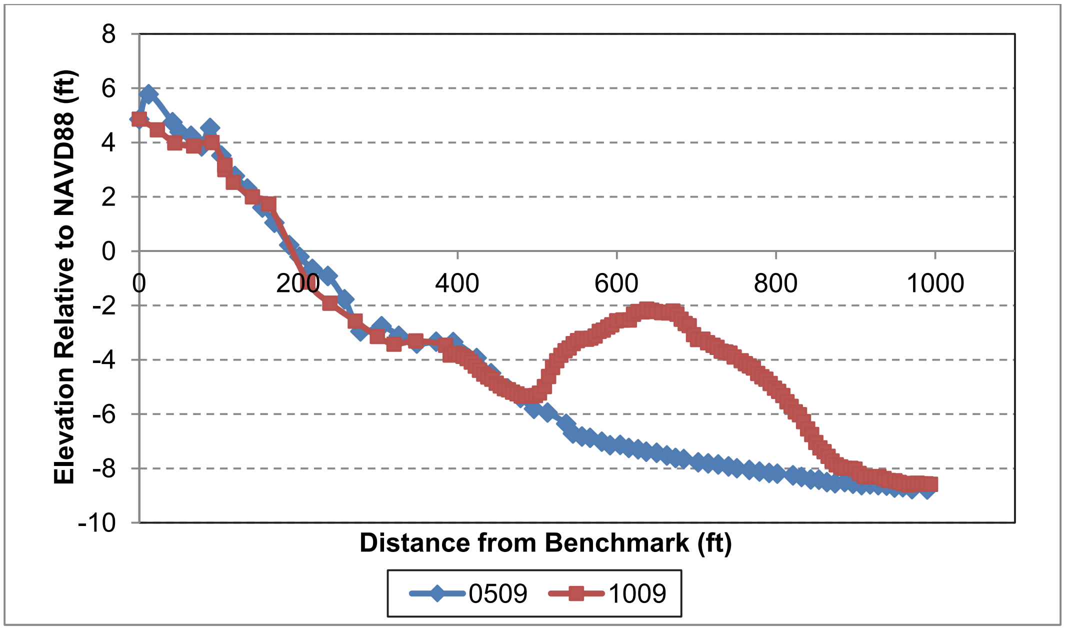
As is apparent from Figure 20, a large standard deviation about the mean occurred along the offshore portion of the profile. This is due to variations in offshore bathymetry, likely controlled by regional geology and the ebb tidal delta at Matanzas Pass (Figure 4). This contrasts the typical trend observed for profile averaging with profiles converging in the offshore region at and seaward of the depth of closure (Larson and Kraus 1992; Wang and Davis 1999; and Wang and Davis 1998). Therefore, no representative spatially averaged profile can be obtained for the entire study area. The method used by Larson and Kraus (1992) cannot be applied here.

Post-construction Berm Morphology

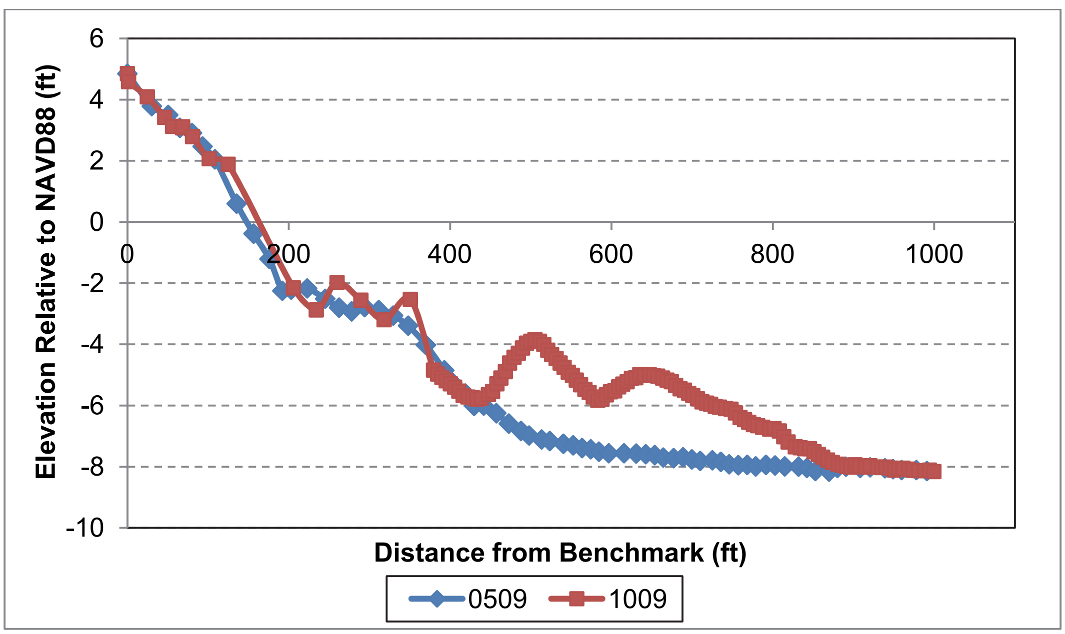
A survey was performed by SAJ nearly 3 months following the berm construction. As discussed earlier, the 3 summer months were very calm, and no significant berm changes were expected. The constructed berm morphology was highly variable alongshore due to the dredging and placing techniques, as described earlier. In addition, the variations in the dredging and placement methods created several gaps and depressions in the constructed berm. Figure 21 shows two examples of the constructed berm profile. The locations of the two profiles are shown in Figure 13. All the profiles surveyed by SAJ are plotted and listed in the Appendix B. Along line USACE 16, the berm was 3.1 ft high with crest elevation of -2.1 ft NAVD88, or slightly above MLLW at -2.29 ft NAVD88. The smooth, symmetrically constructed berm extended about 400 ft across shore measuring up to 6 ft in thickness at the berm crest. A dissimilar berm shape was constructed along profile USACE 19 where the berm was only 2 ft high with crest elevation of -3.9 ft NAVD88, almost 2 ft lower than that at USACE 16. The construction here extended nearly 500 ft across shore with a thickness of about 3 ft at the berm crest. The constructed berm had two peaks and was highly asymmetrical.

All profiles within the berm project area were interpolated and adjusted to MHHW (NAVD88 0.58 ft) and plotted together to observe longshore variations of the berm relative to MHHW (i.e., the dry beach shoreline). The longshore variability of the constructed berm is illustrated in Figure 22. All the distances are referred to the zero MHHW line. Substantial longshore variations occur in every aspect of the profile including foreshore slope, location and depth of the trough; location, height and width of the berm; and the depth and slope of the seaward flank.

Figure 21. Example profiles illustrating differences in the constructed berm.



Profile USACE 16



Profile USACE 19

Figure 22. Longshore variation of post-construction profiles within the project area, profiles surveyed in October 2009.

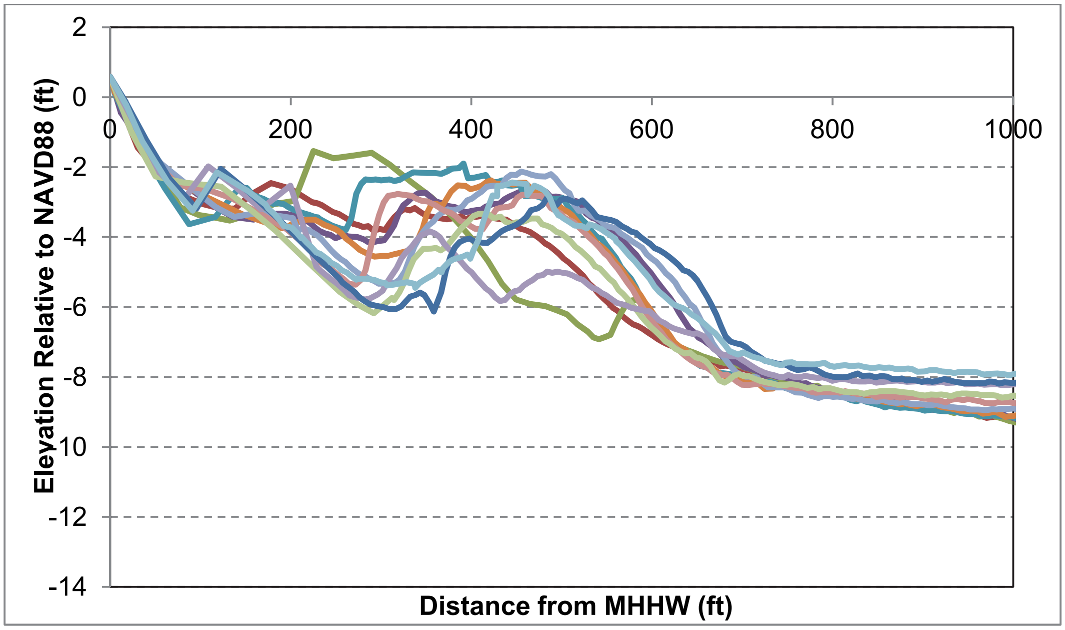


Table 3 summarizes the principal characteristics of the berm profiles obtained from the SAJ post-construction survey and emphasizes the longshore variability. Distance from the MHHW line to the berm crest varied between 280 ft to 480 ft. The height of the berm (defined here as the difference between crest and trough as illustrated in Figure 16) ranged from 0.6 ft to 3.1 ft. The elevation of the berm crest varied from -1.6 ft to -3.9 ft NAVD88. Width of the berm ranged from 270 ft to 440 ft. This great longshore variation in the constructed berm had significant influence on its evolution, as discussed in the following.

Initial volume of the berm was calculated based on the pre-construction survey data from May 2009 and the post-construction data from October 2009. The results were compared with the recorded volume from the dredging operation. The nearshore berm total volume placed was defined as the volume in the post-construction profile above the pre-construction profile, from the deepest trough point to the short-term depth of closure (DOC). The short-term DOC is defined here as the converging point of the time series beach-nearshore profiles.

As recorded in the dredging operation, initial volume of the constructed berm was 229,313 cu yd. Based on the pre-and post-construction profiles, a berm volume of 211,900 cu yd was obtained. This is within 10 percent of the volume reported during construction and may be accounted for by loss

Table 3. Initial Berm Characteristics.

Profile Line	Distance from MHHW to Berm Crest (ft)	Berm Height (ft)	Berm Elevation (NAVD88) (ft)	Berm Width (ft)
USACE 9	328	0.6	-3.2	407
USACE 10	224	1.9	-1.6	436
USACE 12	344	1.4	-2.7	391
USACE 14	283	1.4	-2.4	426
USACE 15	387	2.0	-2.5	338
USACE 16	452	3.1	-2.2	332
USACE 17	315	2.5	-2.8	384
USACE 18	406	2.9	-3.3	274
USACE 19	354	1.9	-3.9	384
USACE 20	481	3.1	-2.9	326
USACE 21	442	3.0	-2.4	293
Average	365 ± 74	2.2 ± 0.8	-2.7 ± 0.6	362 ± 51

of sediment through the dredging and placement operation, as well as potential uncertainties associated with the 3 months between construction and the post-construction survey. It may also be that alongshore coverage of the pre- and post-construction survey data had insufficient resolution to capture the exact lateral ends of the berm, which could account for this small difference. The length of the artificial berm project was calculated from the survey data to be 5,370 ft.

Berm Evolution during the First 2 Years

Most of the existing studies regarding nearshore berms have found that relatively rapid morphology changes occur shortly after placement and, in some cases, just weeks after the construction. Onshore migration was measured for almost all the active berms. Compared to the existing berms (Table 1), the Ft. Myers Beach nearshore berm is the shallowest placement by a large margin. The only exception is the Newport nearshore berm in California, which had a large depth range of placement of 5 to 30 ft. The Ft. Myers Beach berm was constructed mostly in the form of a nearshore bar placed almost entirely in the littoral zone. Findings on performance of this berm should add to the present knowledge on nearhsore berms. Given the Ft. Myers Beach berm's nearshore location as compared to nearly all the previous placements, it provides an excellent opportunity to examine the specific hydrodynamic conditions, morphology form, and temporal-spatial scales of beach nourishment by a nearshore berm.

In the following section, the first 2 years of morphologic evolution of the berm, in comparison to the control sites to the southeast and northwest of the project area, are discussed based on the six semi-annual surveys conducted by USF-CRL and SAJ.

Control Area to the Southeast

The surveyed control area to the southeast extends approximately 1.5 miles southeast of the berm project area. A total of 16 profiles were surveyed. The southeastern-most 10 profiles were spaced 650 ft apart. The 6 profiles that are directly adjacent to the berm project area were spaced 150 ft apart. Figure 23 illustrates a typical beach and nearshore profile in the distal southeast control site, approximately 1.2 miles from the berm. All the surveyed profiles are plotted in Appendix C. Overall, the beach remained stable over the 2-year period. A nearshore bar about 2 ft high developed between June and September 2011, likely resulting from a summer storm (not related to any large scale tropical system) in August 2011 (Figure 24). A large amount of debris was washed onto the beach by that storm (Figure 25), but the wave runup did not reach the vegetation line at this location. The natural small bar became more distinctive and moved offshore for nearly 100 ft.

Figure 23. Profile FMB 3 southeast of the nearshore berm project area.

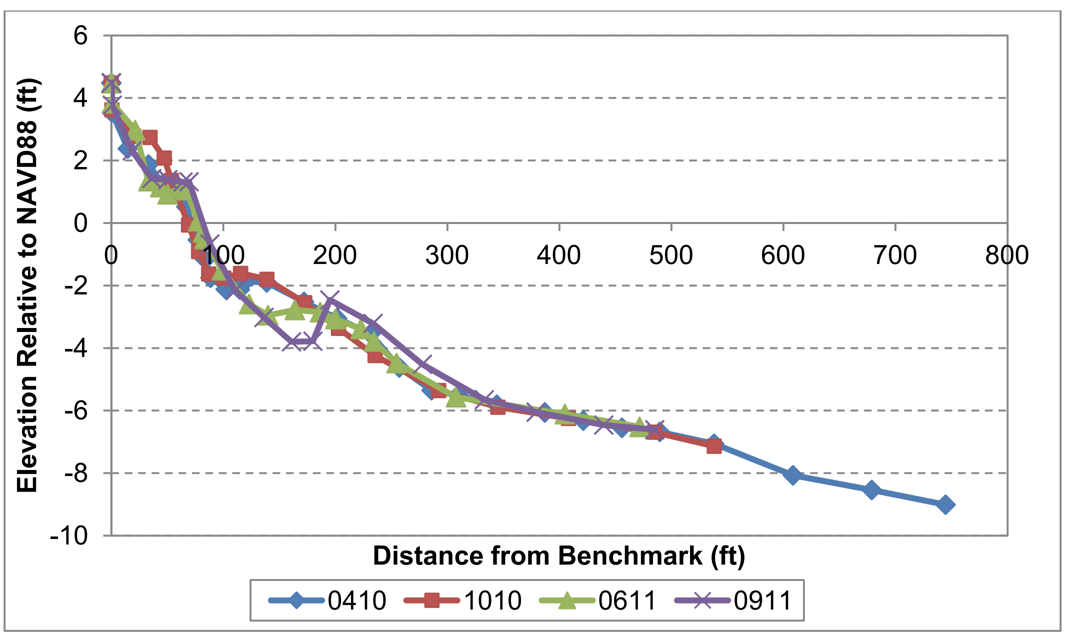


Figure 24. A summer storm in 2011 representing a top 5 percent energetic condition (Table 2) during the 2-year study period.

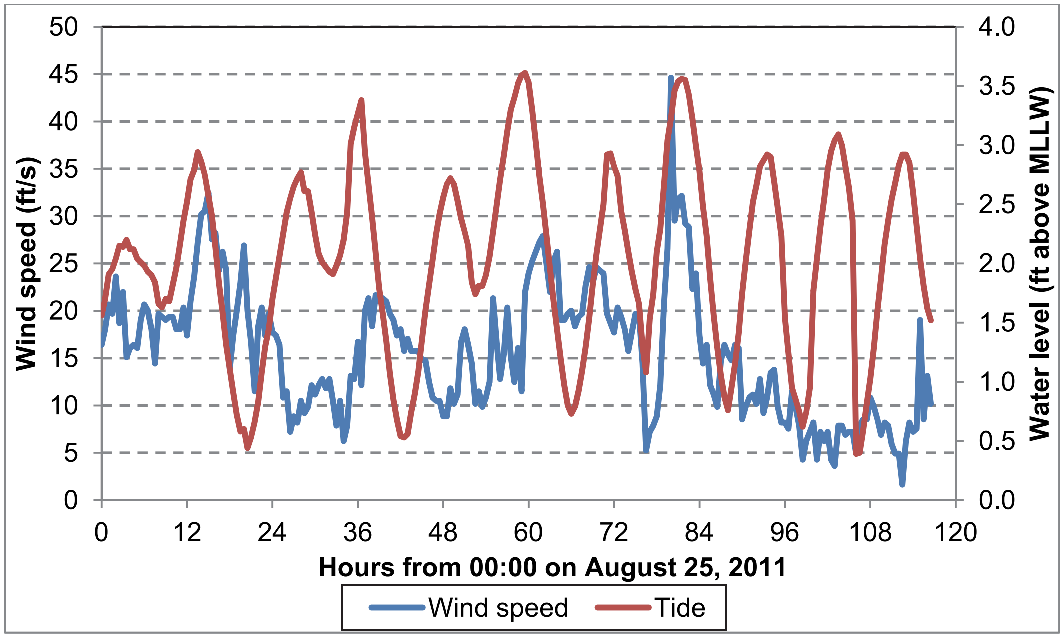


Figure 25. Photo of Ft. Myers Beach taken on September 20, 2011, showing debris that was washed onto the beach by a storm at the end of August.

Figure 26 illustrates the beach-nearshore profiles directly adjacent to the southeast end of the berm project. The evolution of this profile, which is similar to evolution of FMB 14, 15, and 16, is considerably different from profile FMB 3 (Figure 23). A small nearshore bar existed on the profiles surveyed in April and October of 2010 but disappeared in the June 2011 profile. Also, no bar developed on this profile between June 2011 and September 2011. Farther to the southeast, the nearshore bar exists along profiles FMB 1 through FMB 13 (Figure 27) but is absent on profiles FMB 14, 15, and 16 in 2011. It is not clear if, how, or why the nearshore berm would influence the bar development along the directly adjacent beaches.

Overall, the dry beach and intertidal zone extending from the vegetation line to MLW line (-1.68 ft NAVD88) southeast of the nearshore berm remained relatively stable over the 2-year study period. No apparent trend of change can be identified. There is a small and dynamic bar within the control area to the southeast, which existed before the construction of the artificial berm (Figure 19). The bar becomes more and less distinctive, and migrates onshore and offshore corresponding to incident wave conditions. The exact hydrodynamic conditions that correspond to the presence and absence and migration of the bar are not clear, although the independent nature of the bar dynamics from that of the artificial berm was notable. The bar disappeared during the second year after the berm construction within 650 ft from the project (Figure 26). No significant shoreline and profile-volume gains were measured along the control area profile directly adjacent to the berm project (Figure 26).

Figure 26. Profile FMB 15 directly adjacent to the berm project, showing the bar that existed in April and October 2010 disappeared in June and September 2011.

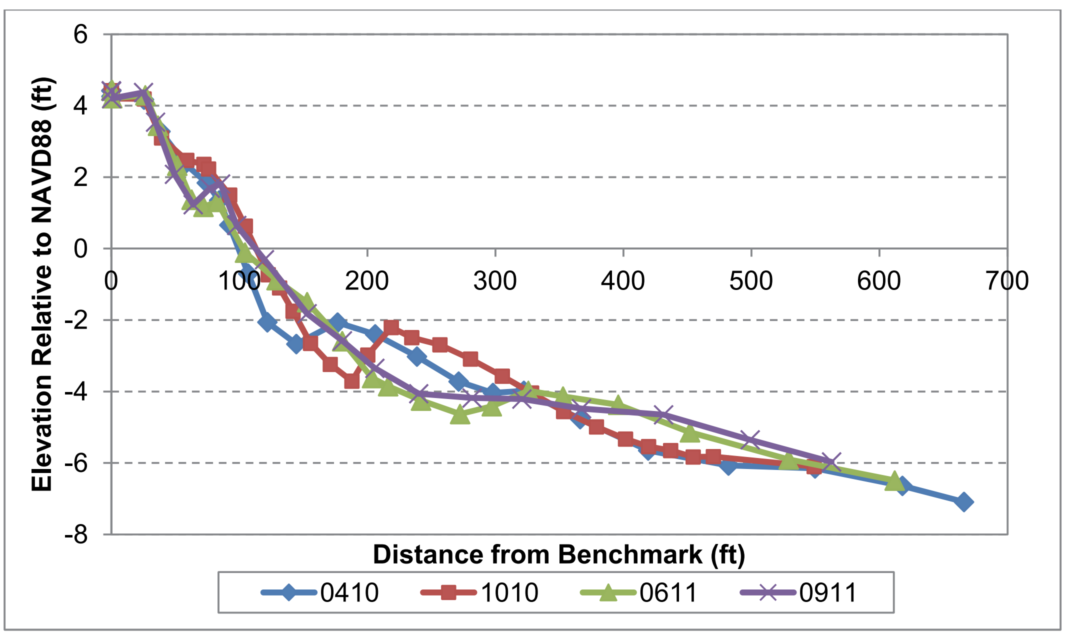
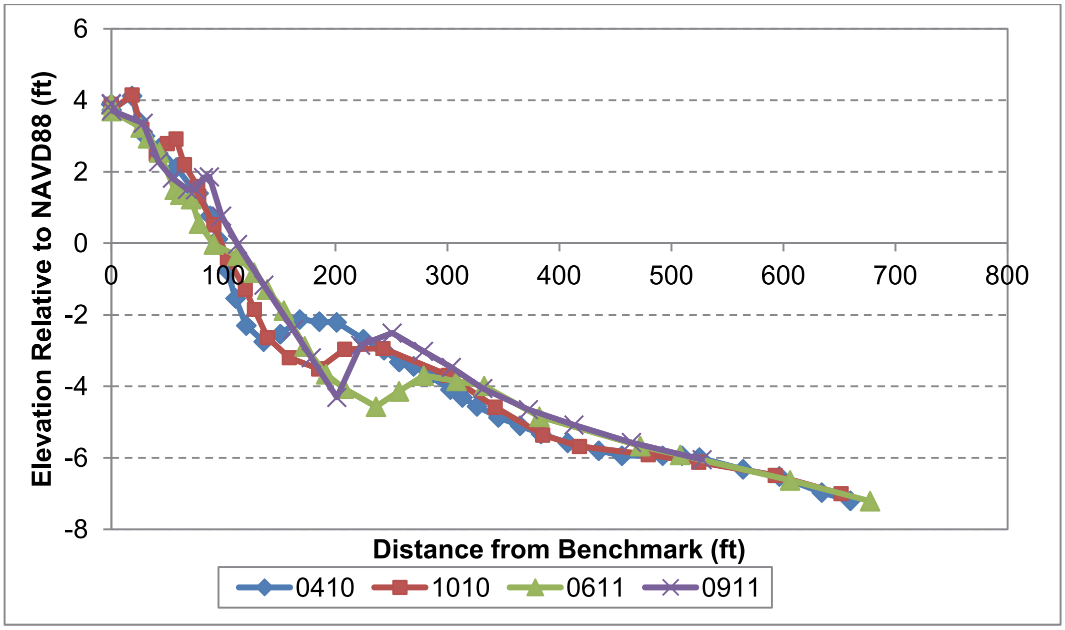


Figure 27. Profile FMB 13 approximately 600 ft from the berm.

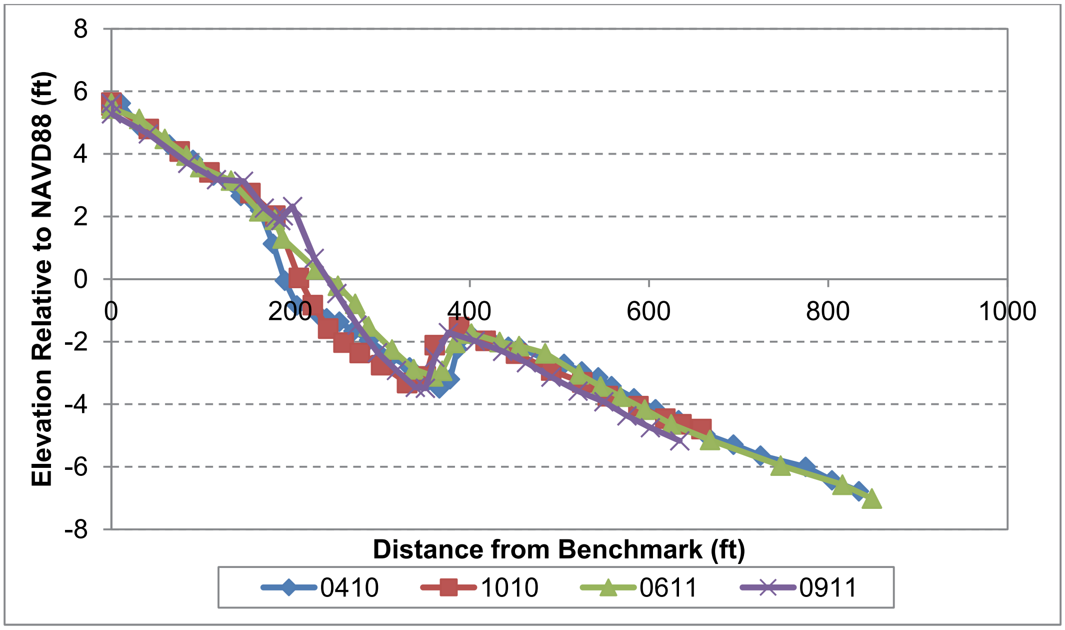


The Artificial Nearshore Berm

Considerable longshore morphologic variations exist along the nearshore berm (Figure 22), originating from the construction. In the following, example profiles from three sections, southeast (Construction Stages Three and Four), middle, and northwest (Construction Stage Two) are first described, followed by a separate discussion on longshore variation.

Profile FMB 17 is located at the very southern end and the tapering zone of the berm project (Figure 28), constructed during Stage Four. This profile, and the adjacent FMB 18 (Appendix C), behave differently from the rest of the berm profiles and the control profiles as discussed above. A small and rather stable bar exists on this profile. Sand accumulation occurred between +2 ft and -2 ft NAVD88. This is likely related to impoundment of longshore moving sand by the nearshore berm, which acts like a submerged breakwater. The volume of sand accumulated at the end of the berm is small, probably related to a small gross longshore transport rate. The remainder of the profile has been stable over the 2-year period. Overall, no significant beach profile changes were measured at the southeast end of the project during the first 2 years. This, combined with the rather stable beach-nearshore profiles in the southeast control site suggests that the artificial berm had little morphologic impact to the southeast beach over the 2-year period.

Figure 28. Profile FMB 17 at the tapering zone of the berm.



Profiles FMB 19 and FMB 20 represent typical behavior of the profiles at the southeastern section of the berm project, constructed during Stage Three. The constructed berm is illustrated by profile USACE 10 (Figure 29). Although the USF-CRL FMB profiles and the USACE profiles do not overlap exactly, they are within 200 ft of each other. The artificial berm constructed in this section of the beach is closer to the shoreline as compared to the rest of the berm, with a wider berm crest. The constructed berm crest was also shallower than -2 ft NAVD88, as compared to the rest of the berm, mostly deeper than -2 ft NAVD88. It is worth noting that the MLLW is at -2.29 ft NAVD88. Therefore, the constructed berm crest would become exposed during MLLW.

By comparing profiles USACE 10 (Figure 29), FMB 19 (Figure 30) and FMB 20 (Figure 31), the nearshore berm had migrated onshore 100-150 ft during the first 6 winter months, a rate of 200-300 ft/yr. The onshore migration slowed subsequently from April 2010 to October 2010 during the first summer season. Two subtle bars of about 1 ft in vertical relief were measured on FMB 20. The 2-bar morphology may be related to an oblique gap within the berm. One profile over, at FMB 19, the berm appeared to have welded to the shoreline after June 2011, eliminating the bar morphology. By June 2011, the bar at FMB 20 also disappeared, though it did not directly weld to the shoreline as indicated by the net volume loss measured across the entire profile. Overall, the dry beach above MHHW along this reach remained stable over the 2-year period. The welding of the berm at

FMB 19 (Figure 30) occurred mostly in the intertidal zone, resulting in a shallow, wider intertidal zone with a gentle slope. The beach above MSL did not receive any additional sand.

Figure 29. Profile USACE 10 showing constructed berm.

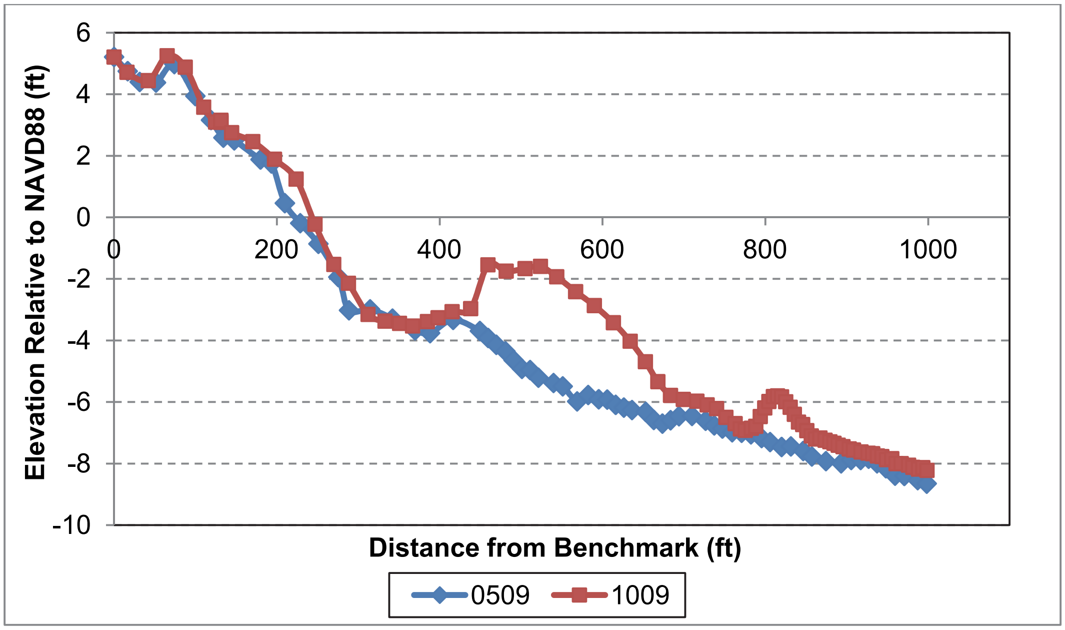


Figure 30. Profile FMB 19 at the southeastern section of the berm project.

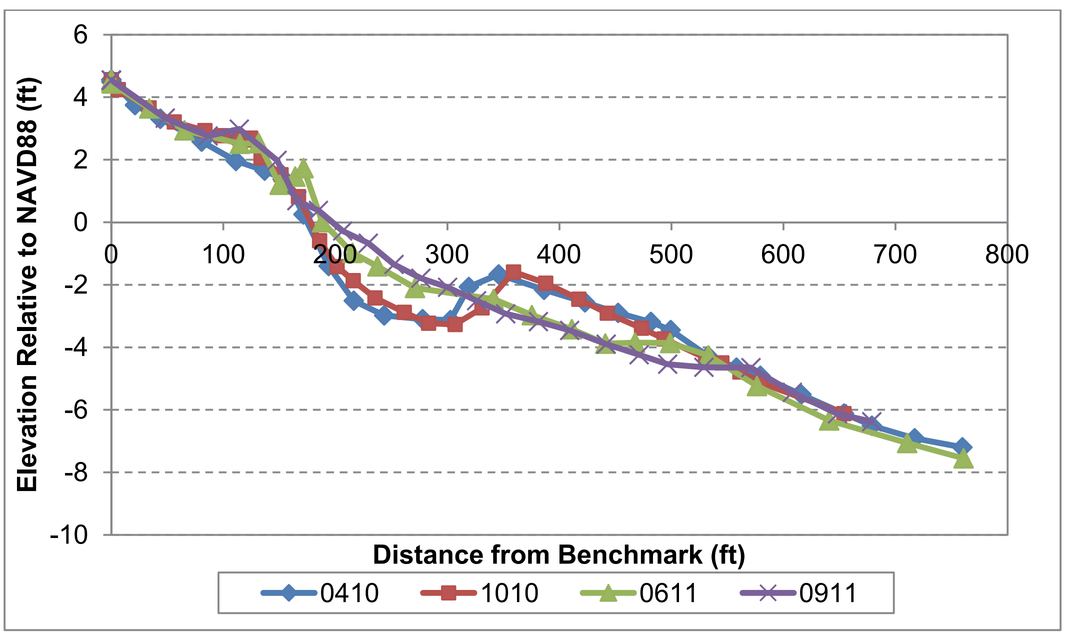
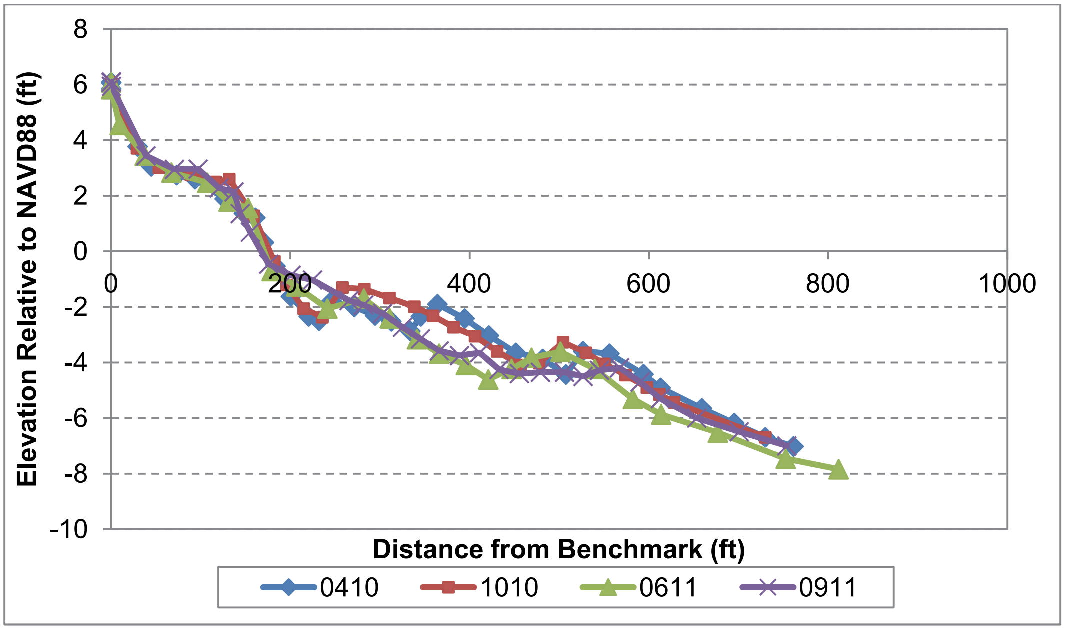


Figure 31. Profile FMB 20 at the southeastern section of the berm project.



Profiles FMB 30 and FMB 32 represent the typical behavior of the profiles in the middle section of the berm project, constructed during Stage Three. These two profiles overlap closely with the USACE profiles (Figures 32 and 33). The nearshore berm migrated about 200 ft onshore during the first 6 winter months, about 400 ft/yr. The onshore migration rate slowed to 60 ft/yr during the summer from April and October 2010, migrating onshore for about 30 ft. Substantial onshore migration occurred again during the winter of 2010-2011, especially at profile FMB 32, where the bar migrated roughly 100 ft onshore, about 200 ft/yr. The elevation of the berm crest increased as it migrated onshore. At FMB 30, the berm-crest elevation increased by nearly 2 ft. The constructed berm crest was just below -2 ft NAVD88, or near MLLW. After 2 years, the berm crest was located between -1 and -2 ft NAVD88, or just below MSL.

In addition to the onshore migration, the shape of the berm in the middle section changed from a rather symmetrical constructed berm to an asymmetrical berm with a steep landward slope. The steep landward slope is characteristic of onshore-migrating bar morphology (Larson and Kraus 1994; Roberts and Wang 2012). Despite the dynamic behavior of the bar, the beach from the vegetation line to the bottom of the trough remained stable over the entire study period, similar to that of the profiles in the southeastern section.

Figure 32. Profile FMB 30 in the middle section of the berm project, showing substantial onshore and upward migration of the berm.

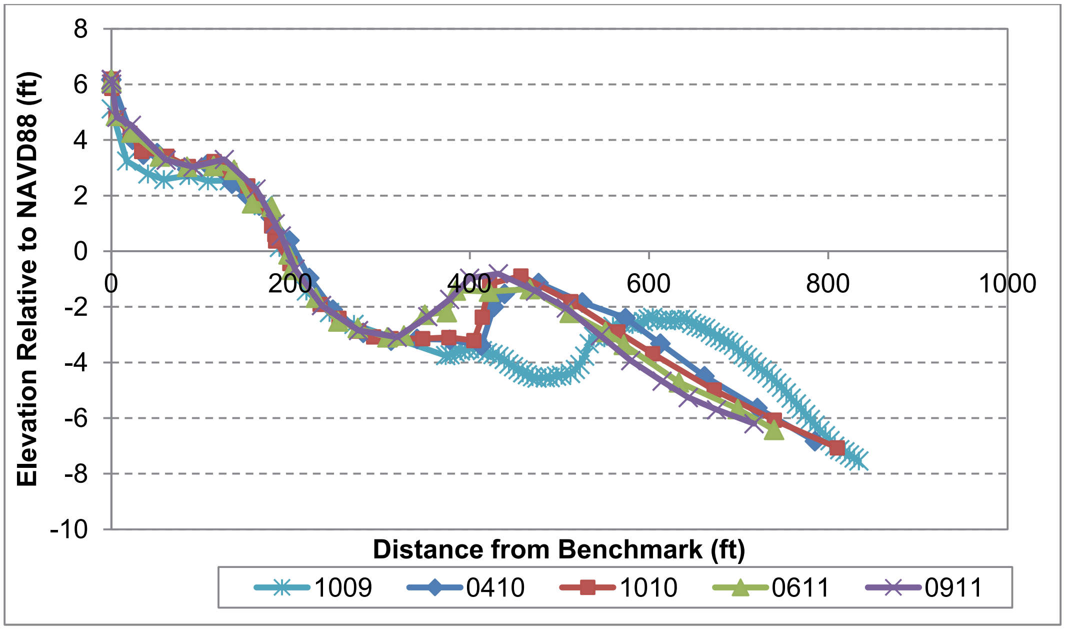
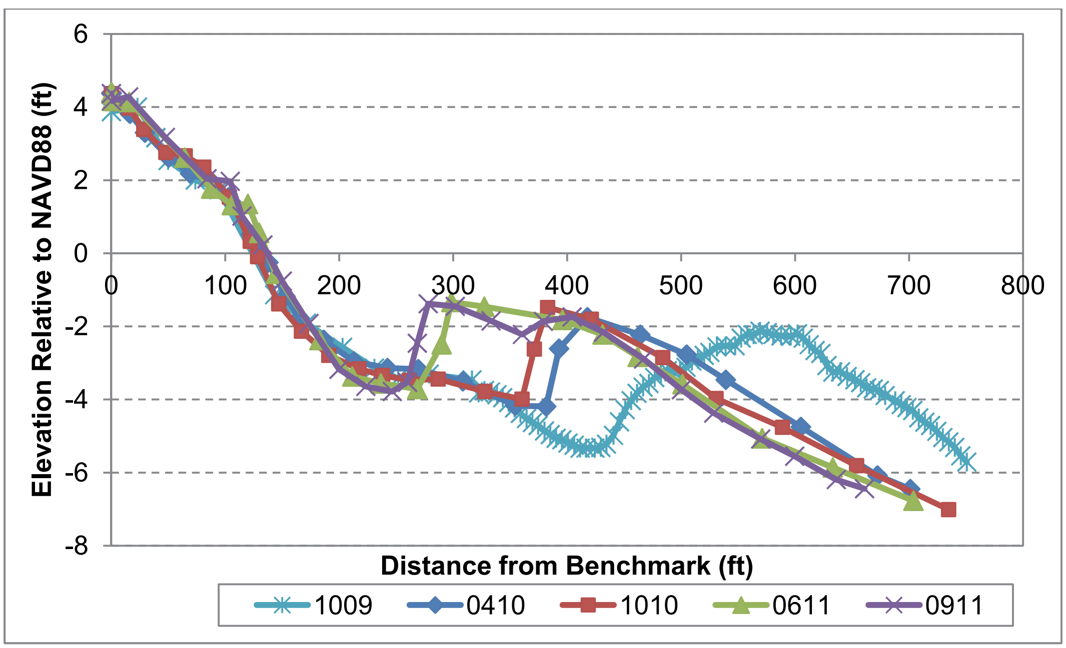


Figure 33. Profile FMB 32 in the middle section of the berm project, showing substantial onshore and upward migration of the berm.



Profiles FMB 43 and FMB 44 represent typical behavior of the profiles at the northwestern section of the berm project. The constructed berm is illustrated by profile USACE 21 (Figure 34). Although the USF-CRL FMB profiles and the USACE profiles do not overlap exactly, here they are within 200 ft of each other. The artificial nearshore berm constructed in this section is relatively narrow as compared to the rest of the berm project, controlled by the construction method discussed earlier (Stage Two construction, Figure 7). A comparison of profiles USACE 21 (Figure 34) and FMB 43 and FMB 44 (Figure 35 and Appendix C) found that the nearshore berm migrated onshore approximately 100-150 ft during the first six winter months, about 200 to 300 ft/yr, and slowed to 60 ft/yr during the summer months from April to October 2010. Substantial onshore migration occurred again during the winter of 2010-2011 and was especially significant at profile FMB 44 (Appendix C) where the bar migrated nearly 100 ft onshore, similar to the trend in the middle section of the berm. In addition to onshore migration, the shape of the berm changed from symmetrical to asymmetrical with a steep landward slope, similar to the middle portion. The dynamic bar behavior is not translated to the shoreline or dry beach, which remained remarkably stable over the entire study period.

Control Area to the Northwest

The survey control area to the northwest extends approximately 1 mile from the berm project area. A total of 10 profiles were surveyed, and the northwestern-most 6 profiles were each spaced 650 ft apart. The 4 profiles that are directly adjacent to the berm project area are spaced at 150-ft intervals. Figure 36 illustrates a typical beach and nearshore profile in the distal northwest control site, roughly 0.9 miles from the berm. Some small winter-summer seasonal fluctuations in morphology were measured, but overall, the beach remained stable over the 2-year period. As compared to most of the profiles discussed previously, a much less pronounced and stable bar was measured.

Figure 34. Profile USACE 21 in the northwestern section of the berm project.

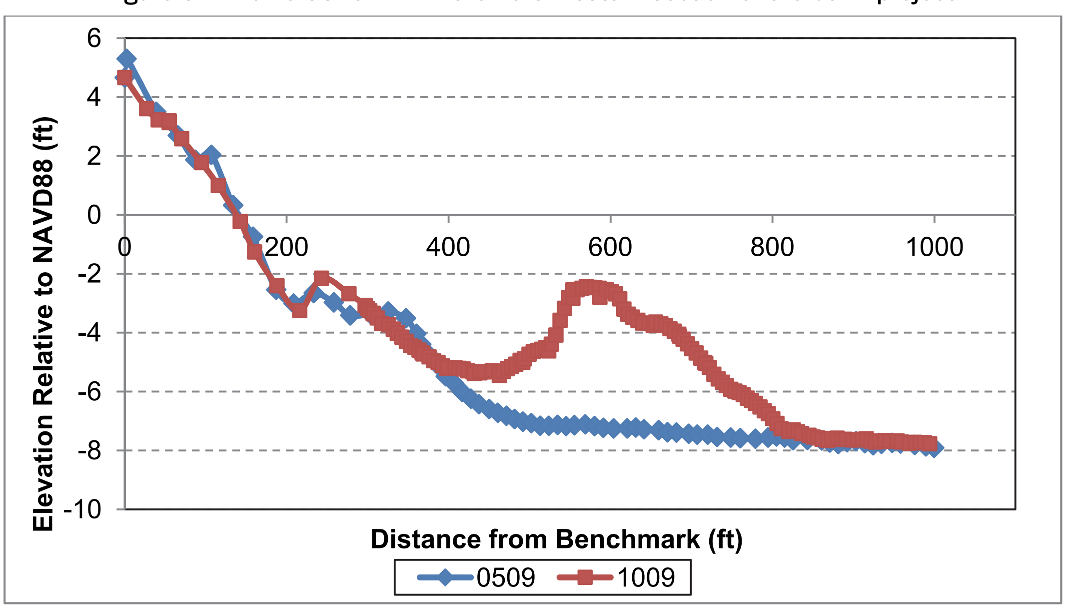


Figure 35. Profile FMB 43 in the northwestern section of the berm project.

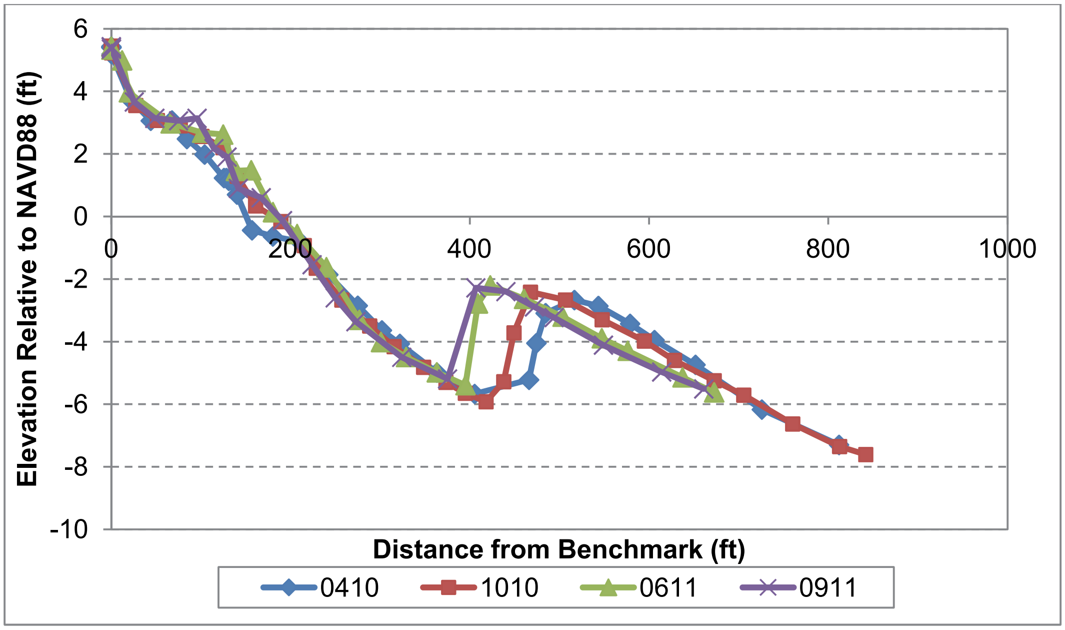
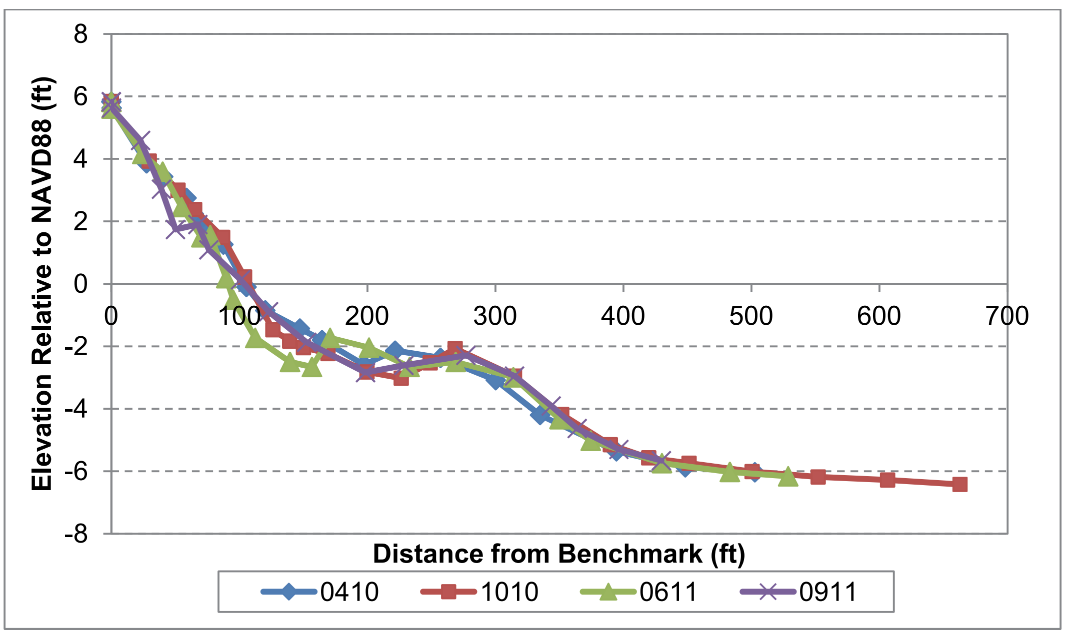


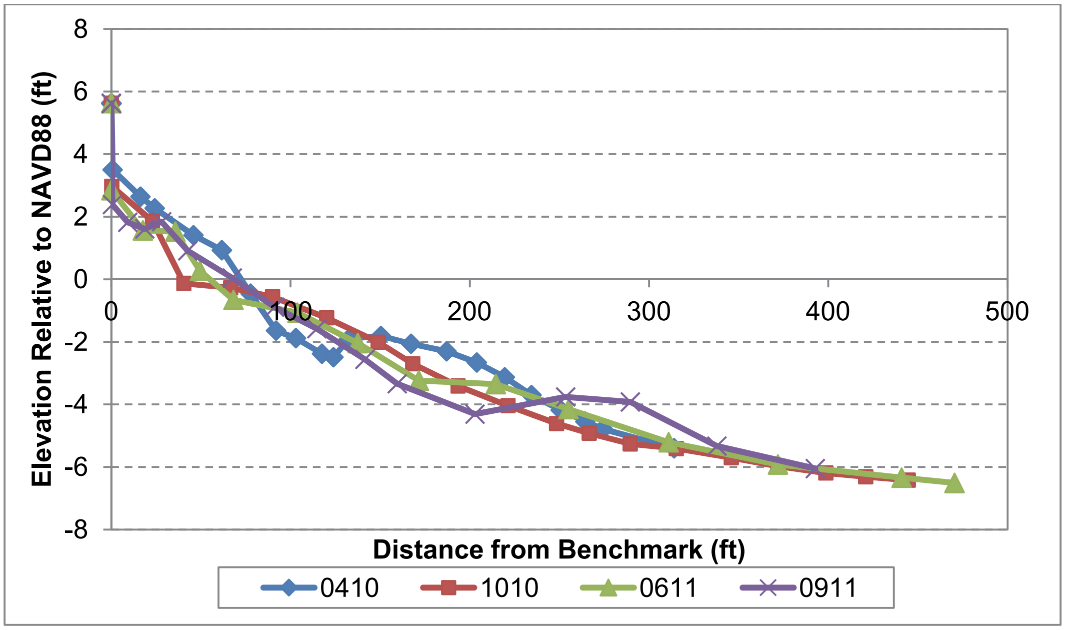
Figure 36. Profile FMB 54 in the control area to the northwest.



Profile FMB 48 (Figure 37) is directly to the northwest of the berm. The profile has an ephemeral subtle bar. This subtle bar feature may relate to the influence of a nearby fishing pier. Similar morphology of a flat platform (subtle bar) associated with porous piers is also observed along west-central Florida barrier-island beaches (Roberts and Wang 2012). The dry beach in the control area directly northwest of the berm showed considerable variations during the study period. Shoreline retreat of 20 ft occurred from

April 2010 to October 2010 at this location (Figure 37), since then the beach has been recovering. Overall, the magnitudes of beach width changes, erosion, and accretion were less than 20 ft over the 2-year period.

Figure 37. Profile FMB 48 in the control area to the northwest.



Overall, the nearshore berm migrated substantially onshore and vertically upward with a large portion of the berm becoming intertidal. Therefore, it has considerable influence on wave propagation and breaking patterns, as observed during field data collection. However, the berm did not have major influence along adjacent beaches in terms of salient and tomobolo developments. This may relate to the fact that, compared to traditional hard breakwaters, the berm is mobile with gradual slopes at the ends and resemble a natural bar; therefore, its influences on morphology of the adjacent beaches may be different from a typical breakwater. At the southern end of the project, small corresponding volumetric and morphologic change suggest an overall low, gross longshore sediment transport rate, due to the low-wave energy.

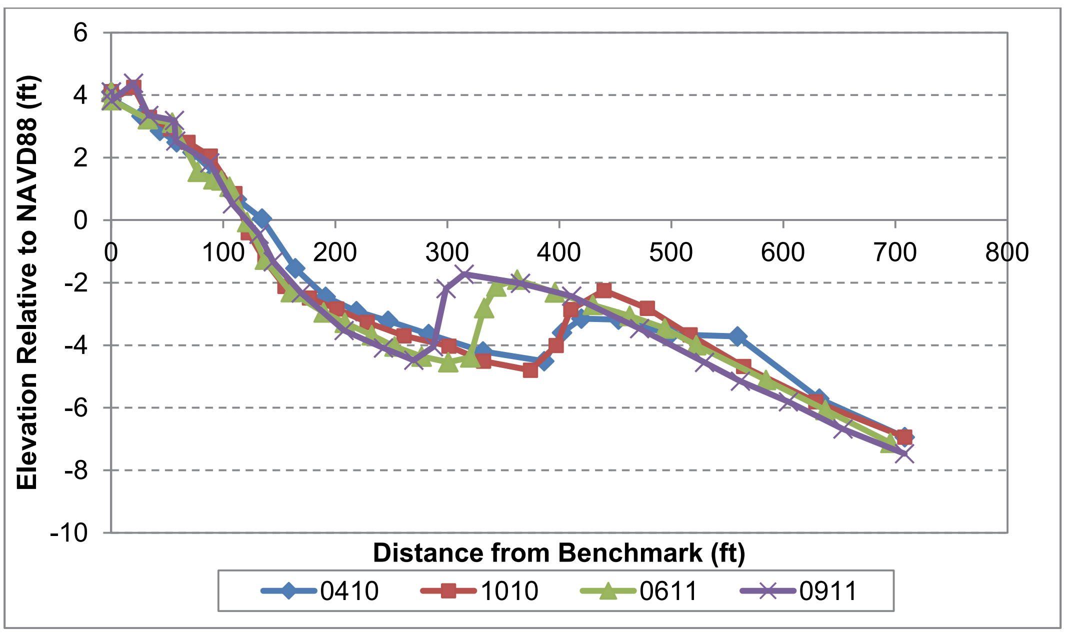
In summary, the artificial nearshore berm at Ft. Myers Beach migrated onshore at a rate of approximately 150 ft/yr (300 ft during the first 2 years) at most of the profiles located over the berm placement. The elevation of the berm crest increased up to 2 ft as the berm migrated onshore. Considerable longshore variations existed in terms of onshore migration distances and upward shoaling magnitudes. After the first 2 years, elevation of the berm crest increased from just below MLLW to slightly below MSL, and, therefore, became exposed during half of the tidal cycle. In addition to the onshore migration, the shape of the berm evolved from a roughly symmetrically constructed shape to an asymmetric shape with a steep landward slope. The berm height defined as the elevation difference between trough and berm crest remained rather constant at about 4 ft in the middle section of the project. The berm migrated roughly 200 ft during the first 6 winter months from October 2009 to April 2010. The rate of onshore migration reduced substantially from 400 ft/yr to 60 ft/yr during the summer of the first year, moving landward less than 40 ft at most locations. Greater onshore migration distances were measured during the second winter season from October 2010 to June 2011. However, the migration rate varied alongshore, ranging from about 100 to 200 ft/yr. A small, roughly 2-ft high sand bar was measured in the control area southeast of the berm project area. The bar is rather dynamic as it migrates onshore and offshore as well as appears and disappears. The morphodynamics of the nearshore bar do not seem to correlate with morphologic changes in the nearshore berm. The beach profiles in the northwest control site are mostly monotonic with an intermittent subtle bar or a flat platform. No significant and persistent abnormal beach changes were measured north of and adjacent to the nearshore berm. The dry beach, extending from the vegetation line to the mean sea level, has remained stable during the 2-year study period within and outside of the berm project area despite the dynamic behavior of the artificial nearshore berm and natural sand bar.

Morphodynamics of the Gaps

Several gaps, or depression features, between the berm crests existed due to the dredging and construction operations as discussed above. A recent aerial photo taken during a low tide illustrates the gaps/depressions (Figure 38), as well as the complex longshore variation of the berm morphology. One of the largest gaps is located from profiles FMB 34 through FMB 36. Substantial profile changes were measured in the vicinity of the gap, indicating that the gap is dynamic in nature and moves alongshore. This may be in part due to wave focusing and refraction effects (McLellan and Kraus 1991) and/or tidal-driven flow through the complex morphology. At FMB 34 (Figure 39), located across the southeast flank of the gap, the April 2010 survey showed a wide, flat, and low-profile berm (with a crest elevation slightly over -4 ft NAVD88). During the subsequent surveys, the berm has grown over a foot higher and adopted the typical asymmetric shape with a steep landward slope, migrating 150 ft landward from October 2010 to September 2011.

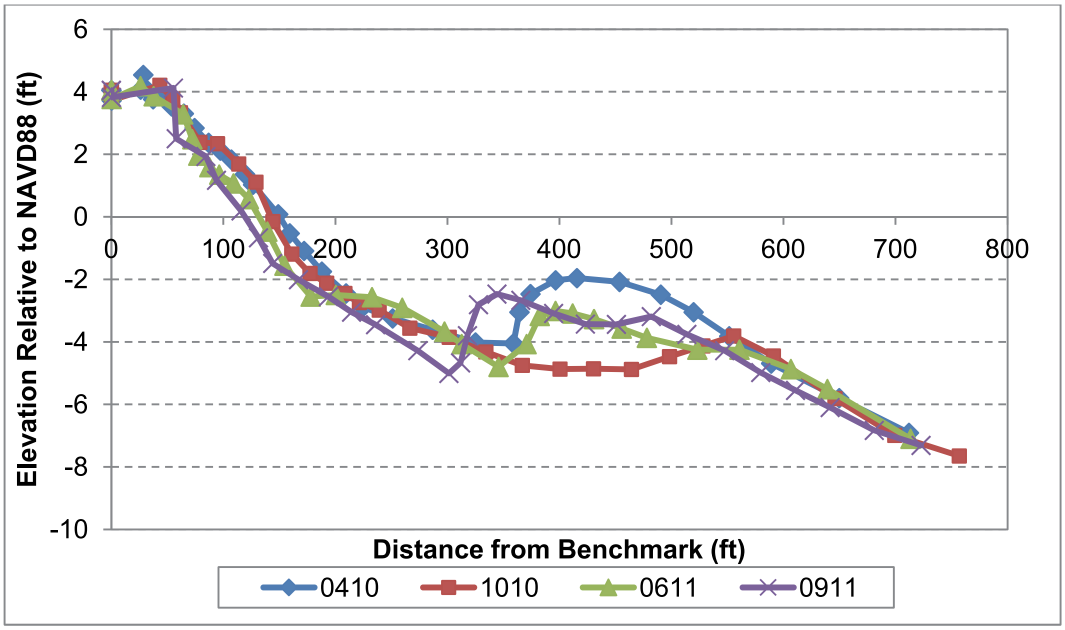
Figure 38. Aerial photo showing the gap in the vicinity of FMB 35, November, 2011. Left of the photo pointing to northwest.

Figure 39. Profile FMB 34 near a gap in the nearshore berm.



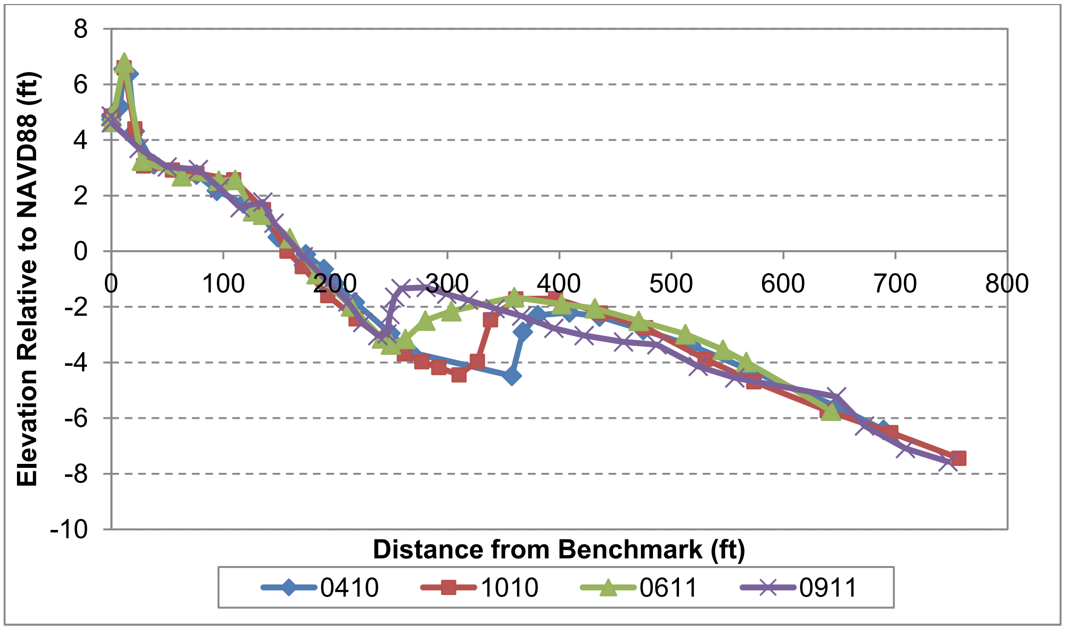
Profile FMB 35 (Figure 40) illustrates the northwest migration (from right to left in the aerial photo; Figure 38) of the gap. A typical berm profile was measured during the April 2010 survey. The entire berm was scoured between April 2010 and October 2010, likely due to the longshore migration of the gap. The large net loss of sediment volume across this profile agrees with the interpretation of alongshore change. However, the sand loss could not be accounted for by gains at the adjacent profiles. One explanation might be that the distance of migration is less than 150 ft, and, therefore, cannot be resolved by the profile survey lines. A small bar measured during the June 2011 survey continued to grow and migrated onshore through September 2011. The large gain of sediment volume indicates longshore-directed change. Based on field observations during the survey, the gap has been migrating toward the northwest. Longshore sediment transport to the northwest observed at the northwestern end of the barrier island does not seem to be the main cause of the gap migration because morphologic evidence at other locations, e.g., significant sand impoundment at the lateral ends of the nearshore berm, was not observed.

Figure 40. Profile FMB 35 near a gap in the nearshore berm.



No gap was measured along profile FMB 36 (Figure 41), which is located just to the northwest of the previously discussed gap. Consistent onshore migration of the nearshore berm was measured at this profile over the 2-year period. In contrast to the highly asymmetric bar profile measured over the rest of the berm project area, a symmetric bar profile was measured at FMB 36 and FMB 37 (Appendix C) by June 2011. The bar then became asymmetric in September 2011 and substantially migrated onshore. The berm at FMB 36 and FMB 37 had migrated to within 50 ft of the shoreline by September 2011, the only profiles to migrate this close in the 2-year monitoring period. This abnormal behavior may relate to the dynamics associated with the gap. Wave and current measurements through the gap are recommended to understand better its dynamics.

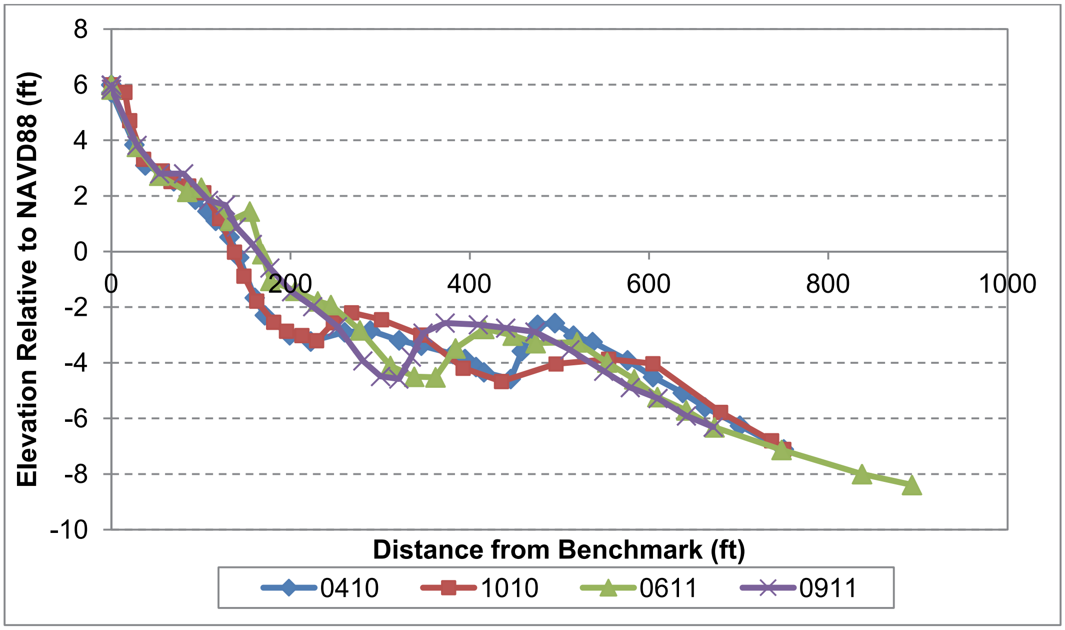
Figure 41. Profile FMB 36 northwest of a gap in the nearshore berm.



The gap discussed above is the largest and deepest one within the berm area. Several smaller and/or shallower gaps also existed along the nearshore berm. The orientation of each gap was found to be roughly perpendicular to the berm (and shoreline) or highly oblique relative to the berm, as discussed above. For example, the two small gaps near the right side of the aerial photo (Figure 38) orient at a large angle with the berm. Profile FMB 22 (Appendix C; not shown in the above aerial photo) illustrates an oblique gap present during April 2010 and October 2010 (Figure 42). The gap was filled in by June 2011, likely due to onshore migration of the second bar. For the case of FMB 22 (Appendix C), the first bar seemed to have migrated and attached to the shoreline, resulting in accumulation in the intertidal zone and modest shoreline advance. This is rather unusual and contrasts to the overall stable shoreline documented for the rest of the berm. The dynamic behavior of this gap is different from the one discussed above in that cross-shore processes dominated its presence and absence rather than longshore processes.

In summary, several gaps and depressions initiated during the different phases of construction and by different construction procedures were analyzed over the 2-year monitoring period throughout the berm project area. The initial gaps were found to be shore (or berm) perpendicular or highly oblique to the shoreline. The gaps were rather dynamic, moving both alongshore and cross-shore. Wave- and possibly tide-generated currents are believed to be responsible for the maintenance and evolution of the gap. The widest and deepest gap moved alongshore, while the example oblique gap moved across-shore. The irregularity in morphology inherited from the construction was maintained during the first 2 years. The berm did not evolve toward a more longshore uniform feature.

Figure 42. Profile FMB 22 across an oblique gap in the nearshore berm.

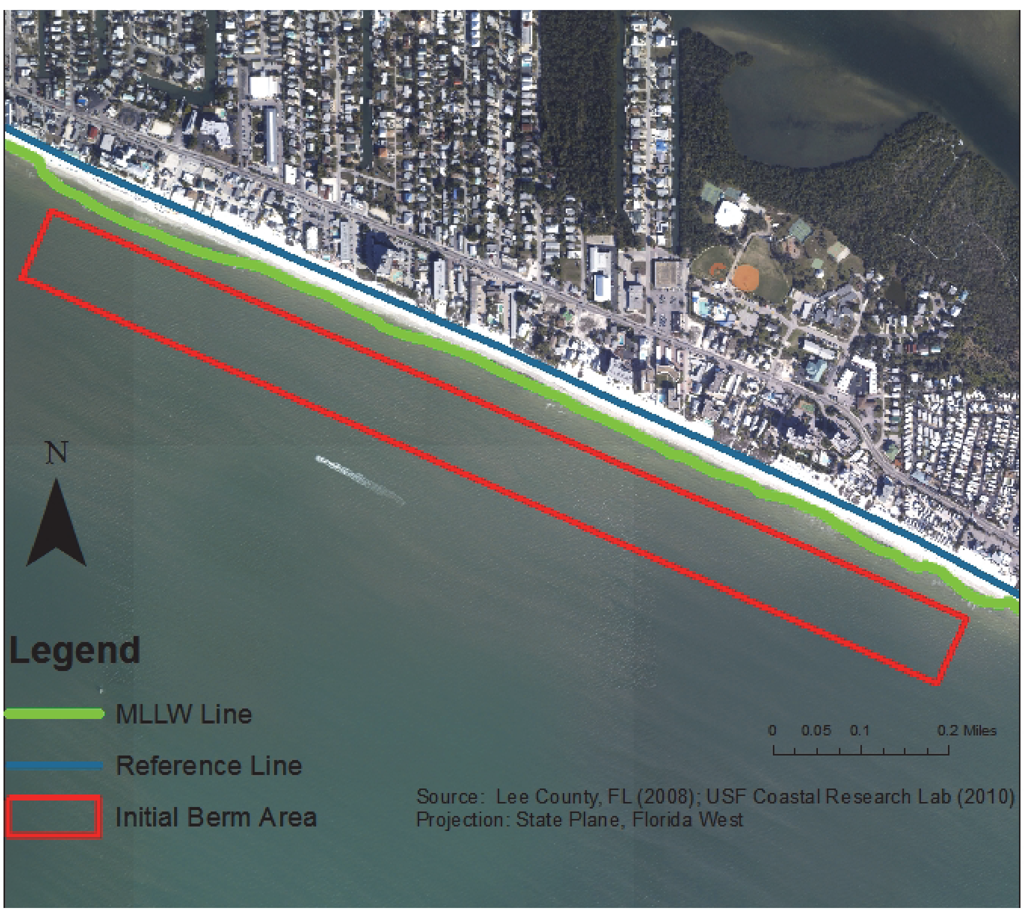


Although not initially designed, the gaps appear to be beneficial to the local water quality, based on field observations. As the berm migrates onshore and upward and becomes intertidal, the gaps serve as drainage channels to prevent possible deterioration of water quality landward of the berm. The gaps also provide access channel for recreational vessels which are very common along Ft. Myers Beach. Based on the above findings, gaps should be considered as an important design parameter for this project and maybe other similar future projects. Gap design should consider drainage and water quality landward of the nearshore berm and other site specific issues, e.g., vessel access to the beach for the Ft. Myers Beach case.

Shoreline Responses to the Nearshore Berm

Given the nearshore nature of the artificial nearshore berm, the berm tends to function as a submerged breakwater, albeit a mobile one. For the artificial berm at Ft. Myers Beach, the natural bar in the adjacent control sites is much smaller than the berm. Differential wave-energy reduction by the berm could have resulted in the development of a salient and/or tombolo. Overall, the shoreline response to the Ft. Myers Beach nearshore berm was not significant as indicated by the stable beach profiles between the vegetation line and the mean low tide line at most locations. However, a subtle and broad salient feature, which was not entirely captured with beach profiles, can be observed at the northwestern end of the project (Figure 43), and landward of the portion of the berm with substantial gaps (Figure 38, middle left). The green line in Figure 43 represents a visually estimated spring low tide line that was mapped using RTK GPS towed behind an ATV (Figure 15) during a spring low tide. The contour line was identified visually in the field by following the water level during the low tide. Several lines, including the visually estimated vegetation line, MHHW, MSL, and MLLW were surveyed. The MLLW is used here because it shows the greatest amount of change. The subtle salient did not result in significant shoreline change of the nearby beaches, particularly directly adjacent to the nearshore berm, as discussed earlier. The gradual shape of the berm, resembling a natural bar, and low gross longshore transport rate are linked to the limited shoreline response along the adjacent beaches.

Figure 43. A spring low tide line (green line) surveyed with RTK GPS in April 2010, showing a broad salient feature landward of the northwestern end of the berm and small salient features associated with gaps.



Profile-Volume Change

A desirable goal of this and most nearshore berm projects is that beach quality sand is transported onshore to nourish the beach. As compared to previous berm nourishments, the Ft. Myers Beach nearshore berm was placed relatively close to the shoreline in shallow water. As discussed above, the berm has migrated onshore approximately 300 ft during the first 2 years. In this section, we examine profile-volume changes. The beach profiles were divided into two sections. The first section extends from the benchmark, which is either located in the dune field or on a seawall, to the MLW line. The MLW is used here to ensure that the nearshore berm and the subsequent onshore migration were not included in the volume calculation of the dry beach and intertidal zone. The second section extends from the MLW line, seaward to the short-term closure depth.

Figure 44 illustrates the profile-volume change between April 2010 and September 2011 above the MLW line (-1.68 ft NAVD88 for the study area), and represents profile-volume changes on the dry beach and in the intertidal zone. Within the nearshore berm project area, profile-volume gains of up to 6 cu yd/ft were measured. Considerable alongshore variations were observed which are largely associated with the dynamic gaps. Most of the profiles within the berm project area gained sand above MLW. No alongshore pattern of the profile-volume change can be identified. Particularly, no increased profile-volume gains were measured at the ends of the berm project, i.e., in the vicinity of profiles FMB 17 and FMB 46, suggesting that the berm is not impounding a significant amount of longshore moving sand. This is interpreted as due to the low rate of longshore sand transport and *natural* shape of the bar instead of negligible influence of the berm on wave propagation patterns. Future numerical modeling studies on hydrodynamics and sediment transport are needed to expand upon this hypothesis.

Small and fairly consistent profile-volume gains of slightly less than 2 cu yd/ft were measured at the southeast control site. No significant change of trend can be identified immediately adjacent to the nearshore berm, confirming that the berm did not impound significant amount of longshore moving sand. Profile-volume losses of less than 2 cu yd/ft were measured at nearly all profiles for the northwest control site. Overall, profile-volume changes above the MLW were small across the berm project area and in the control areas. This is consistent with the above discussion on individual profile changes.

Figure 44. Profile volume change above MLW from April 2010 to September 2011; the nearshore berm area extends from FMB 17 through FMB 46.

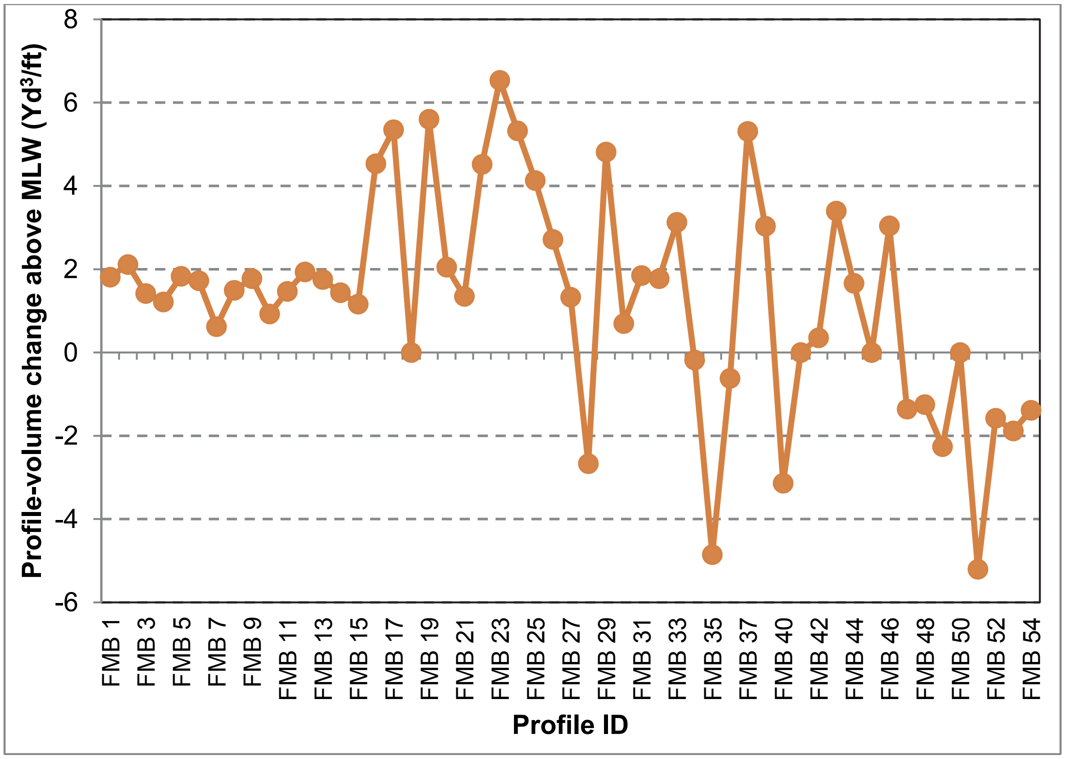


Figure 45 illustrates the profile-volume change across the entire profile. Except for large variations in the vicinity of the gaps (induced by the migration of the gaps), the profile-volume across the entire profile tends to be conserved, indicating the dominance of cross-shore processes and no significant sand loss in the longshore directions from the berm project area. No substantial profile-volume changes were measured at the two ends of the berm (profiles FMB 17 and FMB 46), also indicating that the longshore spreading of the nearshore berm is not significant.

Figures 46 through 51 illustrate the time series bathymetry evolution during the first 2 years. Significant onshore migration of the berm and substantial alongshore variability are apparent. Although the general locations of the gaps are maintained, their movement and associated bathymetric changes were measured. A small degree of alongshore spreading is measured. Overall, most of the placed sand remained in the initial placement area, as also demonstrated quantitatively through profile-volume analysis (Figures 44 and 45).

Figure 45. Profile volume change across the entire profile from April 2010 to September 2011; the nearshore berm area extends from FMB 17 through FMB 48.

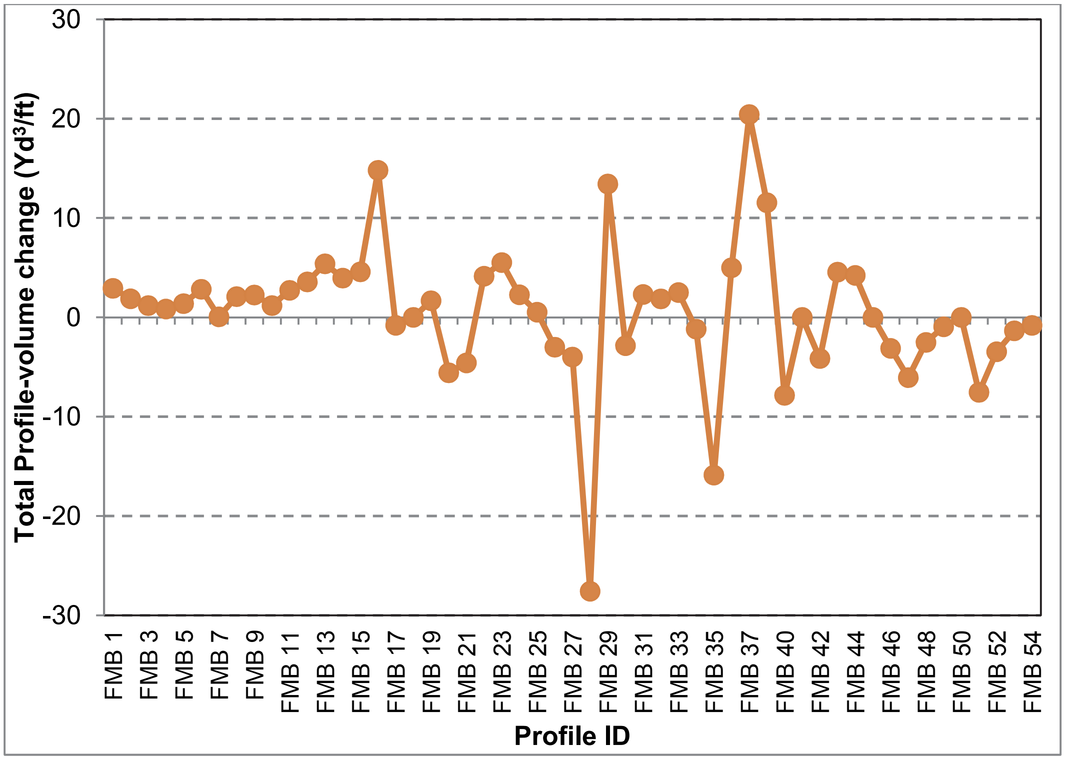


Figure 46. Pre-construction bathymetry of berm area (red box) and immediate vicinity, SAJ survey, May 2009.

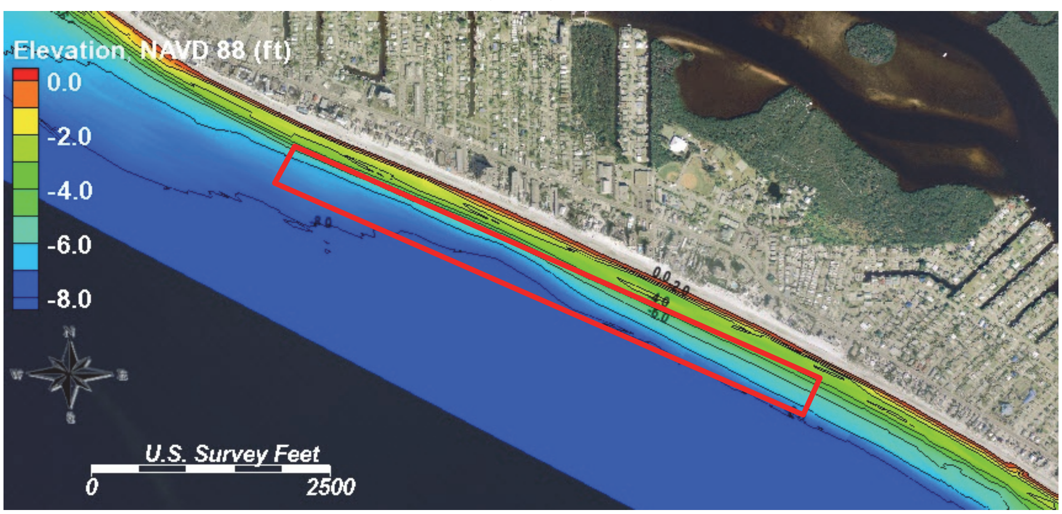


Figure 47. Post-construction bathymetry of berm area (red box) and immediate vicinity, SAJ survey, October 2009.

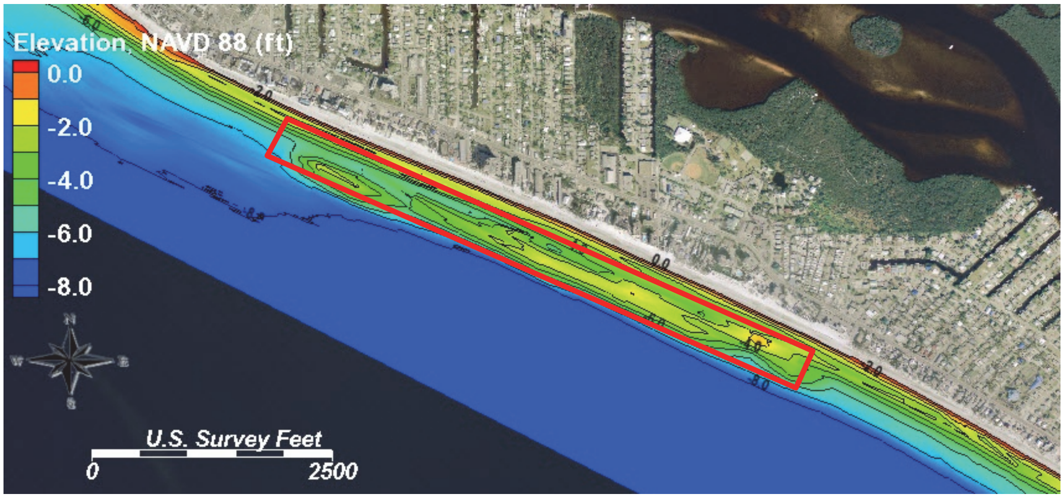


Figure 48. Bathymetry of berm area (red box) and immediate vicinity, USF-CRL survey, April 2010.

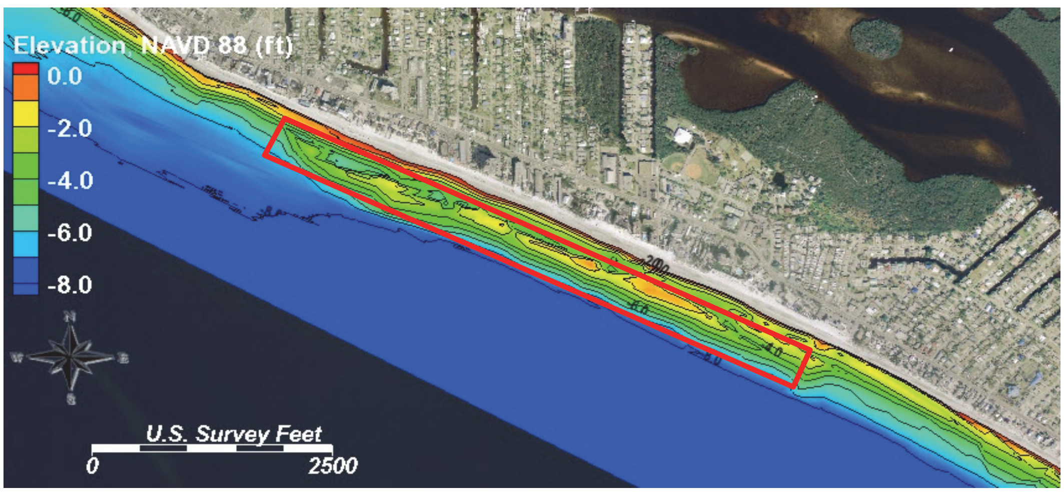


Figure 49. Bathymetry of berm area (red box) and immediate vicinity, USF-CRL survey, October 2010.

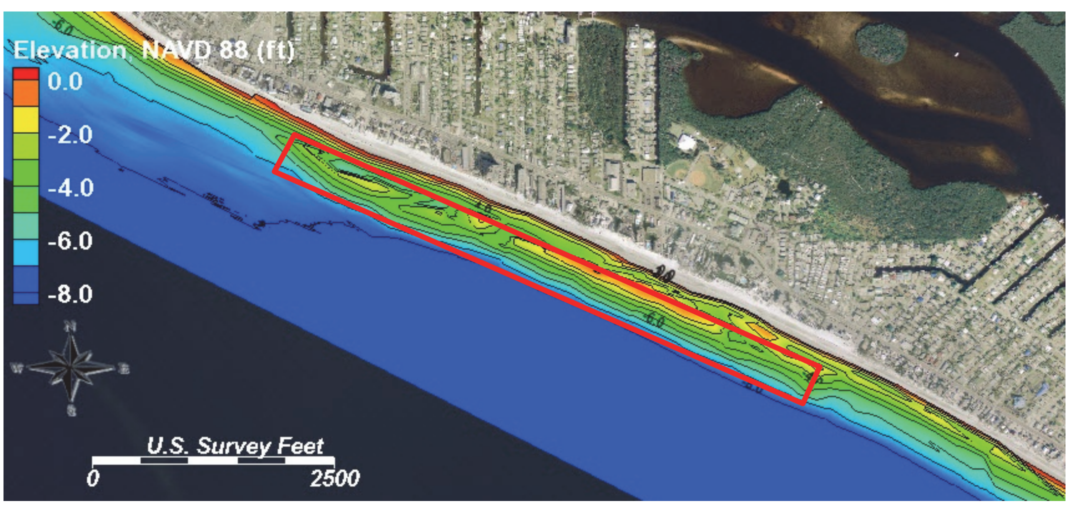


Figure 50. Bathymetry of berm area (red box) and immediate vicinity, USF-CRL survey, June 2011.

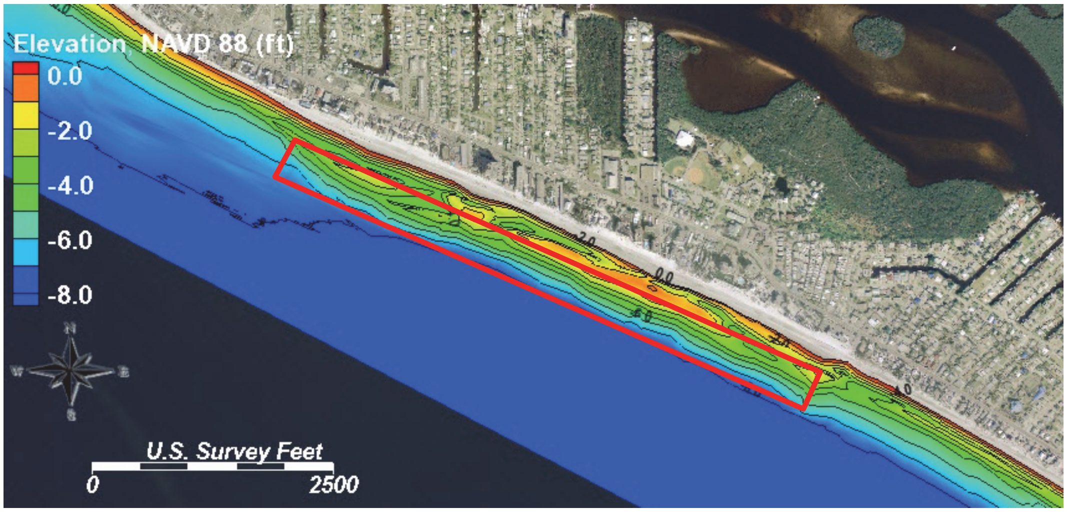


Figure 51. Bathymetry of berm area (red box) and immediate vicinity, USF-CRL survey, September 2011.

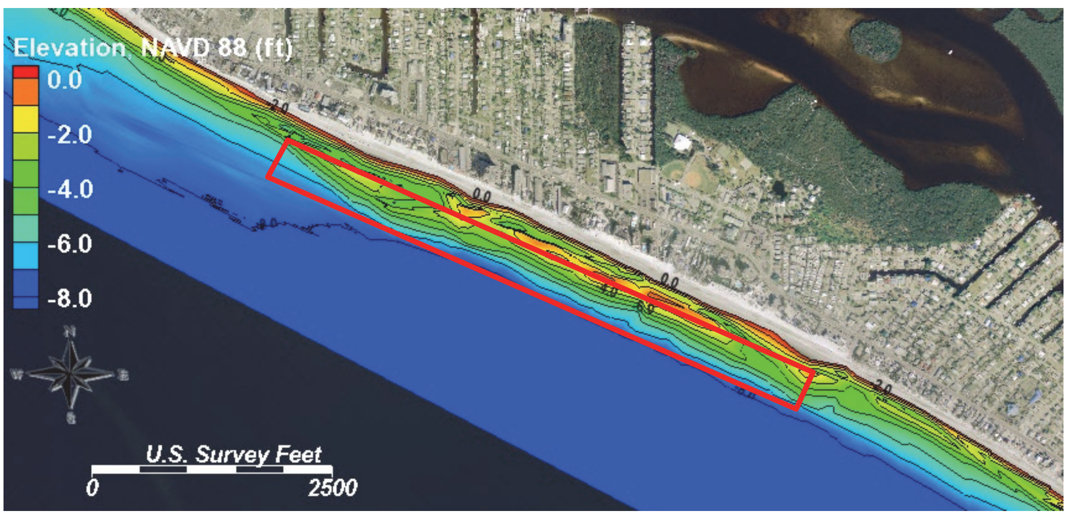


Table 4 summarizes the overall berm-volume and volume change during the 2-year period. The initial berm volume was obtained by subtracting the pre-construction bathymetry from the post-construction bathymetry within the designed berm project area (the red box in Figures 46 through 51). A berm volume of 211,900 cu yd was obtained from the USACE post-construction survey. This compares well with the 229,300 cu yd (7.6 percent difference) reported from the construction note. The time series volumetric change associated with the nearshore berm was obtained by subtracting the bathymetry from survey to survey within the design berm area.

Table 4. Summary of overall berm volume and volume change

Dates	Berm volume (yd^3)	Volume change (yd^3) Designed placement area	Volume change (yd^3) Expanded area
Post-construction	211,900		
04/2010	219,100	7,200	5,200
10/2010	190,000	-29,100	-25,400
06/2011	179,300	-10,700	-6,000
09/2011	177,100	-2,200	-6,400
Total change		-34,800	-32,600

Column 3 in Table 4 summarizes the volume change of the berm within the designed placement area. The goal was to examine the amount of sand that has moved out of the placement area, both alongshore and across-shore. During the first 6 winter months, the onshore movement of the berm was largely contained within the design box, as shown by a small volume gain. During the subsequent 6 summer months and thereafter, some sand was transported out of the design box resulting in a volume loss of 29,100 cu yd. During the 2-year period, a total of 34,800 cu yd (15.2 percent) moved out of the design area.

Owing to the onshore berm migration, it is likely that the above volume loss can be attributed to the berm being moved onshore and out of the design area. In column 4 of Table 4, the area of volume calculation is extended landward for 150 ft to account for some of the onshore migration out of the initial design area. The largest volume loss of 25,400 cu yd (11.1 percent) is also measured during April 2010 and October 2010. During the 2-year period, 32,600 cu yd (14.2 percent), was lost from the landward extended design area. This is similar to the loss from the initial design area. The overall 32,600 cu yd loss (14.2 percent of the placed volume) from the expanded design area was determined to be an alongshore loss. Modest longshore spreading of the nearshore berm can be identified from the contour maps (Figures 46 through 51). Overall, the longshore spreading is less than 15 percent of the placed volume during the first 2 years. The limited degree of longshore spreading is attributed to the low rate of longshore sand transport.

7 Sedimentological Characteristics

A main goal of this study was to document the sedimentological characteristics of the nearshore berm and their temporal evolution. For placement using mixed sediment with a dominant sand fraction and some mud content, selective transport under waves and currents and deposition may sort the sediment naturally. The processes and outcome of the selective transport are crucial aspects of understanding how mixed sediment in a berm nourishment evolves. This section discusses trends of selective sediment transport and deposition based on surface and subsurface sediment sampling. Overall, 104 surface sediment samples, including 61 from the control areas and 43 from the berm area, were collected in April 2010, about 9 months after the completion of the berm construction. A similar amount of samples was collected at similar locations again in June 2011 to examine the changes in sediment characteristics with time. In addition, 20 vibracores were collected in the berm project area and control areas to investigate the differences in surface and subsurface sediments. The sediment characteristics are also compared to those obtained by USACE from the dredge area.

The phi grain size unit is used in the following discussion. The relationship between phi and mm is as follows:

$$d(mm) = 2^{-phi}. \qquad (4)$$

It is worth noting that the phi-size scale (Equation 4) is logarithmic as oppose to the linear mm scale. The sand and mud-sized particles are separated by 4 phi, or 0.063 mm. The term *mud* is used to represent fine grained sediments including silt and clay. Larger phi values correspond to smaller sediment grain sizes.

General Sediment Characteristics in the Study Area

Two sampling episodes were conducted: the first one in April 2010, 9 months after the placement, and the second in June 2011, 23 months after the placement. The samples were collected along the same profiles at similar morphologic locations. The goal of this time series sediment sampling was to examine temporal changes in sediment properties. In the following, the temporal variations of sediment characteristics, including percent mud content and percent carbonate-grain content, are discussed.

Based on the seven vibracores (out of a total of eight) that contained the allowable amount of mud, and one grab sample collected at the tip of Bowditch Point by SAJ, the mean grain size of the dredge material was determined to be approximately 2.6 phi (0.16 mm, fine sand), with a sorting value of 0.65 phi (moderately well sorted). Five of the seven pre-dredging vibracores contained fine-grained layers that had a range of 9.94 percent to 16.15 percent mud content. Composite mud content of the entire dredge cut was determined to be 7.71 percent indicating that the material is overall mostly sand.

Considerable variation of sediment grain-size distribution occurred across-shore in both the control sites and the berm project area. Generally, the dry beach and intertidal zone contained well-sorted fine sand. The swash zone had the coarsest sediment and was composed of poorly-sorted medium, shelly sand, and the nearshore area contained moderately sorted fine sand with an offshore-directed increase in mud content. Figure 52 shows the grain-size distribution across the sample profile FMB 3 in the southeast control area. The peak between 2.5 phi (0.18 mm) and 3.5 phi (0.09 mm) size fractions is primarily composed of fine quartz sand. The variable peak between -2 phi (4.00 mm) to 1 phi (0.50 mm) is mainly composed of shell fragments. This coarse grain peak was highest in the swash zone where energetic swash action selectively transports fine fractions away leaving a relatively high content of shell fragments. The mud content is represented by the size fraction that is finer than 4 phi (0.063 mm). No further size analysis was conducted for grains that are finer than 4 phi (0.063 mm). Therefore, in Figure 52 and the subsequent figures, although the percentage of mud was labeled at 4.25 phi, it represents the overall percentage of grains that are finer than 4.0 phi (0.063 mm).

Figure 53 illustrates results from a sample line FMB 28 from the berm project area. Similar to the southeast control area, the dry beach and intertidal zone contained mostly well-sorted fine sand, and the swash zone had the coarsest moderately-sorted sediment with a high content of shell debris. The trough landward of the berm was generally composed of well-sorted fine sand. Sample FMB 28-8 was collected in the lower part of the steep landward slope, or landward toe, of the berm. Compared to the rest of the sediment samples, this sample contained a higher content of medium and coarse sand fractions. The relatively coarse sediment near the

Figure 52. Grain-size distribution of a typical sample profile southeast of the nearshore berm area.

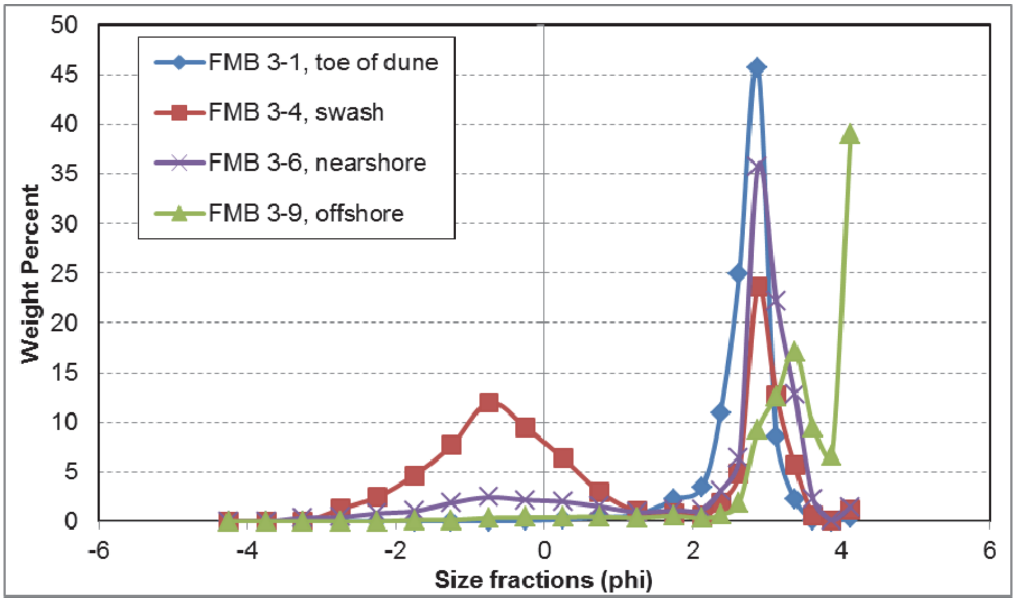
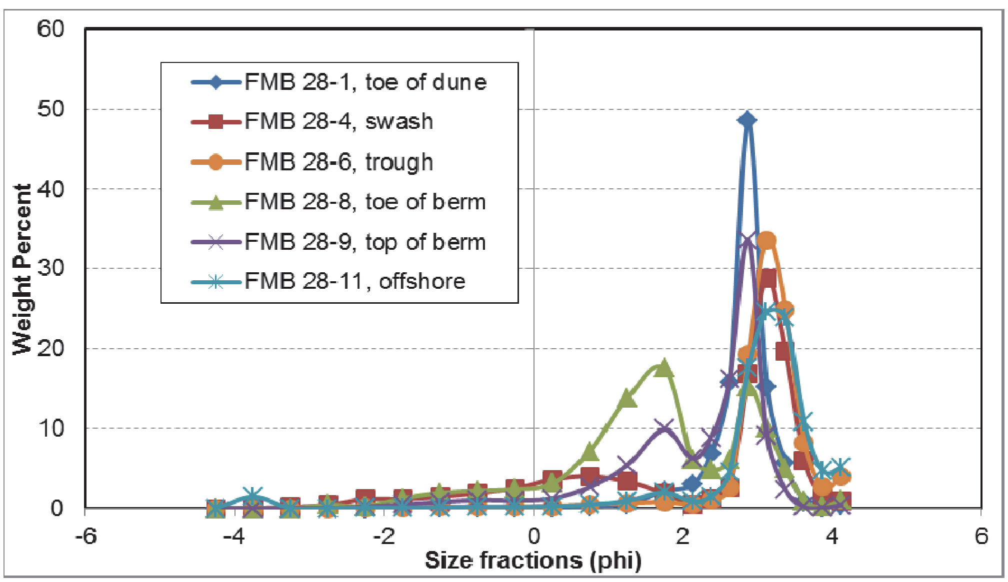


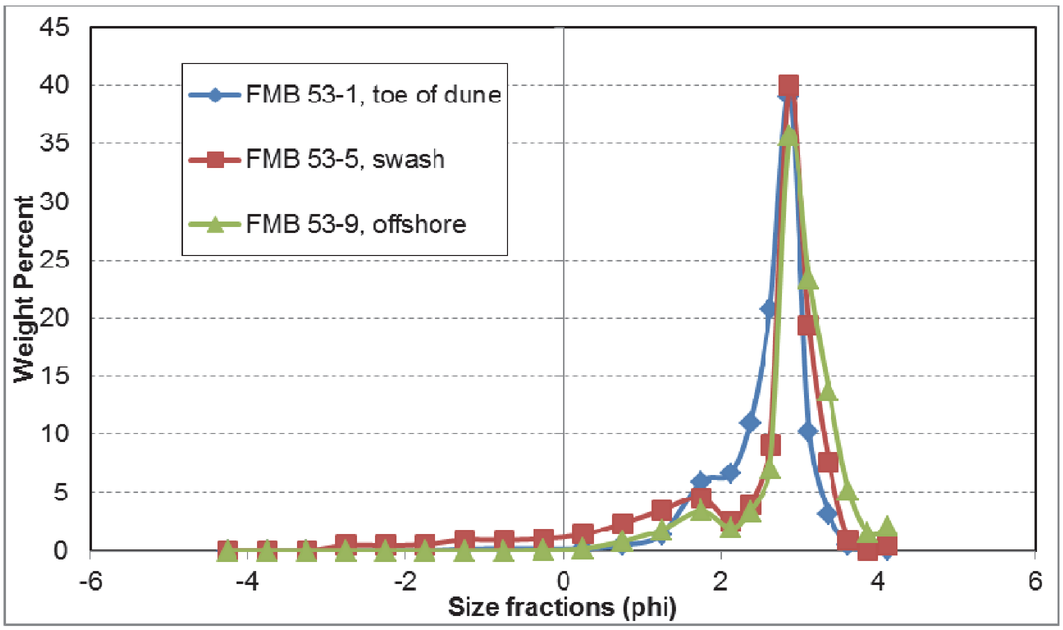
Figure 53. Grain-size distribution of a typical sample profile within the nearshore berm area.



landward terminus of the berm may suggest a landward selective sediment transport of coarser material. The top of the berm was characterized by moderately-sorted fine sand. The sediment along the seaward slope of the berm and offshore was moderately- to well-sorted fine sand. Compared to the southeast control area (Figure 52), the offshore sediment sample contained much less mud.

The control area northwest of the berm generally contained fine to very fine, moderately- to well-sorted sand across the entire profile. Figure 54 shows an example of grain-size distribution along a profile (FMB 53) in this area. Overall, compared to the sediments to the southeast, including both the berm area and the southeast control area, the content of shell debris (the coarser fractions), as well as the content of mud, was less, resulting in more uniform sediment in the northwest control site. The general differences in sediment characteristics between the southeast and northwest control sites are likely controlled by regional geology. Grain-size distribution charts for all sample transects are listed in Appendix D.

Figure 54. Grain-size distribution of a typical sample profile northwest of the nearshore berm area.



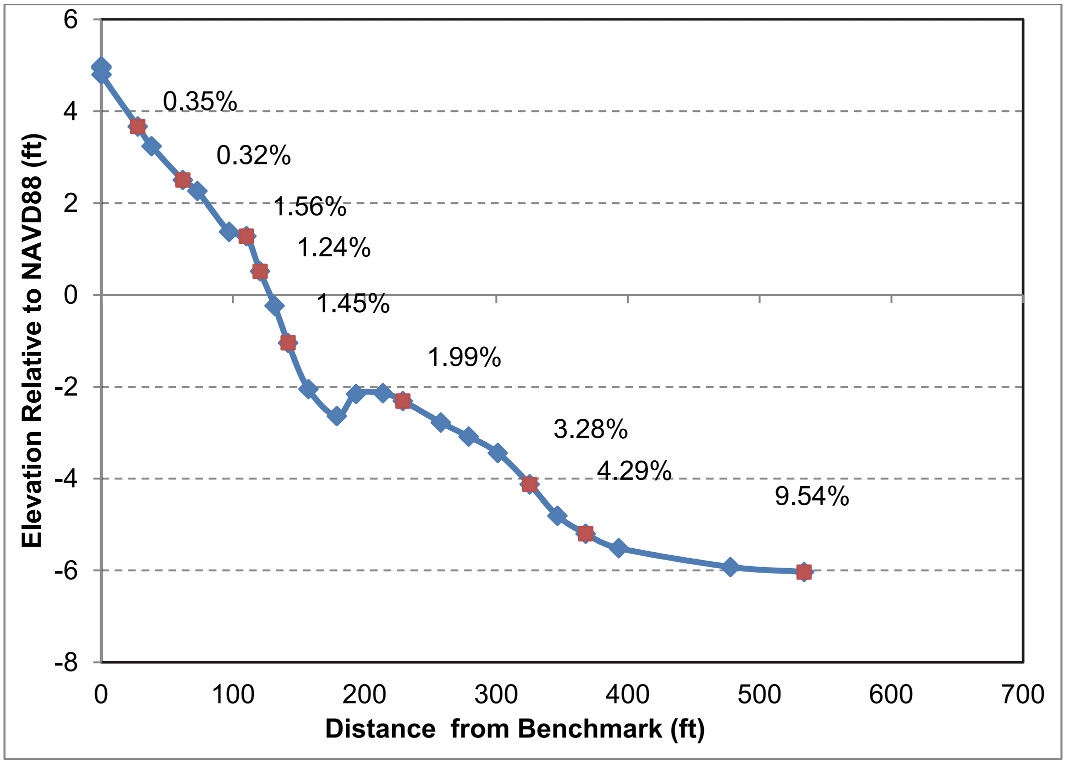
Mud Content and Its Temporal Changes

Mud content and the spatial and temporal redistribution of fine sediments are typically important concerns for beach and nearshore placement, especially nearshore berms where the material does not strictly match native nearshore sediments. In the following, percent mud content in the surface sediment samples collected across the sampling profiles are discussed and compared between the two sampling events on April 2010 and June 2011.

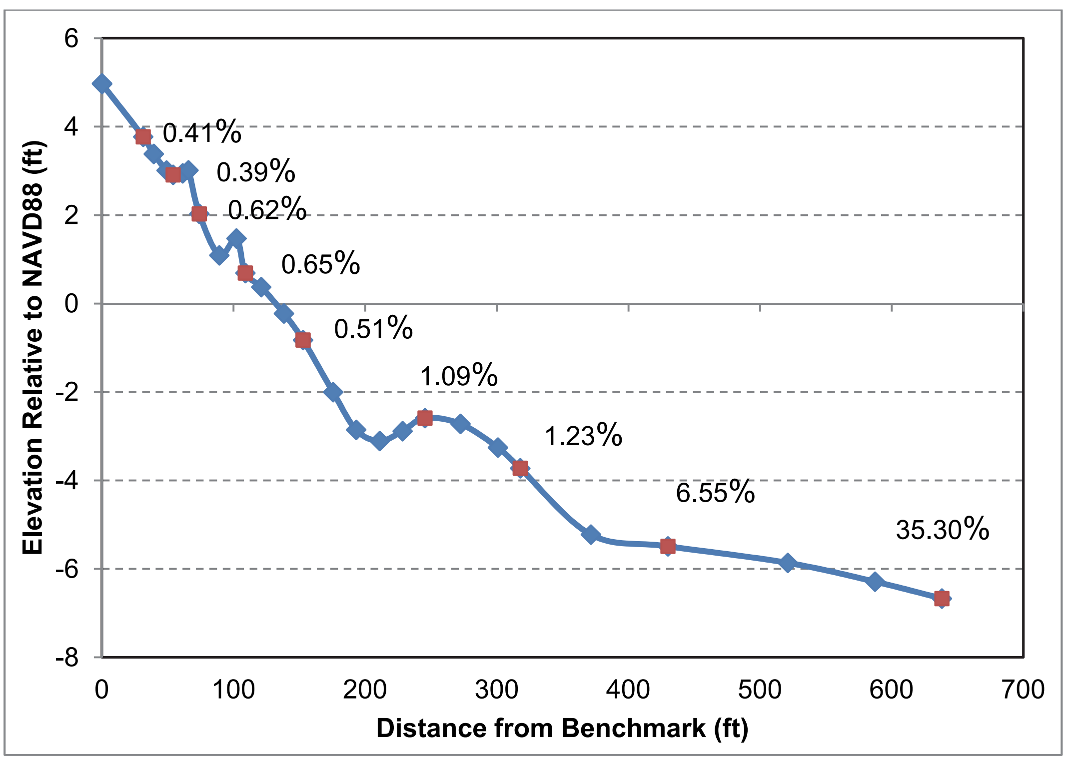
Control Area Southeast of Berm

A seaward increasing trend of mud content was measured at all the profiles in the control area southeast of the berm for both sampling events in April 2010 and June 2011. Figure 55 shows a sample line in the southeast control area with the percentage of mud indicated at each sample location. In the

Figure 55. Sediment samples showing percent mud content for profile FMB 9, southeast control site.



April 2010



June 2011

figure, the top chart illustrates the cross-shore distribution of mud content in the April 2010 samples, while the June 2011 samples are illustrated in the bottom panel for comparison. The percent mud content is plotted over the beach-nearshore profile surveyed at the time of sampling. All the sample lines are illustrated in Appendix E.

Profile FMB 9 is approximately 1500 ft southeast of the project area (Figure 55). Little mud (less than 1 percent) was found on the dry beach during both sampling events. Some mud (less than 2 percent) was found between mean sea level and about 3-ft water depth. Significant mud content of up to 35 percent was found in the surface sediment seaward of the 4-ft water depth with an apparent seaward increasing trend. This trend is identified along all the sampling lines southeast of the berm project (Appendix E) and represents the natural sediment characteristics.

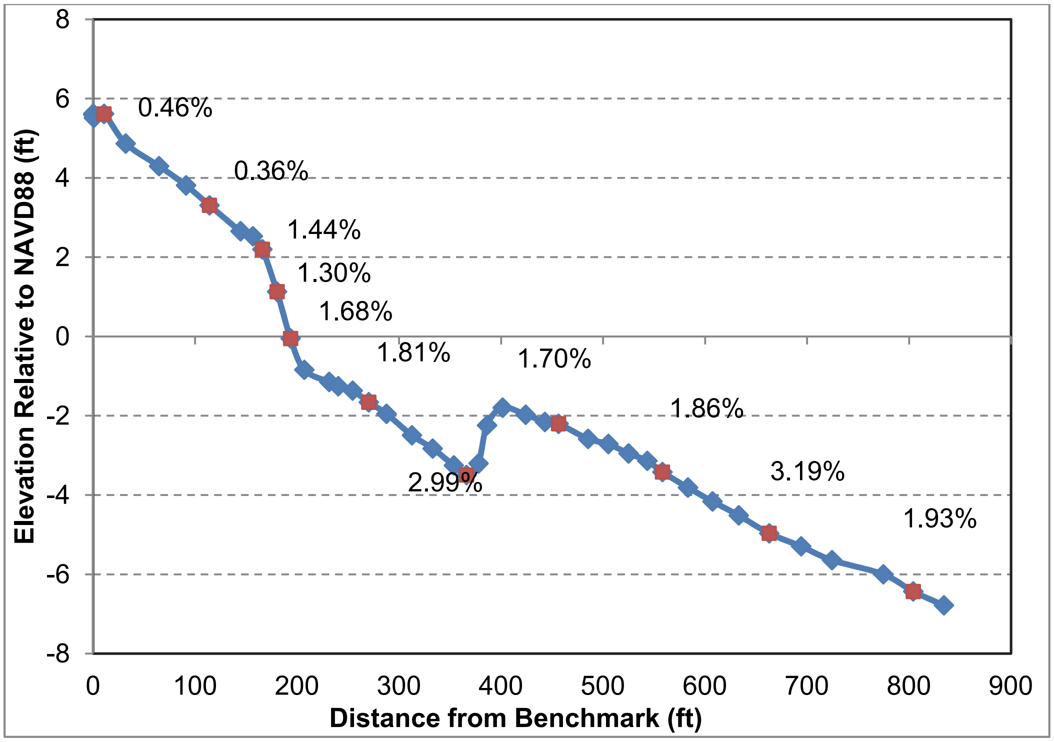
Overall, the sediment composition in April 2010 is quite similar to that in June 2011 at various cross-shore locations. Slightly less mud was found in the surface sediments in the intertidal zone in the June 2011 samples as compared to the April 2010 samples.

The Artifical Berm Area

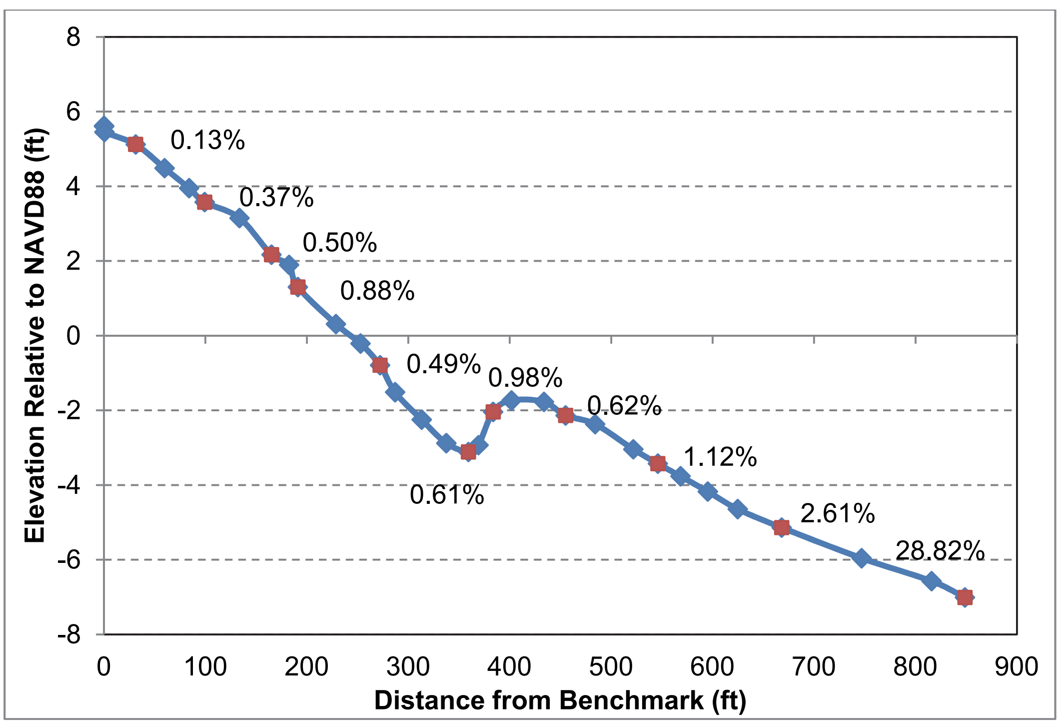
Sediment sampling was conducted along five survey lines within the berm area. Profile FMB 17 is located at the southeast end of the nearshore berm (Figure 56). Little mud was measured on the dry beach above the MHHW line during both sampling events. Similar to the southeast control site, 1 to 2 percent of mud was measured in the intertidal zone from the April 2010 samples, while less than 1 percent mud was measured in the June 2011 samples. A relatively high mud content of 3 percent was measured in the trough, a trend that is observed in the nearshore berm area. The percent mud content in the trough, along with those across much of the berm, decreased by the June 2011 sampling. A substantial increase of mud content was measured in the offshore-most sample along this profile.

Profile FMB 22 was an abnormal transect sampled in April 2010 (Figure 57). Sediments on the dry beach and in the intertidal zone are largely similar to those obtained at most other locations. However, a considerably large concentration of mud was found in the trough landward of the nearshore berm, as illustrated by the high percentage of mud content in several of the samples at that location (Figure 57). The sediment characteristics observed from the June 2011 sampling were significantly

Figure 56. Sediment samples showing percent mud content along profile FMB 17, southeast portion of the berm.

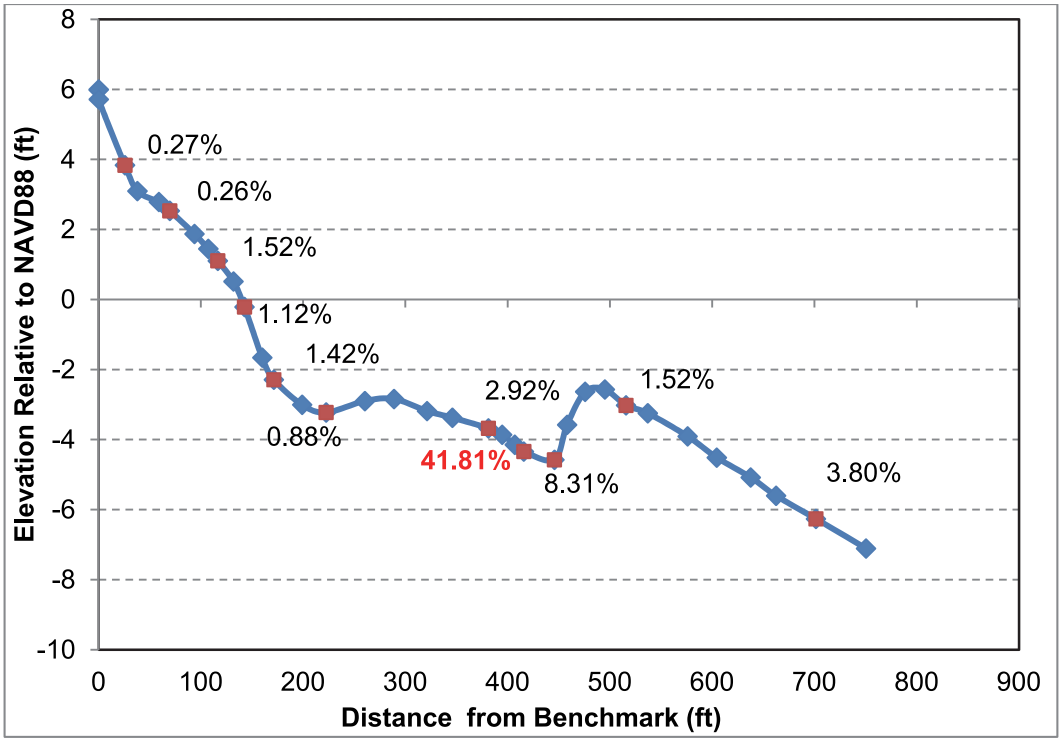


April 2010

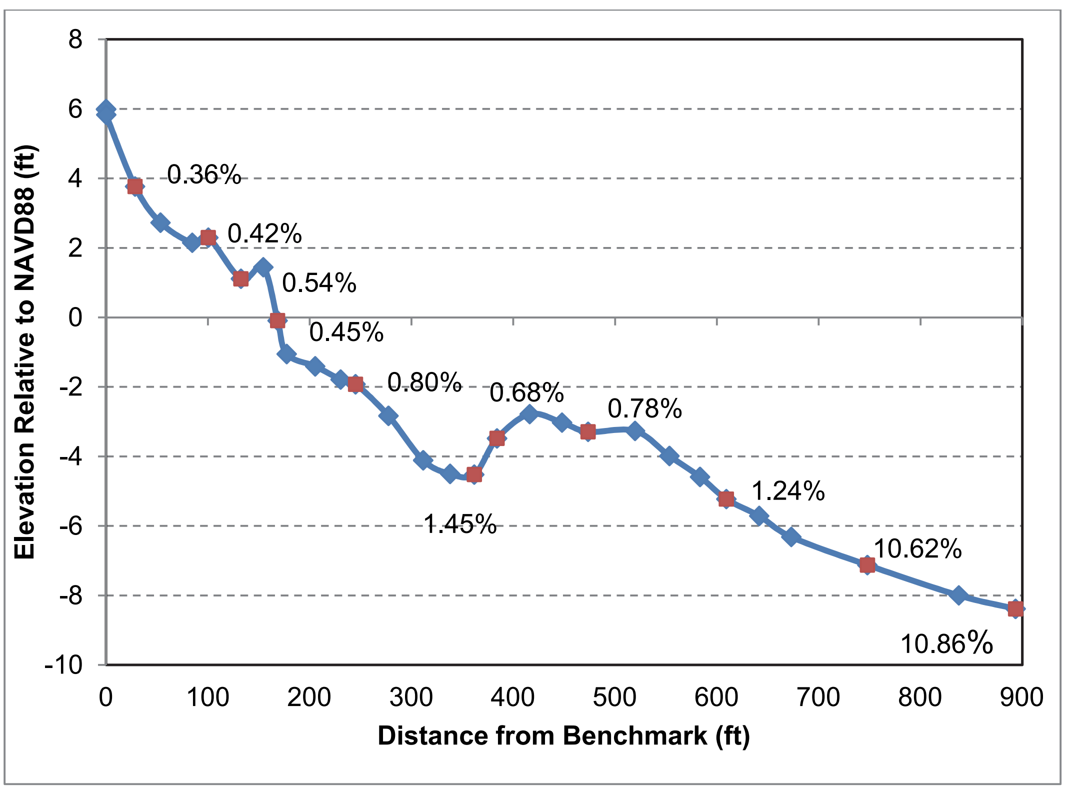


June 2011

Figure 57. Sediment samples showing percent mud content along profile FMB 22, within the berm area.



April 2010



June 2011

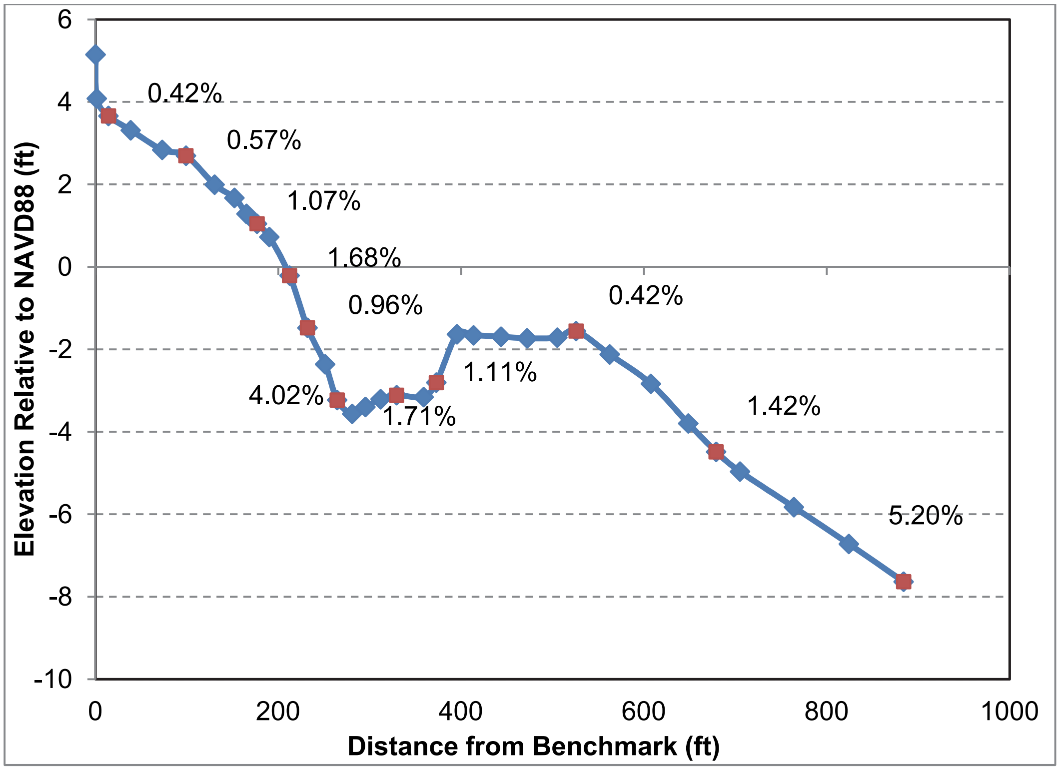
different from those collected in April 2010. The mud patch in the trough was either buried by the onshore migration of the nearshore berm or, more likely, transported away during high energy conditions. The trough in June 2011 was sandy with less than 2 percent mud. Similar to the case observed at FMB 17, percent mud content found in the seaward-most samples increased considerably as compared to that in the April 2010 samples.

Profile FMB 28 represents the typical spatial sediment distribution found over the nearshore berm (Figure 58). Sediments on the dry beach and in the intertidal zone were largely similar to those obtained at most other alongshore locations with less than 2 percent mud. Higher mud content of up to 4 percent was measured in the trough in April 2010. The mud content increases seaward but to a much lesser extent than that measured in the southeast control site. In June 2011, the mud content in the trough decreased, likely being transported away during high energy conditions. Similar to the cases at FMB 17 and FMB 22, mud content in the offshore samples increased.

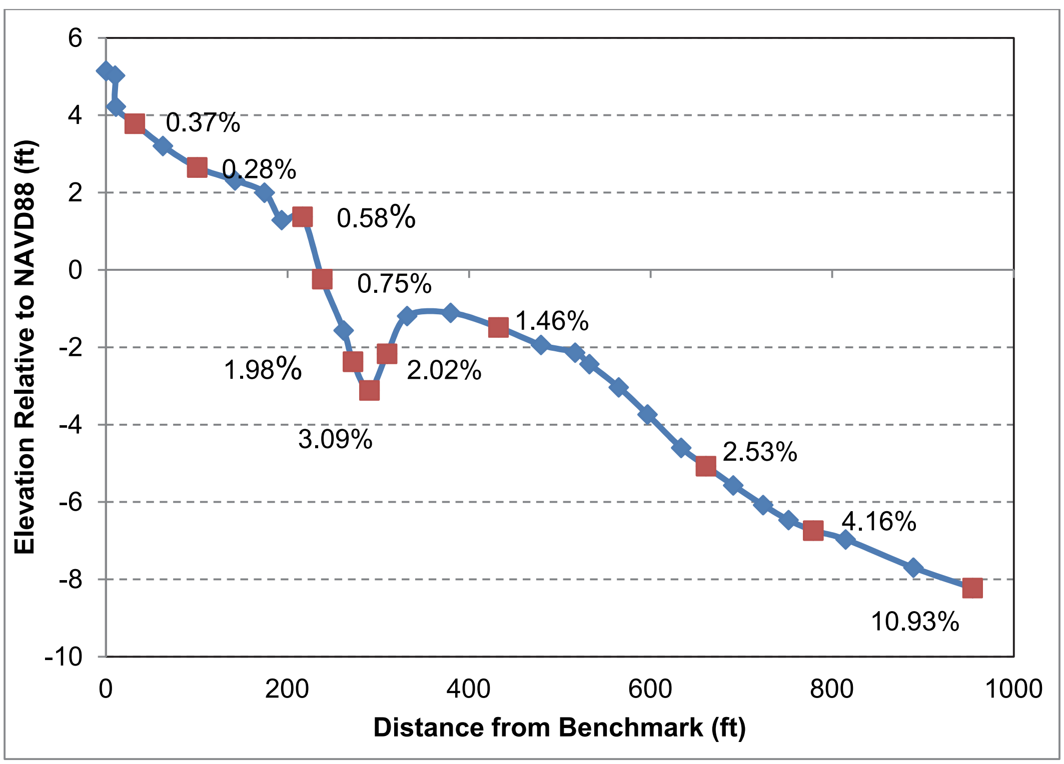
Profile FMB 35 extends through the large gap in the middle of the berm project area (Figure 59). Sediments on the dry beach are similar to those obtained at most other alongshore locations with less than 2 percent mud content. However, sediments in the entire intertidal zone, extending from MHHW to MLLW, had noticeably higher mud content, over 1 percent more, in June 2011 as compared to April 2010. As discussed earlier, the bar that was measured in April 2010 was eroded and reformed in June 2011 (Figure 40). Therefore, the bar on the April 2010 and June 2011 profiles is composed of different bodies of sediment. The surface sediment on the June 2011 bar contains about 1 percent more mud consistently. Similar to other berm profiles, higher content of mud was also measured at the offshore-most sample.

The deposition of mud in the offshore area in combination with the overall reduced mud content in the intertidal zone in the southwest control site and in the berm project site suggests that the finer sediment was transported seaward over time. The offshore trend of mud transport and deposition agrees with and, therefore, explains the cross-shore distribution of sediment properties with an overall coarser sandy sediment on the beach and in the nearshore zone, while finer muddy sediment is found offshore. A possible explanation is that the fine mud-sized particles tend to stay in suspension in turbulent water, e.g., in the nearshore, and can only be deposited in

Figure 58. Sediment samples showing percent mud content along profile FMB 28, within the berm area.

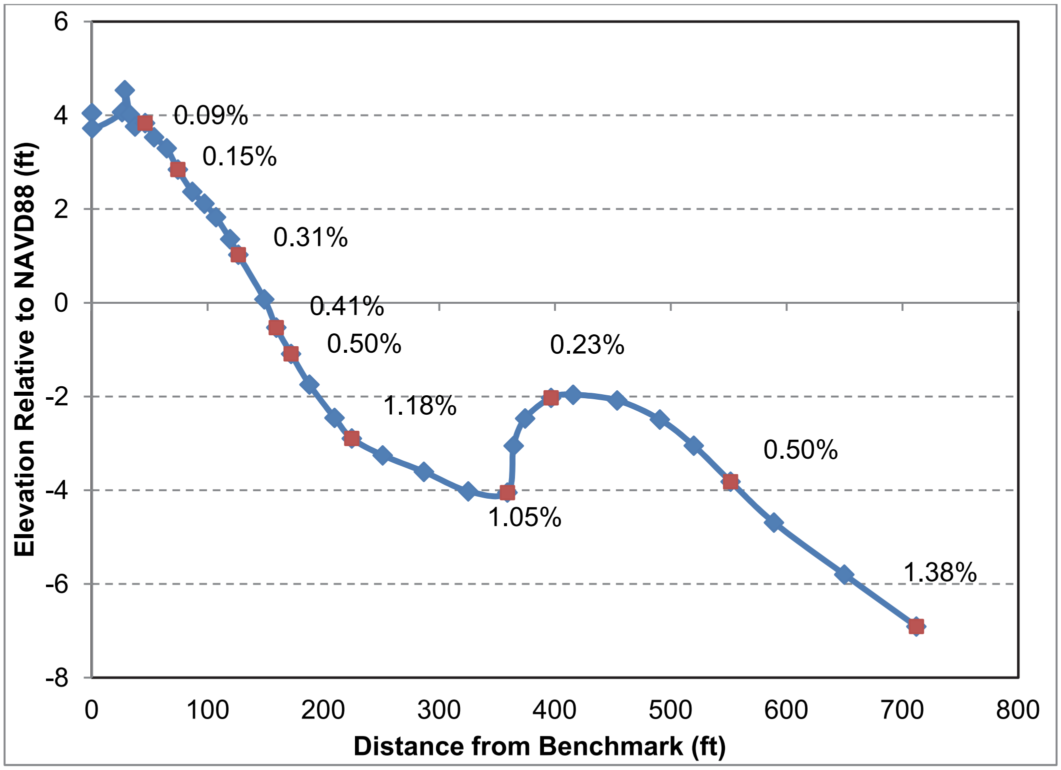


April 2010

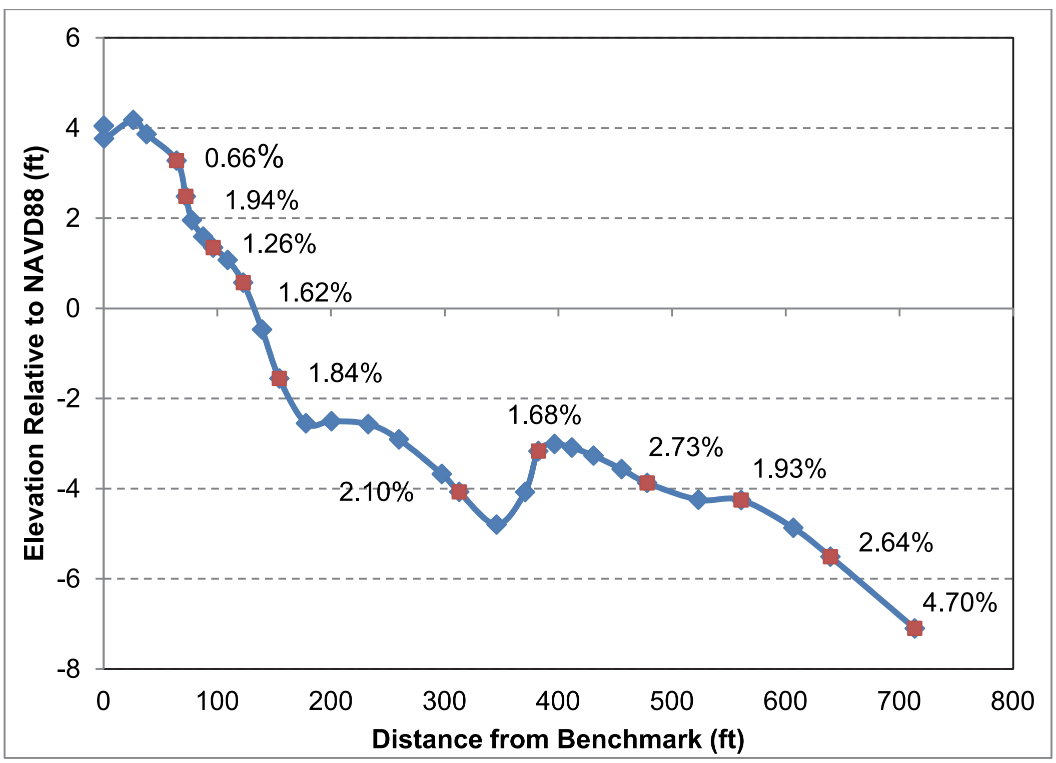


June 2011

Figure 59. Sediment samples showing percent mud content along profile FMB 35, within the berm area.



April 2010



June 2011

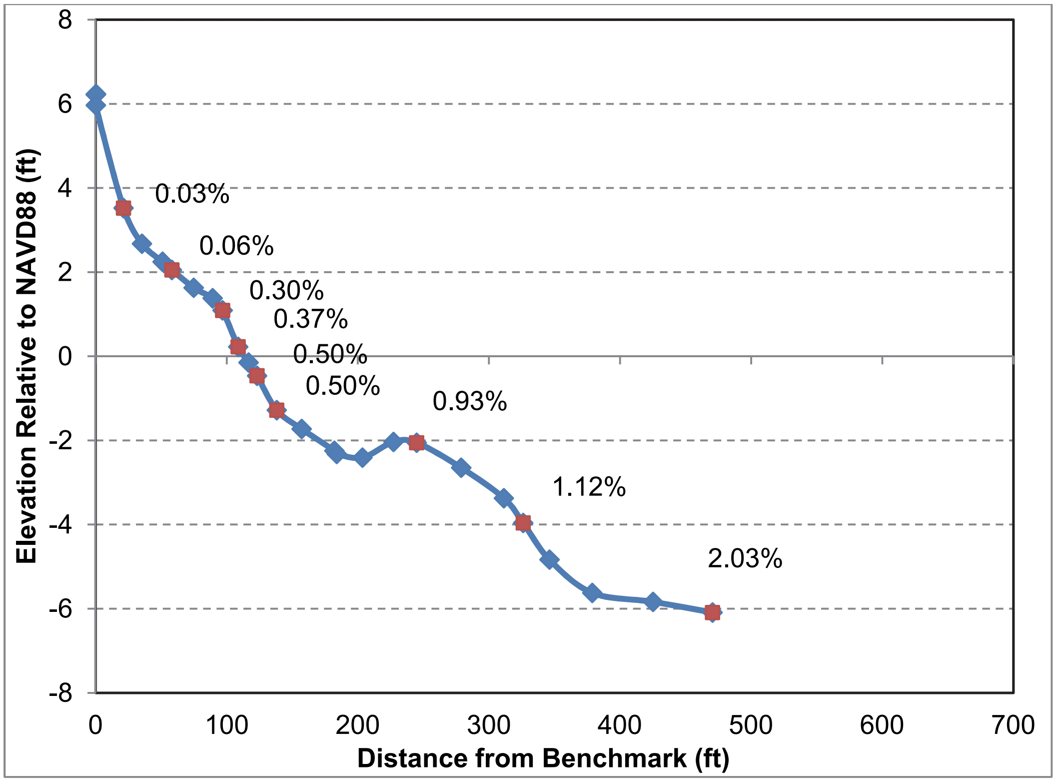
quiescent areas such as the calmer offshore zone or the back bay. In other words, the turbulent energetic conditions in the nearshore zone prevent mud from being deposited and preserved in the long term. Future studies focusing on particle tracking in mud suspension and deposition are recommended to verify the above hypothesis. Regionally, a northwestward decrease of mud content in the offshore area is apparent, likely controlled by regional geology.

Control Area Northwest of Berm

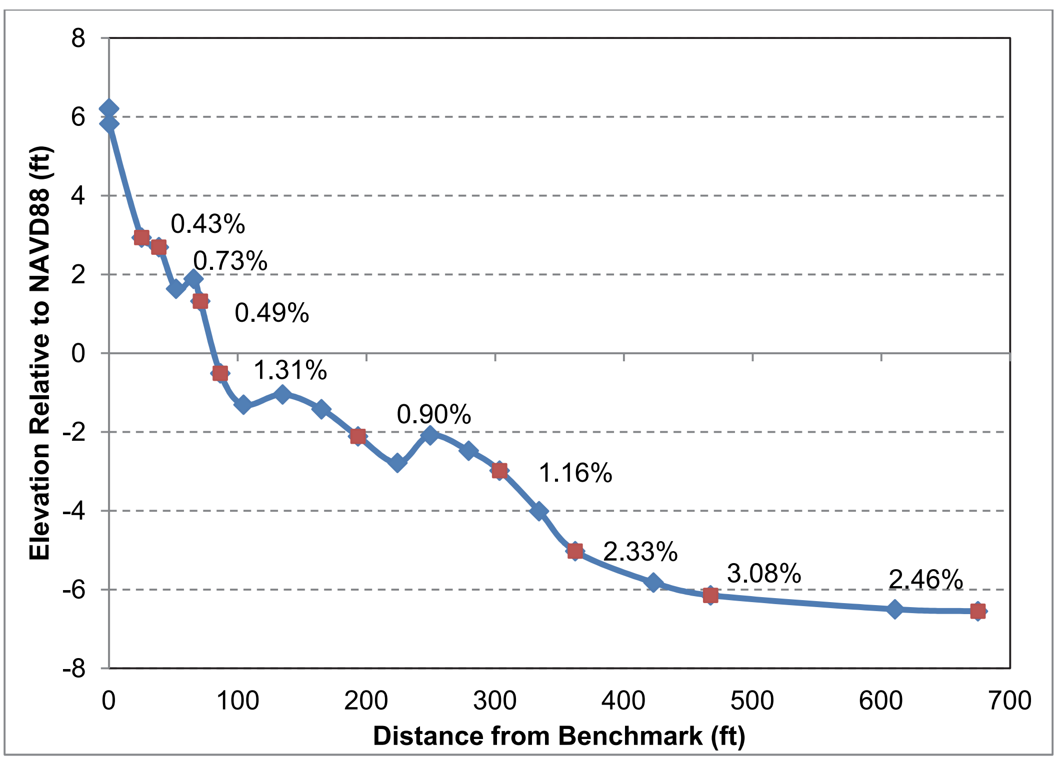
Profile FMB 53 is located in the control area about 2000 ft northwest of the berm project (Figure 60). Approximately 1 percent more mud was measured in the offshore area deeper than 6 ft during the June 2011 sampling as compared to the April 2010 sampling. Other than the slight difference in the offshore samples, mud content in the rest of the samples was within 1 percent in difference. Overall, less than 3 percent of mud was measured across the entire profile in both April 2010 and June 2011. This is quite different from the relatively mud-rich southeast control site, representing a regional trend of northward decreasing mud content in the offshore sediment. Similar spatial and temporal changes of sediment properties were also measured at other sampling lines (Appendix E).

In summary, an apparent regional trend of mud content in the offshore sediment was measured, with much higher mud content in the southeast control site, decreasing toward the northwest. The dry beach and intertidal zone is composed mostly of well-sorted fine sand with less than 3 percent mud content. The berm crest, landward slope of the berm, and seaward slope of the berm are mostly composed of fine sand with generally less than 3 percent mud. Patches of high mud content were measured in the deeper portion of the trough at one location in April 2010. This mud patch was not observed one year later in June 2011. This, along with a general trend of coarsening in the trough area and fining in the offshore area as measured along almost all the sediment sampling lines, suggests a trend of offshore-directed selective transport of fine mud fractions toward deeper and more quiescent waters. It is hypothesized here that energetic and highly turbulent conditions in the nearshore zone should suspend the mud-sized sediments and their suspension be maintained until they are transported to less turbulent water in the offshore zone. Future studies are recommended to verify the above hypothesis.

Figure 60. Sediment samples showing percent mud content along profile FMB 53, northwest control area.



April 2010



June 2011

Carbonate Content and Its Temporal Changes

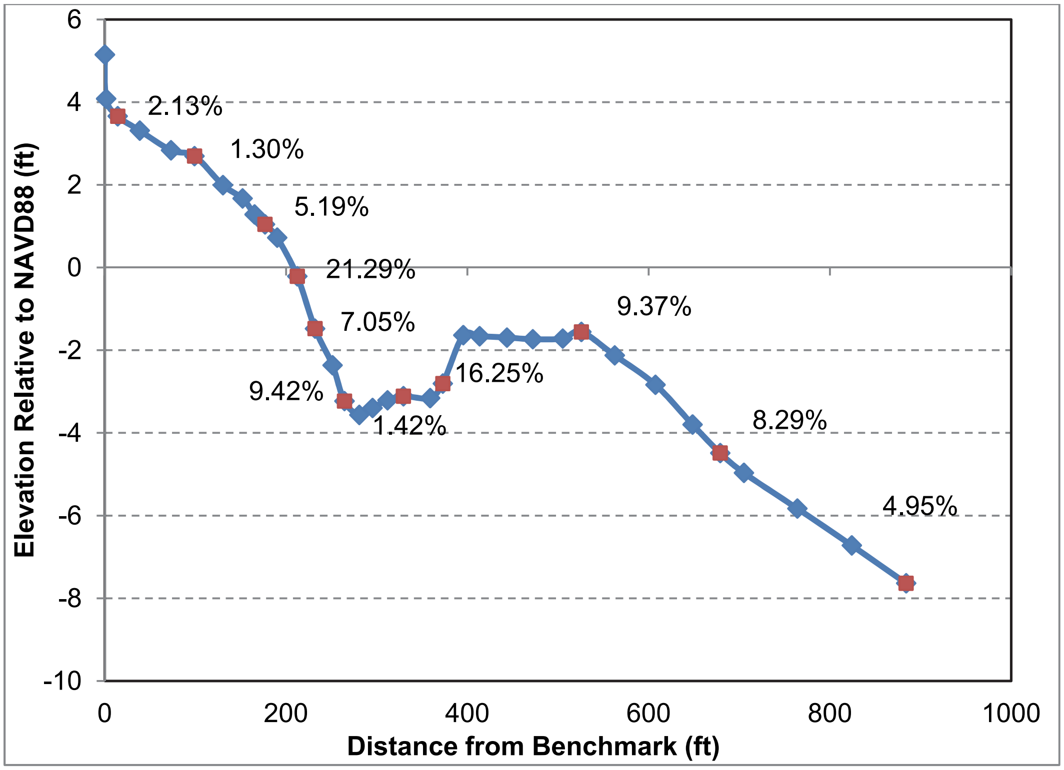
In both the nearshore berm area and the control areas, almost all the larger fractions (gravel to medium sand) are composed of carbonate grains. Therefore, the carbonate concentration can be used qualitatively to indicate the overall fractions of coarse sediment. However, some complications in this characterization arise and are discussed in the following.

Figure 61 illustrates the cross-shore distribution of carbonate contents along a sample line in the middle of the berm project. All of the sample lines are illustrated in Appendix F. Generally, a relatively high content of carbonate grains is found in three zones: the swash, the landward slope of the berm, and the offshore area. Comparisons among all the swash zone samples indicate that the carbonate concentration varies substantially both temporally and spatially (Appendix F). This is influenced by the large cross-shore variation of shell debris in the swash zone and the specific sampling location. During the sampling, a relatively thin line of shell hash was often observed in the swash zone and moves across-shore with tidal fluctuations. If the sample happened to be collected at the shell hash line, a very high carbonate concentration was obtained. Otherwise, relatively lower carbonate concentrations were found in the swash zone. As a result, large variations of percent carbonate shell fragment content, from about 5 percent to nearly 60 percent, are found in the swash zone samples.

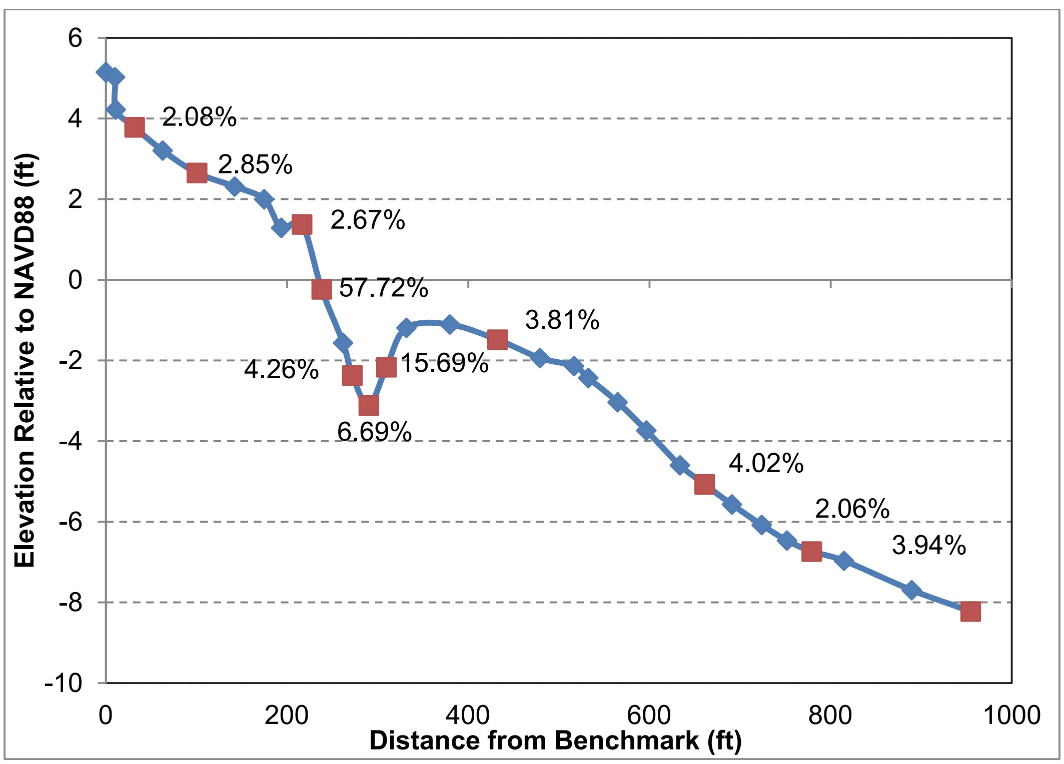
Despite the large variations, carbonate concentration in the swash zone was much higher than that at other locations across the profile. This is related to selective sediment transport processes in the swash zone. Finer grains are suspended in this relatively high energy environment and tend to be transported away from the swash, leaving a zone of concentrated coarse grains.

Relatively high carbonate contents, mostly between 10 percent to 20 percent, were measured at the landward slope of the nearshore berm, or the landward toe of the berm, although considerable longshore variations were observed (Figure 61 and Appendix F). In general, the landward slope of the berm has the highest carbonate content across the entire berm. This suggests that coarser carbonate grains tend to be selectively transported onshore and deposited along the landward slope of the berm. As discussed above, concerning mud contents, the fine mud fractions have a tendency to be transported offshore while the coarser sand fractions tend to be transported onshore.

Figure 61. Sediment samples showing percent calcium carbonate along profile FMB 28, middle of berm project.



April 2010



June 2011

A moderately high concentration of carbonate was also measured in some of the offshore samples, especially those from the southeastern portion of the berm project area, e.g., at FMB 17 (Appendix F). This seems to conflict with the high content of mud there. However, visual inspections of the sediment samples revealed that the shells in the offshore samples are often whole, articulated shells that grew in-situ, as opposed to shell debris in the swash zone. Therefore, the carbonate content in the muddy offshore samples should not indicate active selective transport of coarse grains (as illustrated in the swash zone and along the landward slope of the berm); instead, the offshore area favors the deposition of fine grains with in-situ biogenic grains.

Temporal and Spatial Variations of Overall Sediment Characteristics

This section summarizes the overall characteristics of the sediment through spatial and temporal averaging. The goal is to summarize the sediment characteristics. Figure 62 illustrates the temporally-averaged mean grain size of April 2010 and June 2011 samples from the dry beach, intertidal zone, and offshore areas. As expected, the offshore area has the finest sediment, ranging from approximately 3.0 phi in the berm project area and northwest control area to 3.6 phi in the southeast control area. The intertidal zone has the coarsest sediment ranging from 2.1 phi to 2.5 phi. The intertidal zone also has the largest standard deviation about the mean as indicated by the long error bar. The dry beach has the most uniform sediment of approximately 2.7 phi along the entire study area including both the berm area and control areas.

At the southeast control site, the June 2011 samples are slightly finer on the dry beach and in the offshore areas than the April 2010 samples (Figure 63). The finer intertidal samples in June 2011 are likely influenced by sampling variations in the swash zone, as discussed above.

Within the berm area, two additional sub-zones, the trough and berm crest, were distinguished and spatially averaged (Figure 64). Similar to the southeast control site, the dry beach is slightly finer, and the intertidal zone is modestly finer in June 2011 as compared to April 2010 samples. However, the trough area became considerably coarser in June 2011, due to the disappearance of the muddy patch along profile FMB 22 and overall decrease of mud in the trough. The berm crest and offshore area became considerably finer. This temporal change seems to confirm the tendency of offshore-directed transport of muddy components discussed above, based on cross-shore distribution of mean grain size and mud content.

Figure 62. Temporally-averaged mean grain size of April 2010 and June 2011 samples from the dry beach, intertidal zone, and offshore areas, illustrating spatial variations in grain size.

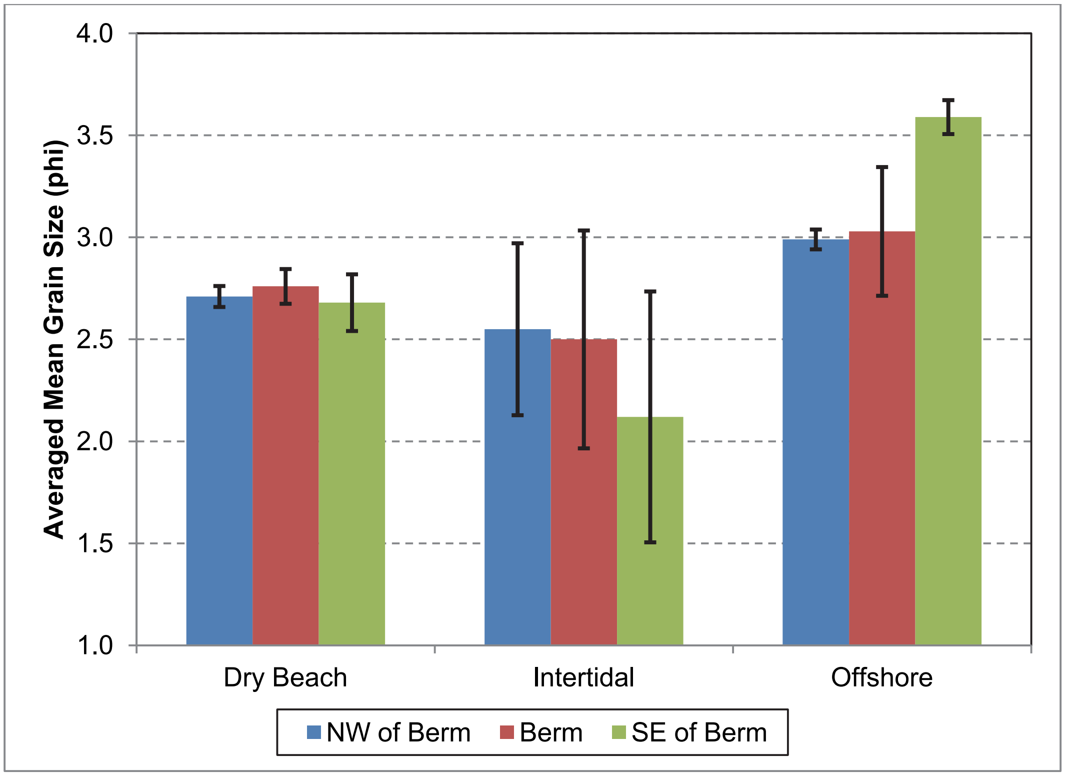


Figure 63. Averaged mean grain size of samples from the dry beach, intertidal zone, and offshore areas southeast of the berm, illustrating spatial and temporal variations in grain size.

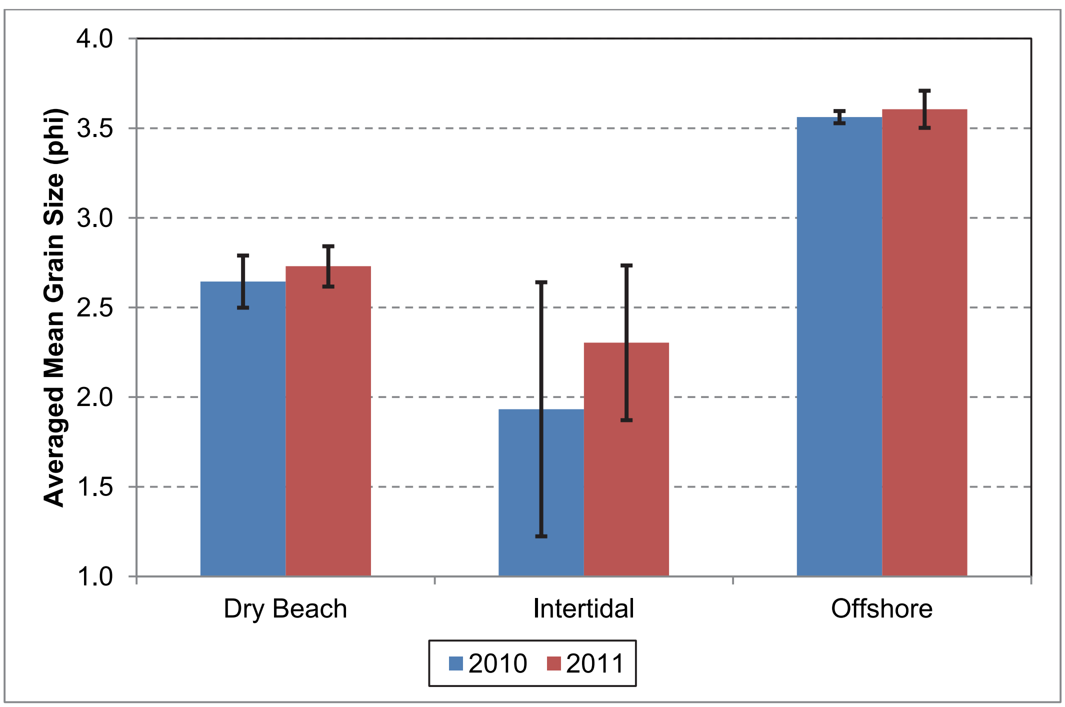
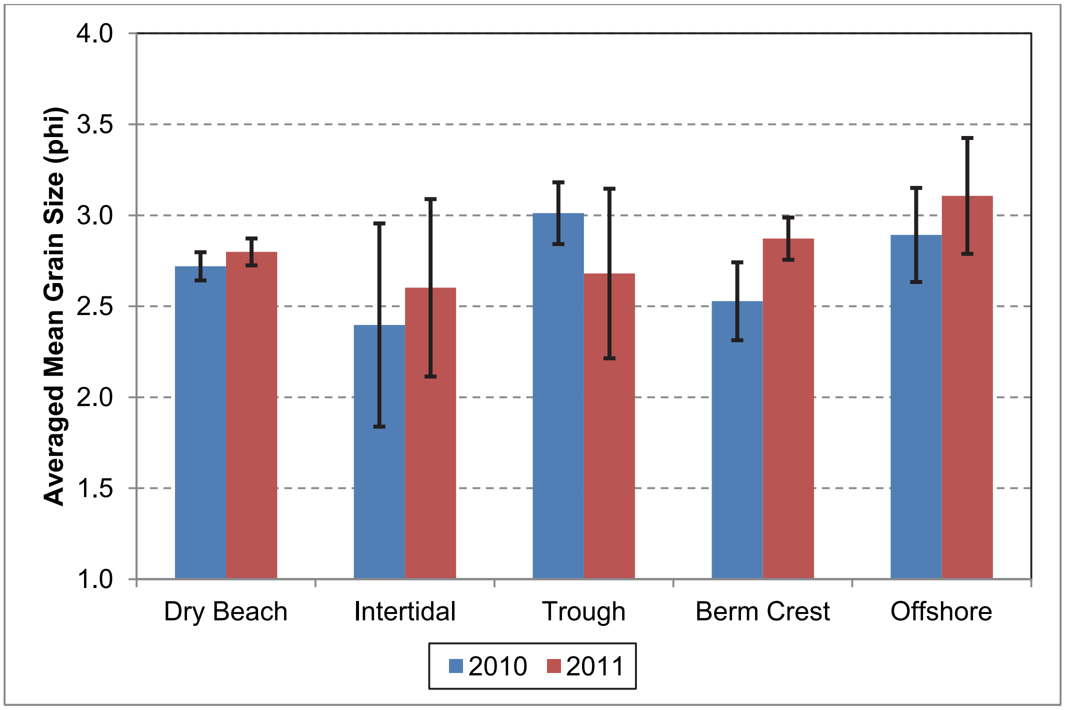


Figure 64. Averaged mean grain size of samples from the dry beach, intertidal zone, and offshore areas in the berm area, illustrating spatial and temporal variations in grain size.

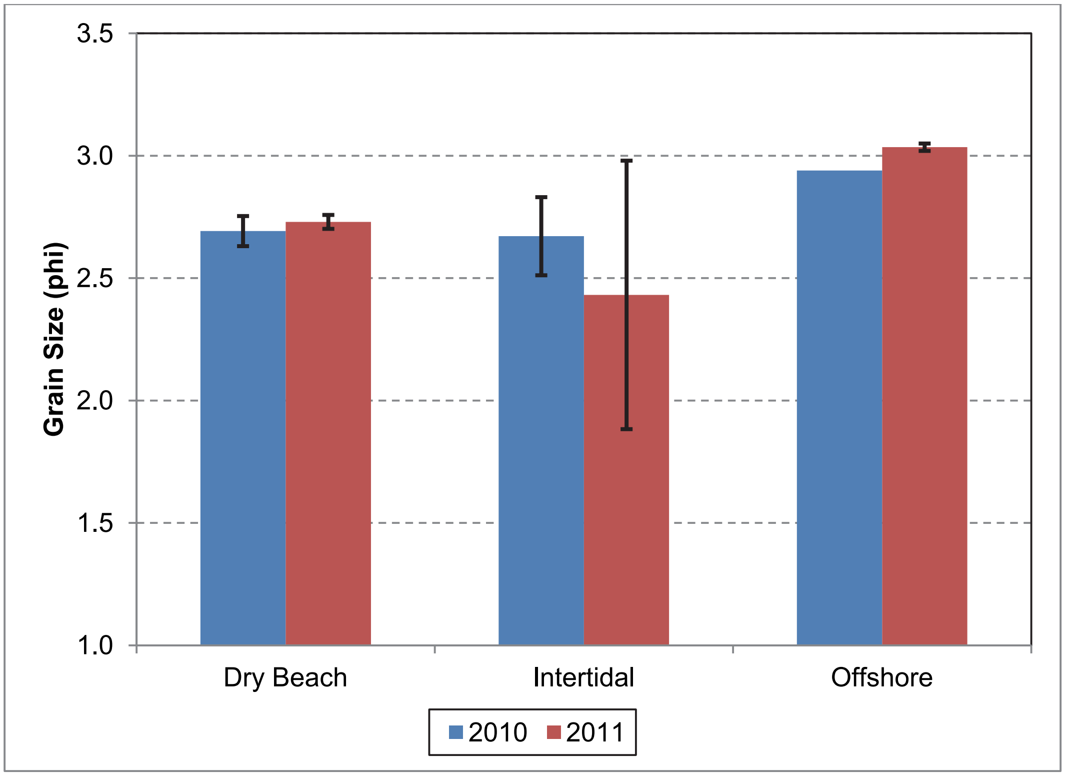


In the northwest control site, the dry beach and offshore area became slightly finer in June 2011, as compared to April 2010 (Figure 65), similar to that at the southeast control site. However, the intertidal zone became coarser, likely influenced by the sampling variations in the highly variable swash zone. Overall, throughout the entire study area including both the berm area and the control areas, the dry beach sediment remains rather constant over time and space, with a mean grain size of 2.7 phi. This suggests that the berm nourishment did not have any influence on the sediment characteristics over the dry beach both temporally or spatially. Specifically, the finer sediment and the finer fractions in the placement material had no influence on the sand quality on the dry beach. This also agrees with the limited morphology changes measured along the dry beach.

Comparison of Surface and Subsurface Samples

The goals of coring in the berm project and control areas were to distinguish the nourished sediment from the native sediment and to determine if the fine sediment in the offshore was limited to the surface or distributed throughout a certain depth. Figure 66 shows several examples of the cores. Comparing the core through the berm crest and the nearshore cores in the control areas, it is difficult to identify the boundary between the nourished

Figure 65. Averaged mean grain size of samples from the dry beach, intertidal zone, and offshore areas northwest of the berm, illustrating spatial and temporal variations in grain size.



sediment and the native sediment. The muddy sediment distributed on the surface in the offshore area, especially in the southeast control area, also extends a considerable depth beneath the surface. In other words, the muddy sediment in the offshore area is not solely related to the berm nourishment but is likely controlled by the regional geological characteristics of the offshore portion of the greater study area.

Surface sediment is, on average, coarser than the subsurface sediments in the trough, over the berm crest, and in the offshore area (Figure 67). Although it is not certain why the surface sediment is overall coarser than the subsurface sediment, it is likely that some of the finer fraction is winnowed away from the surface sediment especially in the nearshore zone.

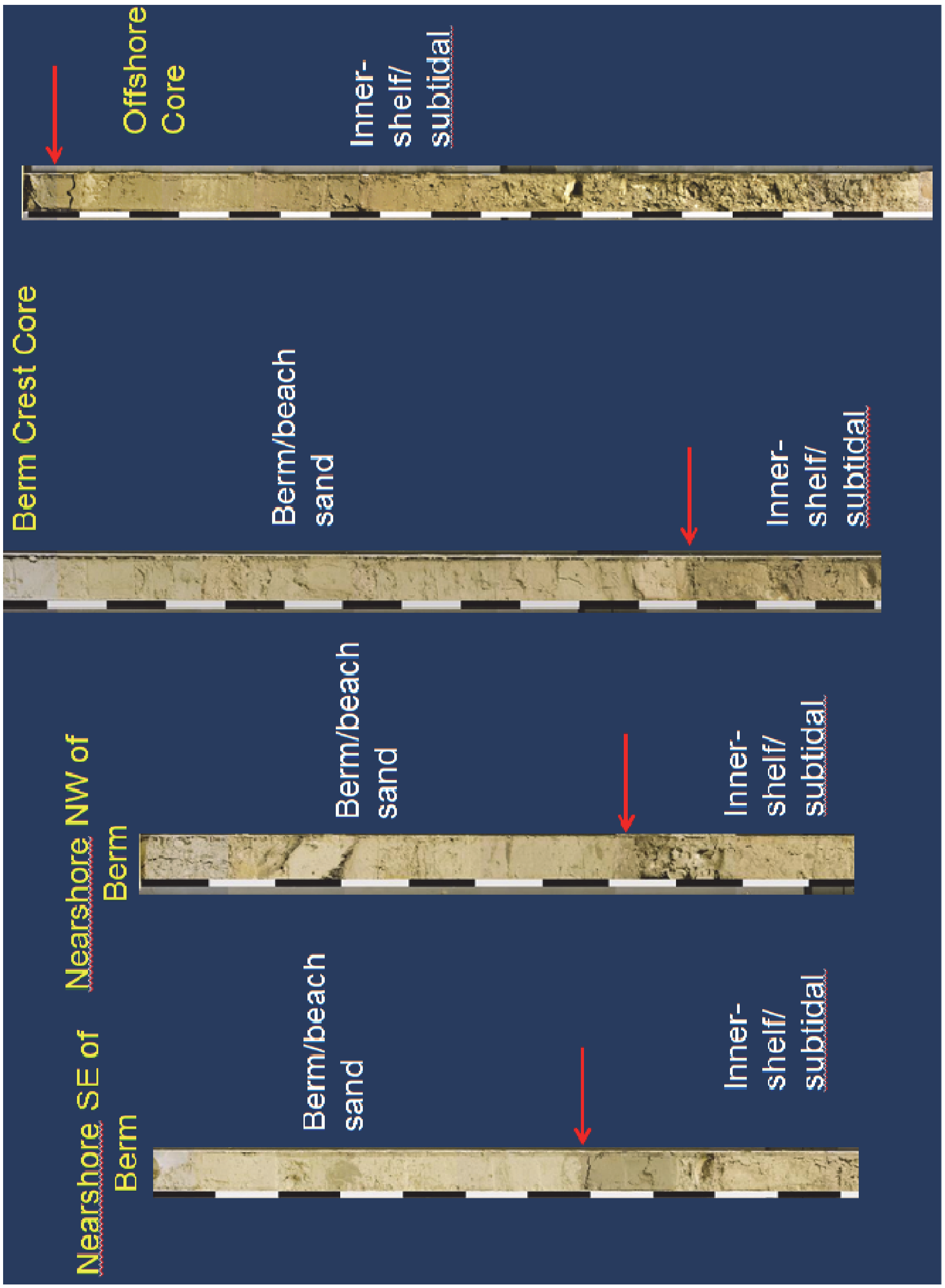
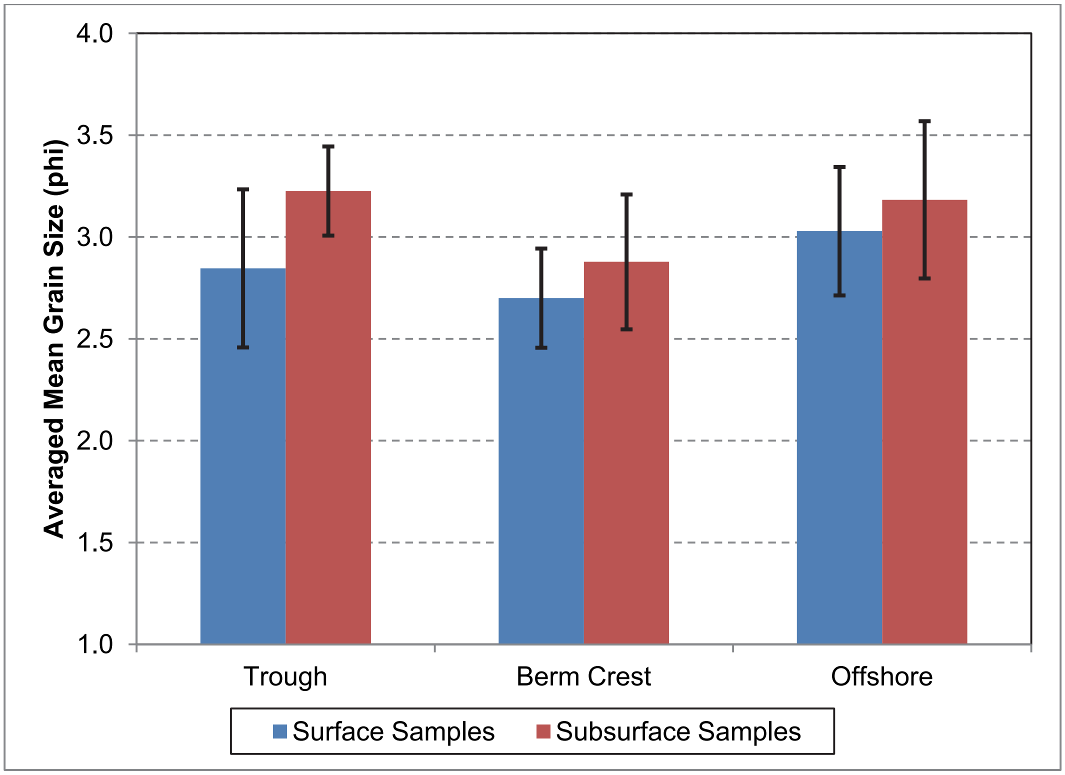


Figure 66. Example of core photos; the black and white scale is at 10-cm intervals.

Figure 67. Overall comparison of surface and subsurface samples.



8 Discussion of Findings

In comparison to other monitoring studies in the literature (Table 1), the Ft. Myers Beach nearshore berm was one of the shallowest placements studied, and under a low-wave energy regional setting. The berm was constructed in the morphologic form of a nearshore bar with several gaps and depressions initiated during dredging-construction operations. This section discusses the findings of the detailed morphologic and sedimentologic evolution of the artificial nearshore berm based on intensive field data collection and analysis.

Morphological Evolution of the Artificial Nearshore Berm

Compared to most of the relatively well documented existing artificial nearshore berm projects (Table 1), the Ft. Myers Beach nearshore berm was placed in much shallower water at -5 to -9 ft NAVD88. The entire berm was placed in the littoral zone and subject to active sediment transport induced by breaking waves during both stormy and normal conditions. The berm was constructed in the shape of a nearshore bar but with considerable longshore variations in terms of berm height, width, berm-crest elevation, overall shape, and distance to shoreline. In addition, several gaps or depressions, which were created during the construction, served as return flow access channels through the bar. These gaps/depressions may be necessary to maintain adequate water circulation and therefore water quality landward of the nearshore berm. At Ft. Myers Beach, the gaps also provide a positive recreational use as they allow an entrance channel used by various recreational vehicles, e.g., jet skis and parasail boats, to access the shoreline. The morphologic evolution of the nearshore berm and the gaps/depressions is discussed here based on the time-series beach evolution.

The study area is characteristic of a low-wave energy environment. The protruding Sanibel Island to the north reduces the influence of passages of winter cold fronts by limiting the fetch of north to northwest winds. The frequent passages of winter cold fronts, every 10 to 14 days, and associated relatively high and obliquely north incident waves, and the subsequent net southerly longshore sediment transport are the main drivers of the morphodynamics along the West-Florida Gulf coast barrier islands (Wang and Beck 2012). However, due to the reduced forcing from the north by the sheltering of Sanibel Island, net longshore transport along the study area does not appear to be directed to the south. No apparent morphologic evidence can be found to suggest an apparent direction of net longshore transport. In the immediate vicinity of Matanzas Pass, the longshore sediment transport is toward the north, as illustrated by the northward growth of the spit. Along the project area, net trend of longshore transport is not apparent.

During the 2-year study period, no extreme tropical storm impacted the study area. Therefore, the findings here do not represent changes induced by extreme storms. Typical winter storms and localized summer storms comprise the energetic conditions during the study period.

Similar to the initial morphologic response of many existing active berms that were placed farther offshore and in deeper water, onshore migration of the Ft. Myers Beach nearshore berm was measured over the 2-year study period. The onshore migration was especially active during the initial 9 months, especially the first winter season following construction. Also, similar to the findings on many existing deeper berms, no offshore-directed migration was measured during the 2-year period. Qualitatively, the rate of onshore migration is proportional to the overall wave energy during the study period. A greater rate of onshore migration of the berm was measured during the more energetic winter season than during the calmer summer season. In addition, the rate of onshore migration is also a function of time after construction, i.e., decreasing with the time interval after construction. The initial migration rate of 200-300 ft/yr of the constructed symmetrical berm was much faster during the first winter season than during the rest of the 2-year study period. The average winter season berm migration rates were 150-200 ft/yr with much lower summer rates of 50-75 ft/yr. Overall, although considerable longshore variations existed, the nearshore berm has migrated onshore for approximately 300 ft with the berm crest elevation increased up to 2 ft. On average, the constructed berm was about 370 ft from the MHHW (Table 3). Therefore, at the end of the 2 years, the berm has migrated onshore covering over 80 percent of the original distance to the shoreline. In addition to the low-wave energy setting, this lack of appreciable alongshore volumetric change may be indicative of the project being located at the local nodal zone of net alongshore sediment transport.

The constructed berm has a symmetrical bell shape. The shape of the berm changed rather rapidly during the first winter season to an asymmetrical shape that is commonly observed for an onshore migrating bar (Larson and

Kraus 1992; Roberts and Wang 2012). This asymmetrical shape was maintained over the 2-year period. Morphodynamics of natural bars in a state of dynamic equilibrium differ from that seen at Ft. Myers Beach. Natural bars tend to migrate offshore and become symmetrical during energetic proximal storm conditions and migrate onshore, becoming asymmetrical, during prolonged calm weather, as documented in various locations, e.g., west-central Florida coast (Roberts and Wang 2012; Roberts et al. 2009) and Duck North Carolina (Larson and Kraus 1994). No offshore migration or bar-shape change toward a symmetric shape was measured during the 2-year period. This may be influenced by the overall low wave energy at the project site and absence of any extreme storms during the 2-year period.

The gaps/depressions originated from the berm construction were dynamically maintained during the 2-year study period. Some of the gaps were perpendicular to the berm while some were highly oblique. Longshore migration of the shore-perpendicular gaps was measured, although with limited migration distance. Some of the highly oblique depressions were filled as the berm migrated onshore. No apparent trend toward longshore uniformity over the entire project area was measured during the 2 years. This seemed to indicate that the morphologic variations, in this case artificially initiated, had substantial influence on the morphodynamics of the nearshore berm placed in a low-wave energy environment. If we assume that the beach profile shape before berm placement and in the control areas represent an equilibrium state, then the beach-nearshore profile within the berm project area has not yet reached equilibrium after the first 2 years. This is different from the findings of van Duin et al. (2004) and Kroon et al. (1994) along the much higher energy Terschelling and Egmond coasts in the Netherlands, where the equilibrium 2-bar profile was restored within 2 years after the berm placement.

Based on field observations during the profile survey and sediment sampling, the gaps/depressions within the berm project area served several beneficial functions including water circulation and vessel access. The gaps/depressions in the Ft. Myers Beach berm were originated during dredging-construction operations as opposed to being designed. The relatively wider and deeper gaps were dynamically maintained during the 2-year period. Based on the findings from this study, designed gaps for littoral zone nearshore berms, especially those under low-wave energy settings, are recommended. The gaps can have several beneficial functions including 1) improving the flushing capacity of the trough to maintain ambient water quality measures, 2) allowing a controllable amount of wave energy to arrive at the shoreline, and 3) providing recreational vessel access to the beach. Therefore, gap design should at least consider the aforementioned three factors.

The overall volume of the Ft. Myers Beach nearshore berm was largely maintained within the design area during the first 2 years, decreasing only 15 percent. This suggests that longshore spreading was not significant. It is worth noting that the design berm placement area included some distance onshore. In other words, a portion of the nearly 300-ft onshore berm-crest migration was within the designed berm area. The distance of onshore migration of the berm crest is also partially influenced by the change in shape of the berm from a symmetrically constructed bell shape to an asymmetrical shape with a steep landward slope.

Although the nearshore berm has migrated onshore and become quite close to the MSL shoreline, most sections of the berm have not attached to the shoreline. The shoreline and dry beach above MSL remained stable over the 2-year period within the berm project area as well as along the adjacent beaches. The nearshore berm remains located within the surf zone under typical weather conditions and functions as a submerged, intertidal breakwater. Contrary to the typical behavior of submerged, intertidal breakwater, the impacts on the landward shoreline, especially that near the two ends of the berm, have not been significant in that no large salients or tombolos were developed at the two ends of the project. This may be controlled by the overall low incident wave energy and small gross longshore transport rate along the study area particularly during this 2-year monitoring period with no significant tropical storms. The *natural* sand-bar shape of the artificial nearshore berm with gentle end slopes may also contribute to the limited end effects.

Future studies should include continued monitoring of the morphologic evolution of the nearshore berm. Questions to answer include the following:

1. With time, will the berm reach a dynamic equilibrium shape and respond to high energy conditions by moving offshore and swell conditions by moving onshore, as observed by Roberts and Wang (2012) along west-central Florida Gulf barrier islands?

2. Will the onshore berm migration continue and result in an eventual MSL shoreline attachment?
3. What hydrodynamic conditions would trigger shoreline attachment: A gradual process or an event driven process?
4. If the berm attaches, the shoreline configuration will be changed considerably; how will this influence the adjacent beaches?
5. If the berm attaches, will the sand be transported above MHHW and accrete the dry beach and how?
6. How will the gaps evolve in the long term?

Temporal and Spatial Distribution of Sediment Characteristics

Based on pre-construction surface and subsurface sediment sampling and analysis, the dredged materials were determined to have an overall 7.71 percent mud content. The spatial distribution of the mud was not uniform, with some cores containing layers of fine grained sediment with mud content ranging between 9.9 percent to 16.2 percent. It is therefore expected that certain areas of the nearshore berm may contain more fine grained sediment than other portions. This resulted in some heterogenity in the sediment properties of the nearshore berm as reflected in a few areas of concentrated mud patches in the trough (e.g., at profile FMB 22 during the April 2010 sampling, Appendix E), and several thin (< 1 in.) layers of fine sediment in the cores from the nearshore berm. The patches of fine sediment were transported and dispersed offshore by the second year as indicated by the June 2011 sampling.

Overall properties of the nearshore berm sediment compare well with sediment from similar cross-shore locations in the control areas. In most of the cores drilled through the artifical berm, the boundary between the artifical berm and the native sediment was not readily identifiable especially for the cores through the landward slope, the berm crest, and the nearshore portion of the seaward slope. No significant differences in sediment properties, e.g., mean grain size, sorting, and mud content, could be identified among sediment samples from comparable morphologic locations (e.g., berm crest and bar crest) at the aritfical berm and in the control areas. However, there is a regional trend in the offshore area with much finer sediment in the southeastern portion of the study area as compared to the sandy northwest area.

Overall, the dry beach was composed of well-sorted fine sand in both the berm project area and control areas. The sediment properties on the dry beach remained stable over the 2-year study period. Surface sediment in the intertidal zone ranges from bi-modal shelly sand in the active swash zone to well-sorted fine sand in the rest of the intertidal zone in both the project area and control areas. The overall surface sediment grain sizes were slightly finer during the June 2011 sampling as compared to the April 2010 sampling, likely influenced by the particular wave energy during the sampling of this dynamic zone. The placement of the nearshore berm and the subsequent onshore migration of the berm had little to no influence on the dry beach sediment properties over the 2-year period.

During the April 2010 sampling, 9 months after the berm placement, the trough between the nearshore berm and the intertidal zone was found to have the finest sediment with relatively higher mud content. Several patches of fine-grain sediment were observed during the field campaign with a sampling line extending through a patch. The high mud content of over 40 percent measured in a sample collected in April 2010 was not measured 1 year later in the June 2011 sample from the similar location. Over time, the sediment in the trough has become coarser.

The surface sediments from the landward slope of the artifical berm are generally coarser with higher content of coarse shell debris than sediment from the berm crest and along the seaward slope of the berm. The berm crest and seaward slope of the berm is composed of well sorted fine sand. The surface sediment characteristics from the artifical berm crest and the seaward slope of the berm have remained rather constant over time. The relatively coarse and also temporally coarsening sediments along the landward toe of the berm suggest that coarser fraction of the berm material has been transported and deposited onshore.

The surface sediments in the offshore region have the greatest change in sediment characteristics. A regional trend of sediment grain size and mud content was measured: Finer sediment with higher mud content occured in the southeast offshore control area, with mean grain size increasing and mud content decreasing toward the northwest. This regional trend is controlled by the original compostion and regional geology. However, a higher mud content was measured in nearly all of the offshore sediment samples collected in June 2011 than in April 2010, indicating that the offshore sediment has gained finer material over time. On average, the surface sediments in the berm area were coarser with less mud content than the sub-surface sediments. This, combined with the occurance of coarsening sediment along the landward slope of the berm and increasing fines in the offshore, suggest that as the nearshore berm migrated toward the shore, selective sediment transport and deposition resulted in onshore transport and deposition of coarser sediment and offshore transport and deposition of the finer sediment. It is hypothesized that the transport of coarse sand landward over the berm occurred as bedload transport and that the fines were transported offshore as suspended-load transport.

9 Summary and Future Study

The Ft. Myers Beach nearshore berm migrated onshore as a discrete morphologic form of a nearshore bar. The onshore migration continued during the 2-year study period with little to no impact to the adjacent shoreline and dry-beach profile. The berm migrated onshore for nearly 300 ft during the first 2 years. The crest elevation of the bar-shaped berm increased up to 2 ft, roughly at or below MLLW immediately post-construction to slightly below MSL 2 years afterward. Generally, nearly half, or about 150 ft, of the onshore migration occurred during the first 6 winter months after the construction. More active onshore migration was measured during the more energetic winter season than during the calmer summer season. Migration rates varied between 150-200 ft/yr in the winter to 50-75 ft/yr during the summer. No offshore migration was measured during the 2-year study period.

The shape of the artificial nearshore berm evolved from a roughly symmetrical bell-shaped bar to a highly asymmetrical shape with a steep landward slope typical of a landward migrating nearshore bar. At the end of the 2-year study period, the nearshore berm migrated to approximately 50 to 150 ft from the MSL shoreline. The nearshore berm has not attached to the shoreline at the end of the 2-year study. The dry beach above the MSL along the entire study area, the berm location and adjacent beaches, remained largely stable over the 2-year period. The overall volume of the berm was largely maintained within the designed placement area with a decrease of only 15 percent over the first 2 years, indicating limited longshore spreading. In addition to the low-wave energy setting, this lack of appreciable alongshore volumetric change may be indicative of the project being located at the local nodal zone of net alongshore sediment transport.

Considerable longshore variations in the constructed berm morphology occurred during the three phases of placement. The berm height, width, elevation, distance to MHHW shoreline, and overall shape varied considerably alongshore. In addition, several gaps/depressions existed. Despite onshore migration and upward aggradation of the berm and change in berm shape, the large variability in longshore morphology persisted and did not evolve toward alongshore uniformity during the 2-year study period. The gaps were largely maintained over the 2-year study period despite some measured longshore and cross-shore changes. The gaps in the nearshore berm served several beneficial functions. It is recommended that gaps, or depressional features, should be considered as an environmental design parameter.

A primary concern of this project was the dispersion and subsequent deposition of finer sediment following placement. Results of surficial and substrate sampling indicated that some of the finer material initially migrated into the nearshore trough and then was dispersed further offshore after a little over one year. Sediments along the shoreface, within the swash zone and intertidal zone, were found to have a considerable variability in grain sizes from well-sorted fine sand to poorly-sorted shelly sand. Based on time series sediment sampling in the berm project area and control areas, the nearshore berm had negligible influence on the characteristics of the dry beach sediment which remained to be well-sorted fine sand. Over time, the sediment along the landward slope of the berm was found to become coarser than the original placement material, suggesting that the coarser sandy fractions of the sediment were being transported and deposited landward, likely in the mode of bedload transport. The time series sediment sampling and analyses also revealed an increased concentration of mud in the offshore which suggests an offshore-directed transport and deposition of the finer muddy fractions, likely in the mode of suspended load transport.

Overall, a trend of onshore-directed transport and deposition of coarser sand fractions of the dredged material and offshore directed transport and deposition of fine fractions was revealed by the sediment sampling and analyses. This provides a favorable condition for nearshore placement of dredged material composed of mixed sand and mud.

Future studies on the evolution of the Ft. Myers Nearshore Berm should include continued monitoring of the berm and any future modifications to the region. Next steps and crucial questions not addressed in this study include the following:

1. If the trend of onshore migration continues, when and under what wave conditions will the berm become attached to the shoreline?
2. Over a longer term, will the berm profile evolve toward the regional equilibrium beach profile?
3. Over a longer term, will the berm evolve toward longshore uniformity?

4. Over the 2-year study period, no significant tropical storms impacted the study area: How will the berm behave under the extreme wave conditions associated with tropical storms?
5. Future work should include more process based measurements and numerical modeling of hydrodynamics and the processes of sediment transport and deposition to verify the interpretation and hypotheses generated here, including, the nearshore berm's influence on wave propagation patterns, flows through the gaps, and the mode of selective sediment transport and deposition of mixed sediments.

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Appendix A: Sediment Analysis Data

The following appendix contains grain size analysis data for each of the samples collected. Percentages of gravel, sand, mud, and carbonates are given. Mean grain size (x_Φ) and sorting (σ_Φ) were calculated using the moment method and recorded in the tables along with their corresponding size and sorting class according to the Wentworth scale. Both wet and dry color is recorded using the Munsell Color Chart. The dry color is recorded for the coarse fraction only. Sample lines FMB 3, FMB 6, FMB 9, FMB 13, FMB 53, and FMB 56 are within the control areas outside of the berm project area. Sample lines FMB 17, FMB 22, FMB 28, FMB 35, and FMB 46 are located within the berm project area. Sample number increases seaward starting at sample 1. In the control areas, surface sediment samples were taken at approximately the toe of the dune (where present), backbeach, high tide line, mean sea level, low tide line, 2-ft water depth, 4-ft water depth, 6-ft water depth, and 8-ft water depth. In the berm area, surface sediment samples were taken at approximately the toe of the dune (where present), backbeach, high tide line, mean seal level, low tide line, roughly in the middle between the berm and the shoreline, landward toe of the berm, midway up the landward slope of the berm, top of the berm, and seaward approximately every 100 ft until about 8-ft water depth, and at 8-ft water depth relative to NAVD88. Figure A1 illustrates the locations of the sample lines.

Figure A1. Locations of sediment sampling transects.

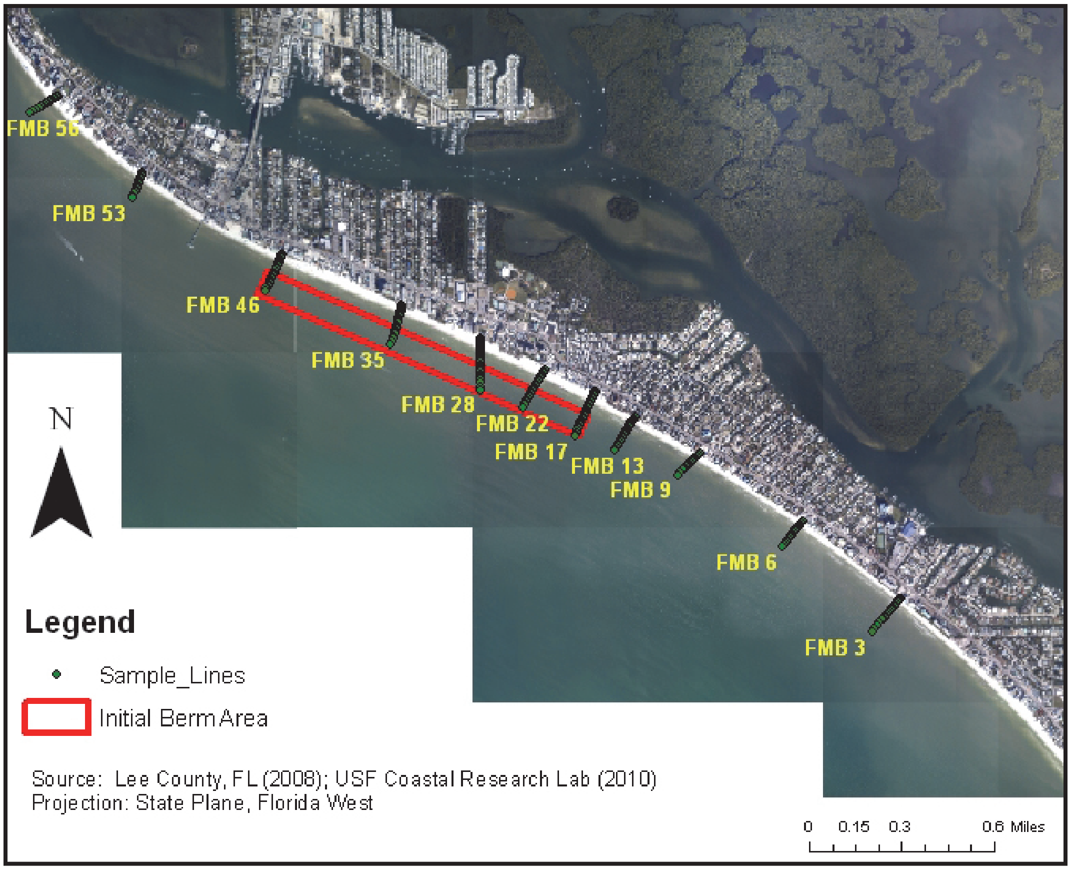


Table A1. Grain Size and Color Analysis Data from FMB 3 (2010), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 3-1	% Gravel	0.00	xΦ=	2.71	σΦ=		0.38
	% Sand	99.68	Size:	Fine Sand	Sorting:	Well sorted	
	% Mud	0.32					
	% Carbonates	8.82					
FMB 3-2	% Gravel	0.00	xΦ=	2.73	σΦ=		0.36
	% Sand	99.57	Size:	Fine Sand	Sorting:	Well Sorted	
	% Mud	0.43					
	% Carbonates	3.23					
FMB 3-3	% Gravel	2.34	xΦ=	2.42	σΦ=		1.12
	% Sand	96.47	Size:	Fine Sand	Sorting:	Poorly Sorted	
	% Mud	1.19					
	% Carbonates	16.20					
FMB 3-4	% Gravel	16.08	xΦ=	1.21	σΦ=		1.94
	% Sand	82.68	Size:	Medium Sand	Sorting:	Poorly Sorted	
	% Mud	1.24					
	% Carbonates	49.78					
FMB 3-5	% Gravel	0.55	xΦ=	2.85	σΦ=		0.67
	% Sand	97.66	Size:	Fine Sand	Sorting:	Moderately Well sorted	
	% Mud	1.79					
	% Carbonates	7.18					
FMB 3-6	% Gravel	4.55	xΦ=	2.51	σΦ=		1.33
	% Sand	93.97	Size:	Fine Sand	Sorting:	Poorly Sorted	
	% Mud	1.48					
	% Carbonates	15.46					
FMB 3-7	% Gravel	0.02	xΦ=	3.30	σΦ=		0.32
	% Sand	95.57	Size:	Very Fine Sand	Sorting:	Very Well Sorted	
	% Mud	4.41					
	% Carbonates	3.76					
FMB 3-8	% Gravel	0.00	xΦ=	3.79	σΦ=		0.38
	% Sand	58.60	Size:	Very Fine Sand	Sorting:	Well Sorted	
	% Mud	41.40					
	% Carbonates	20.39					
FMB 3-9	% Gravel	0.30	xΦ=	3.53	σΦ=		0.76
	% Sand	60.69	Size:	Fine Sand	Sorting:	Moderately Sorted	
	% Mud	39.01					
	% Carbonates	12.84					

Table A2. Grain Size and Color Analysis Data from FMB 3 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 3-1	% Gravel	1.53	xΦ=	2.54	σΦ=	0.94
	% Sand	98.03	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.44			Color:	
	% Carbonates	11.50	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 3-2	% Gravel	0.14	xΦ=	2.76	σΦ=	0.48
	% Sand	99.58	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.28			Color:	
	% Carbonates	3.24	Wet:	5Y 8/1	Dry:	5Y 8/1
FMB 3-3	% Gravel	0.52	xΦ=	2.76	σΦ=	0.67
	% Sand	98.99	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.49			Color:	
	% Carbonates	5.35	Wet:	5Y 7/2	Dry:	5Y 8/1
FMB 3-4	% Gravel	5.44	xΦ=	2.05	σΦ=	1.47
	% Sand	94.32	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.24			Color:	
	% Carbonates	26.19	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 3-5	% Gravel	3.29	xΦ=	2.46	σΦ=	1.20
	% Sand	96.30	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.41			Color:	
	% Carbonates	16.70	Wet:	5Y 7/1	Dry:	5Y 7/1
FMB 3-6	% Gravel	1.05	xΦ=	2.86	σΦ=	0.81
	% Sand	98.10	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.85			Color:	
	% Carbonates	7.55	Wet:	5Y 5/1	Dry:	5Y 7/1
FMB 3-7	% Gravel	0.42	xΦ=	3.07	σΦ=	0.54
	% Sand	98.84	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.74			Color:	
	% Carbonates	3.11	Wet:	5Y 6/2	Dry:	5Y 7/1
FMB 3-8	**Lost**					
FMB 3-9	% Gravel	0.06	xΦ=	3.60	σΦ=	0.40
	% Sand	83.83	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	16.12			Color:	
	% Carbonates	6.55	Wet:	5Y 5/1	Dry:	5Y 7/1

Table A3. Grain Size and Color Analysis Data from FMB 6 (2010), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 6-1	**Lost**					
FMB 6-2	% Gravel	1.36	$x\Phi$=	2.70	$\sigma\Phi$=	0.75
	% Sand	98.58	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.07			Color:	
	% Carbonates	4.17	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 6-3	% Gravel	1.77	$x\Phi$=	2.57	$\sigma\Phi$=	0.94
	% Sand	97.44	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.79			Color:	
	% Carbonates	10.42	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 6-4	**Lost**					
FMB 6-5	% Gravel	17.73	$x\Phi$=	1.05	$\sigma\Phi$=	1.94
	% Sand	80.87	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.40			Color:	
	% Carbonates	52.83	Wet:	2.5Y 6/1	Dry:	2.5Y 8/1
FMB 6-6	**Lost**					
FMB 6-7	% Gravel	0.15	$x\Phi$=	3.21	$\sigma\Phi$=	0.39
	% Sand	96.62	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	3.23			Color:	
	% Carbonates	2.48	Wet:	5Y 4/1	Dry:	5Y 8/1
FMB 6-8	% Gravel	0.02	$x\Phi$=	3.61	$\sigma\Phi$=	0.41
	% Sand	79.98	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	20.00			Color:	
	% Carbonates	8.68	Wet:	5Y 6/2	Dry:	5Y 7/1
FMB 6-9	**Lost**					

Table A4. Grain Size and Color Analysis Data from FMB 6 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 6-1	% Gravel	0.43	xΦ=	2.76	σΦ=		0.52
	% Sand	99.08	Size:	Fine Sand	Sorting:	Moderately Well Sorted	
	% Mud	0.49			Color:		
	% Carbonates	3.24	Wet:	5Y 7/1	Dry:	5Y 8/1	
FMB 6-2	% Gravel	0.00	xΦ=	2.84	σΦ=		0.27
	% Sand	99.73	Size:	Fine Sand	Sorting:	Very Well Sorted	
	% Mud	0.27			Color:		
	% Carbonates	1.14	Wet:	5Y 8/1	Dry:	5Y 8/1	
FMB 6-3	% Gravel	1.42	xΦ=	2.62	σΦ=		0.84
	% Sand	98.23	Size:	Fine Sand	Sorting:	Moderately Sorted	
	% Mud	0.35			Color:		
	% Carbonates	11.81	Wet:	5Y 7/1	Dry:	5Y 8/1	
FMB 6-4	% Gravel	3.81	xΦ=	2.40	σΦ=		1.17
	% Sand	95.68	Size:	Fine Sand	Sorting:	Poorly Sorted	
	% Mud	0.51			Color:		
	% Carbonates	14.50	Wet:	2.5Y 7/1	Dry:	5Y 8/1	
FMB 6-5	% Gravel	4.82	xΦ=	1.67	σΦ=		1.46
	% Sand	94.74	Size:	Medium Sand	Sorting:	Poorly Sorted	
	% Mud	0.44			Color:		
	% Carbonates	41.12	Wet:	5Y 7/1	Dry:	5Y 8/1	
FMB 6-6	% Gravel	1.11	xΦ=	3.05	σΦ=		0.74
	% Sand	97.71	Size:	Very Fine Sand	Sorting:	Moderately Sorted	
	% Mud	1.18			Color:		
	% Carbonates	4.80	Wet:	5Y 5/1	Dry:	5Y 8/1	
FMB 6-7	% Gravel	0.82	xΦ=	3.07	σΦ=		0.65
	% Sand	98.23	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted	
	% Mud	0.95			Color:		
	% Carbonates	4.12	Wet:	5Y 6/1	Dry:	5Y 8/1	
FMB 6-8	% Gravel	0.00	xΦ=	3.46	σΦ=		0.34
	% Sand	91.30	Size:	Very Fine Sand	Sorting:	Very Well Sorted	
	% Mud	8.70			Color:		
	% Carbonates	5.73	Wet:	5Y 5/1	Dry:	5Y 7/1	
FMB 6-9	% Gravel	0.00	xΦ=	3.70	σΦ=		0.41
	% Sand	74.25	Size:	Very Fine Sand	Sorting:	Well Sorted	
	% Mud	25.75			Color:		
	% Carbonates	11.05	Wet:	5Y 4/1	Dry:	5Y 7/1	

Table A5. Grain Size and Color Analysis Data from FMB 9 (2010), where x_{Φ} and σ_{Φ} are the mean grain size and standard deviation (sorting), respectively.

FMB 9-1	% Gravel	0.00	$x\Phi$=	2.77	$\sigma\Phi$=	0.34
	% Sand	99.65	Size:	Fine Sand	Sorting:	Very Well Sorted
	% Mud	0.35		Color:		
	% Carbonates	1.28	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 9-2	% Gravel	0.26	$x\Phi$=	2.73	$\sigma\Phi$=	0.42
	% Sand	99.43	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.32		Color:		
	% Carbonates	2.39	Wet:	5Y 8/1	Dry:	2,5Y 8/1
FMB 9-3	% Gravel	1.75	$x\Phi$=	2.69	$\sigma\Phi$=	0.84
	% Sand	96.70	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	1.56		Color:		
	% Carbonates	7.06	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 9-4	% Gravel	9.13	$x\Phi$=	1.58	$\sigma\Phi$=	1.68
	% Sand	89.63	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.24		Color:		
	% Carbonates	39.32	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 9-5	% Gravel	25.20	$x\Phi$=	1.14	$\sigma\Phi$=	2.20
	% Sand	73.35	Size:	Medium Sand	Sorting:	Very Poorly Sorted
	% Mud	1.45		Color:		
	% Carbonates	44.08	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 9-6	% Gravel	0.17	$x\Phi$=	3.00	$\sigma\Phi$=	0.45
	% Sand	97.84	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	1.99		Color:		
	% Carbonates	2.58	Wet:	5Y 6/2	Dry:	2.5Y 8/1
FMB 9-7	% Gravel	0.06	$x\Phi$=	3.22	$\sigma\Phi$=	0.32
	% Sand	96.65	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	3.28		Color:		
	% Carbonates	1.92	Wet:	5Y 5/1	Dry:	2.5Y 8/1
FMB 9-8	% Gravel	0.00	$x\Phi$=	3.36	$\sigma\Phi$=	0.30
	% Sand	95.71	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	4.29		Color:		
	% Carbonates	2.49	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 9-9	% Gravel	0.00	$x\Phi$=	3.53	$\sigma\Phi$=	0.30
	% Sand	90.46	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	9.54		Color:		
	% Carbonates	4.81	Wet:	5Y 5/2	Dry:	2.5Y 8/1

Table A6. Grain Size and Color Analysis Data from FMB 9 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 9-1	% Gravel	0.07	xΦ=	2.84	σΦ=		0.35
	% Sand	99.52	Size:	Fine Sand	Sorting:	Well Sorted	
	% Mud	0.41			Color:		
	% Carbonates	1.51	Wet:	2.5Y 7/1	Dry:	2.5Y 8/1	
FMB 9-2	% Gravel	0.27	xΦ=	2.78	σΦ=		0.49
	% Sand	99.35	Size:	Fine Sand	Sorting:	Well Sorted	
	% Mud	0.39			Color:		
	% Carbonates	3.36	Wet:	5Y 7/1	Dry:	2.5Y 8/1	
FMB 9-3	% Gravel	0.00	xΦ=	2.82	σΦ=		0.32
	% Sand	99.38	Size:	Fine Sand	Sorting:	Very Well Sorted	
	% Mud	0.62			Color:		
	% Carbonates	1.24	Wet:	2.5Y 7/1	Dry:	2.5Y 8/1	
FMB 9-4	% Gravel	1.98	xΦ=	2.53	σΦ=		1.09
	% Sand	97.37	Size:	Fine Sand	Sorting:	Poorly Sorted	
	% Mud	0.65			Color:		
	% Carbonates	17.98	Wet:	5Y 7/2	Dry:	5Y 8/1	
FMB 9-5	% Gravel	4.86	xΦ=	2.22	σΦ=		1.37
	% Sand	94.63	Size:	Fine Sand	Sorting:	Poorly Sorted	
	% Mud	0.51			Color:		
	% Carbonates	21.88	Wet:	5Y 7/1	Dry:	5Y 8/1	
FMB 9-6	% Gravel	0.15	xΦ=	3.14	σΦ=		0.44
	% Sand	98.76	Size:	Very Fine Sand	Sorting:	Well Sorted	
	% Mud	1.09			Color:		
	% Carbonates	2.48	Wet:	5Y 7/1	Dry:	5Y 8/1	
FMB 9-7	% Gravel	0.88	xΦ=	3.09	σΦ=		0.70
	% Sand	97.89	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted	
	% Mud	1.23			Color:		
	% Carbonates	5.08	Wet:	5Y 6/1	Dry:	5Y 8/1	
FMB 9-8	% Gravel	0.00	xΦ=	3.48	σΦ=		0.31
	% Sand	93.45	Size:	Very Fine Sand	Sorting:	Very Well Sorted	
	% Mud	6.55			Color:		
	% Carbonates	5.04	Wet:	5Y 5/1	Dry:	5Y 8/1	
FMB 9-9	% Gravel	0.06	xΦ=	3.76	σΦ=		0.45
	% Sand	64.64	Size:	Very Fine Sand	Sorting:	Well Sorted	
	% Mud	35.30			Color:		
	% Carbonates	14.63	Wet:	5Y 4/1	Dry:	5Y 7/1	

Table A7. Grain Size and Color Analysis Data from FMB 13 (2010), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 13-1	% Gravel	0.16	xΦ=	2.66	σΦ=	0.47
	% Sand	99.51	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.34			Color:	
	% Carbonates	2.75	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 13-2	% Gravel	4.39	xΦ=	2.29	σΦ=	1.30
	% Sand	95.16	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.45			Color:	
	% Carbonates	13.33	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 13-3	% Gravel	3.24	xΦ=	2.68	σΦ=	1.09
	% Sand	96.01	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.75			Color:	
	% Carbonates	6.56	Wet:	5Y 7/2	Dry:	5Y 8/1
FMB 13-4	% Gravel	9.71	xΦ=	2.05	σΦ=	1.67
	% Sand	88.99	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.31			Color:	
	% Carbonates	23.70	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 13-5	% Gravel	22.54	xΦ=	1.02	σΦ=	2.11
	% Sand	76.11	Size:	Medium Sand	Sorting:	Very Poorly Sorted
	% Mud	1.35			Color:	
	% Carbonates	47.62	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 13-6	% Gravel	0.11	xΦ=	2.97	σΦ=	0.35
	% Sand	98.19	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	1.70			Color:	
	% Carbonates	1.73	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 13-7	% Gravel	0.06	xΦ=	3.27	σΦ=	0.31
	% Sand	96.60	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	3.34			Color:	
	% Carbonates	1.36	Wet:	5Y 5/1	Dry:	2.5Y 8/1
FMB 13-8	% Gravel	0.27	xΦ=	3.34	σΦ=	0.43
	% Sand	95.07	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	4.66			Color:	
	% Carbonates	2.32	Wet:	5Y 5/1	Dry:	2.5Y 8/1
FMB 13-9	% Gravel	0.05	xΦ=	3.58	σΦ=	0.55
	% Sand	74.24	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	25.71			Color:	
	% Carbonates	8.36	Wet:	5Y 4/1	Dry:	5Y 7/1

Table A8. Grain Size and Color Analysis Data from FMB 13 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 13-1	**Lost**					
FMB 13-2	**Lost**					
FMB 13-3	**Lost**					
FMB 13-4	% Gravel	2.18	xΦ=	2.45	σΦ=	1.12
	% Sand	97.25	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.57		Color:		
	% Carbonates	18.50	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 13-5	% Gravel	13.61	xΦ=	1.36	σΦ=	1.83
	% Sand	85.85	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	0.54		Color:		
	% Carbonates	45.67	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 13-6	% Gravel	0.52	xΦ=	3.10	σΦ=	0.57
	% Sand	97.86	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.62		Color:		
	% Carbonates	3.59	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 13-7	% Gravel	0.07	xΦ=	3.22	σΦ=	0.34
	% Sand	98.57	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	1.36		Color:		
	% Carbonates	1.96	Wet:	5Y 6/2	Dry:	5Y 7/1
FMB 13-8	% Gravel	0.00	xΦ=	3.34	σΦ=	0.31
	% Sand	96.40	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	3.60		Color:		
	% Carbonates	3.38	Wet:	5Y 6/2	Dry:	5Y 7/1
FMB 13-9	% Gravel	0.01	xΦ=	3.54	σΦ=	0.33
	% Sand	90.15	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	9.85		Color:		
	% Carbonates	5.91	Wet:	5Y 5/2	Dry:	5Y 7/1
FMB 13-10	% Gravel	0.06	xΦ=	3.67	σΦ=	0.48
	% Sand	73.67	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	26.27		Color:		
	% Carbonates	10.64	Wet:	5Y 5/2	Dry:	5Y 7/1

Table A9. Grain Size and Color Analysis Data from FMB 17 (2010), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 17-1	% Gravel	0.59	xΦ=	2.80	σΦ=	0.58
	% Sand	98.94	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.46			Color:	
	% Carbonates	1.76	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 17-2	% Gravel	0.99	xΦ=	2.61	σΦ=	0.73
	% Sand	98.65	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.36			Color:	
	% Carbonates	6.27	Wet:	5Y 8/1	Dry:	2.5Y 8/1
FMB 17-3	% Gravel	4.78	xΦ=	2.51	σΦ=	1.26
	% Sand	93.78	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.44			Color:	
	% Carbonates	11.50	Wet:	2.5Y 8/1	Dry:	2.5Y 8/1
FMB 17-4	% Gravel	5.77	xΦ=	1.96	σΦ=	1.54
	% Sand	92.93	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.30			Color:	
	% Carbonates	30.67	Wet:	5Y 8/2	Dry:	2.5Y 8/1
FMB 17-5	% Gravel	21.70	xΦ=	1.00	σΦ=	2.04
	% Sand	76.62	Size:	Medium Sand	Sorting:	Very Poorly Sorted
	% Mud	1.68			Color:	
	% Carbonates	53.96	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-6	% Gravel	0.81	xΦ=	2.96	σΦ=	0.69
	% Sand	97.38	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.81			Color:	
	% Carbonates	3.36	Wet:	2.5Y 6/2	Dry:	5Y 8/1
FMB 17-7	% Gravel	0.26	xΦ=	3.15	σΦ=	0.51
	% Sand	96.75	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	2.99			Color:	
	% Carbonates	3.32	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-8	% Gravel	1.38	xΦ=	2.64	σΦ=	0.87
	% Sand	96.92	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	1.70			Color:	
	% Carbonates	4.31	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 17-9	% Gravel	0.94	xΦ=	2.71	σΦ=	0.85
	% Sand	97.20	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	1.86			Color:	
	% Carbonates	4.83	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-10	% Gravel	3.27	xΦ=	2.48	σΦ=	1.27
	% Sand	93.54	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	3.19			Color:	
	% Carbonates	10.47	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-11	% Gravel	8.06	xΦ=	1.34	σΦ=	1.47
	% Sand	90.01	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.93			Color:	
	% Carbonates	29.49	Wet:	5Y 7/2	Dry:	5Y 8/1

Table A10. Grain Size and Color Analysis Data from FMB 17 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 17-1	% Gravel	0.14	xΦ=	2.78	σΦ=	0.41
	% Sand	99.73	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.13		Color:		
	% Carbonates	1.92	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 17-2	% Gravel	0.37	xΦ=	2.72	σΦ=	0.57
	% Sand	99.26	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.37		Color:		
	% Carbonates	4.17	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 17-3	% Gravel	0.35	xΦ=	2.82	σΦ=	0.49
	% Sand	99.15	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.50		Color:		
	% Carbonates	4.95	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 17-4	% Gravel	1.77	xΦ=	2.57	σΦ=	1.01
	% Sand	97.35	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.88		Color:		
	% Carbonates	13.47	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 17-5	% Gravel	4.56	xΦ=	2.48	σΦ=	1.34
	% Sand	94.95	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.49		Color:		
	% Carbonates	16.06	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 17-6	% Gravel	8.93	xΦ=	1.79	σΦ=	1.65
	% Sand	90.46	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	0.61		Color:		
	% Carbonates	18.46	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-7	% Gravel	0.02	xΦ=	2.97	σΦ=	0.49
	% Sand	98.99	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.98		Color:		
	% Carbonates	2.68	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 17-8	% Gravel	0.18	xΦ=	2.93	σΦ=	0.48
	% Sand	99.19	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.62		Color:		
	% Carbonates	1.95	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-9	% Gravel	1.28	xΦ=	2.88	σΦ=	0.90
	% Sand	97.60	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	1.12		Color:		
	% Carbonates	4.93	Wet:	2.5Y 7/1	Dry:	5Y 8/1
FMB 17-10	% Gravel	4.18	xΦ=	2.38	σΦ=	1.37
	% Sand	93.21	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	2.61		Color:		
	% Carbonates	12.20	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 17-11	% Gravel	0.19	xΦ=	3.62	σΦ=	0.59
	% Sand	70.99	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	28.82		Color:		
	% Carbonates	10.10	Wet:	5Y 5/2	Dry:	2.5Y 7/1

Table A11. Grain Size and Color Analysis Data from FMB 22 (2010), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 22-1	% Gravel	0.14	xΦ=	2.70	σΦ=		0.46
	% Sand	99.58	Size:	Fine Sand	Sorting:	Well Sorted	
	% Mud	0.27			Color:		
	% Carbonates	2.61	Wet:	5Y 7/1	Dry:	5Y 8/1	
FMB 22-2	% Gravel	0.03	xΦ=	2.59	σΦ=		0.44
	% Sand	99.71	Size:	Fine Sand	Sorting:	Well Sorted	
	% Mud	0.26			Color:		
	% Carbonates	2.01	Wet:	5Y 7/1	Dry:	5Y 8/1	
FMB 22-3	% Gravel	0.00	xΦ=	2.95	σΦ=		0.36
	% Sand	98.48	Size:	Fine Sand	Sorting:	Well Sorted	
	% Mud	1.52			Color:		
	% Carbonates	4.48	Wet:	5Y 7/2	Dry:	2.5Y 8/1	
FMB 22-4	% Gravel	15.07	xΦ=	1.69	σΦ=		2.03
	% Sand	83.81	Size:	Medium Sand	Sorting:	Very Poorly Sorted	
	% Mud	1.12			Color:		
	% Carbonates	35.09	Wet:	5Y 7/1	Dry:	2.5Y 8/1	
FMB 22-5	% Gravel	4.54	xΦ=	2.73	σΦ=		1.23
	% Sand	94.04	Size:	Fine Sand	Sorting:	Poorly Sorted	
	% Mud	1.42			Color:		
	% Carbonates	9.59	Wet:	5Y 7/1	Dry:	2.5Y 8/1	
FMB 22-6	% Gravel	0.10	xΦ=	3.02	σΦ=		0.34
	% Sand	99.02	Size:	Very Fine Sand	Sorting:	Very Well Sorted	
	% Mud	0.88			Color:		
	% Carbonates	2.12	Wet:	5Y 7/2	Dry:	5Y 8/1	
FMB 22-7	% Gravel	0.00	xΦ=	3.02	σΦ=		0.35
	% Sand	97.08	Size:	Very Fine Sand	Sorting:	Well Sorted	
	% Mud	2.92			Color:		
	% Carbonates	1.87	Wet:	5Y 7/1	Dry:	5Y 8/1	
FMB 22-8	% Gravel	0.07	xΦ=	3.55	σΦ=		0.59
	% Sand	58.12	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted	
	% Mud	41.81			Color:		
	% Carbonates	6.75	Wet:	5Y 5/1	Dry:	5Y 8/1	
FMB 22-9	% Gravel	0.98	xΦ=	2.79	σΦ=		0.84
	% Sand	90.71	Size:	Fine Sand	Sorting:	Moderately Sorted	
	% Mud	8.31			Color:		
	% Carbonates	5.22	Wet:	5Y 4/2	Dry:	5Y 8/1	
FMB 22-10	% Gravel	1.79	xΦ=	2.78	σΦ=		0.88
	% Sand	96.69	Size:	Fine Sand	Sorting:	Moderately Sorted	
	% Mud	1.52			Color:		
	% Carbonates	3.59	Wet:	5Y 7/1	Dry:	5Y 8/1	
FMB 22-11	% Gravel	0.98	xΦ=	3.13	σΦ=		0.68
	% Sand	95.22	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted	
	% Mud	3.80			Color:		
	% Carbonates	3.58	Wet:	5Y 7/1	Dry:	5Y 8/1	

Table A12. Grain Size and Color Analysis Data from FMB 22 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 22-1	% Gravel	0.52	xΦ=	2.68	σΦ=	0.63
	% Sand	99.12	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.36			Color:	
	% Carbonates	4.26	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 22-2	% Gravel	0.01	xΦ=	2.83	σΦ=	0.32
	% Sand	99.57	Size:	Fine Sand	Sorting:	Very Well Sorted
	% Mud	0.42			Color:	
	% Carbonates	1.18	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 22-3	% Gravel	0.14	xΦ=	2.91	σΦ=	0.42
	% Sand	99.32	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.54			Color:	
	% Carbonates	2.86	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 22-4	% Gravel	6.52	xΦ=	2.25	σΦ=	1.46
	% Sand	93.04	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.45			Color:	
	% Carbonates	18.85	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 22-5	% Gravel	0.00	xΦ=	3.04	σΦ=	0.27
	% Sand	99.20	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	0.80			Color:	
	% Carbonates	2.00	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 22-6	% Gravel	0.18	xΦ=	3.08	σΦ=	0.44
	% Sand	98.37	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	1.45			Color:	
	% Carbonates	3.40	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 22-7	% Gravel	0.16	xΦ=	2.98	σΦ=	0.38
	% Sand	99.16	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.68			Color:	
	% Carbonates	1.69	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 22-8	% Gravel	0.11	xΦ=	3.02	σΦ=	0.37
	% Sand	99.11	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	0.78			Color:	
	% Carbonates	1.28	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 22-9	% Gravel	0.03	xΦ=	3.06	σΦ=	0.42
	% Sand	98.73	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	1.24			Color:	
	% Carbonates	3.12	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 22-10	% Gravel	0.00	xΦ=	3.42	σΦ=	0.43
	% Sand	89.38	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	10.62			Color:	
	% Carbonates	4.01	Wet:	5Y 5/2	Dry:	5Y 7/1
FMB 22-11	% Gravel	0.53	xΦ=	3.35	σΦ=	0.70
	% Sand	88.61	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	10.86			Color:	
	% Carbonates	5.24	Wet:	5Y 4/1	Dry:	5Y 7/1

Table A13. Grain Size and Color Analysis Data from FMB 28 (2010), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 28-1	% Gravel	0.13	xΦ=	2.80	σΦ=	0.44
	% Sand	99.44	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.42			Color:	
	% Carbonates	2.13	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 28-2	% Gravel	0.00	xΦ=	2.82	σΦ=	0.32
	% Sand	99.43	Size:	Fine Sand	Sorting:	Very Well Sorted
	% Mud	0.57			Color:	
	% Carbonates	1.30	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 28-3	% Gravel	0.11	xΦ=	2.93	σΦ=	0.48
	% Sand	98.81	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	1.07			Color:	
	% Carbonates	5.19	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 28-4	% Gravel	4.48	xΦ=	2.48	σΦ=	1.43
	% Sand	94.56	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.96			Color:	
	% Carbonates	21.29	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 28-5	% Gravel	0.75	xΦ=	2.97	σΦ=	0.65
	% Sand	97.57	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.68			Color:	
	% Carbonates	7.05	Wet:	2.5Y 7/1	Dry:	5Y 8/1
FMB 28-6	% Gravel	0.34	xΦ=	3.14	σΦ=	0.58
	% Sand	95.63	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	4.02			Color:	
	% Carbonates	9.42	Wet:	5Y 4/1	Dry:	2.5Y 8/1
FMB 28-7	% Gravel	0.02	xΦ=	3.10	σΦ=	0.31
	% Sand	98.27	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	1.71			Color:	
	% Carbonates	1.42	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 28-8	% Gravel	3.96	xΦ=	1.87	σΦ=	1.25
	% Sand	94.92	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.11			Color:	
	% Carbonates	16.25	Wet:	5Y 4/1	Dry:	5Y 8/1
FMB 28-9	% Gravel	1.54	xΦ=	2.36	σΦ=	0.92
	% Sand	98.03	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.42			Color:	
	% Carbonates	9.37	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 28-10	% Gravel	2.27	xΦ=	2.78	σΦ=	1.03
	% Sand	96.31	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.42			Color:	
	% Carbonates	8.29	Wet:	2.5Y 7/1	Dry:	2.5Y 8/1
FMB 28-11	% Gravel	1.80	xΦ=	3.04	σΦ=	1.05
	% Sand	93.00	Size:	Very Fine Sand	Sorting:	Poorly Sorted
	% Mud	5.20			Color:	
	% Carbonates	4.95	Wet:	5Y 5/1	Dry:	5Y 8/1

Table A14. Grain Size and Color Analysis Data from FMB 28 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 28-1	% Gravel	0.04	xΦ=	2.88	σΦ=	0.41
	% Sand	99.59	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.37			Color:	
	% Carbonates	2.08	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 28-2	% Gravel	0.10	xΦ=	2.85	σΦ=	0.46
	% Sand	99.62	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.28			Color:	
	% Carbonates	2.85	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 28-3	% Gravel	0.03	xΦ=	2.91	σΦ=	0.42
	% Sand	99.39	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.58			Color:	
	% Carbonates	2.67	Wet:	5Y 7/2	Dry:	5Y 8/1
FMB 28-4	% Gravel	16.27	xΦ=	1.05	σΦ=	1.96
	% Sand	82.98	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	0.75			Color:	
	% Carbonates	57.72	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 28-5	% Gravel	0.26	xΦ=	2.97	σΦ=	0.55
	% Sand	97.76	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.98			Color:	
	% Carbonates	4.26	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 28-6	% Gravel	1.30	xΦ=	2.72	σΦ=	0.96
	% Sand	95.60	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	3.09			Color:	
	% Carbonates	6.69	Wet:	5Y 6/2	Dry:	5Y 8/1
FMB 28-7	% Gravel	4.78	xΦ=	2.25	σΦ=	1.38
	% Sand	93.19	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	2.02			Color:	
	% Carbonates	15.69	Wet:	5Y 6/2	Dry:	5Y 8/1
FMB 28-8	% Gravel	0.75	xΦ=	2.82	σΦ=	0.65
	% Sand	97.79	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.46			Color:	
	% Carbonates	3.81	Wet:	2.5Y 6/1	Dry:	5Y 8/1
FMB 28-9	% Gravel	0.13	xΦ=	3.05	σΦ=	0.50
	% Sand	97.34	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	2.53			Color:	
	% Carbonates	4.02	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 28-10	% Gravel	0.05	xΦ=	3.10	σΦ=	0.41
	% Sand	95.80	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	4.16			Color:	
	% Carbonates	2.06	Wet:	5Y 6/2	Dry:	5Y 8/1
FMB 28-11	% Gravel	0.16	xΦ=	3.36	σΦ=	0.59
	% Sand	88.91	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	10.93			Color:	
	% Carbonates	3.94	Wet:	5Y 4/1	Dry:	5Y 7/1

Table A15. Grain Size and Color Analysis Data from FMB 35 (2010), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 35-1	% Gravel	0.05	xΦ=	2.79	σΦ=	0.37
	% Sand	99.86	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.09			Color:	
	% Carbonates	1.88	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 35-2	% Gravel	0.54	xΦ=	2.72	σΦ=	0.58
	% Sand	99.31	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.15			Color:	
	% Carbonates	2.98	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 35-3	% Gravel	0.18	xΦ=	2.95	σΦ=	0.44
	% Sand	99.51	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.31			Color:	
	% Carbonates	3.01	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 35-4	% Gravel	4.34	xΦ=	2.44	σΦ=	1.41
	% Sand	95.25	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.41			Color:	
	% Carbonates	17.86	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 35-5	% Gravel	2.86	xΦ=	2.72	σΦ=	1.12
	% Sand	96.64	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.50			Color:	
	% Carbonates	10.60	Wet:	5Y 6/1	Dry:	2.5Y 8/1
FMB 35-6	% Gravel	0.13	xΦ=	3.04	σΦ=	0.45
	% Sand	98.69	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	1.18			Color:	
	% Carbonates	2.90	Wet:	5Y 6/2	Dry:	5Y 8/1
FMB 35-7	% Gravel	0.68	xΦ=	2.82	σΦ=	0.74
	% Sand	98.27	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	1.05			Color:	
	% Carbonates	5.45	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 35-8	% Gravel	2.85	xΦ=	2.20	σΦ=	1.04
	% Sand	96.92	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.23			Color:	
	% Carbonates	9.36	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 35-9	% Gravel	3.27	xΦ=	2.54	σΦ=	1.11
	% Sand	96.22	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.50			Color:	
	% Carbonates	7.90	Wet:	5Y 7/2	Dry:	5Y 8/1
FMB 35-10	% Gravel	2.37	xΦ=	2.46	σΦ=	1.07
	% Sand	96.25	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	1.38			Color:	
	% Carbonates	9.54	Wet:	5Y 7/1	Dry:	5Y 8/1

Table A16. Grain Size and Color Analysis Data from FMB 35 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 35-1	% Gravel	0.08	xΦ=	2.85	σΦ=	0.43		
	% Sand	99.26	Size:	Fine Sand	Sorting:	Well Sorted		
	% Mud	0.66			Color:			
	% Carbonates	2.23	Wet:	5Y 7/1	Dry:	5Y 8/1		
FMB 35-2	% Gravel	0.01	xΦ=	2.91	σΦ=	0.37		
	% Sand	98.05	Size:	Fine Sand	Sorting:	Well Sorted		
	% Mud	1.94			Color:			
	% Carbonates	1.61	Wet:	5Y 7/1	Dry:	5Y 8/1		
FMB 35-3	% Gravel	0.12	xΦ=	2.90	σΦ=	0.43		
	% Sand	98.63	Size:	Fine Sand	Sorting:	Well Sorted		
	% Mud	1.26			Color:			
	% Carbonates	2.13	Wet:	5Y 7/1	Dry:	5Y 8/1		
FMB 35-4	% Gravel	5.06	xΦ=	2.23	σΦ=	1.51		
	% Sand	93.31	Size:	Fine Sand	Sorting:	Poorly Sorted		
	% Mud	1.62			Color:			
	% Carbonates	25.31	Wet:	5Y 7/2	Dry:	5Y 8/1		
FMB 35-5	% Gravel	7.04	xΦ=	2.42	σΦ=	1.53		
	% Sand	91.11	Size:	Fine Sand	Sorting:	Poorly Sorted		
	% Mud	1.84			Color:			
	% Carbonates	18.07	Wet:	5Y 7/1	Dry:	5Y 8/1		
FMB 35-6	% Gravel	0.49	xΦ=	3.03	σΦ=	0.62		
	% Sand	97.41	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted		
	% Mud	2.10			Color:			
	% Carbonates	3.12	Wet:	5Y 6/2	Dry:	5Y 8/1		
FMB 35-7	% Gravel	0.42	xΦ=	2.86	σΦ=	0.52		
	% Sand	97.90	Size:	Fine Sand	Sorting:	Moderately Well Sorted		
	% Mud	1.68			Color:			
	% Carbonates	2.48	Wet:	5Y 7/2	Dry:	5Y 8/1		
FMB 35-8	% Gravel	0.17	xΦ=	2.96	σΦ=	0.52		
	% Sand	97.10	Size:	Fine Sand	Sorting:	Moderately Well Sorted		
	% Mud	2.73			Color:			
	% Carbonates	2.12	Wet:	5Y 7/1	Dry:	5Y 8/1		
FMB 35-9	% Gravel	0.05	xΦ=	2.93	σΦ=	0.60		
	% Sand	98.02	Size:	Fine Sand	Sorting:	Moderately Well Sorted		
	% Mud	1.93			Color:			
	% Carbonates	10.07	Wet:	5Y 7/2	Dry:	5Y 8/1		
FMB 35-10	% Gravel	2.09	xΦ=	2.71	σΦ=	0.96		
	% Sand	95.26	Size:	Fine Sand	Sorting:	Moderately Sorted		
	% Mud	2.64			Color:			
	% Carbonates	5.35	Wet:	5Y 7/1	Dry:	5Y 8/1		
FMB 35-11	% Gravel	3.56	xΦ=	2.74	σΦ=	1.31		
	% Sand	91.73	Size:	Fine Sand	Sorting:	Poorly Sorted		
	% Mud	4.70			Color:			
	% Carbonates	9.15	Wet:	5Y 5/1	Dry:	5Y 8/1		

Table A17. Grain Size and Color Analysis Data from FMB 46 (2010), where x_{Φ} and σ_{Φ} are the mean grain size and standard deviation (sorting), respectively.

FMB 46-1	% Gravel	0.37	xΦ=	2.68	σΦ=	0.59
	% Sand	99.47	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.16			Color:	
	% Carbonates	3.32	Wet:	2.5Y 7/1	Dry:	2.5Y 8/1
FMB 46-2	% Gravel	0.23	xΦ=	2.69	σΦ=	0.50
	% Sand	99.65	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.12			Color:	
	% Carbonates	2.52	Wet:	2.5Y 7/1	Dry:	2.5Y 8/1
FMB 46-3	% Gravel	0.37	xΦ=	2.48	σΦ=	0.70
	% Sand	99.34	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.28			Color:	
	% Carbonates	6.30	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 46-4	% Gravel	12.93	xΦ=	1.65	σΦ=	1.77
	% Sand	87.00	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	0.07			Color:	
	% Carbonates	27.83	Wet:	2.5Y 5/1	Dry:	5Y 8/1
FMB 46-5	% Gravel	2.63	xΦ=	2.50	σΦ=	1.12
	% Sand	97.04	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.34			Color:	
	% Carbonates	7.72	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 46-6	% Gravel	0.00	xΦ=	3.14	σΦ=	0.34
	% Sand	99.19	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	0.81			Color:	
	% Carbonates	2.52	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 46-7	% Gravel	0.36	xΦ=	3.16	σΦ=	0.50
	% Sand	98.72	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	0.91			Color:	
	% Carbonates	2.87	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 46-8	% Gravel	0.82	xΦ=	2.66	σΦ=	0.68
	% Sand	98.75	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.43			Color:	
	% Carbonates	4.36	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 46-9	% Gravel	0.11	xΦ=	2.94	σΦ=	0.56
	% Sand	98.02	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.87			Color:	
	% Carbonates	2.68	Wet:	2.5Y 5/2	Dry:	5Y 8/1

Table A18. Grain Size and Color Analysis Data from FMB 46 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 46-1	% Gravel	0.10	xΦ=	2.78	σΦ=	0.46
	% Sand	99.60	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.30			Color:	
	% Carbonates	2.41	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 46-2	% Gravel	1.01	xΦ=	2.71	σΦ=	0.72
	% Sand	98.74	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.25			Color:	
	% Carbonates	3.37	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 46-3	% Gravel	0.16	xΦ=	2.75	σΦ=	0.39
	% Sand	99.41	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.44			Color:	
	% Carbonates	2.11	Wet:	5Y 7/2	Dry:	5Y 8/1
FMB 46-4	% Gravel	1.35	xΦ=	2.74	σΦ=	0.94
	% Sand	97.93	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.73			Color:	
	% Carbonates	6.24	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 46-5	% Gravel	0.50	xΦ=	2.99	σΦ=	0.73
	% Sand	98.56	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.93			Color:	
	% Carbonates	4.44	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 46-6	% Gravel	4.52	xΦ=	2.78	σΦ=	1.30
	% Sand	94.57	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.91			Color:	
	% Carbonates	8.02	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 46-7	% Gravel	3.16	xΦ=	2.11	σΦ=	1.16
	% Sand	96.09	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.75			Color:	
	% Carbonates	11.05	Wet:	5Y 6/2	Dry:	5Y 7/1
FMB 46-8	% Gravel	2.09	xΦ=	2.69	σΦ=	1.05
	% Sand	97.14	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.77			Color:	
	% Carbonates	4.44	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 46-9	% Gravel	0.09	xΦ=	3.00	σΦ=	0.45
	% Sand	98.93	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	0.98			Color:	
	% Carbonates	2.02	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 46-10	% Gravel	0.32	xΦ=	3.01	σΦ=	0.67
	% Sand	91.96	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	7.72			Color:	
	% Carbonates	3.05	Wet:	5Y 6/2	Dry:	5Y 8/1
FMB 46-11	% Gravel	0.00	xΦ=	2.96	σΦ=	0.60
	% Sand	96.17	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	3.83			Color:	
	% Carbonates	2.31	Wet:	2.5Y 5/3	Dry:	5Y 8/1

Table A19. Grain Size and Color Analysis Data from FMB 53 (2010), where x_{Φ} and σ_{Φ} are the mean grain size and standard deviation (sorting), respectively.

FMB 53-1	% Gravel	0.16	xΦ=	2.64	σΦ=	0.51
	% Sand	99.81	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.03			Color:	
	% Carbonates	2.58	Wet:	2.5Y 6/1	Dry:	2.5Y 8/1
FMB 53-2	% Gravel	0.00	xΦ=	2.79	σΦ=	0.37
	% Sand	99.94	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.06			Color:	
	% Carbonates	1.54	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 53-3	% Gravel	0.04	xΦ=	2.77	σΦ=	0.54
	% Sand	99.66	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.30			Color:	
	% Carbonates	3.18	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 53-4	% Gravel	0.14	xΦ=	2.76	σΦ=	0.53
	% Sand	99.50	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.37			Color:	
	% Carbonates	3.14	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 53-5	% Gravel	2.36	xΦ=	2.54	σΦ=	1.03
	% Sand	97.14	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.50			Color:	
	% Carbonates	9.11	Wet:	5Y 7/2	Dry:	5Y 8/1
FMB 53-6	% Gravel	0.72	xΦ=	2.86	σΦ=	0.65
	% Sand	98.78	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.50			Color:	
	% Carbonates	2.66	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 53-7	% Gravel	0.09	xΦ=	3.07	σΦ=	0.44
	% Sand	98.98	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	0.93			Color:	
	% Carbonates	1.63	Wet:	5Y 6/2	Dry:	5Y 8/1
FMB 53-8	% Gravel	0.31	xΦ=	3.10	σΦ=	0.56
	% Sand	98.58	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	1.12			Color:	
	% Carbonates	2.15	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 53-9	% Gravel	0.00	xΦ=	2.94	σΦ=	0.53
	% Sand	97.97	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	2.03			Color:	
	% Carbonates	1.81	Wet:	5Y 4/1	Dry:	5Y 8/1

Table A20. Grain Size and Color Analysis Data from FMB 53 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 53-1	% Gravel	0.18	xΦ=	2.73	σΦ=	0.50
	% Sand	99.39	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.43			Color:	
	% Carbonates	2.30	Wet:	2.5Y 7/1	Dry:	5Y 8/1
FMB 53-2	% Gravel	0.00	xΦ=	2.77	σΦ=	0.41
	% Sand	99.27	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.73			Color:	
	% Carbonates	2.19	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 53-3	% Gravel	0.05	xΦ=	2.66	σΦ=	0.46
	% Sand	99.47	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.49			Color:	
	% Carbonates	1.60	Wet:	5Y 8/1	Dry:	5Y 8/1
FMB 53-4	% Gravel	6.62	xΦ=	1.95	σΦ=	1.53
	% Sand	92.07	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	1.31			Color:	
	% Carbonates	19.31	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 53-5	% Gravel	0.11	xΦ=	3.11	σΦ=	0.40
	% Sand	98.99	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	0.90			Color:	
	% Carbonates	1.55	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 53-6	% Gravel	0.13	xΦ=	3.15	σΦ=	0.42
	% Sand	98.71	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	1.16			Color:	
	% Carbonates	1.65	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 53-7	% Gravel	0.00	xΦ=	3.17	σΦ=	0.52
	% Sand	97.67	Size:	Very Find Sand	Sorting:	Moderately Well Sorted
	% Mud	2.33			Color:	
	% Carbonates	1.56	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 53-8	% Gravel	0.00	xΦ=	2.98	σΦ=	0.58
	% Sand	96.92	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	3.08			Color:	
	% Carbonates	1.44	Wet:	5Y 5/2	Dry:	5Y 8/1
FMB 53-9	% Gravel	0.00	xΦ=	3.02	σΦ=	0.48
	% Sand	97.54	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	2.46			Color:	
	% Carbonates	1.18	Wet:	5Y 4/2	Dry:	5Y 8/1

Table A21. Grain Size and Color Analysis Data from FMB 56 (2010), where x_{Φ} and σ_{Φ} are the mean grain size and standard deviation (sorting), respectively.

FMB 56-1	% Gravel	0.20	xΦ=	2.70	σΦ=	0.50
	% Sand	99.66	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.14			Color:	
	% Carbonates	2.48	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 56-2	% Gravel	0.29	xΦ=	2.64	σΦ=	0.56
	% Sand	99.52	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.19			Color:	
	% Carbonates	3.03	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 56-3	% Gravel	0.19	xΦ=	2.74	σΦ=	0.44
	% Sand	99.68	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.13			Color:	
	% Carbonates	3.40	Wet:	5Y 7/2	Dry:	2.5Y 8/1
FMB 56-4	% Gravel	0.98	xΦ=	2.38	σΦ=	0.79
	% Sand	98.80	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.22			Color:	
	% Carbonates	5.46	Wet:	5Y 7/1	Dry:	2.5Y 8/1
FMB 56-5	% Gravel	0.79	xΦ=	2.84	σΦ=	0.59
	% Sand	98.95	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.26			Color:	
	% Carbonates	2.02	Wet:	5Y 6/1	Dry:	5Y 8/1
FMB 56-6	% Gravel	1.46	xΦ=	2.90	σΦ=	0.77
	% Sand	98.08	Size:	Fine Sand	Sorting:	Moderately Sorted
	% Mud	0.45			Color:	
	% Carbonates	3.18	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 56-7	% Gravel	0.03	xΦ=	2.94	σΦ=	0.47
	% Sand	99.00	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.97			Color:	
	% Carbonates	1.42	Wet:	5Y 6/2	Dry:	5Y 8/2

Table A22. Grain Size and Color Analysis Data from FMB 56 (2011), where x_Φ and σ_Φ are the mean grain size and standard deviation (sorting), respectively.

FMB 56-1	% Gravel	0.23	$x\Phi$=	2.69	$\sigma\Phi$=	0.53
	% Sand	99.61	Size:	Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	0.17			Color:	
	% Carbonates	2.54	Wet:	2.5Y 7/1	Dry:	2.5Y 8/1
FMB 56-2	% Gravel	0.21	$x\Phi$=	2.73	$\sigma\Phi$=	0.49
	% Sand	99.53	Size:	Fine Sand	Sorting:	Well Sorted
	% Mud	0.26			Color:	
	% Carbonates	2.22	Wet:	2.5Y 7/1	Dry:	2.5Y 8/1
FMB 56-3	% Gravel	4.26	$x\Phi$=	2.11	$\sigma\Phi$=	1.34
	% Sand	95.24	Size:	Fine Sand	Sorting:	Poorly Sorted
	% Mud	0.50			Color:	
	% Carbonates	18.03	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 56-4	% Gravel	13.78	$x\Phi$=	1.69	$\sigma\Phi$=	1.93
	% Sand	85.70	Size:	Medium Sand	Sorting:	Poorly Sorted
	% Mud	0.52			Color:	
	% Carbonates	29.54	Wet:	5Y 7/1	Dry:	5Y 8/1
FMB 56-5	% Gravel	0.02	$x\Phi$=	3.07	$\sigma\Phi$=	0.33
	% Sand	98.89	Size:	Very Fine Sand	Sorting:	Very Well Sorted
	% Mud	1.09			Color:	
	% Carbonates	1.38	Wet:	5Y 5/1	Dry:	5Y 8/1
FMB 56-6	% Gravel	0.52	$x\Phi$=	3.10	$\sigma\Phi$=	0.63
	% Sand	97.31	Size:	Very Fine Sand	Sorting:	Moderately Well Sorted
	% Mud	2.17			Color:	
	% Carbonates	2.76	Wet:	2.5Y 6/2	Dry:	5Y 8/1
FMB 56-7	% Gravel	0.01	$x\Phi$=	3.05	$\sigma\Phi$=	0.47
	% Sand	98.00	Size:	Very Fine Sand	Sorting:	Well Sorted
	% Mud	2.00			Color:	
	% Carbonates	1.27	Wet:	5Y 4/1	Dry:	5Y 8/1

Appendix B: SAJ Survey Data: pre- and post-construction beach-nearshore profiles

The following appendix includes beach profiles created from survey data recorded by SAJ pre- and post-construction of the berm (May 2009 and October 2009, respectively). Figure B1 is a map showing the location of each beach profile. All elevations are relative to NAVD88, and all distances are relative to a benchmark.

Figure B1. USACE survey line locations.

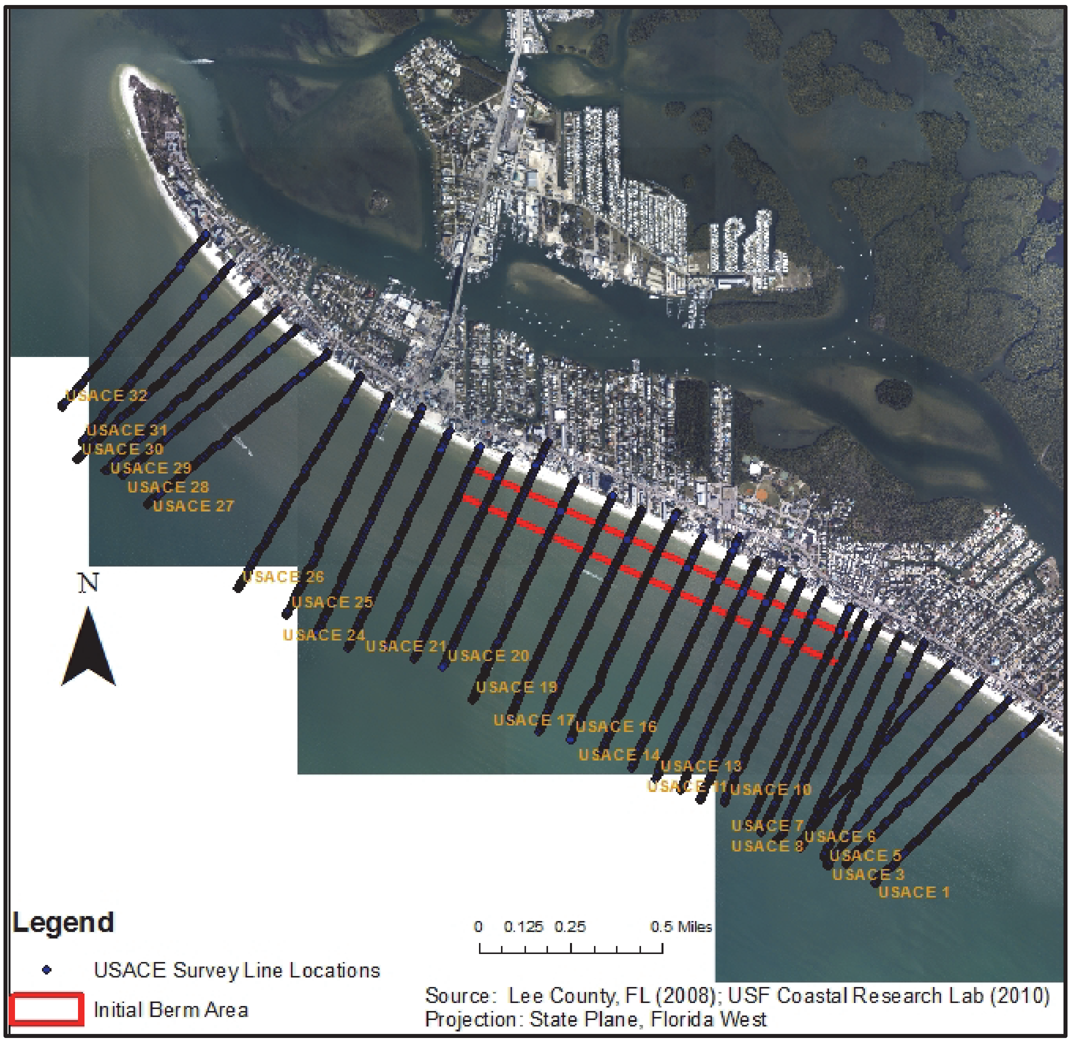


Figure B2. Profile USACE 1.

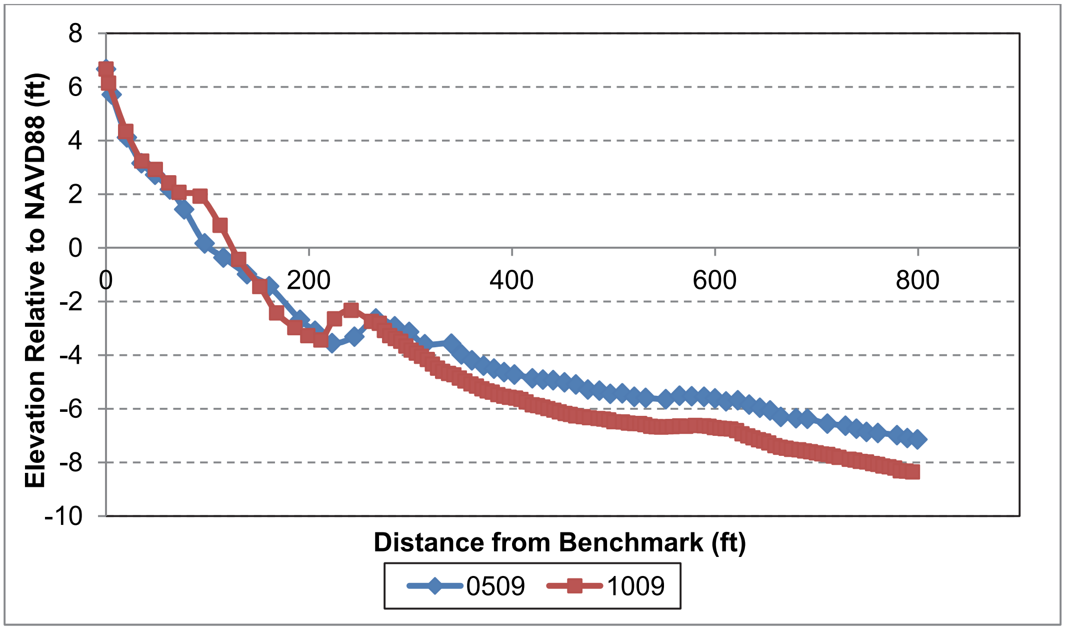


Figure B3. Profile USACE 2.

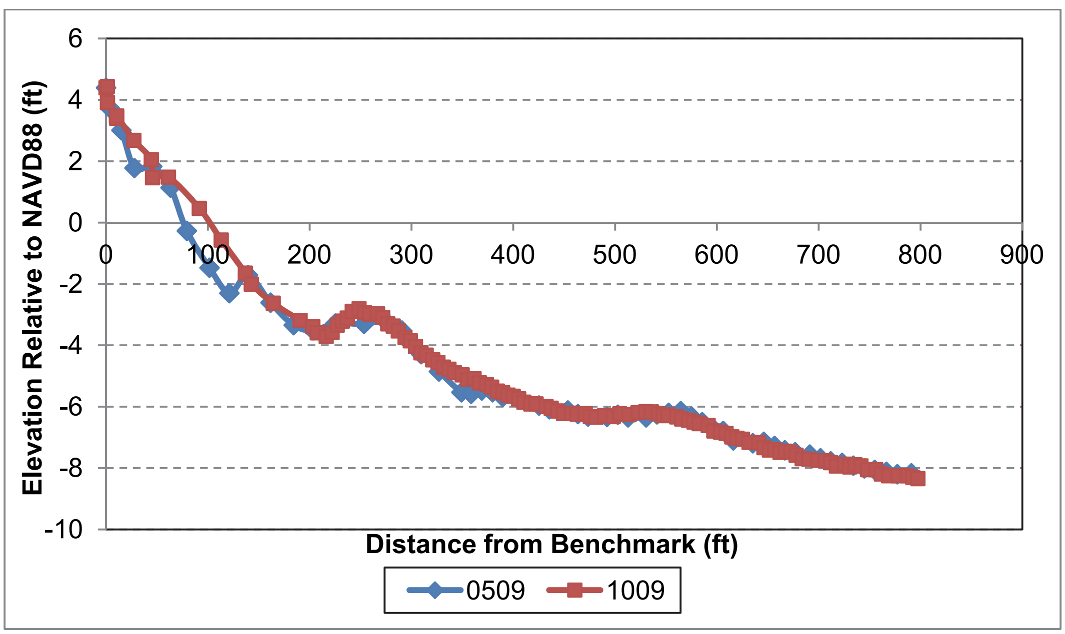


Figure B4. Profile USACE 3.

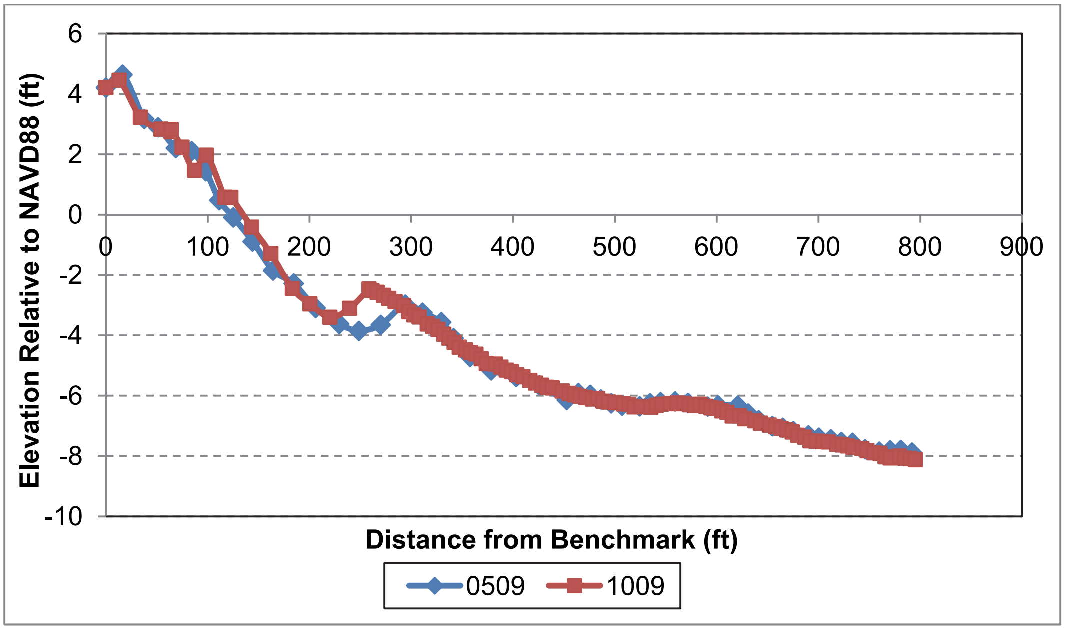


Figure B5. Profile USACE 4.

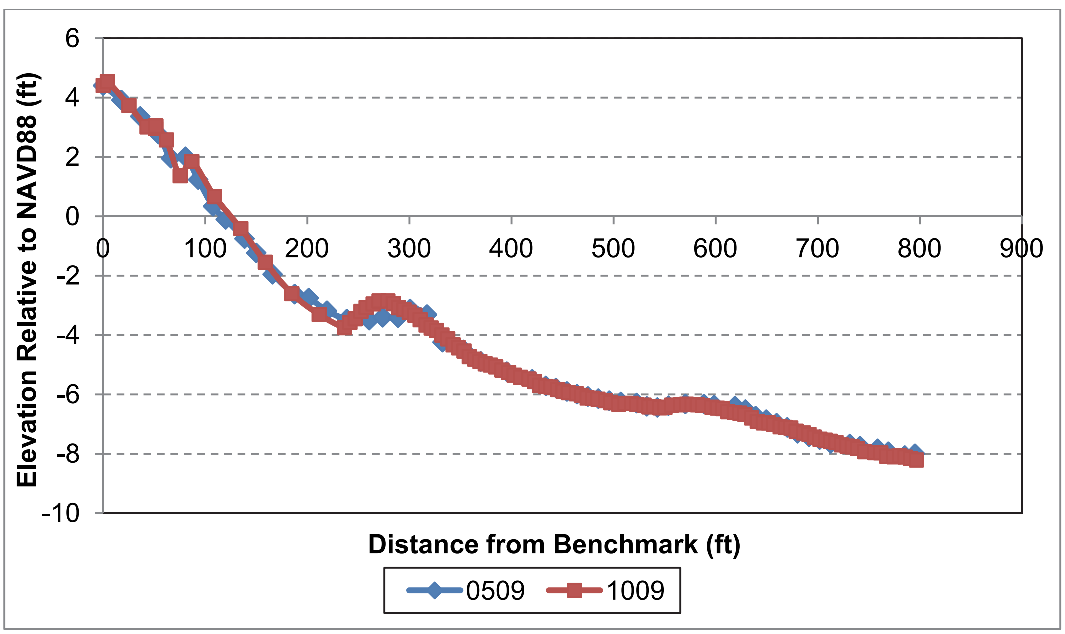


Figure B6. Profile USACE 5.

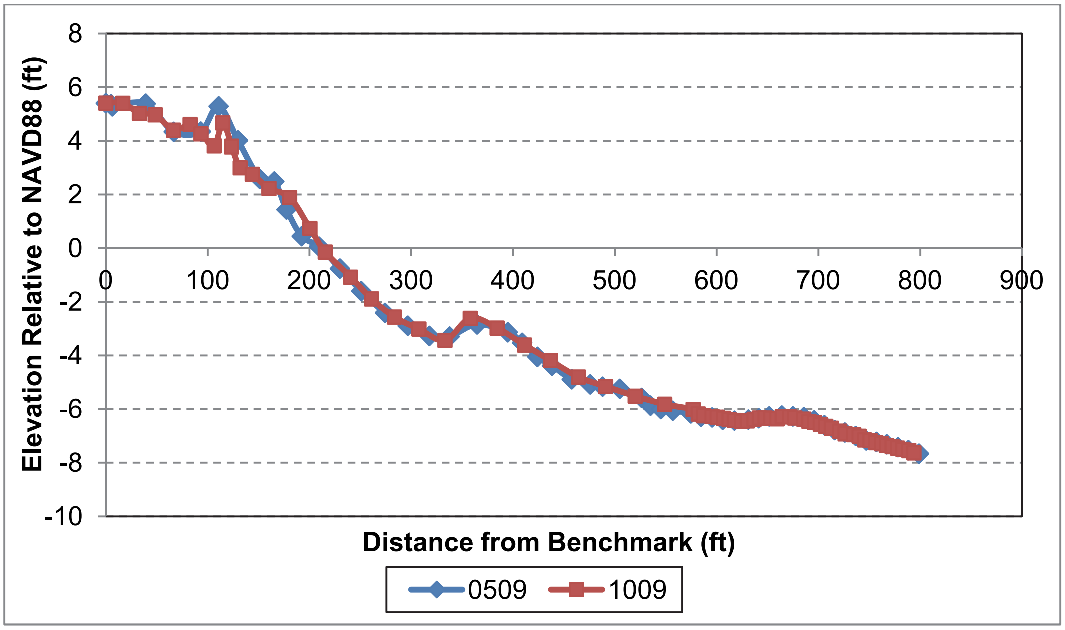


Figure B7. Profile USACE 6.

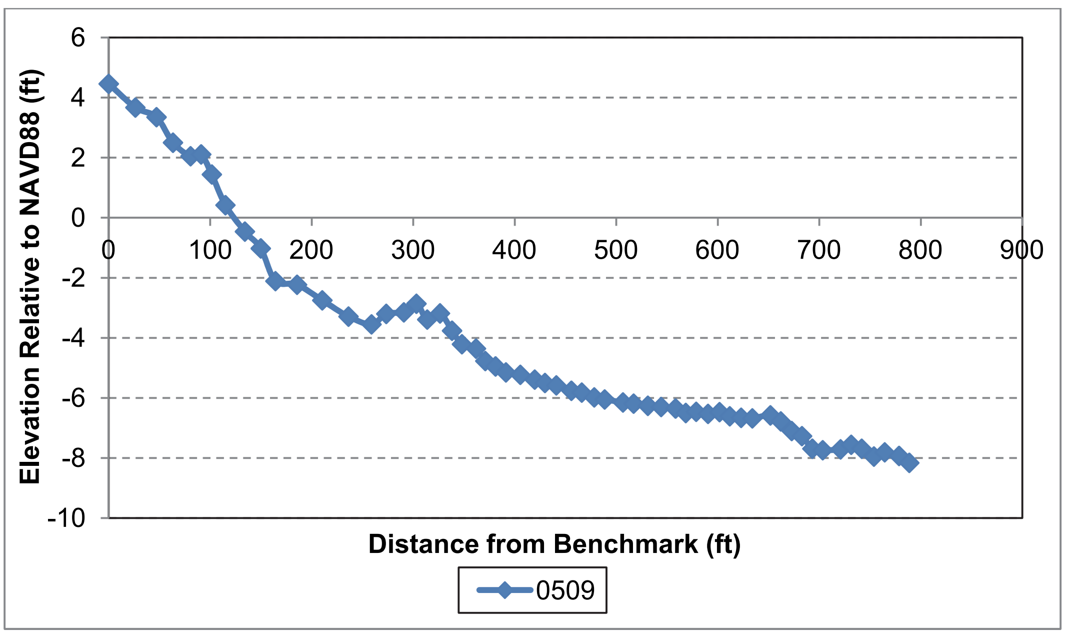


Figure B8. Profile USACE 7.

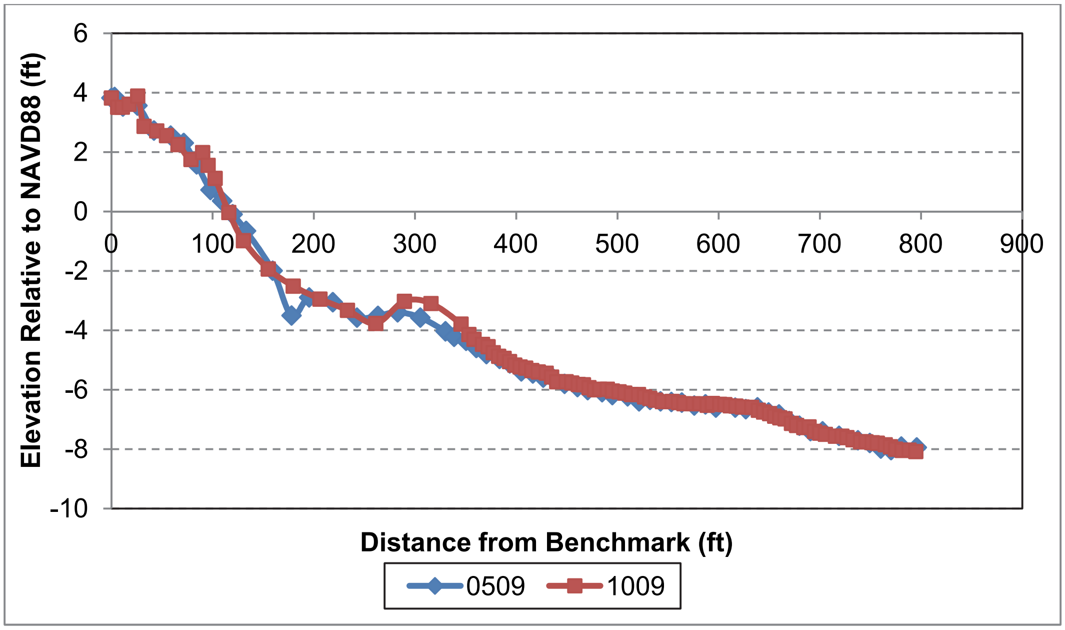


Figure B9. Profile USACE 8.

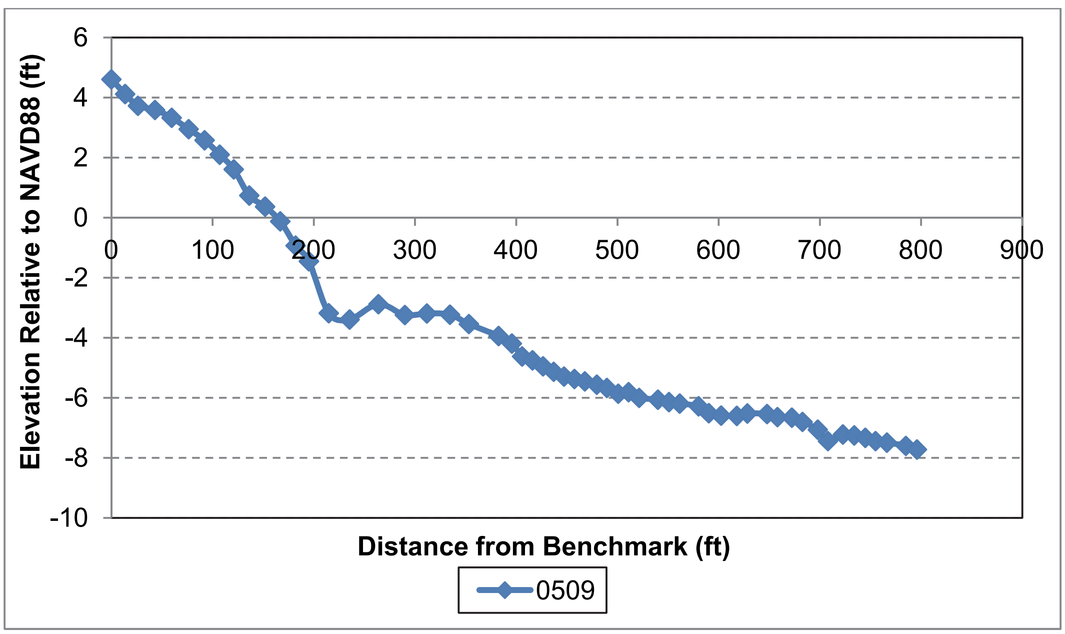


Figure B10. Profile USACE 9.

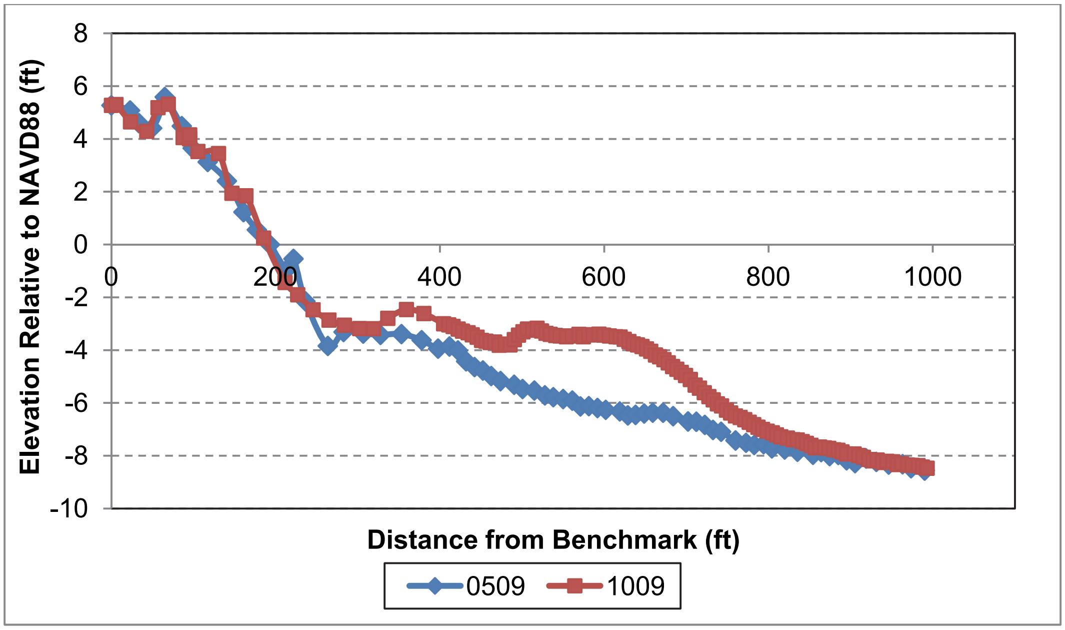


Figure B11. Profile USACE 10.

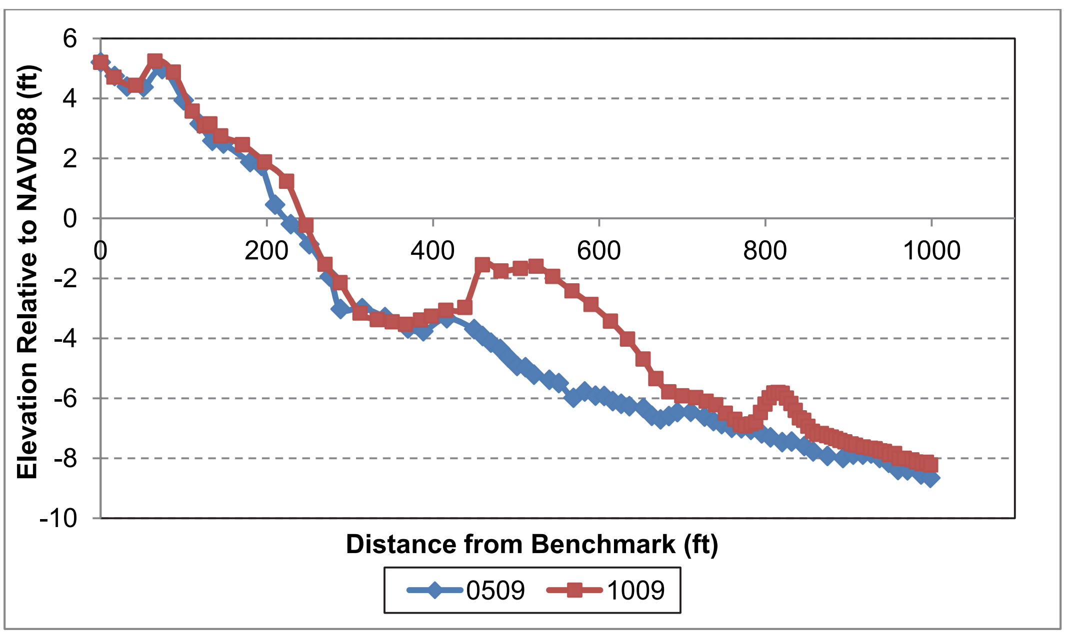


Figure B12. Profile USACE 11.

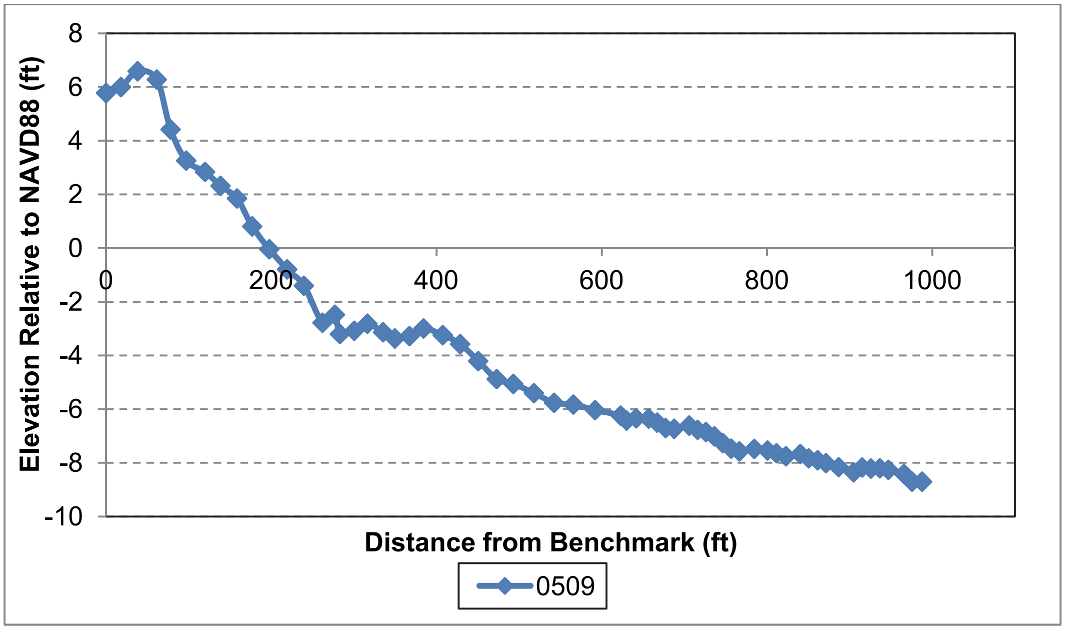


Figure B13. Profile USACE 12.

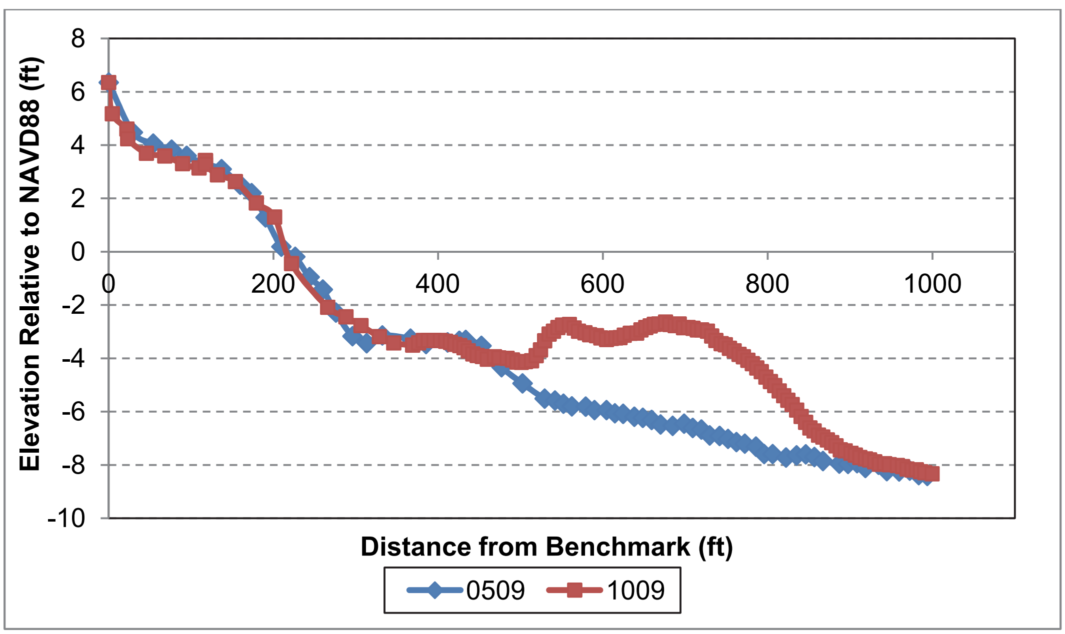


Figure B14. Profile at USACE 13.

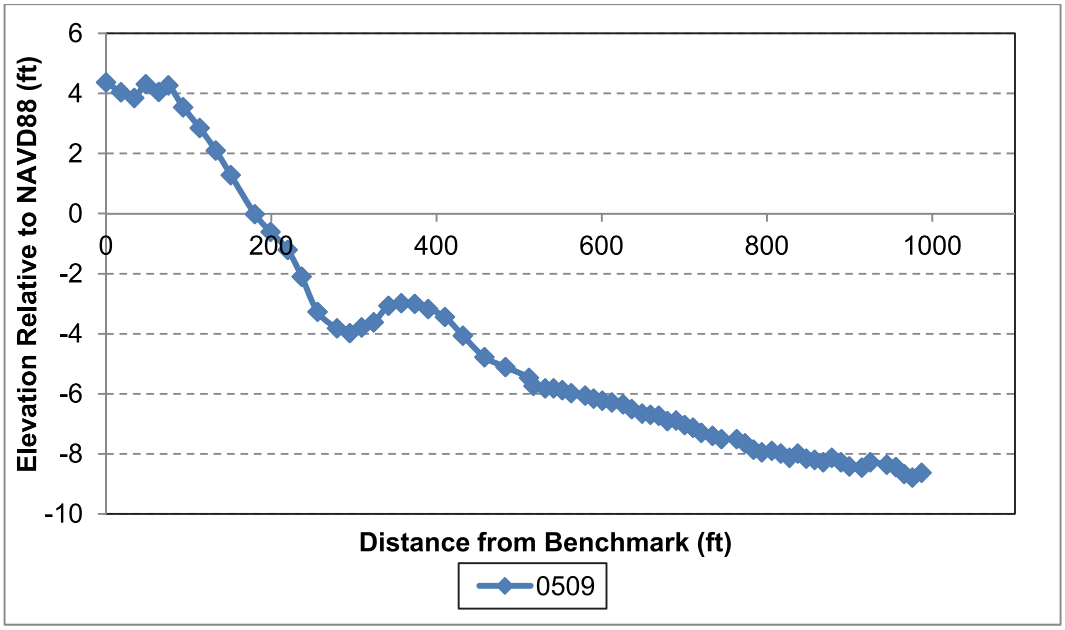


Figure B15. Profile at USACE 14.

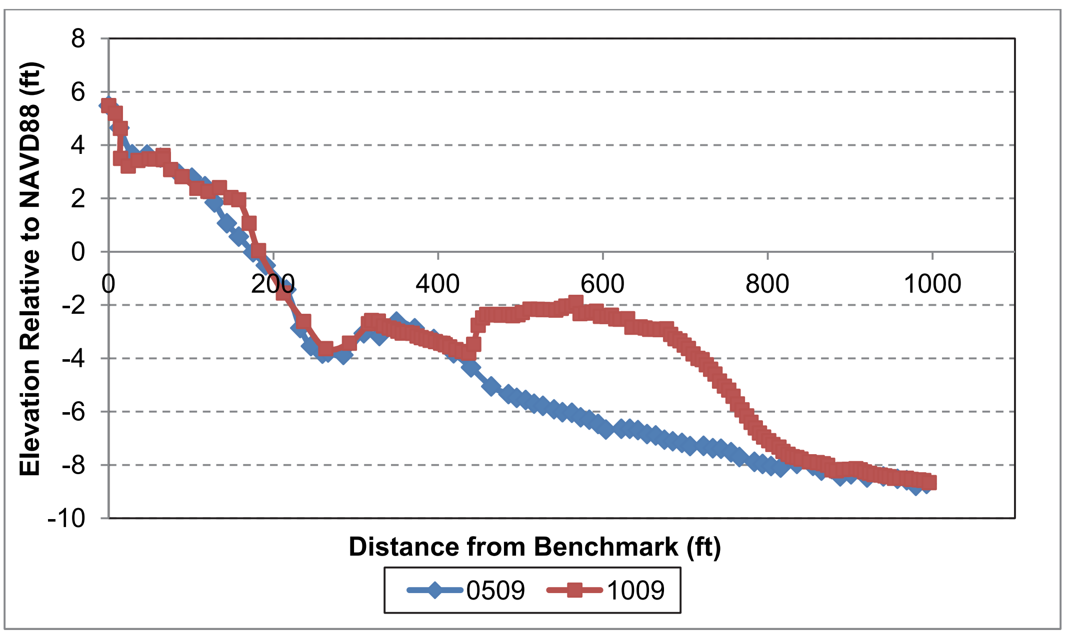


Figure B16. Profile at USACE 15.

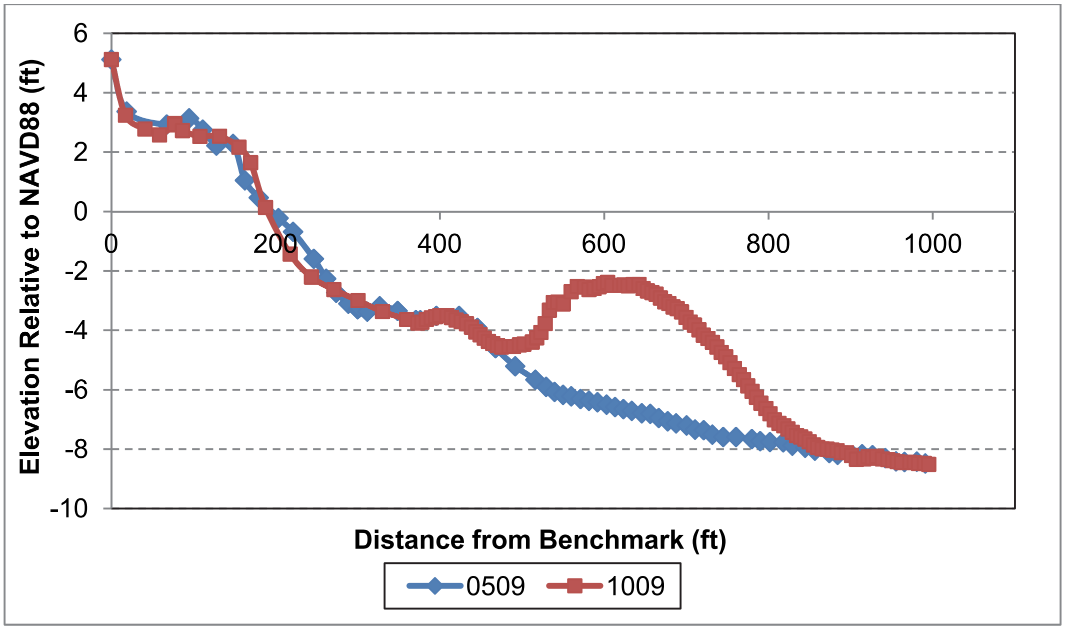


Figure B17. Profile at USACE 16.

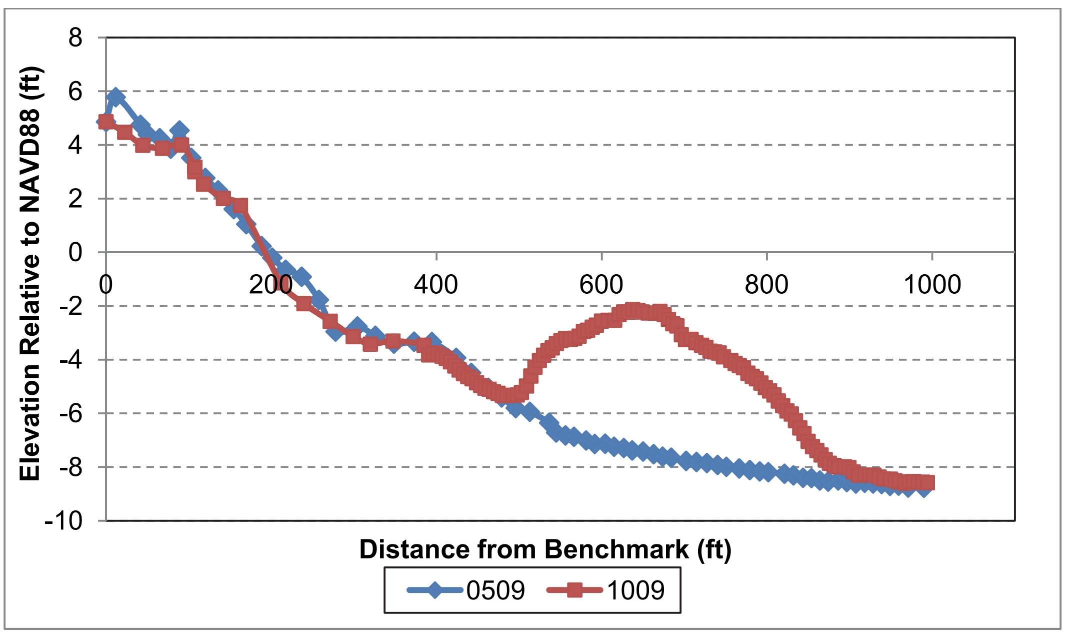


Figure B18. Profile at USACE 17.

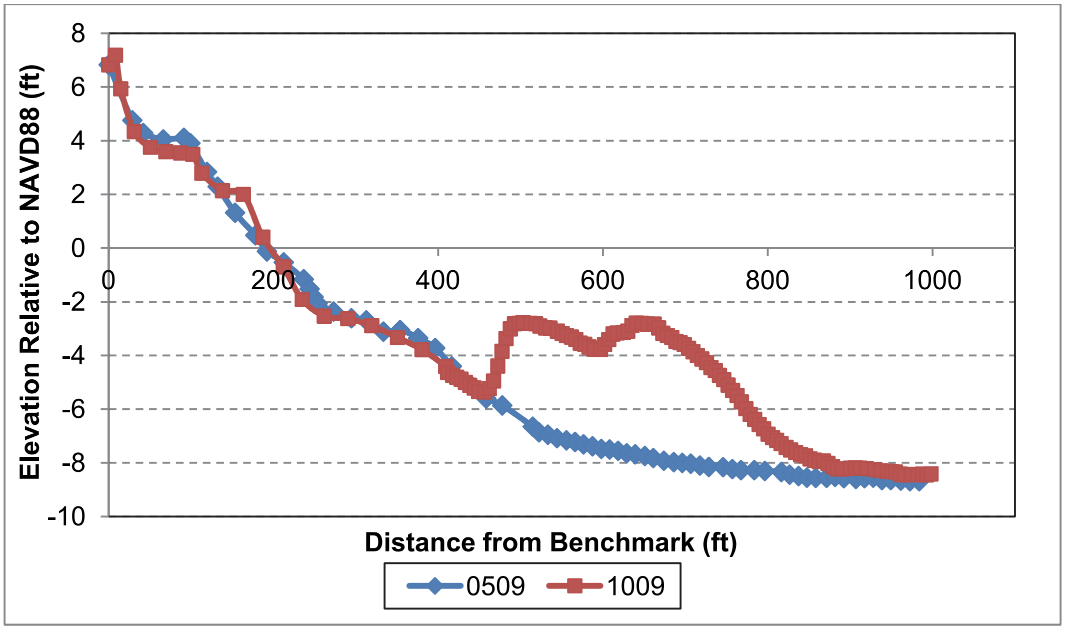


Figure B19. Profile at USACE 18.

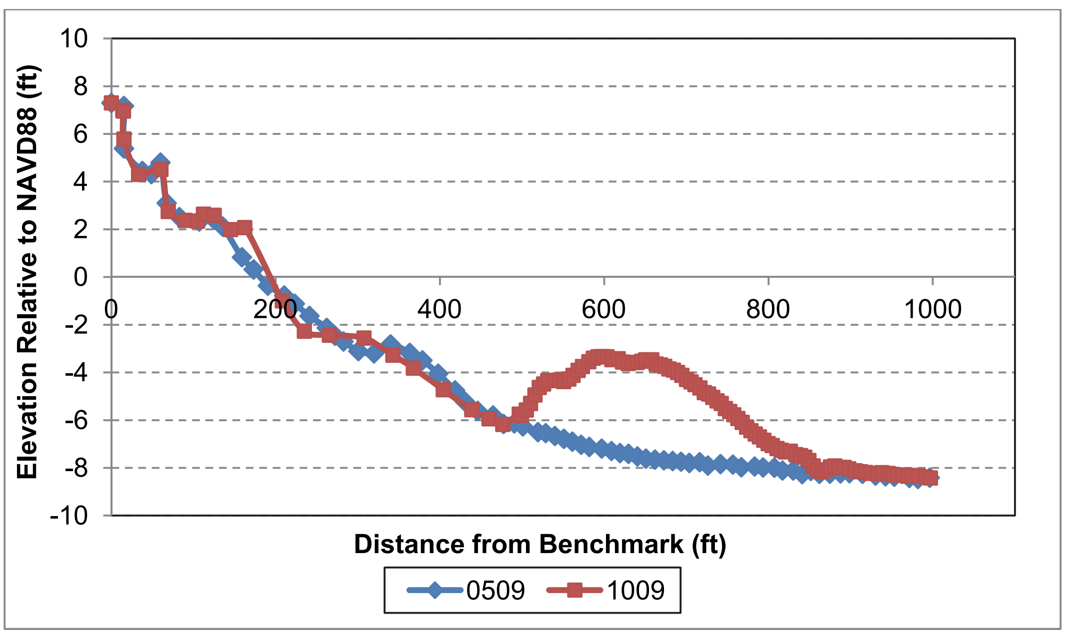


Figure B20. Profile at USACE 19.

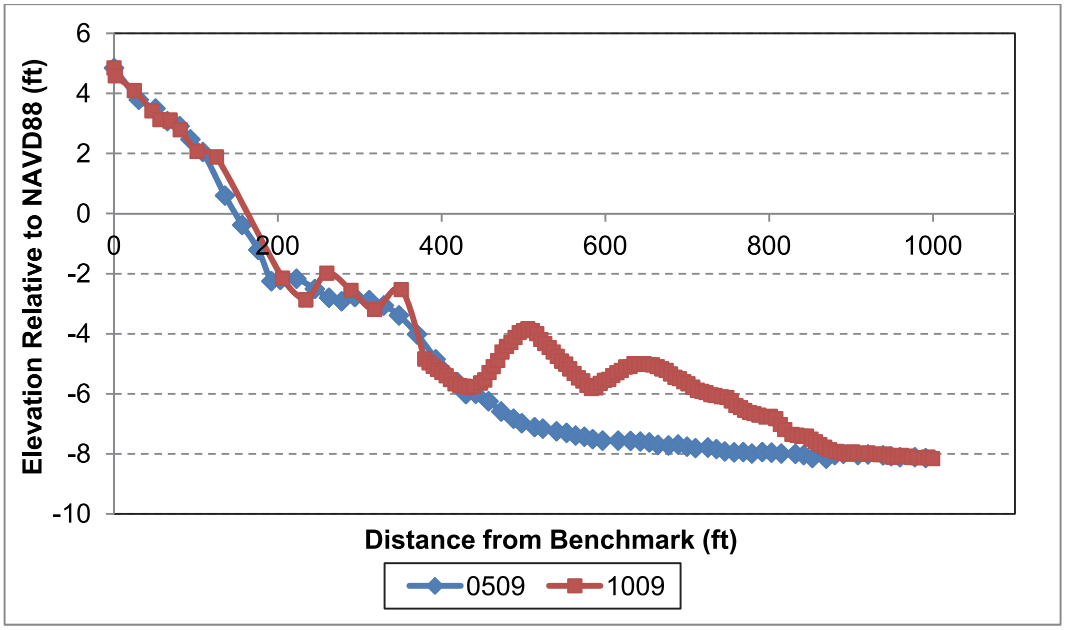


Figure B21. Profile at USACE 20.

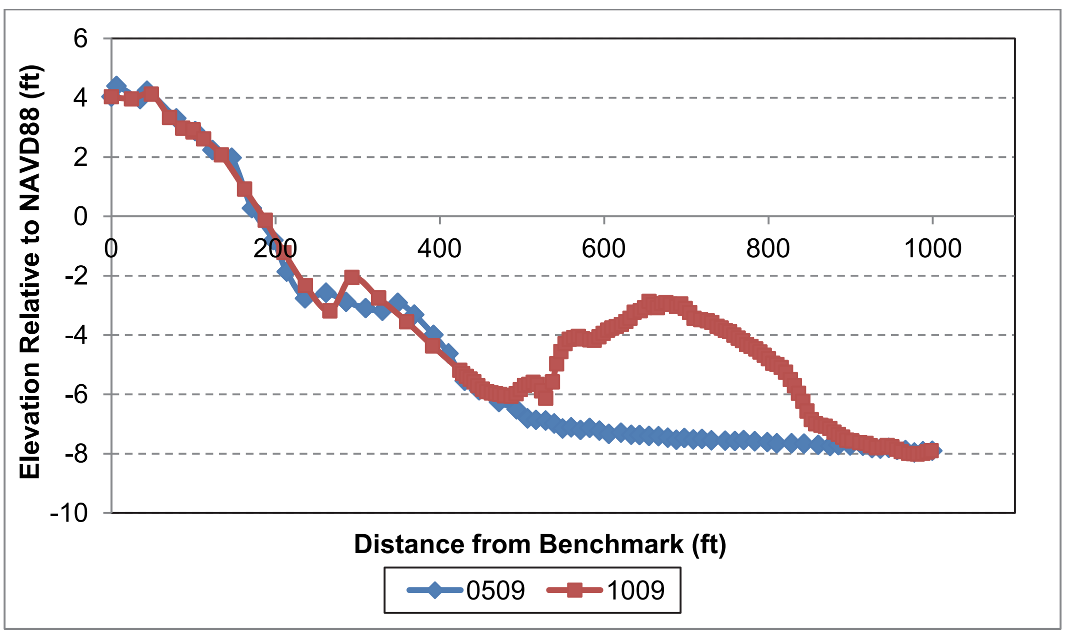


Figure B22. Profile at USACE 21.

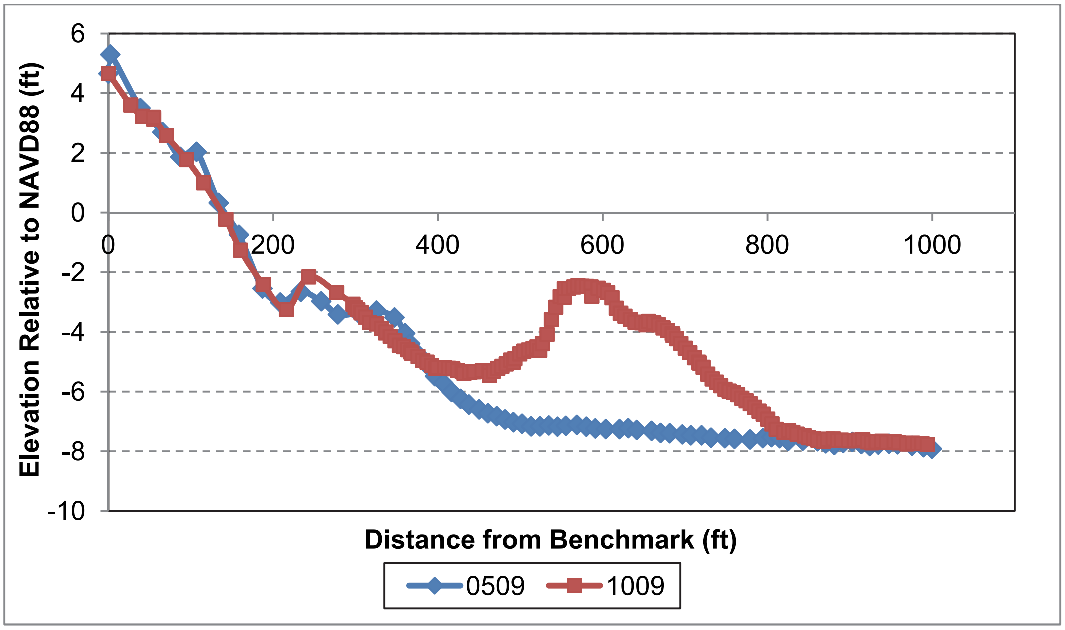


Figure B23. Profile at USACE 22.

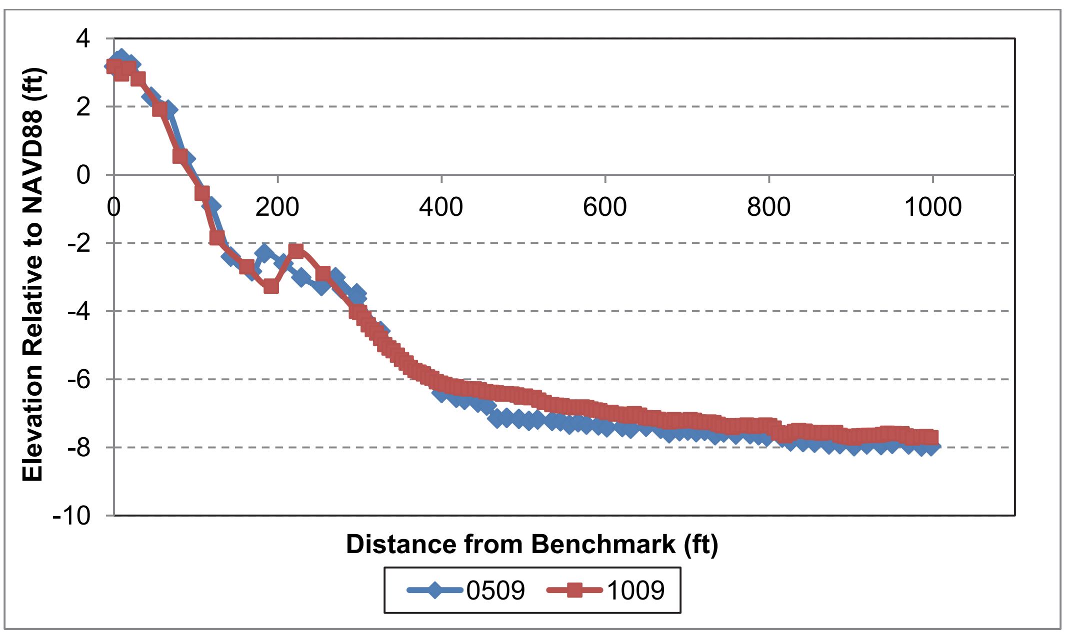


Figure B24. Profile at USACE 23.

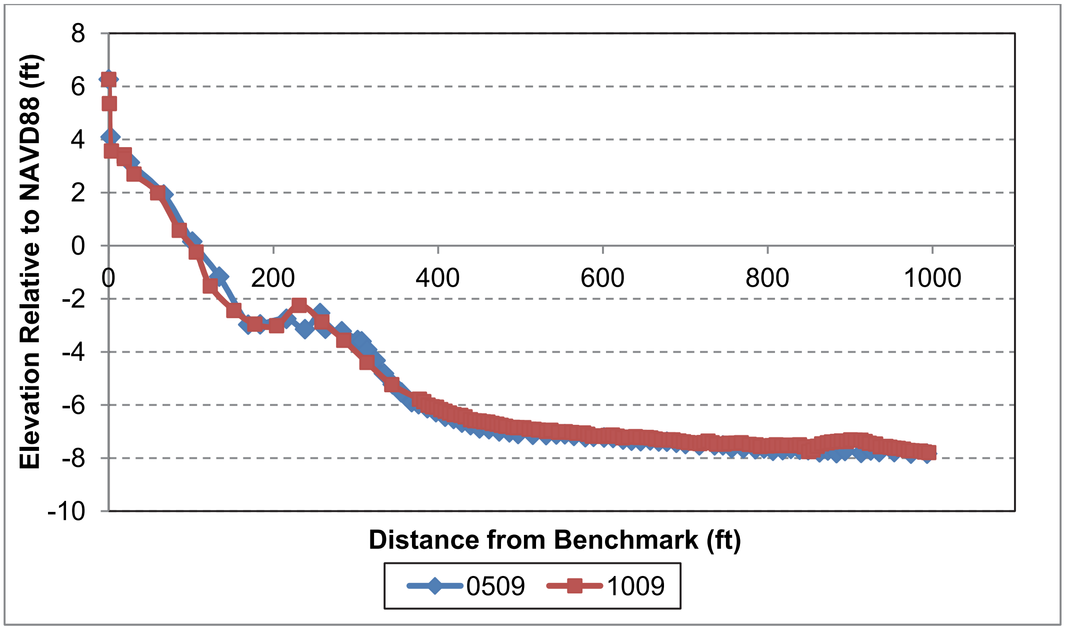


Figure B25. Profile at USACE 24.

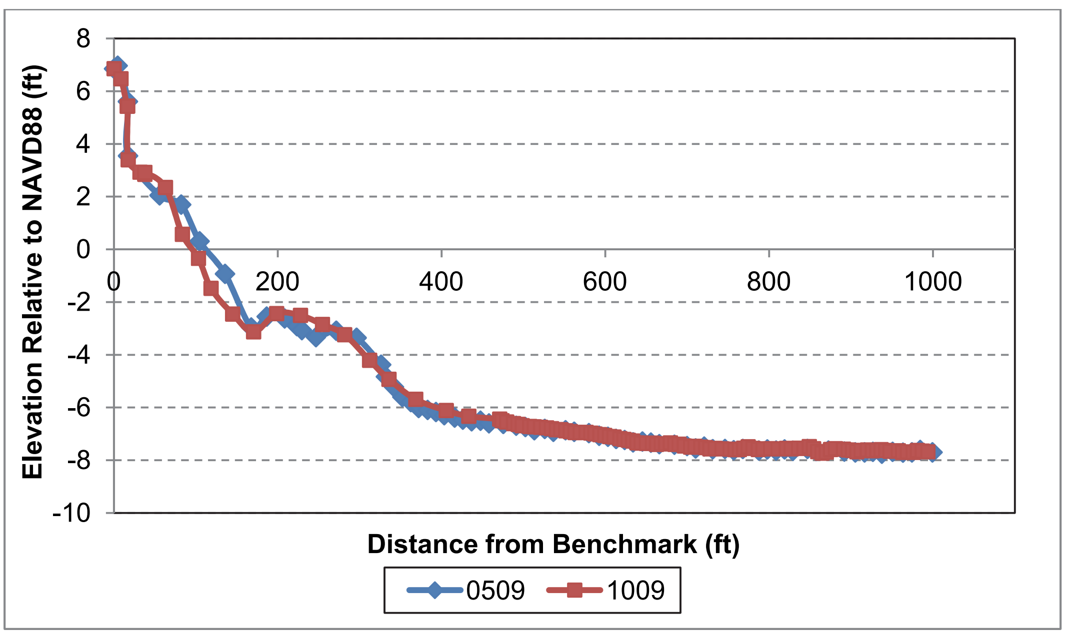


Figure B26. Profile at USACE 25.

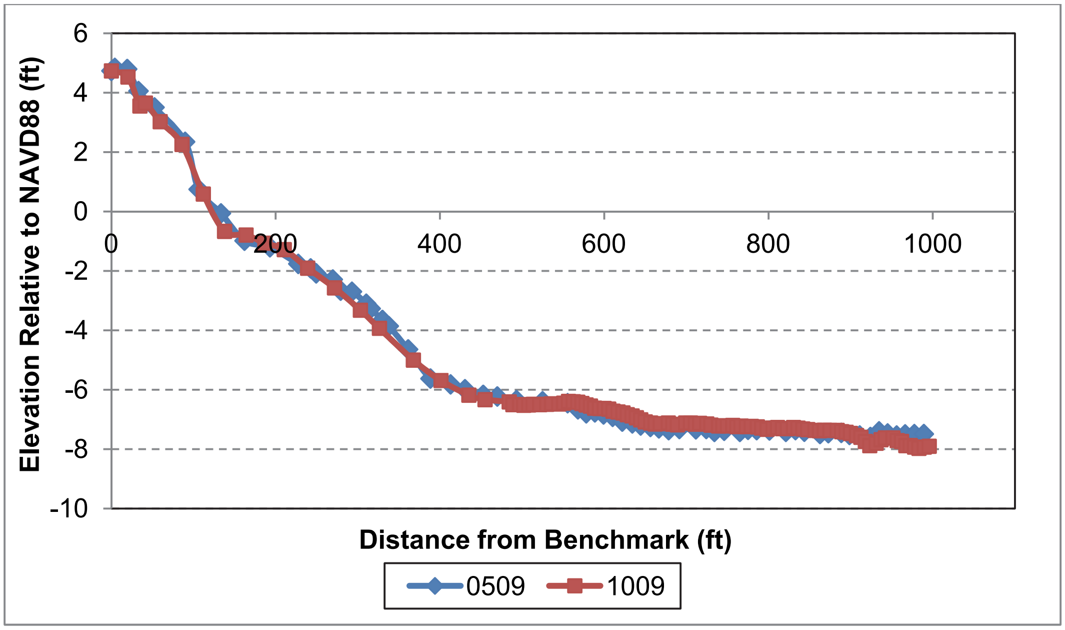


Figure B27. Profile at USACE 26.

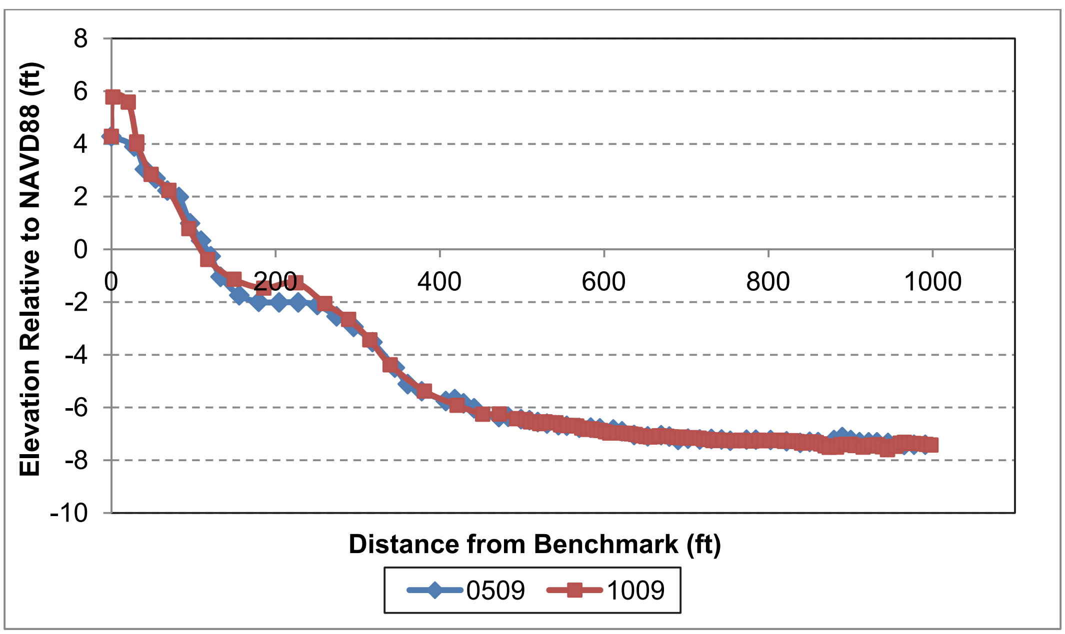


Figure B28. Profile at USACE 27.

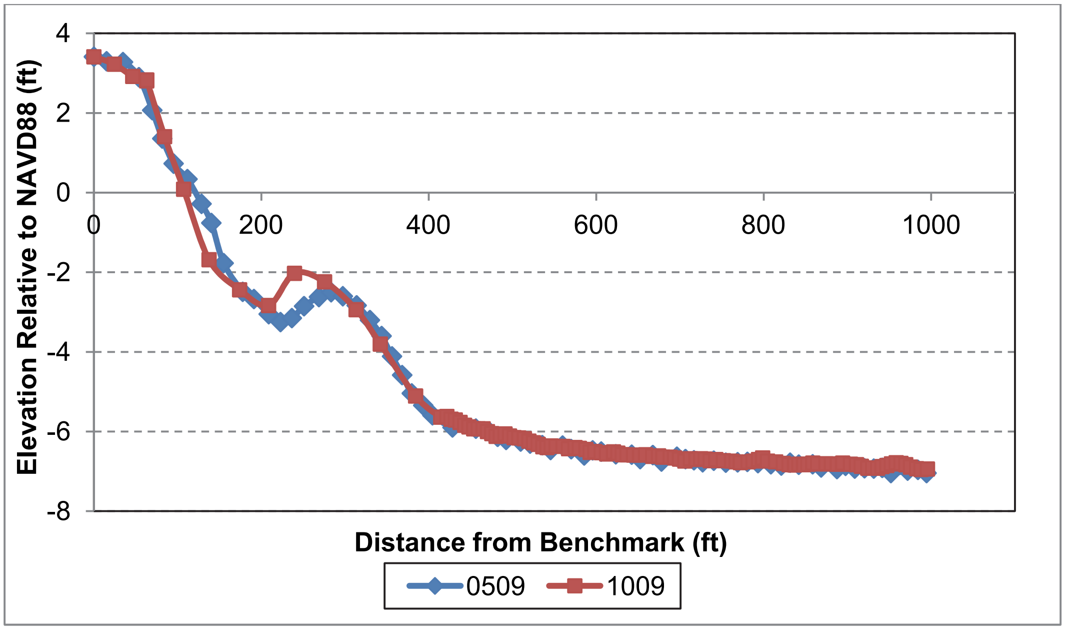


Figure B29. Profile at USACE 28.

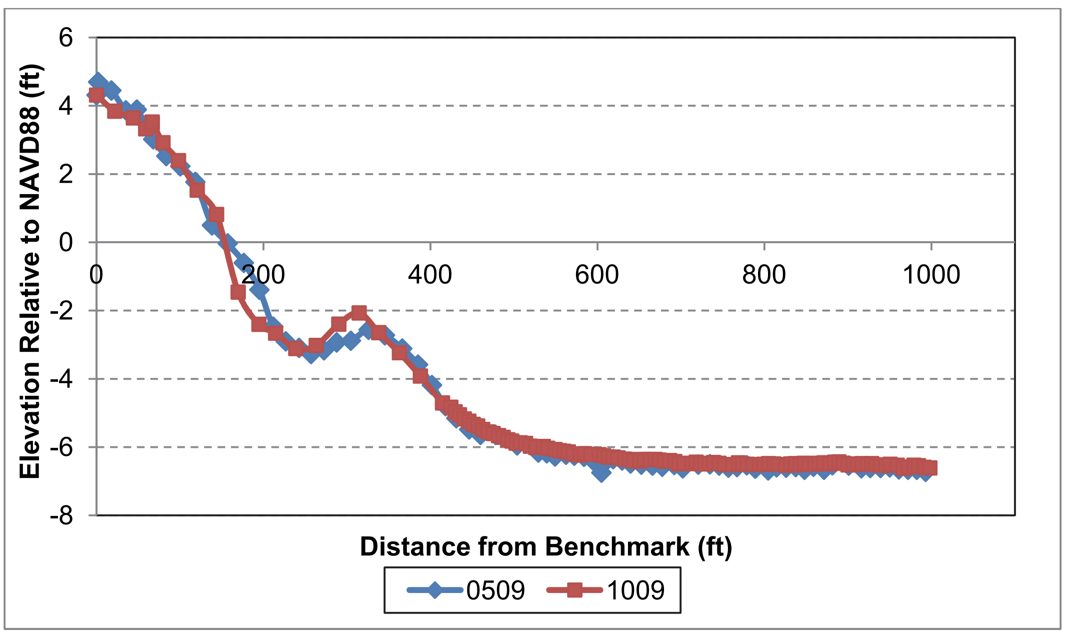


Figure B30. Profile at USACE 29.

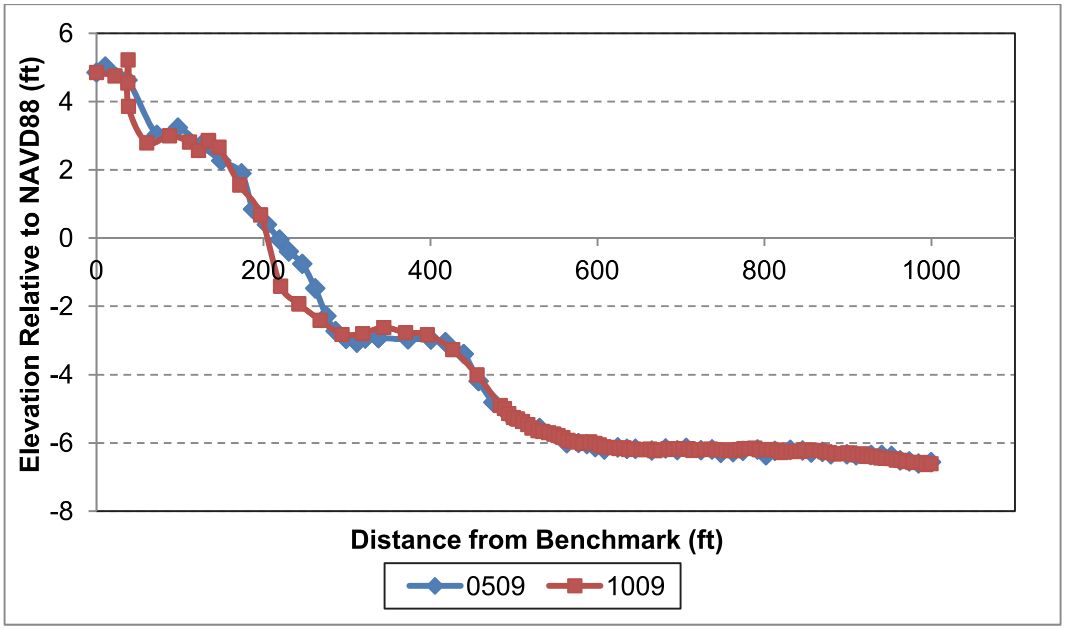


Figure B31. Profile at USACE 30.

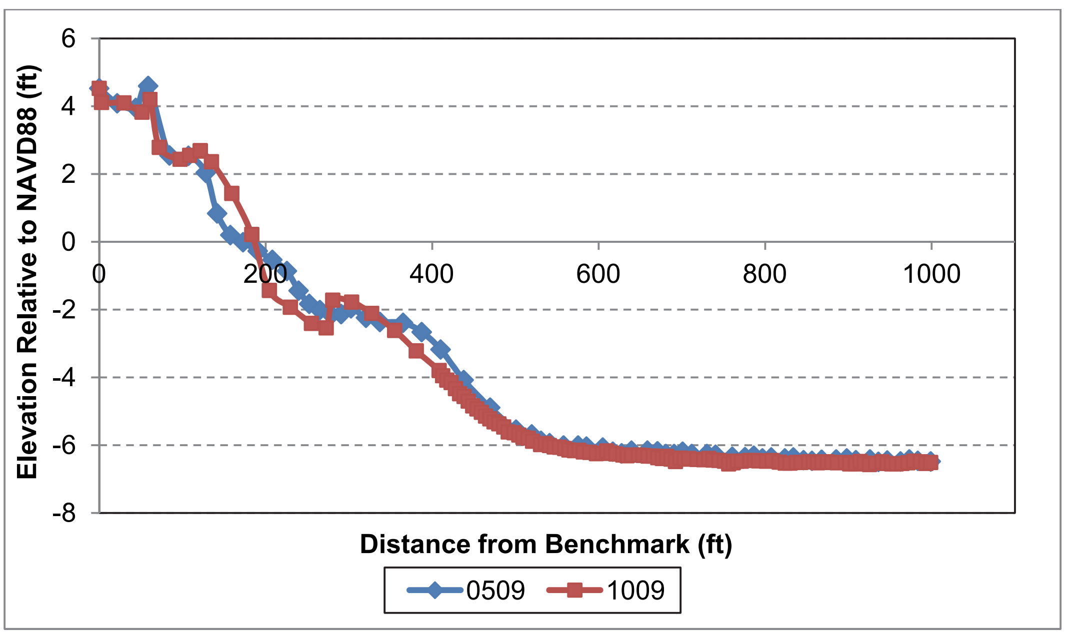


Figure B32. Profile at USACE 31.

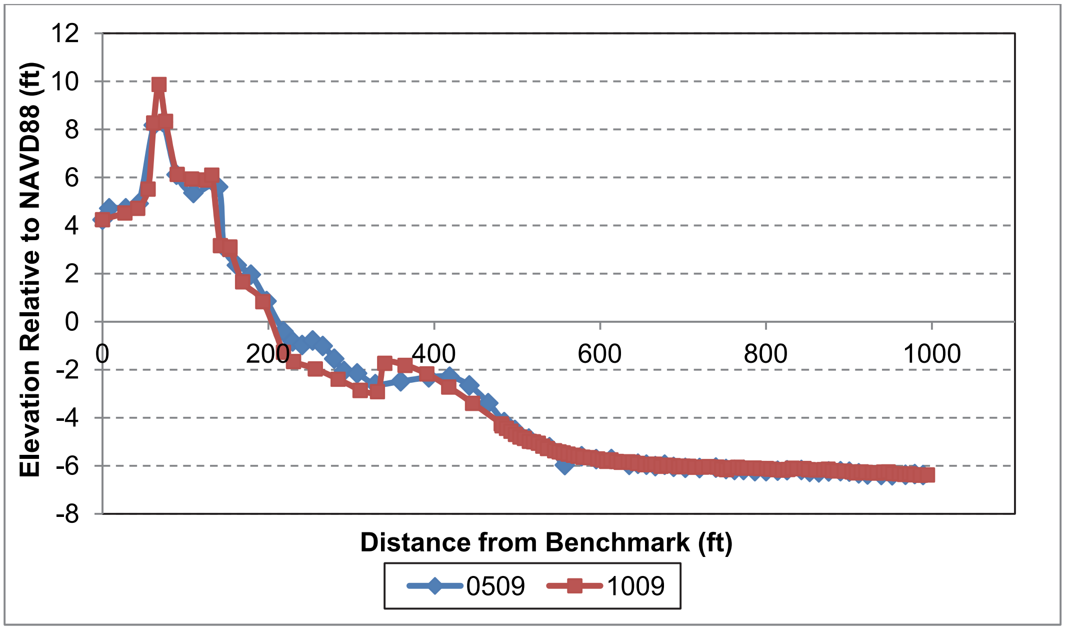
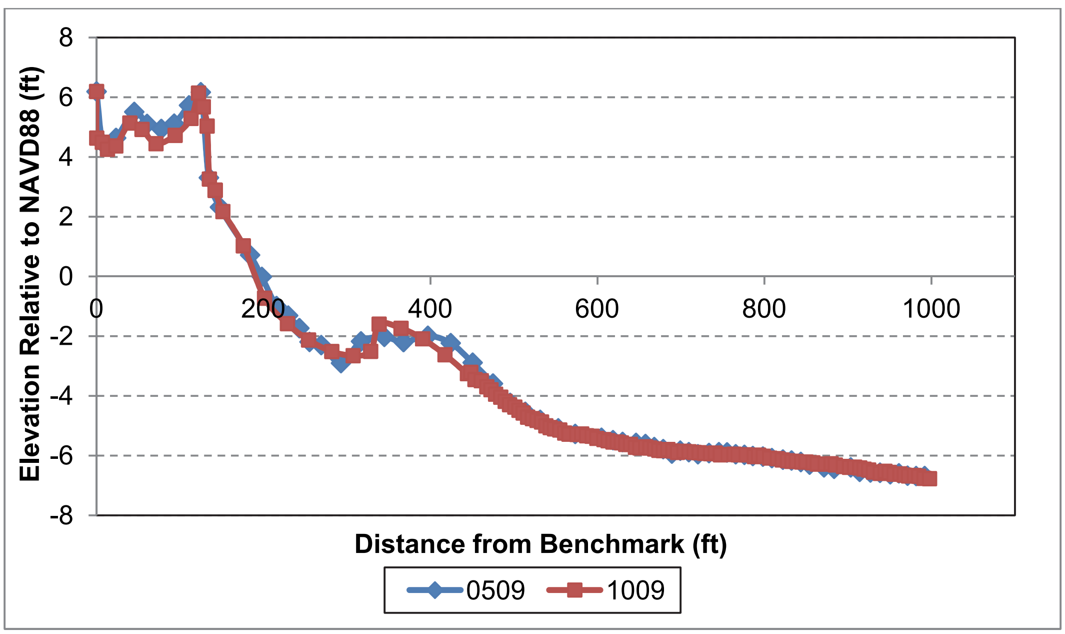


Figure B33. Profile at USACE 32.



Appendix C: USF-CRL Survey Data: morphologic evolution during the first 2 years post construction

The following appendix includes beach profiles created from survey data recorded by USF CRL in April 2010, October 2010, June 2011, and September 2011. Figure C1 is a map showing the location of each beach profile. All elevations are relative to NAVD88, and all distances are relative to a benchmark.

Figure C1. USF CRL survey line locations.

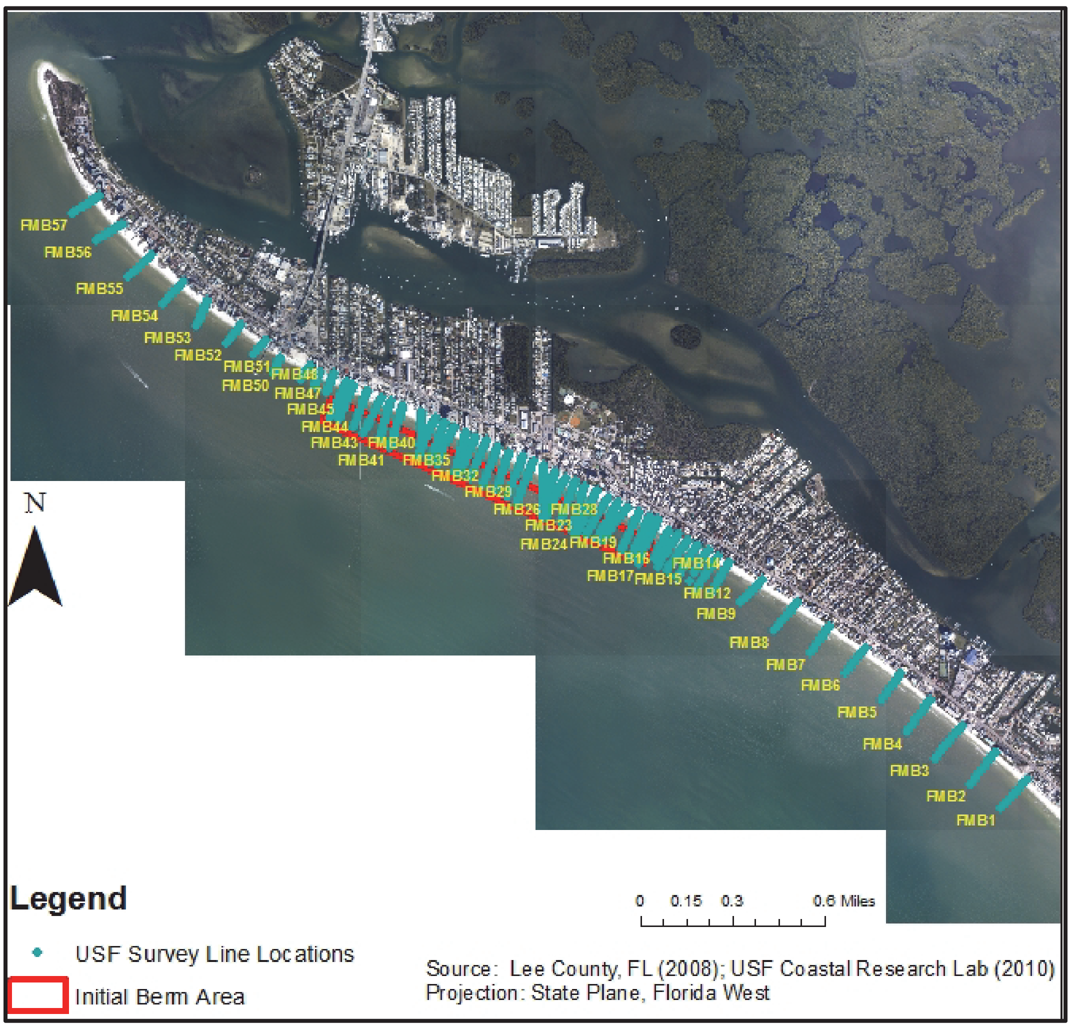


Figure C2. Profile at FMB 1.

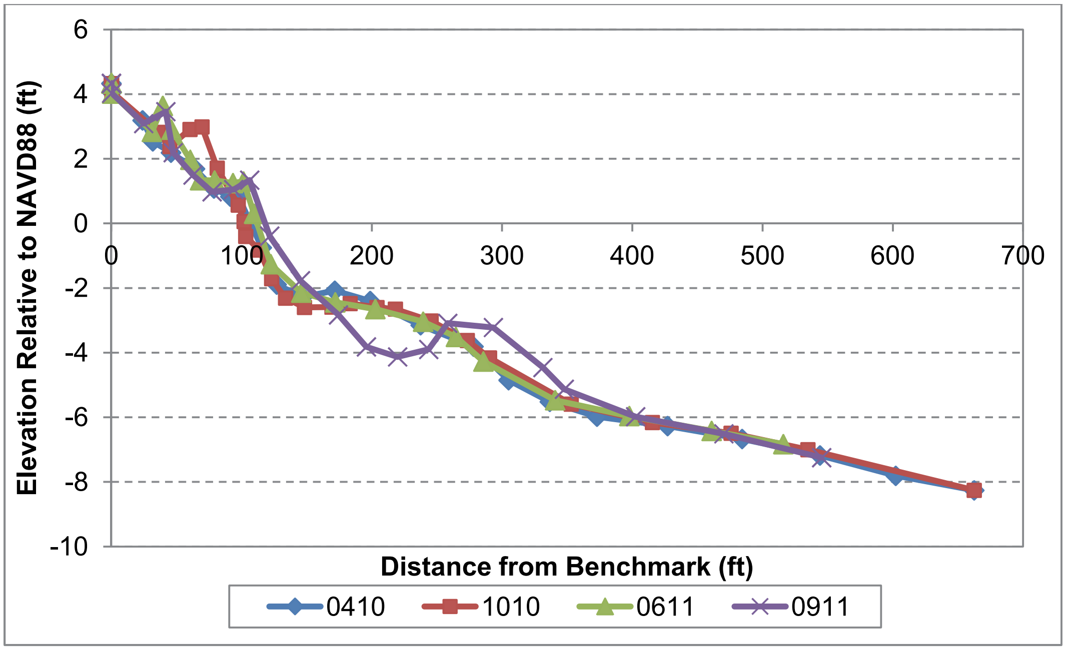


Figure C3. Profile at FMB 2.

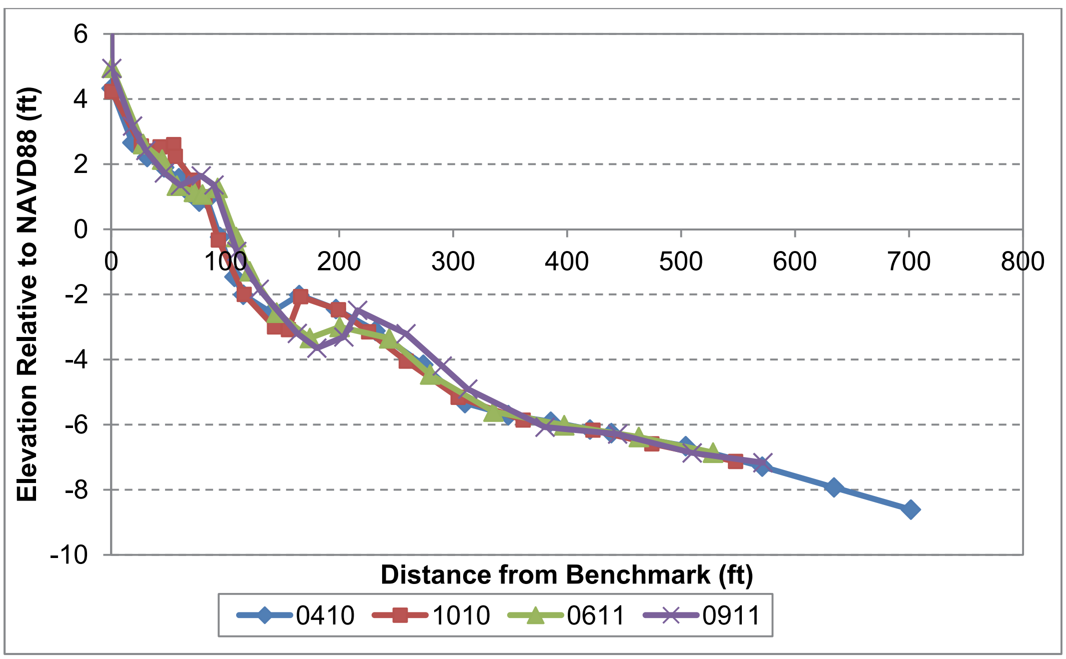


Figure C4. Profile at FMB 3.

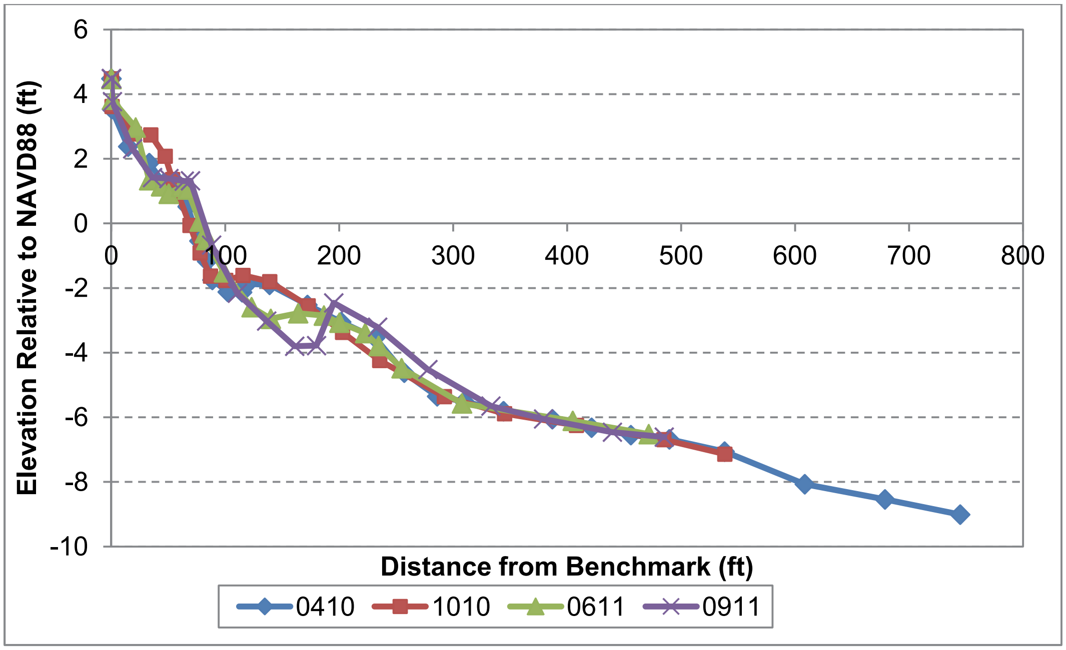


Figure C5. Profile at FMB 4.

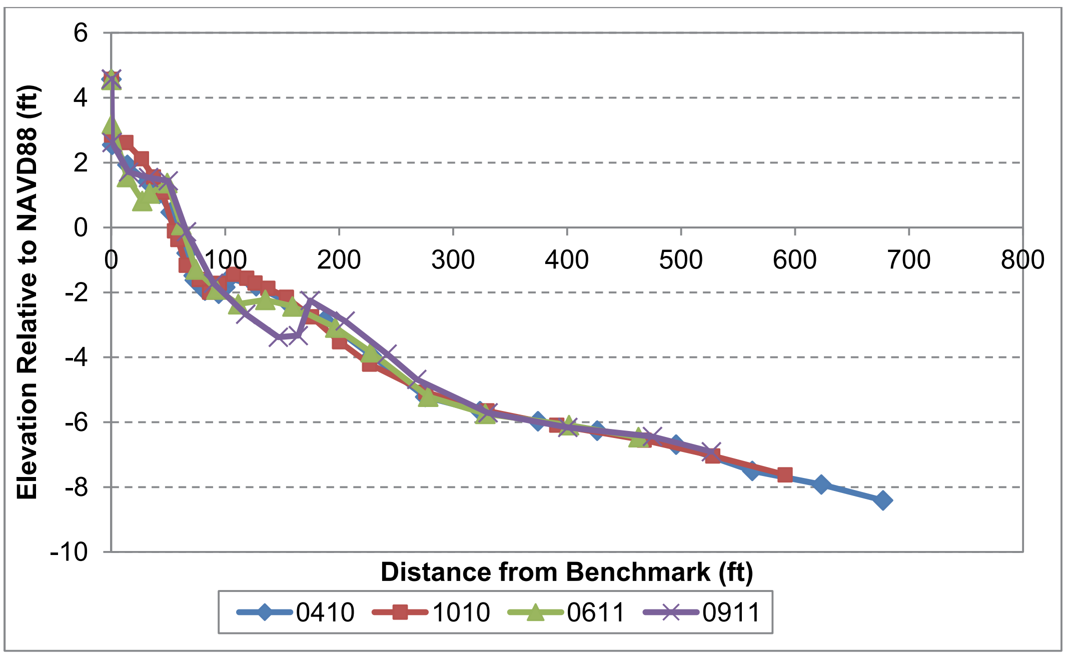


Figure C6. Profile at FMB 5.

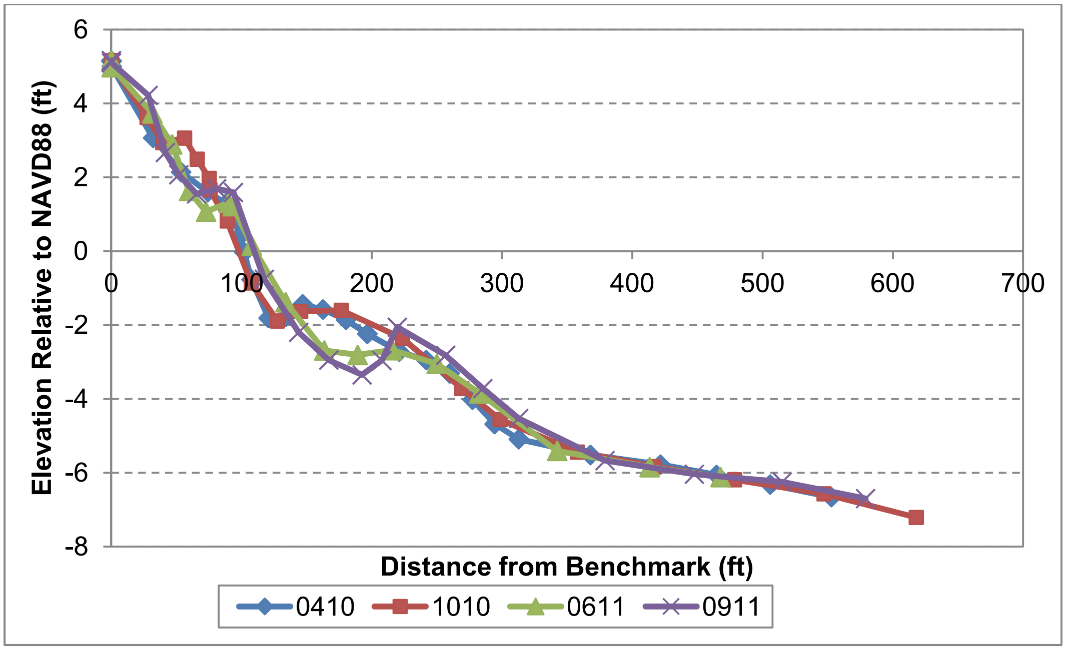


Figure C7. Profile at FMB 6.

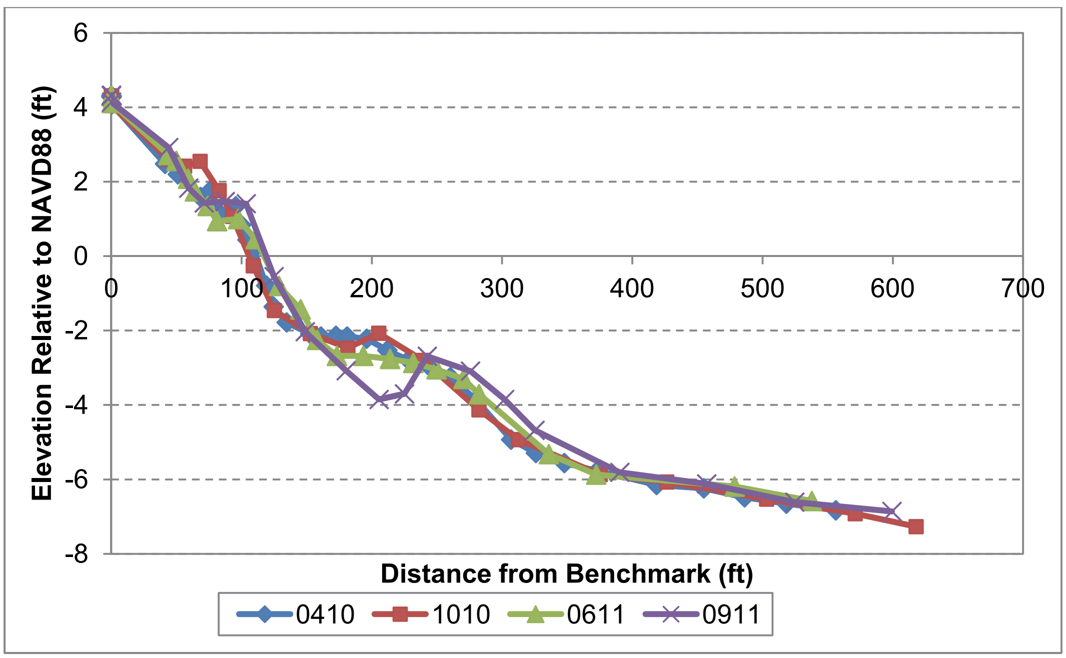


Figure C8. Profile at FMB 7.

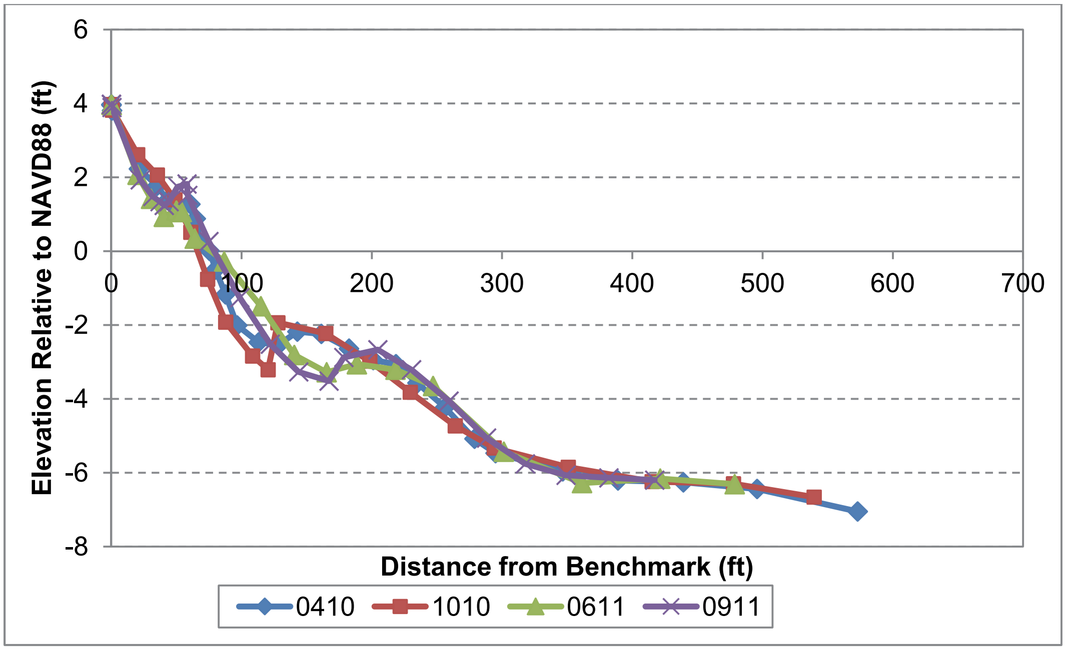


Figure C9. Profile at FMB 8.

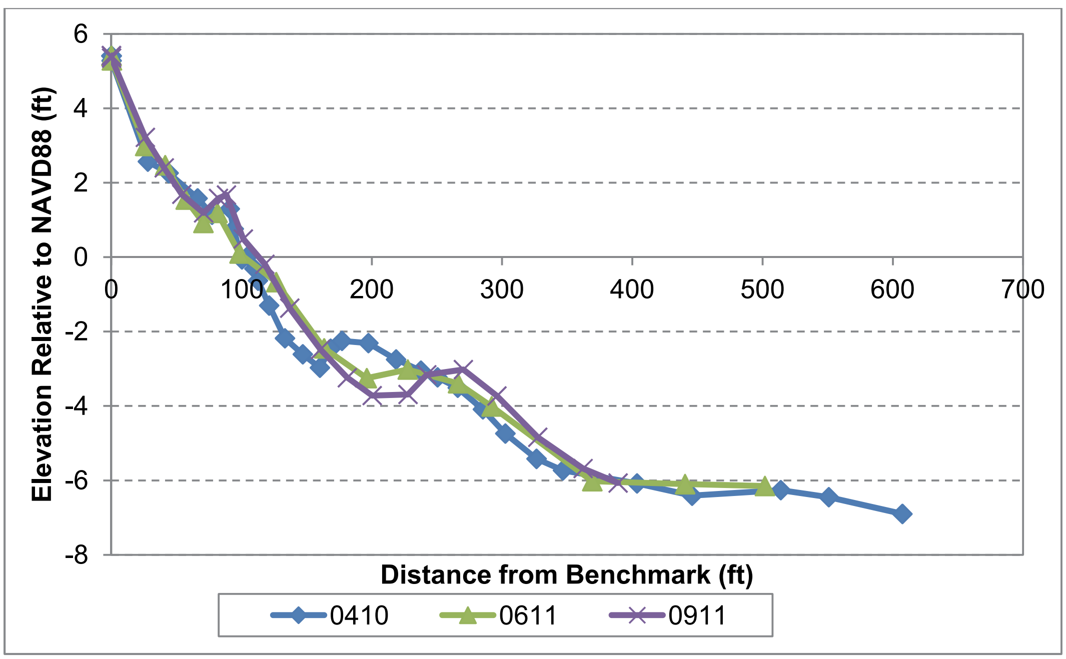


Figure C10. Profile at FMB 9.

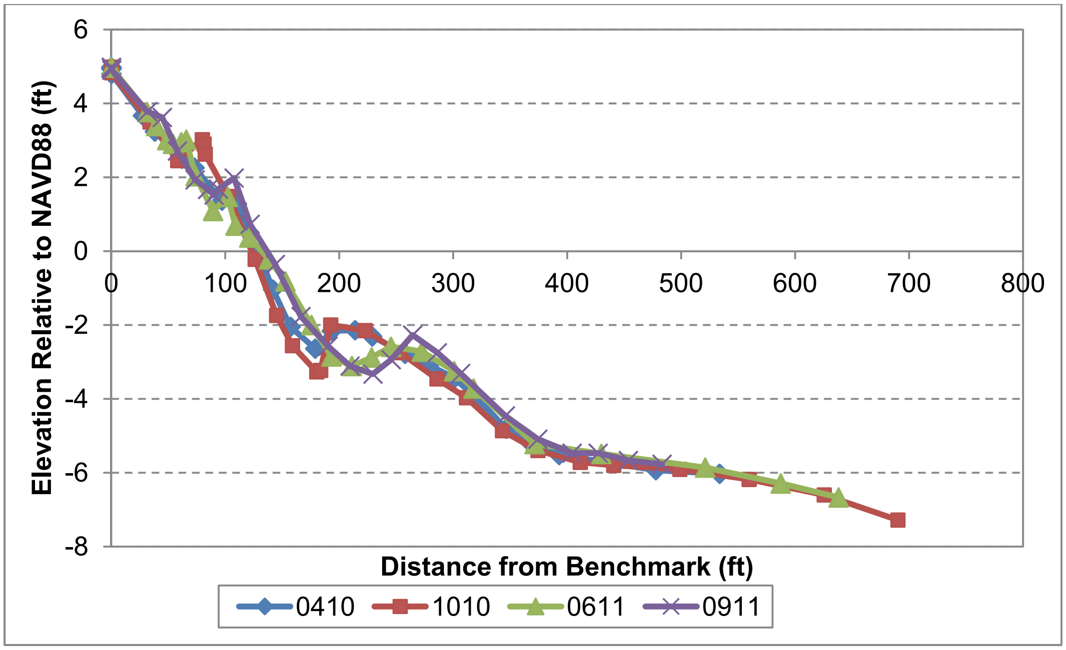


Figure C11. Profile at FMB 10.

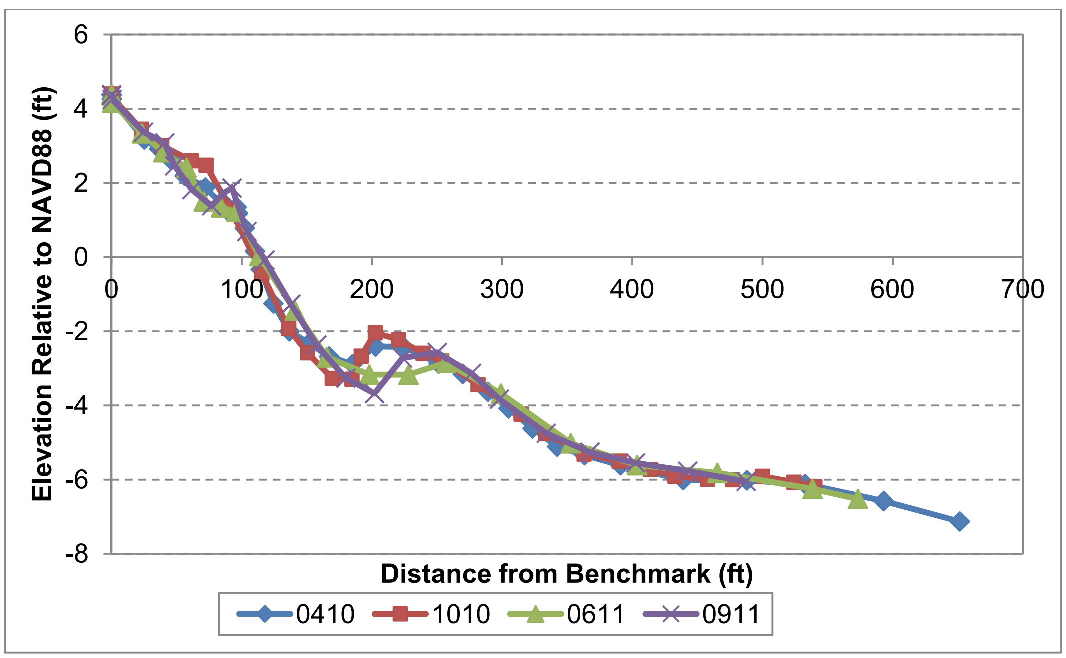


Figure C12. Profile at FMB 11.

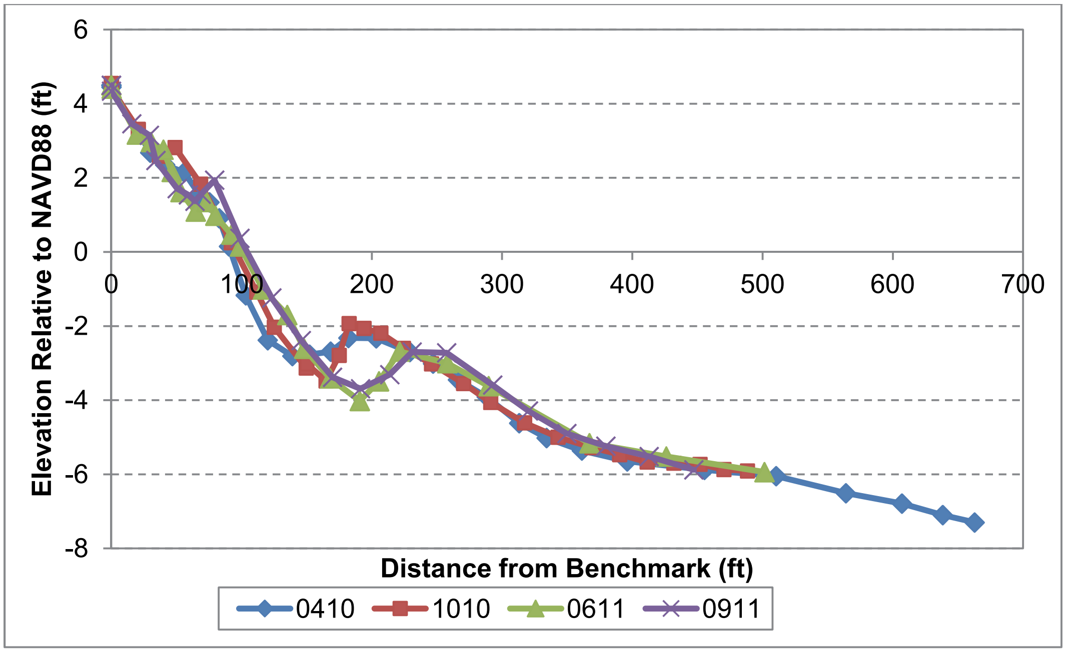


Figure C13. Profile at FMB 12.

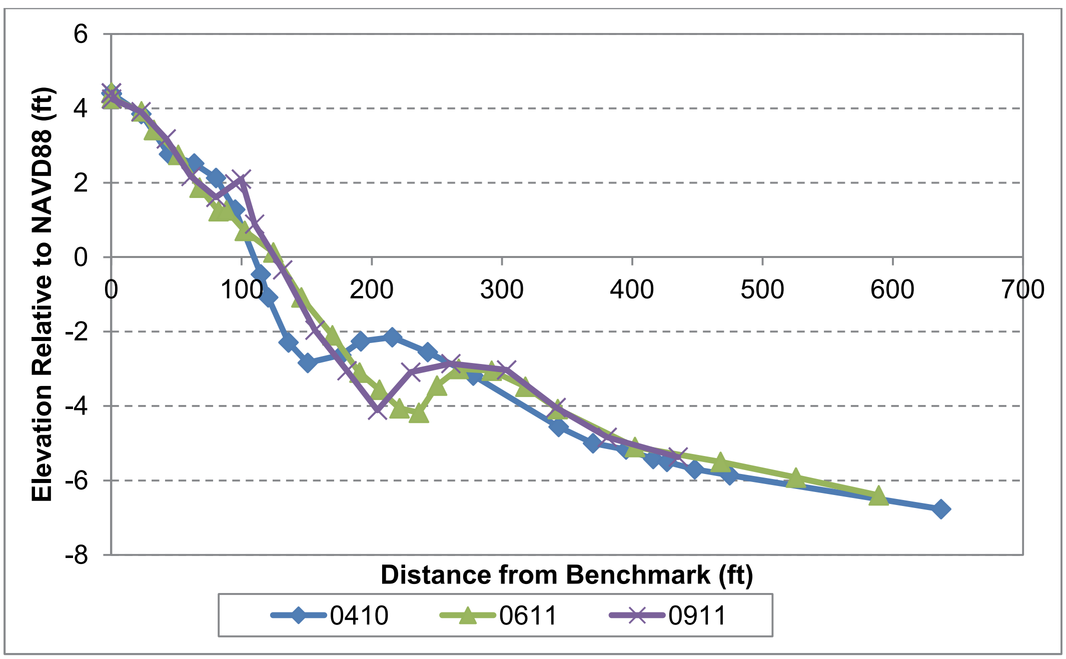


Figure C14. Profile at FMB 13.

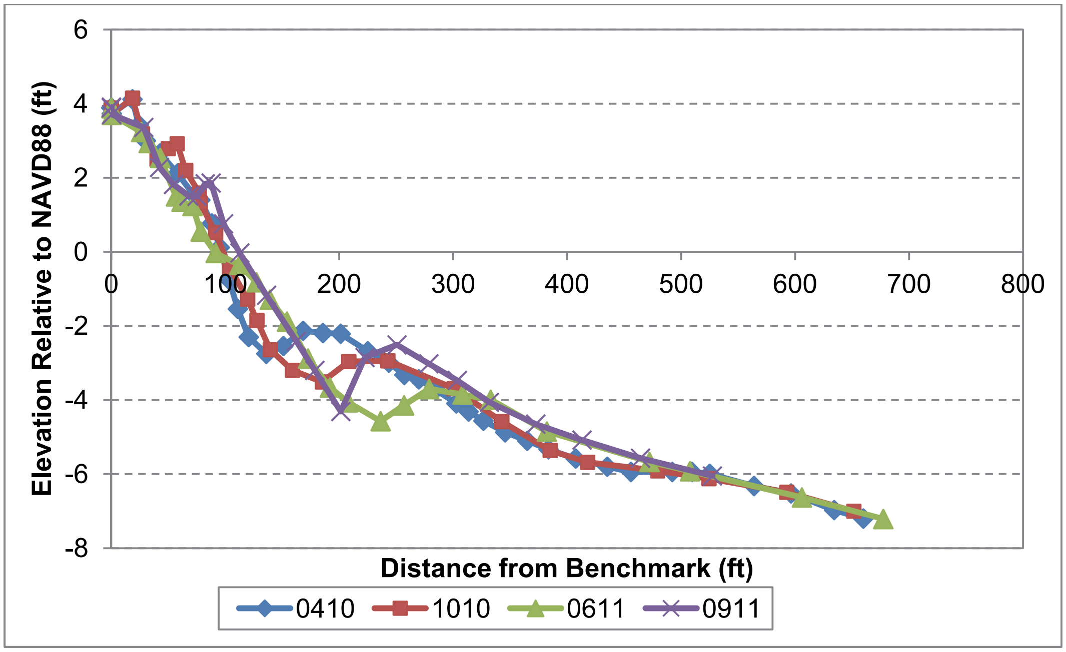


Figure C15. Profile at FMB 14.

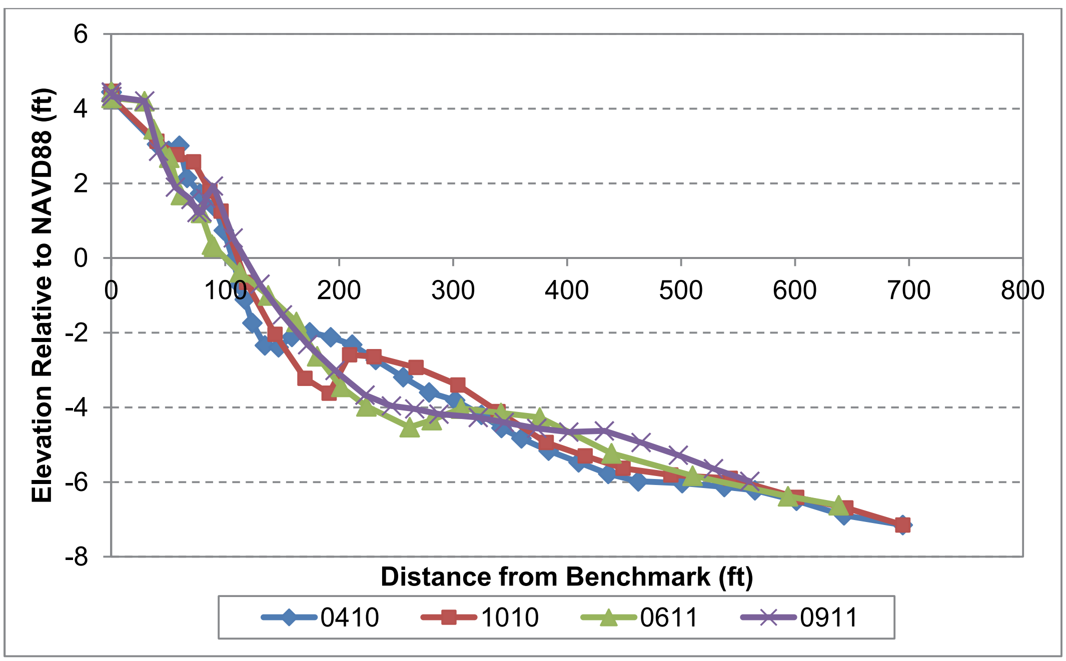


Figure C16. Profile at FMB 15.

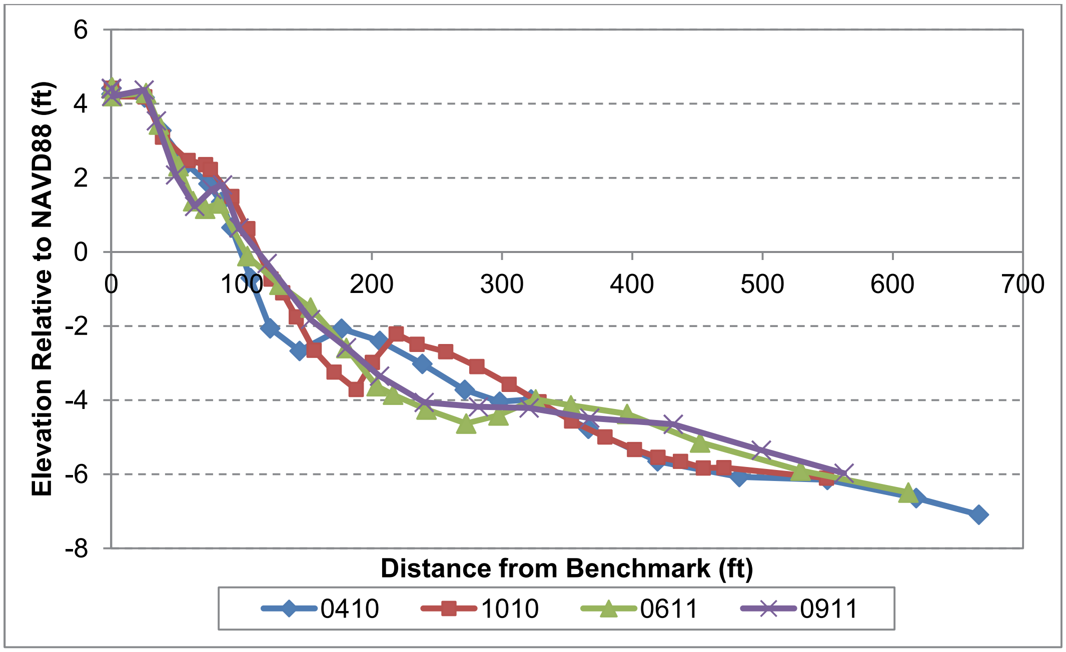


Figure C17. Profile at FMB 16.

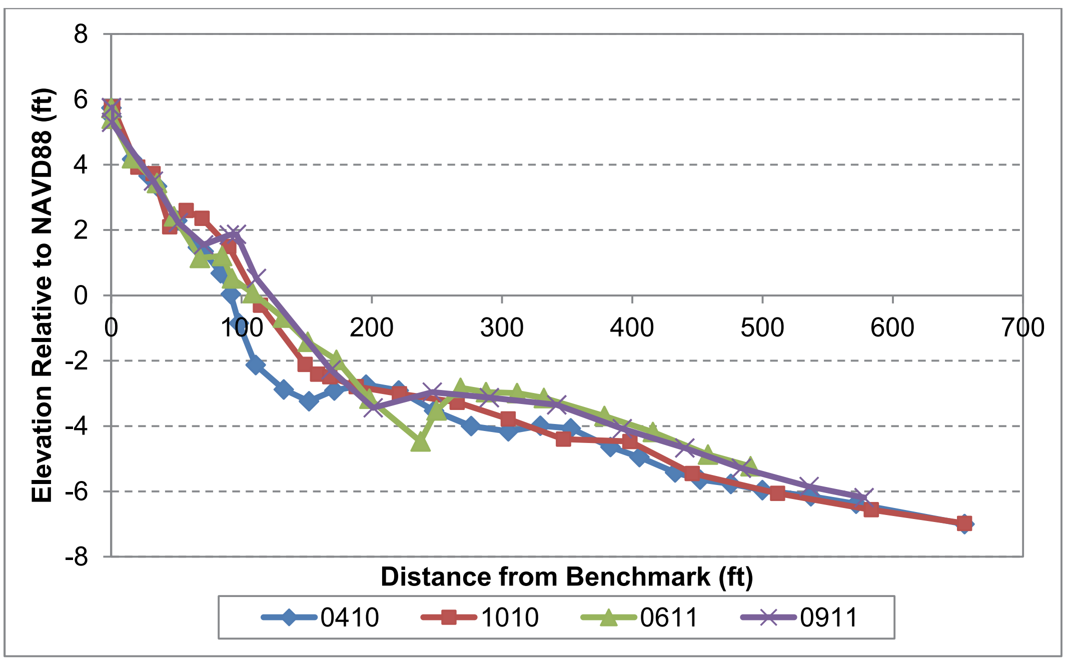


Figure C18. Profile at FMB 17.

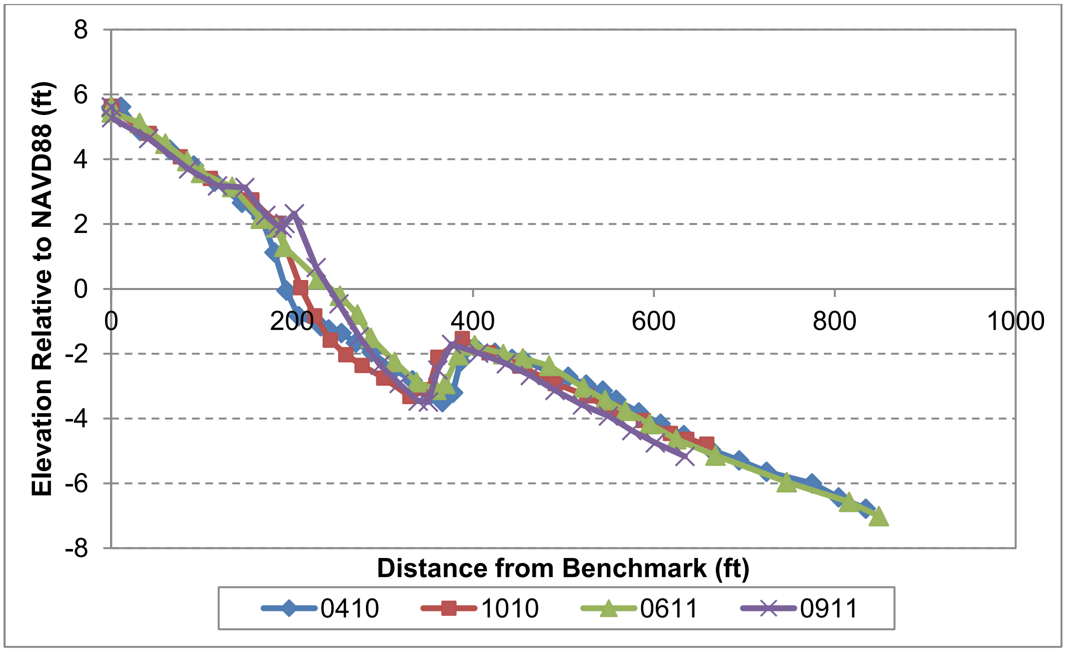


Figure C19. Profile at FMB 18.

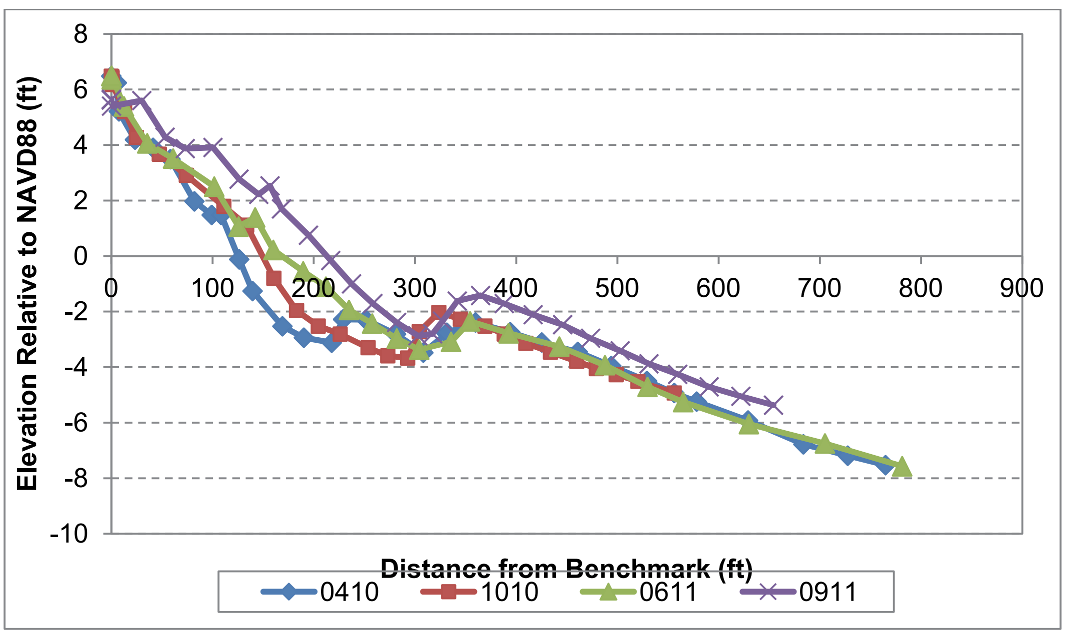


Figure C20. Profile at FMB 19.

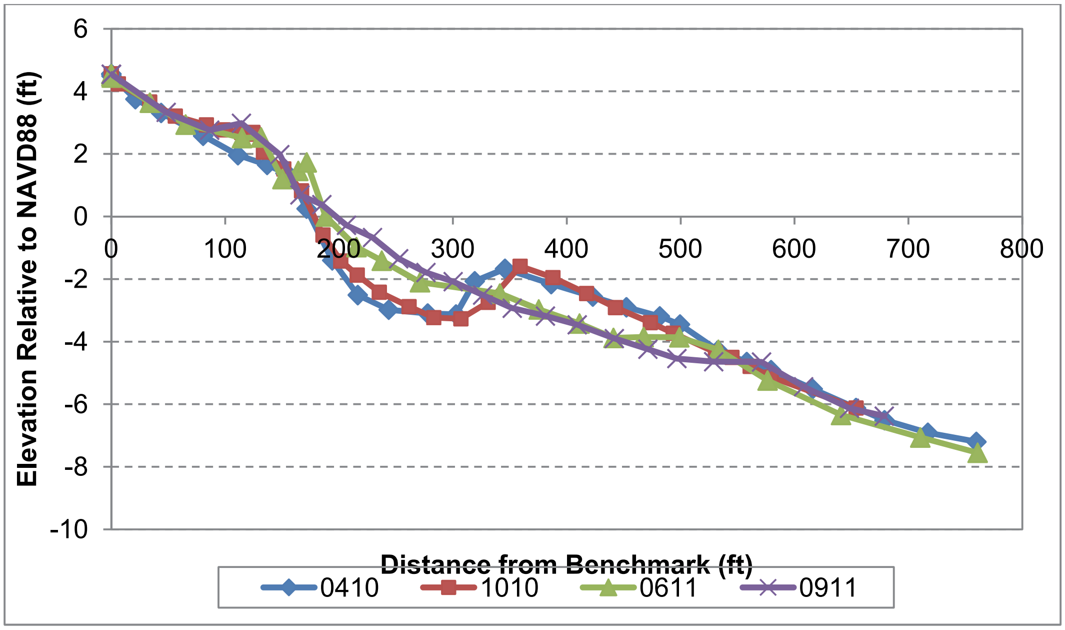


Figure C21. Profile at FMB 20.

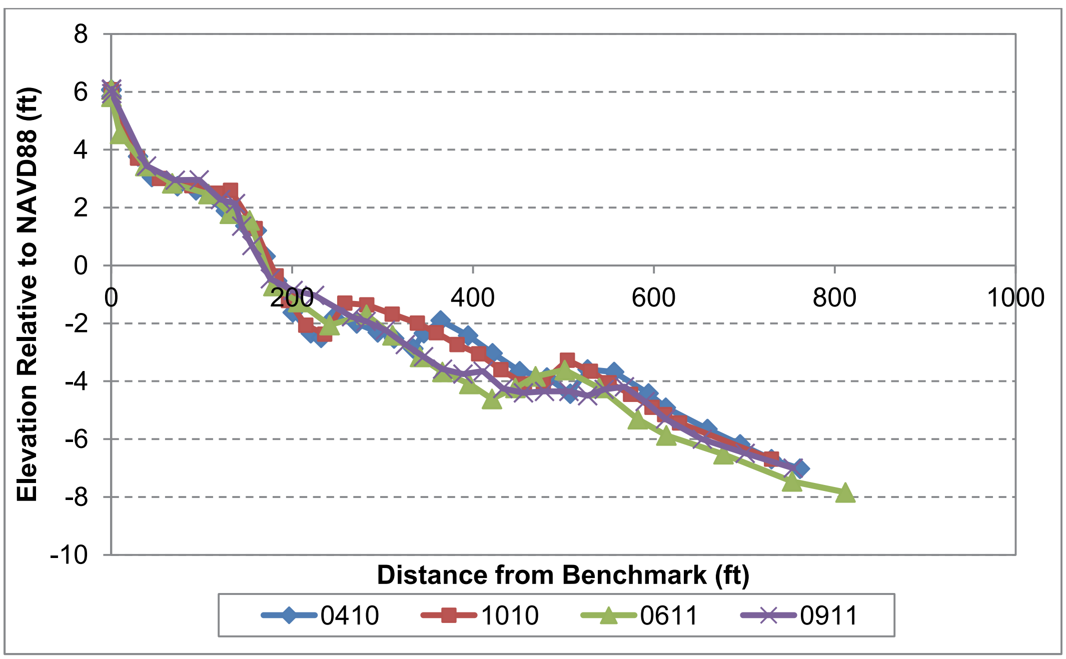


Figure C22. Profile at FMB 21.

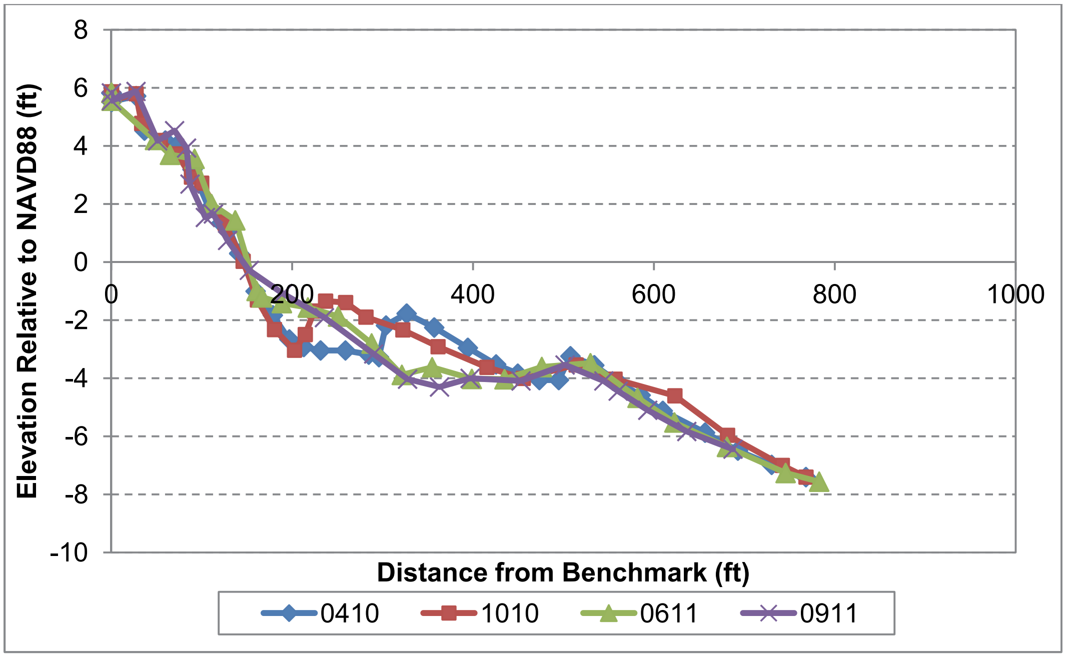


Figure C23. Profile at FMB 22.

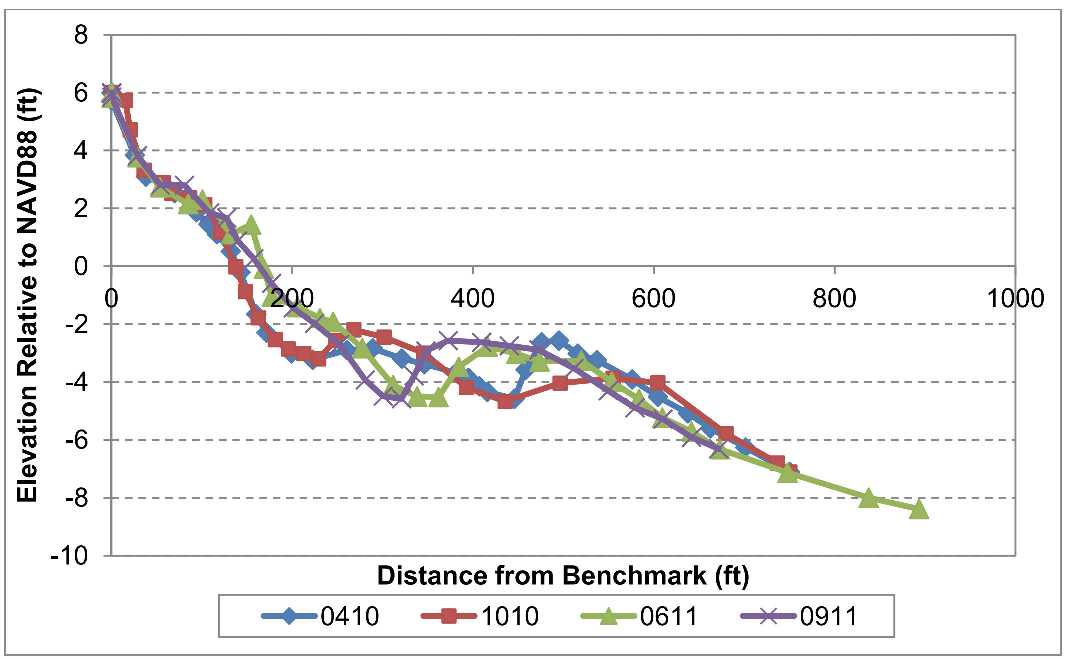


Figure C24. Profile at FMB 23.

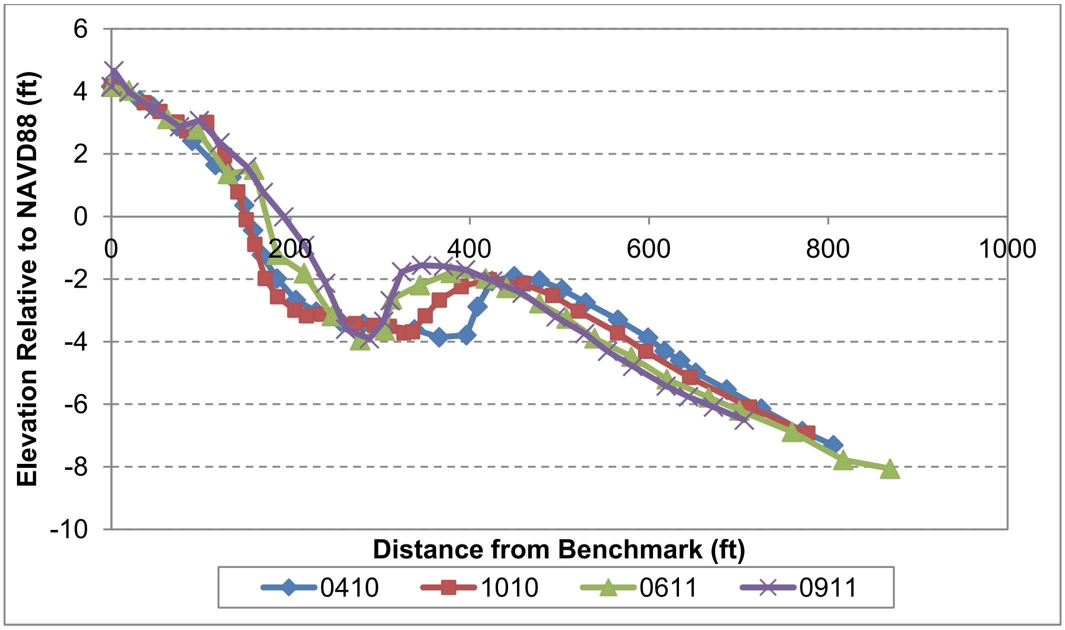


Figure C25. Profile at FMB 24.

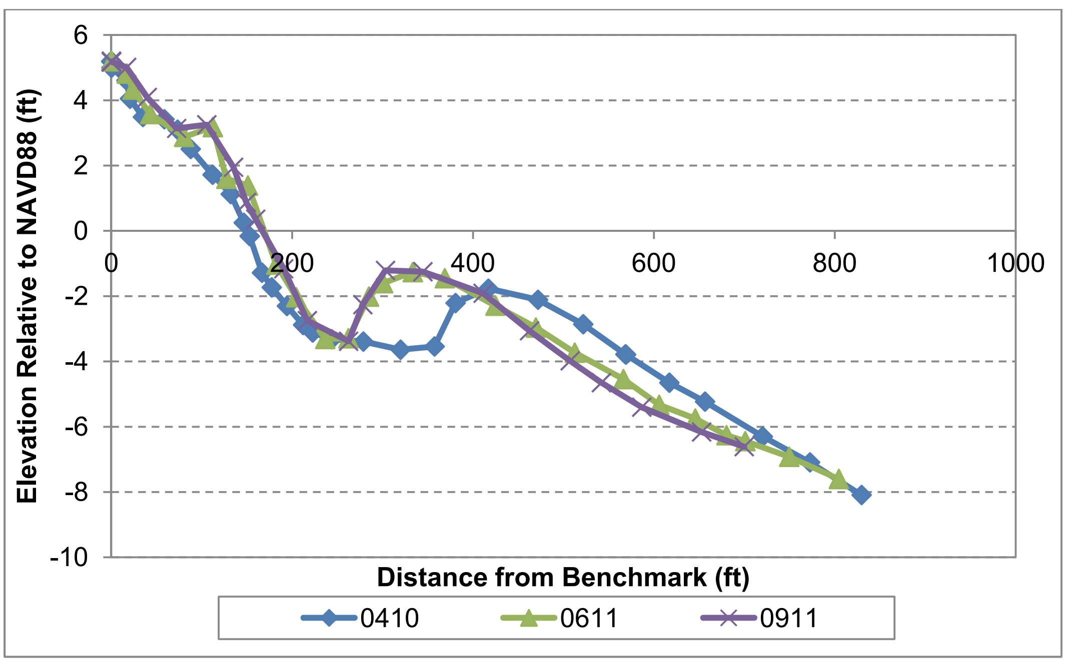


Figure C26. Profile at FMB 25.

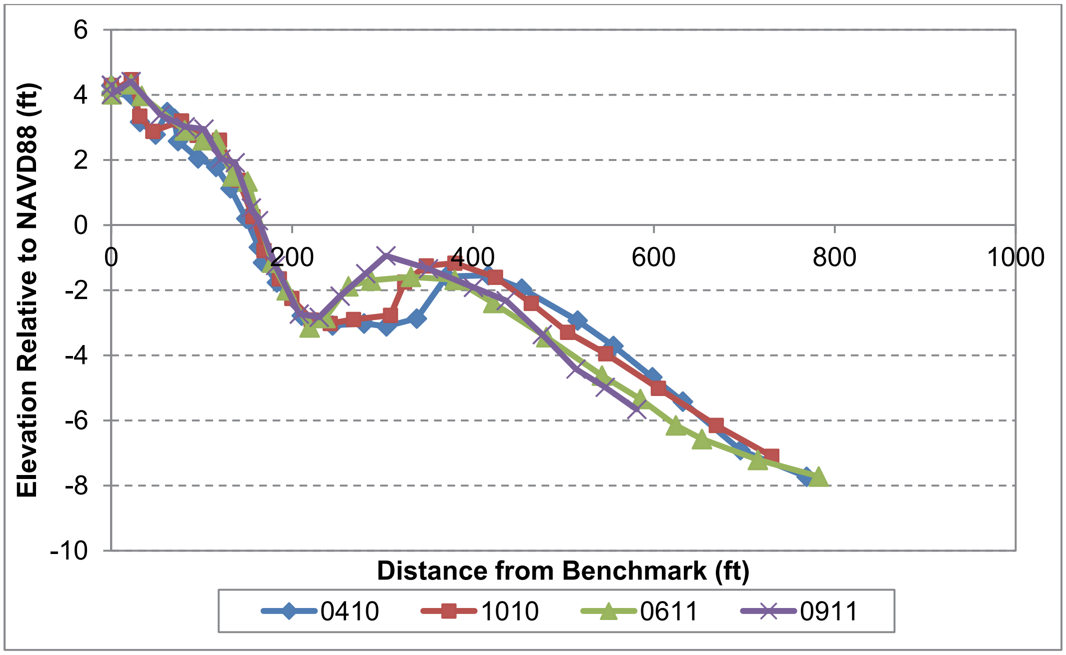


Figure C27. Profile at FMB 26.

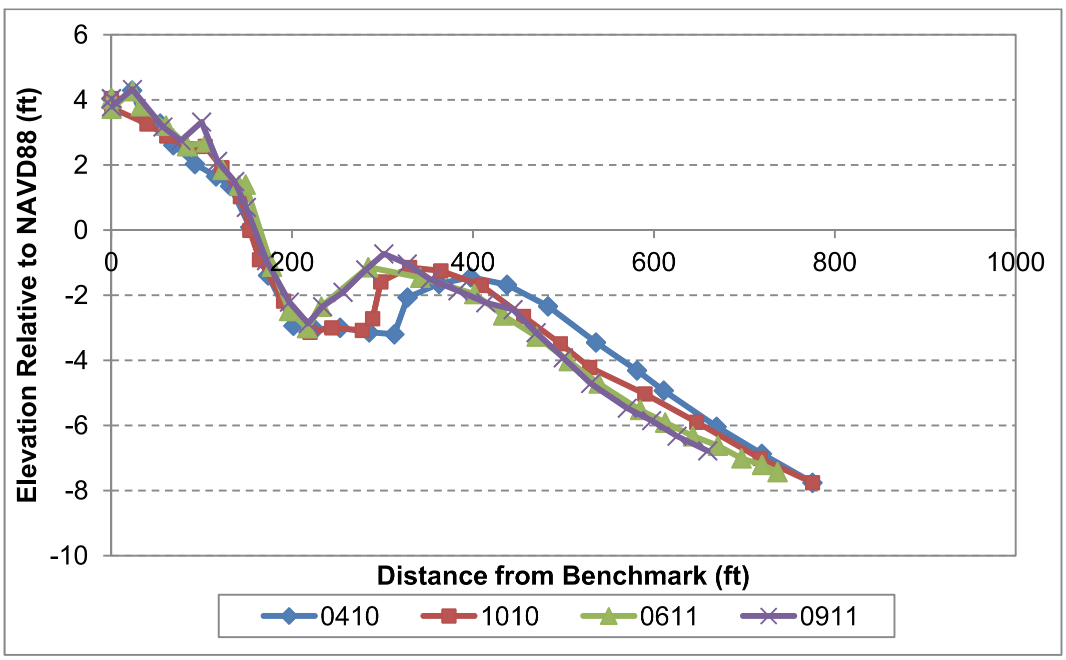


Figure C28. Profile at FMB 27.

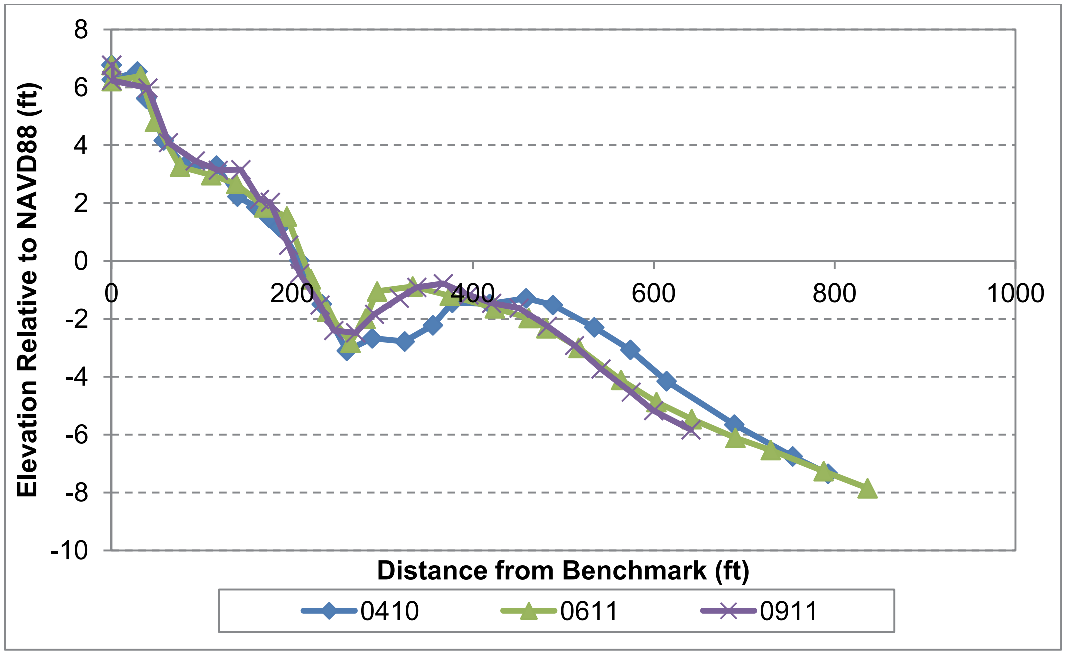


Figure C29. Profile at FMB 28.

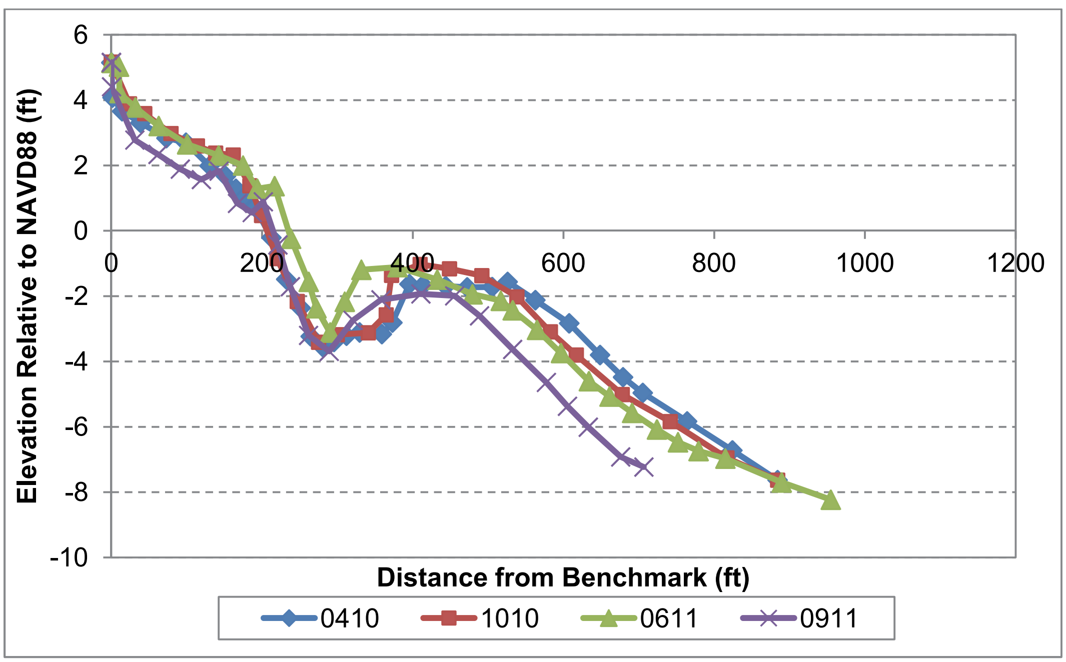


Figure C30. Profile at FMB 29.

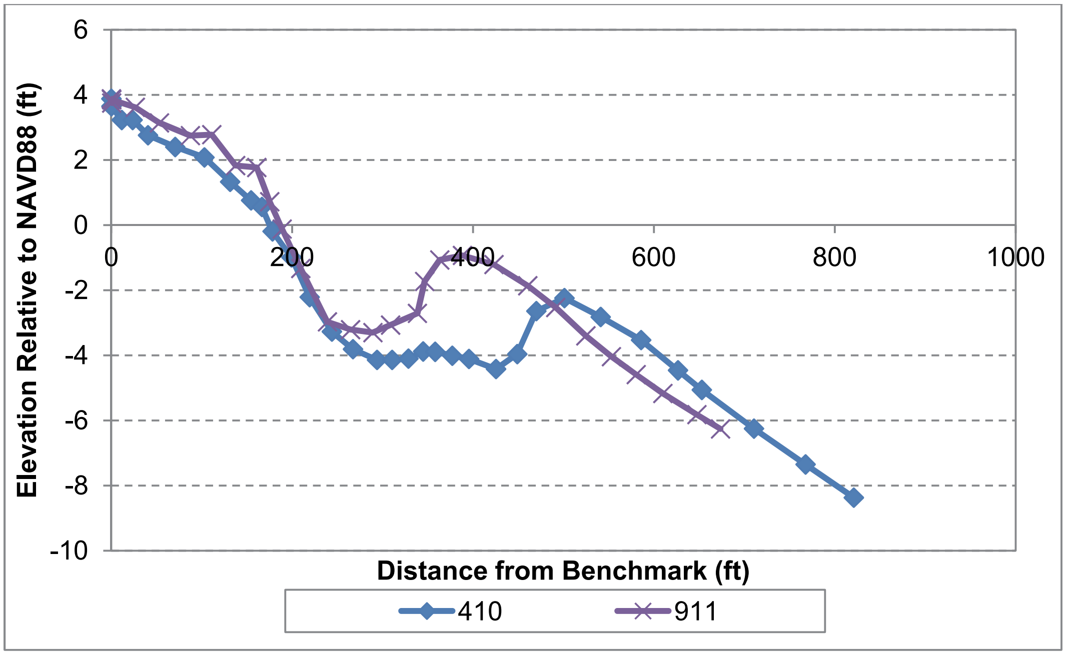


Figure C31. Profile at FMB 30 (including USACE 1009 survey).

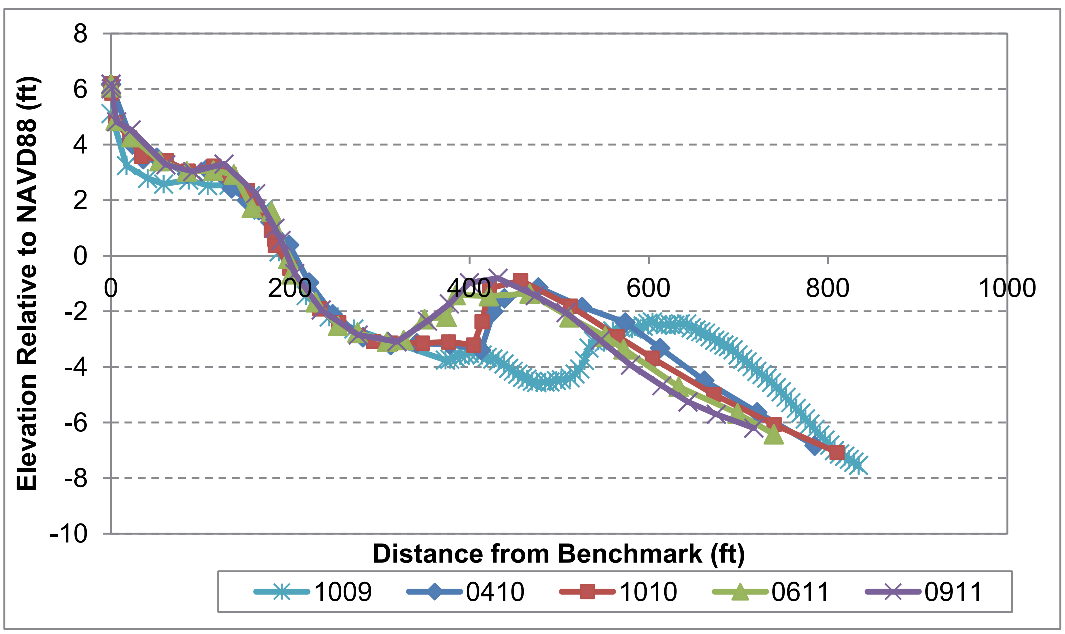


Figure C32. Profile at FMB 31.

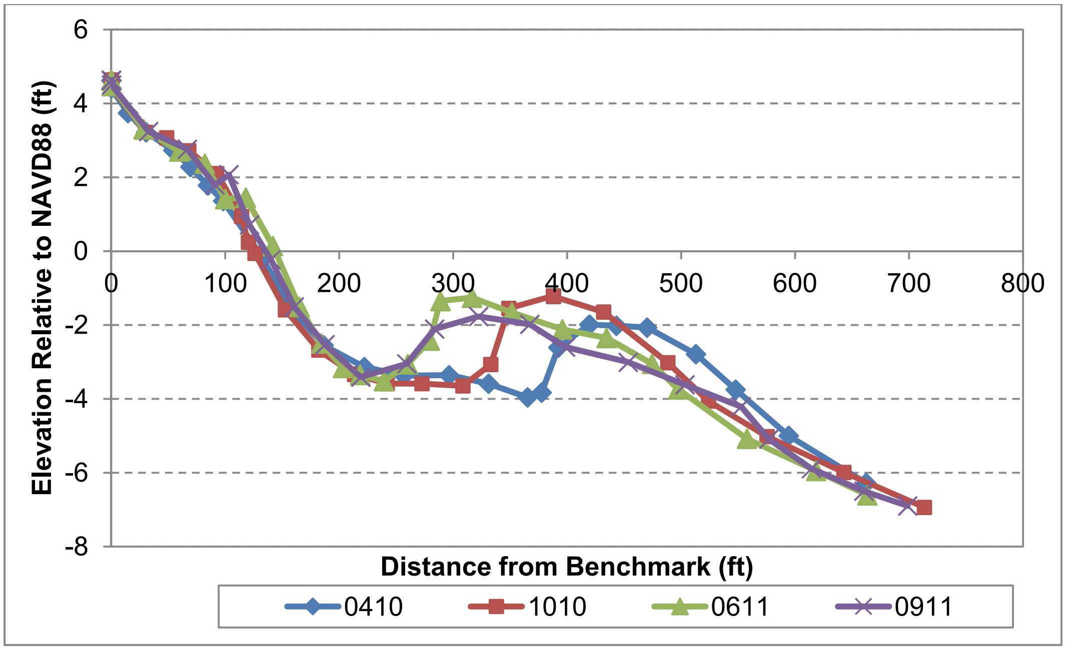


Figure C33. Profile at FMB 32 (including USACE 1009 survey).

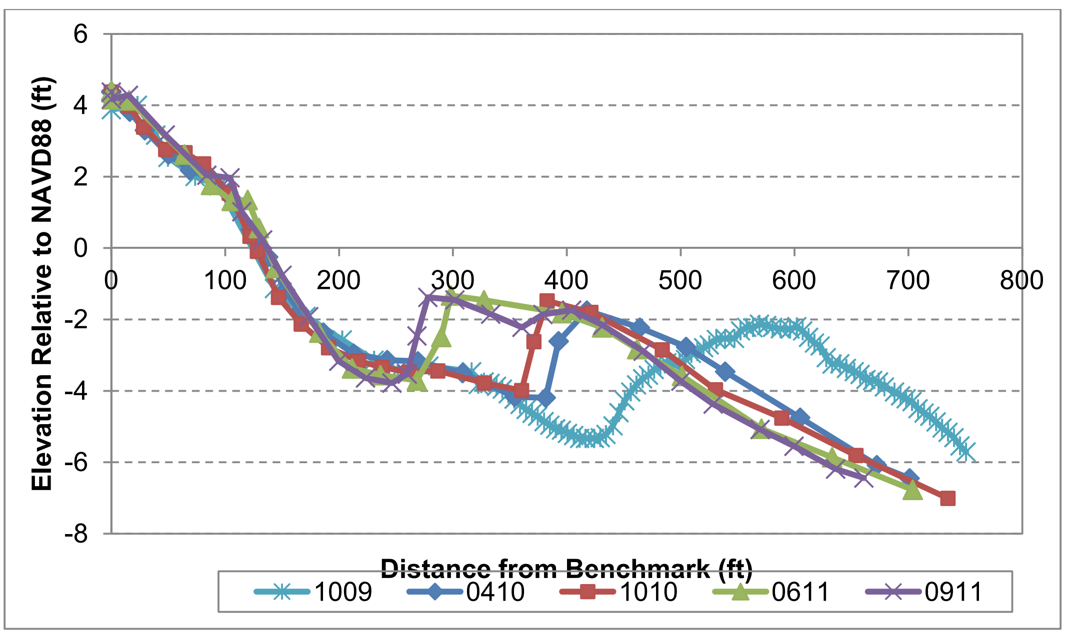


Figure C34. Profile at FMB 33.

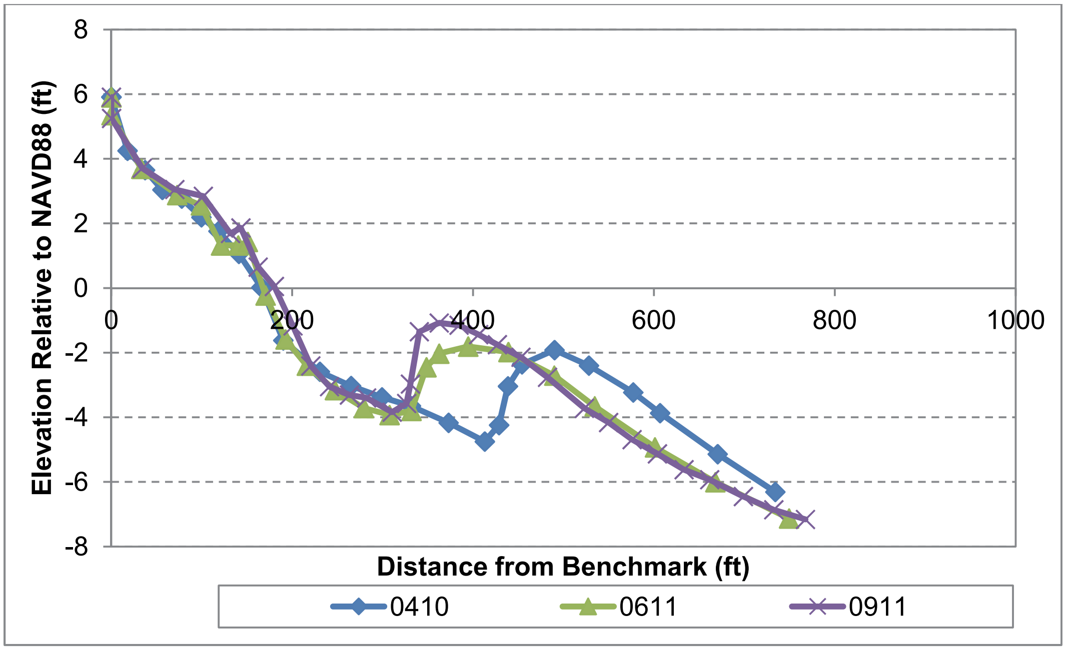


Figure C35. Profile at FMB 34.

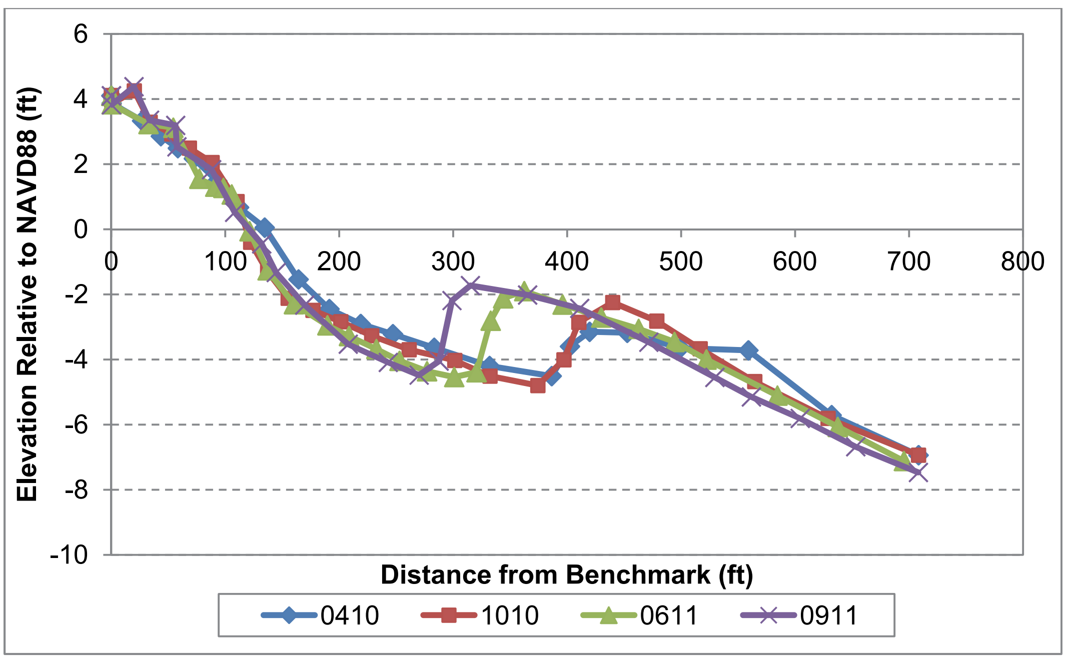


Figure C36. Profile at FMB 35.

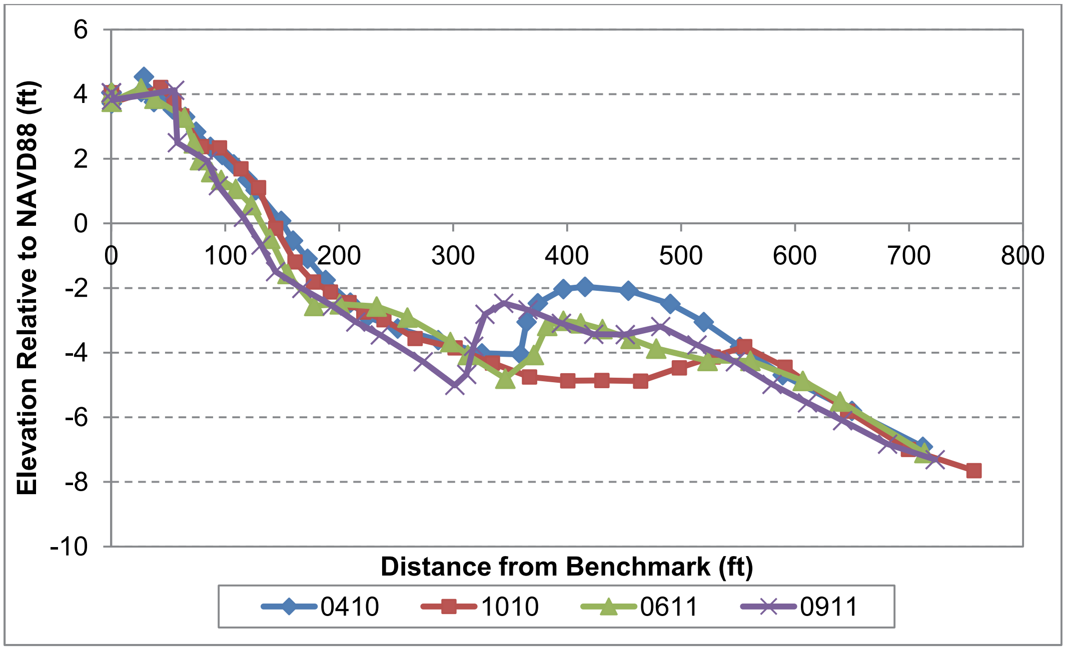


Figure C37. Profile at FMB 36.

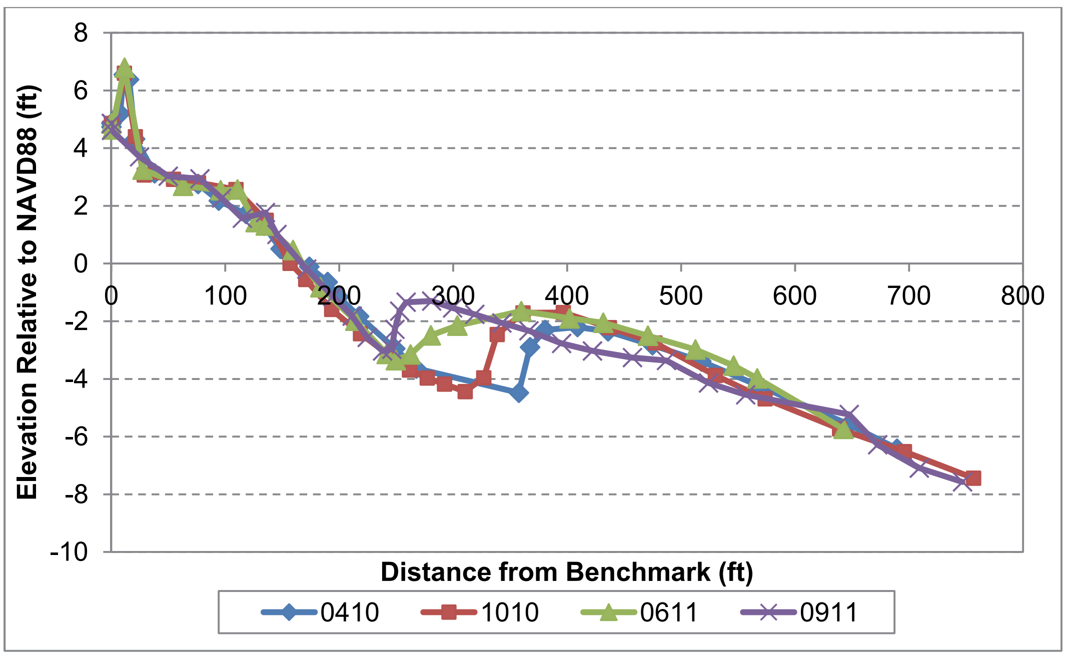


Figure C38. Profile at FMB 37.

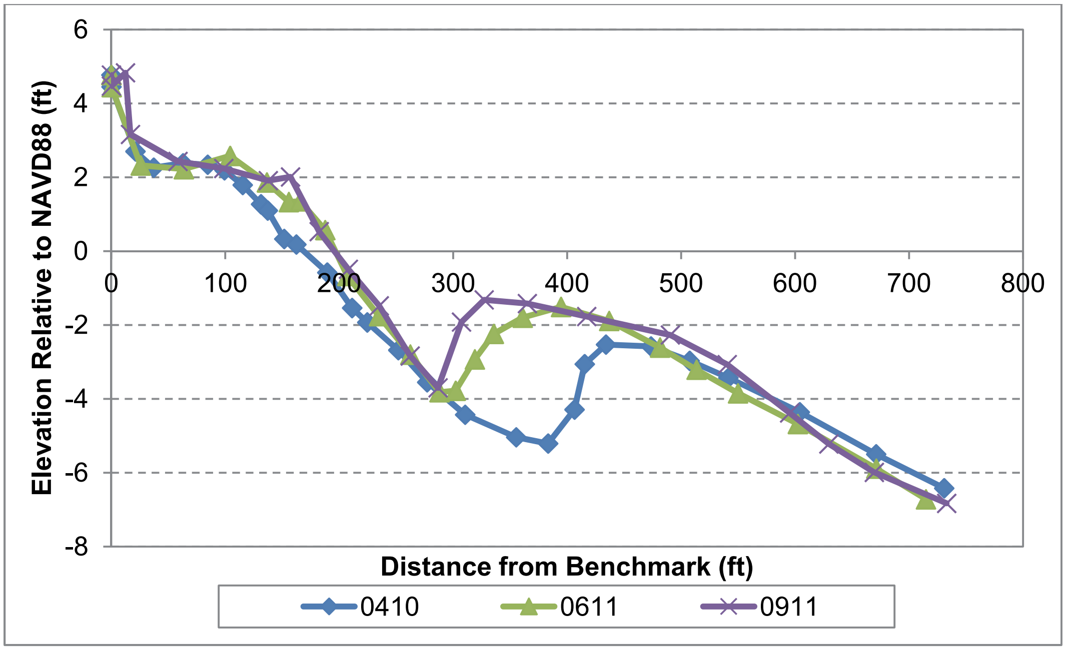


Figure C39. Profile at FMB 38.

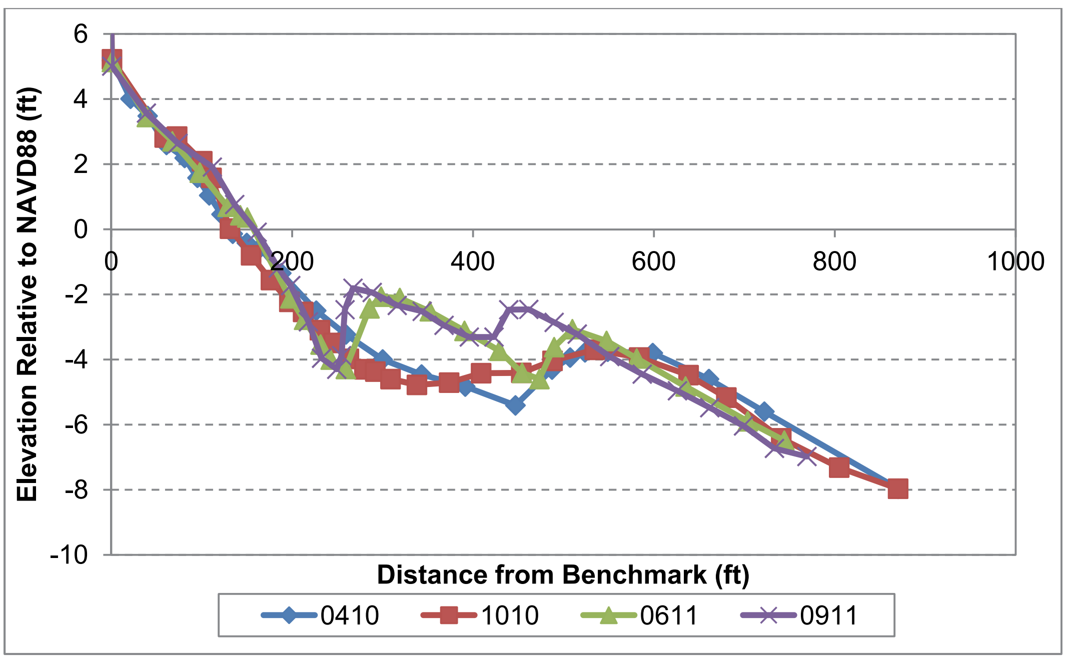


Figure C40. Profile at FMB 40.

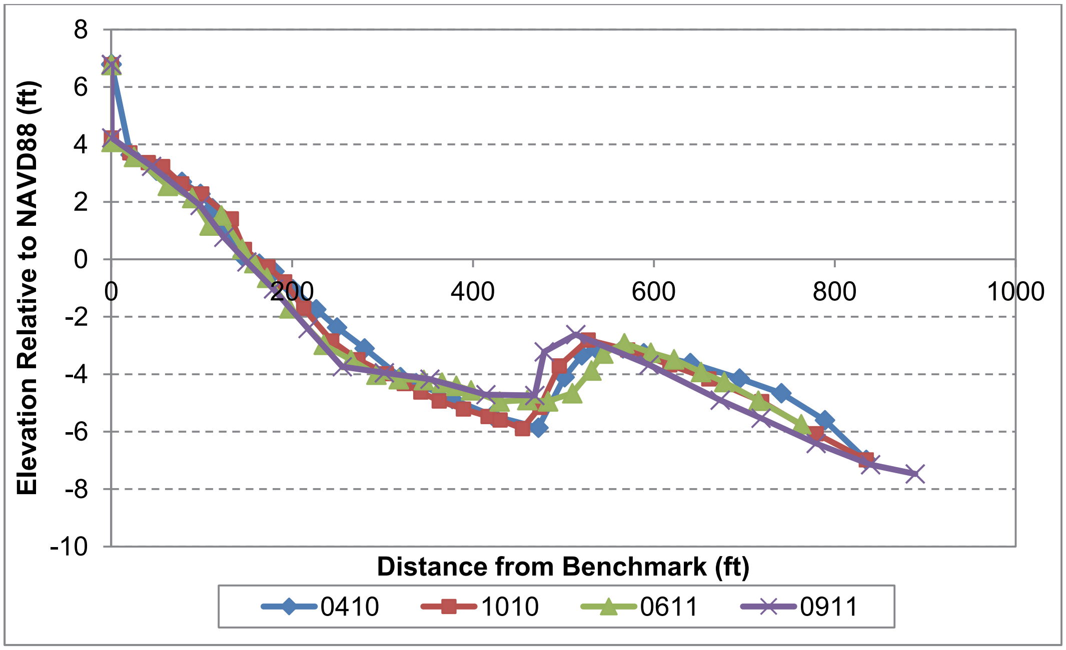


Figure C41. Profile at FMB 41.

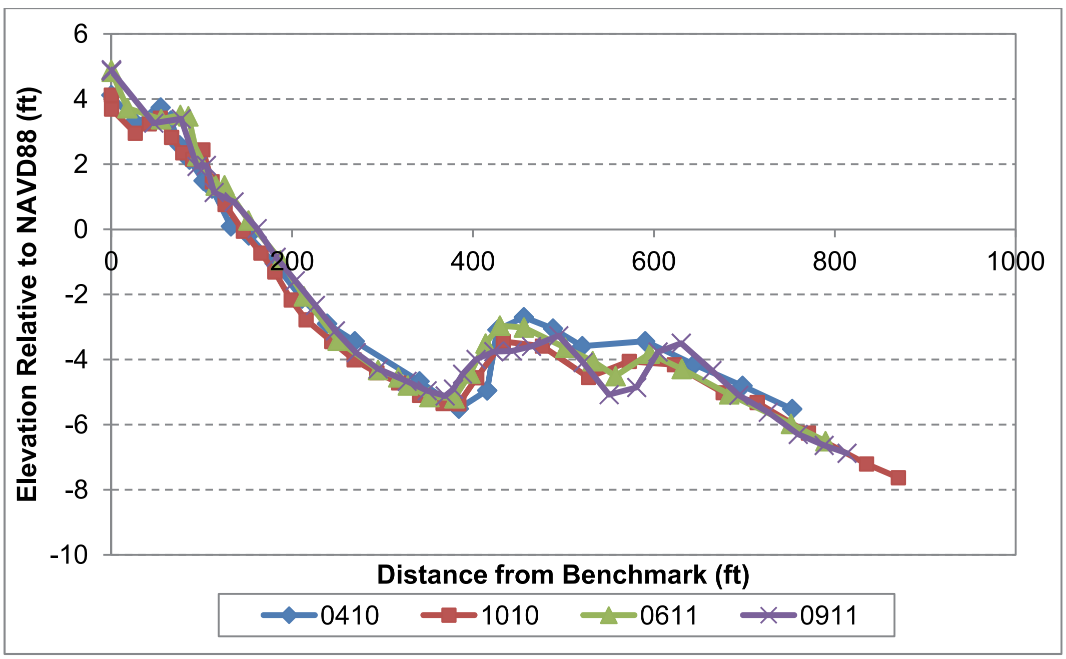


Figure C42. Profile at FMB 42.

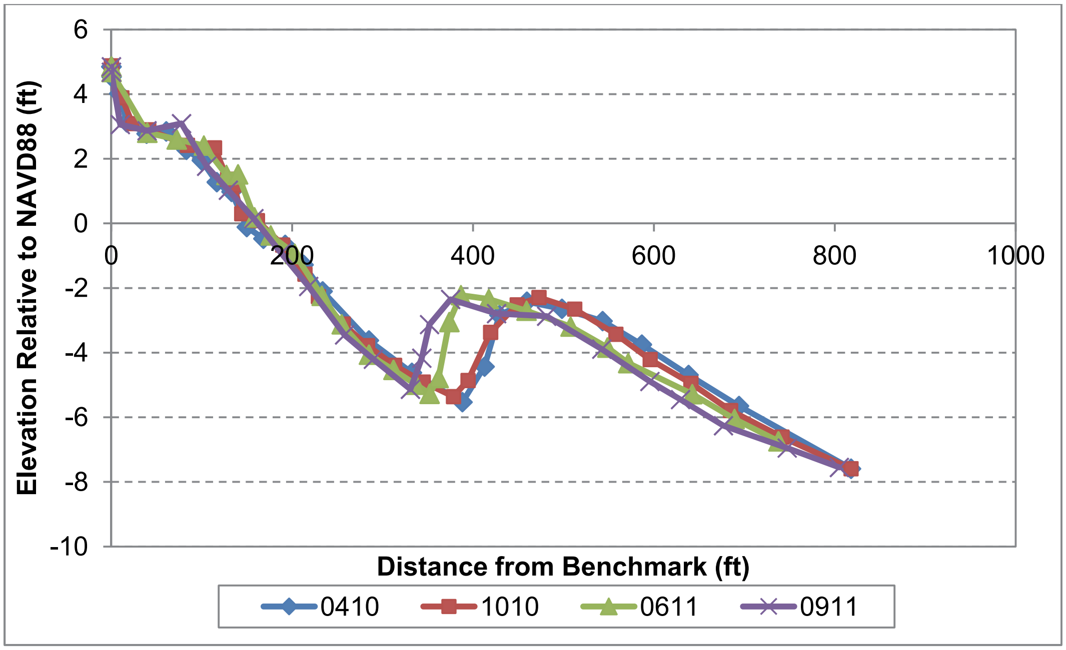


Figure C43. Profile at FMB 43.

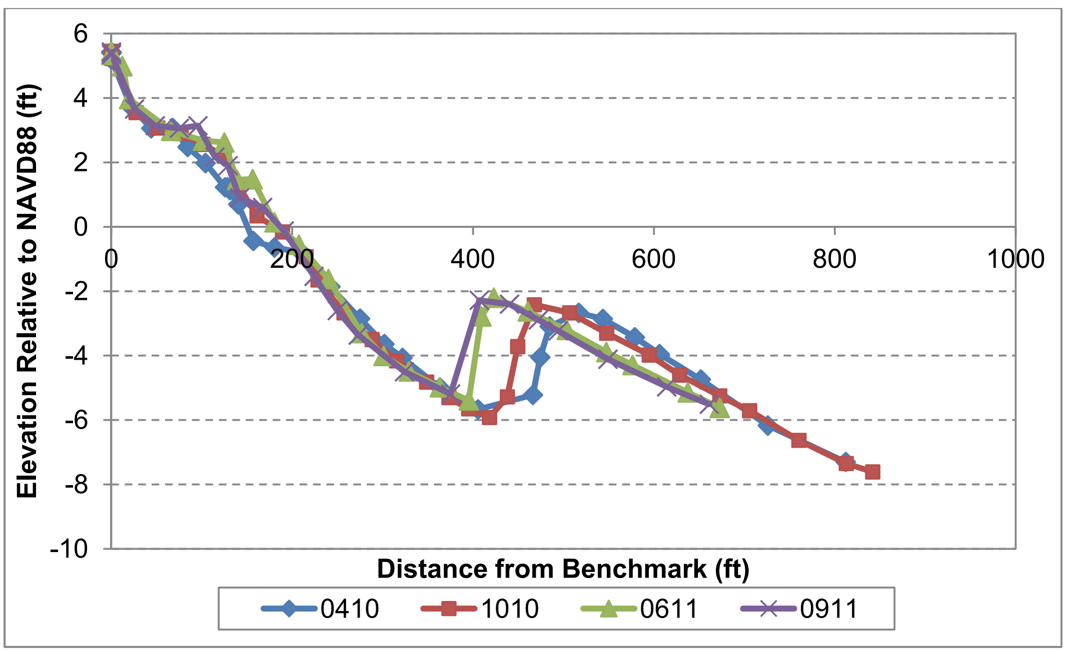


Figure C44. Profile at FMB 44.

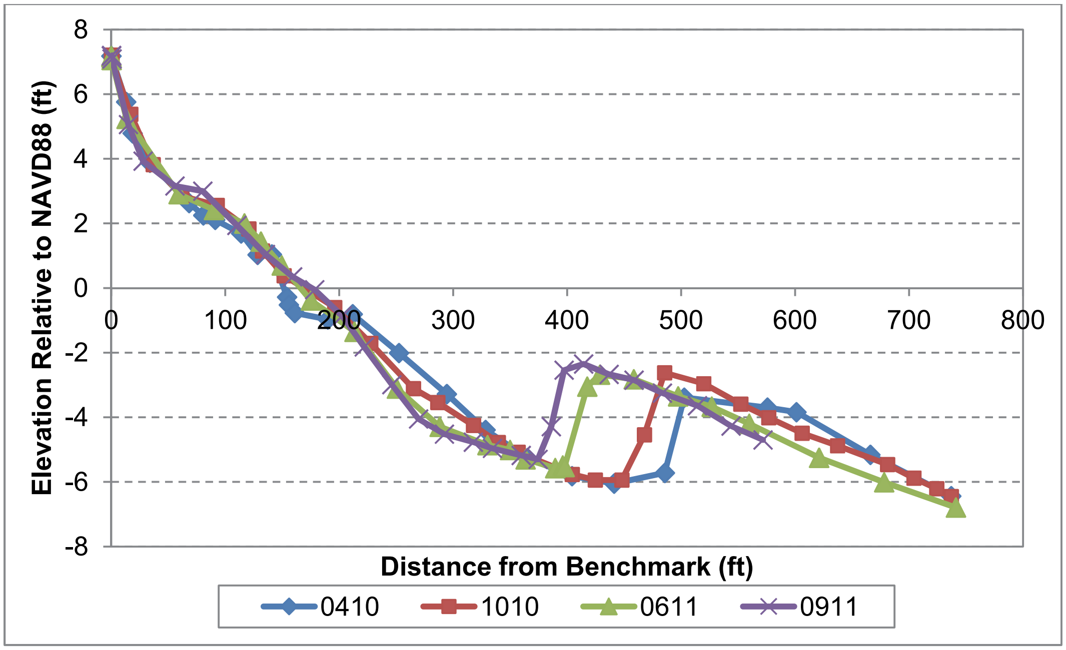


Figure C45. Profile at FMB 45.

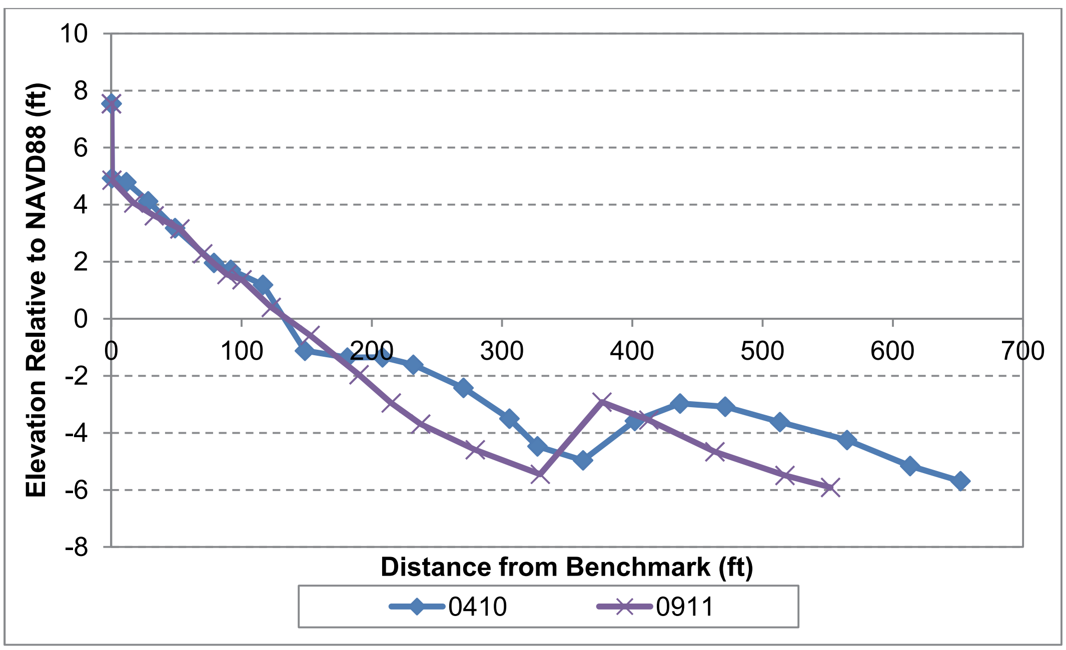


Figure C46. Profile at FMB 46.

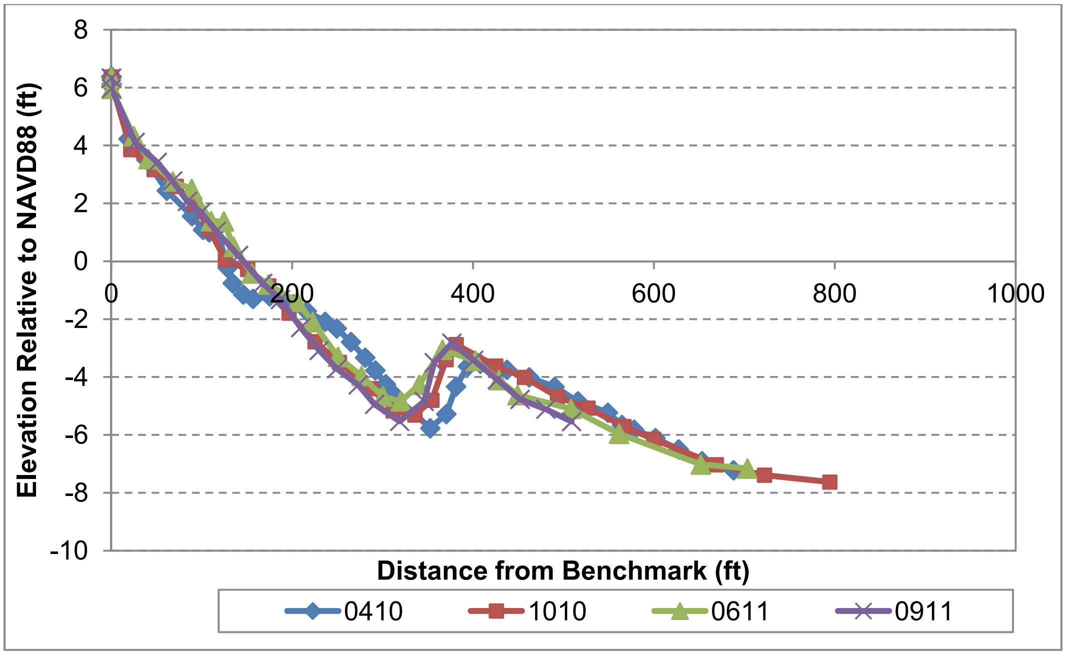


Figure C47. Profile at FMB 47.

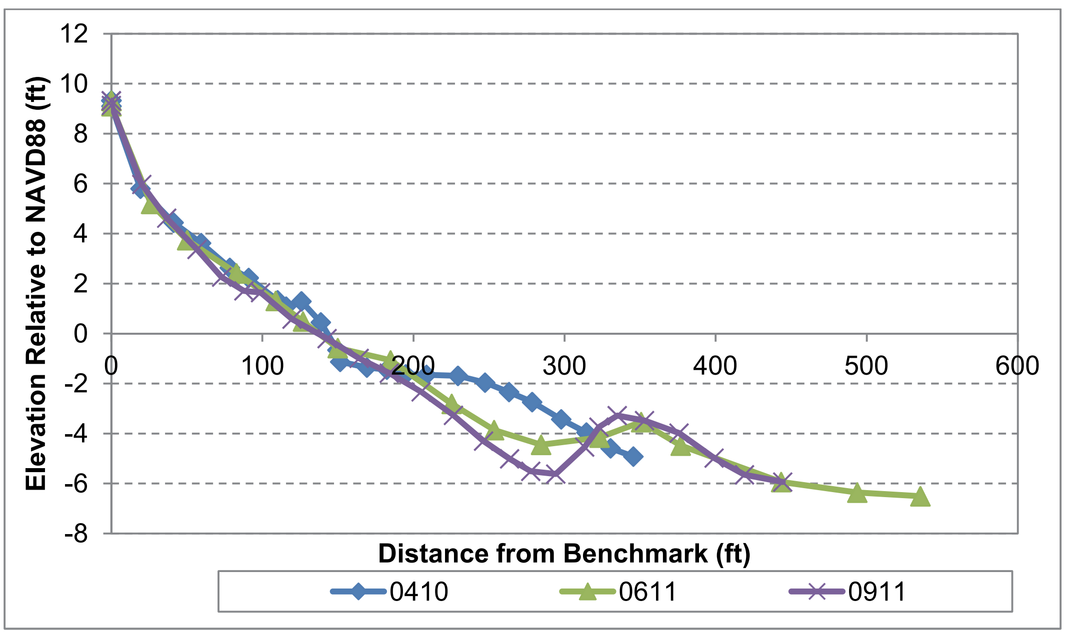


Figure C48. Profile at FMB 48.

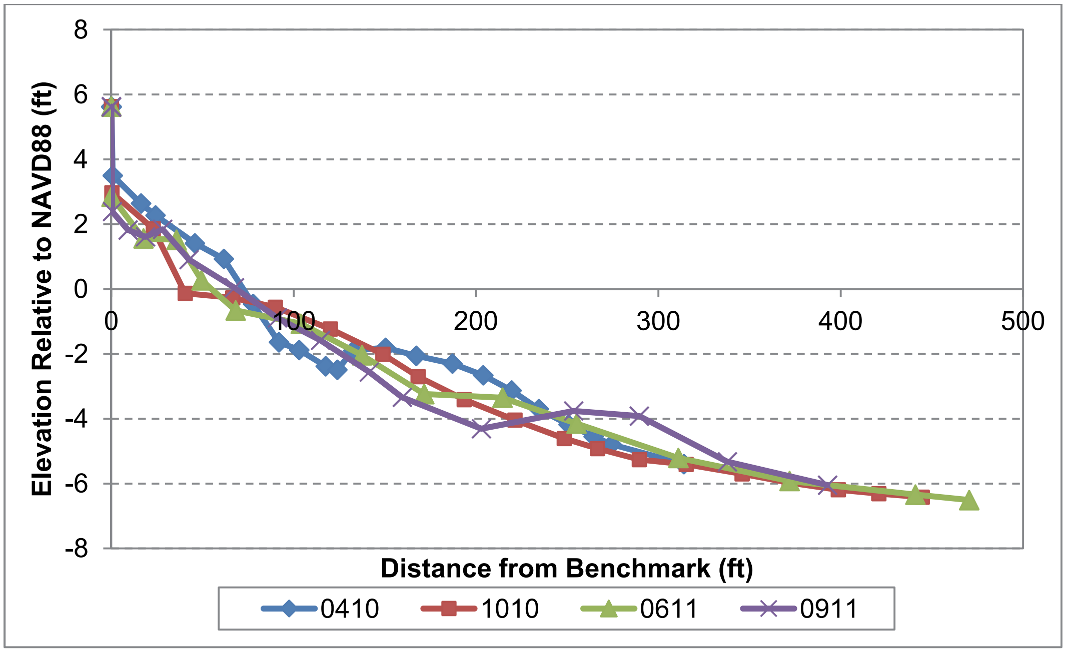


Figure C49. Profile at FMB 49.

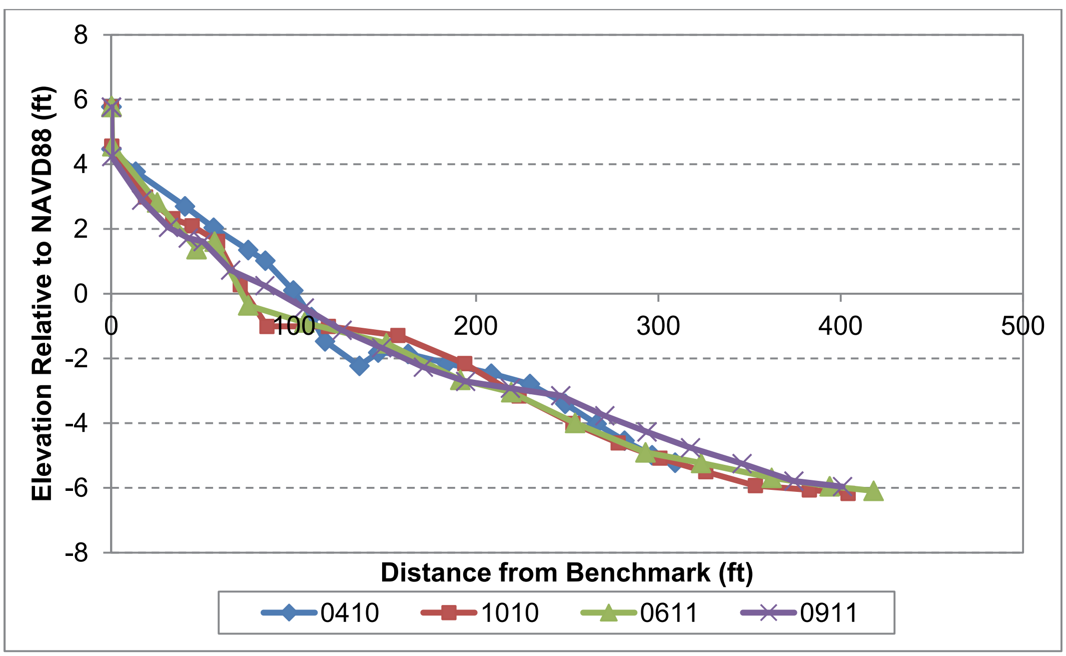


Figure C50 Profile at FMB 50.

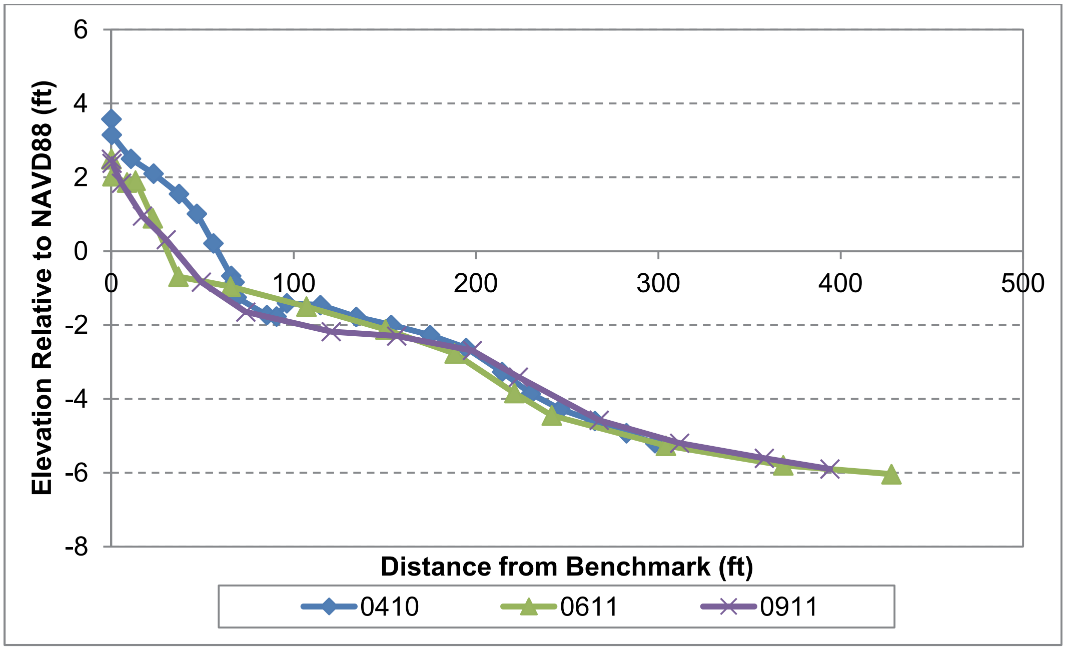


Figure C51 Profile at FMB 51.

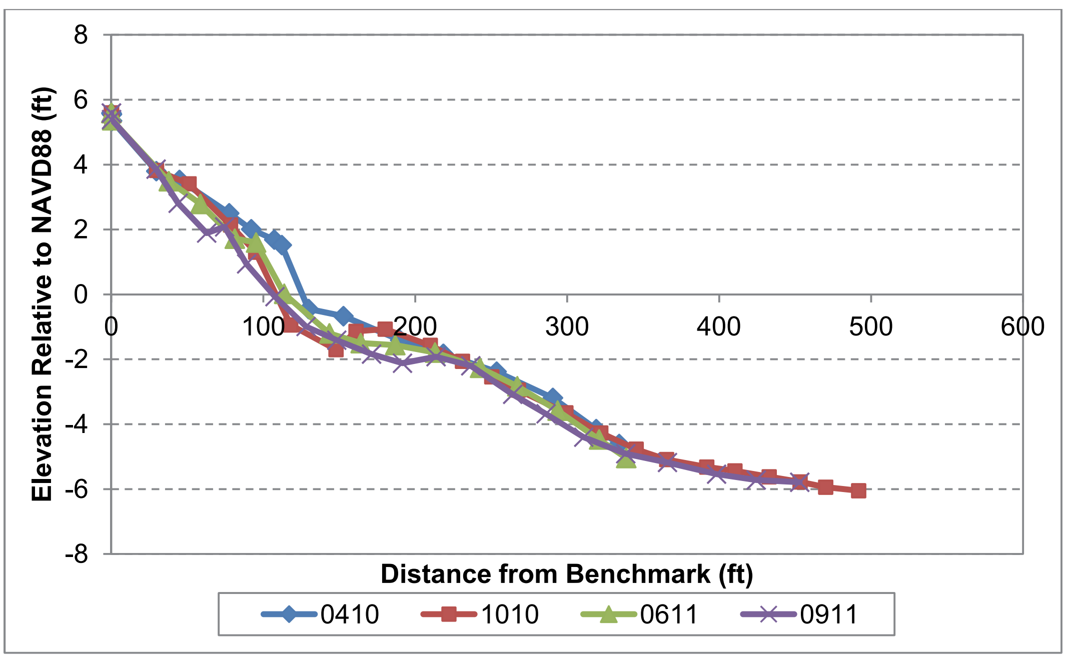


Figure C52. Profile at FMB 52.

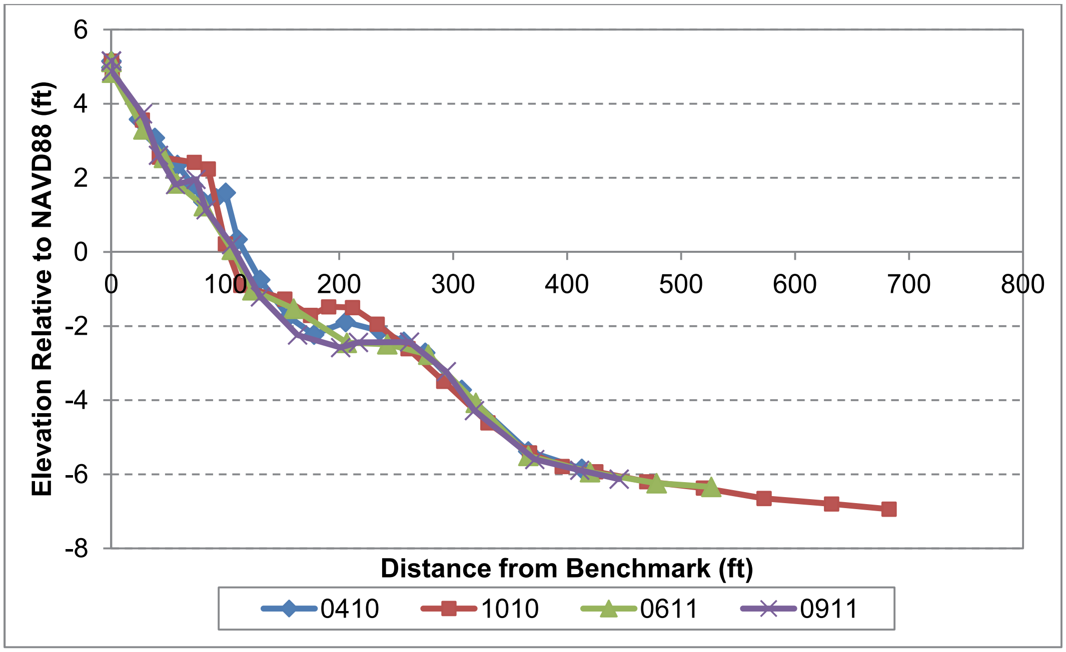


Figure C53. Profile at FMB 53.

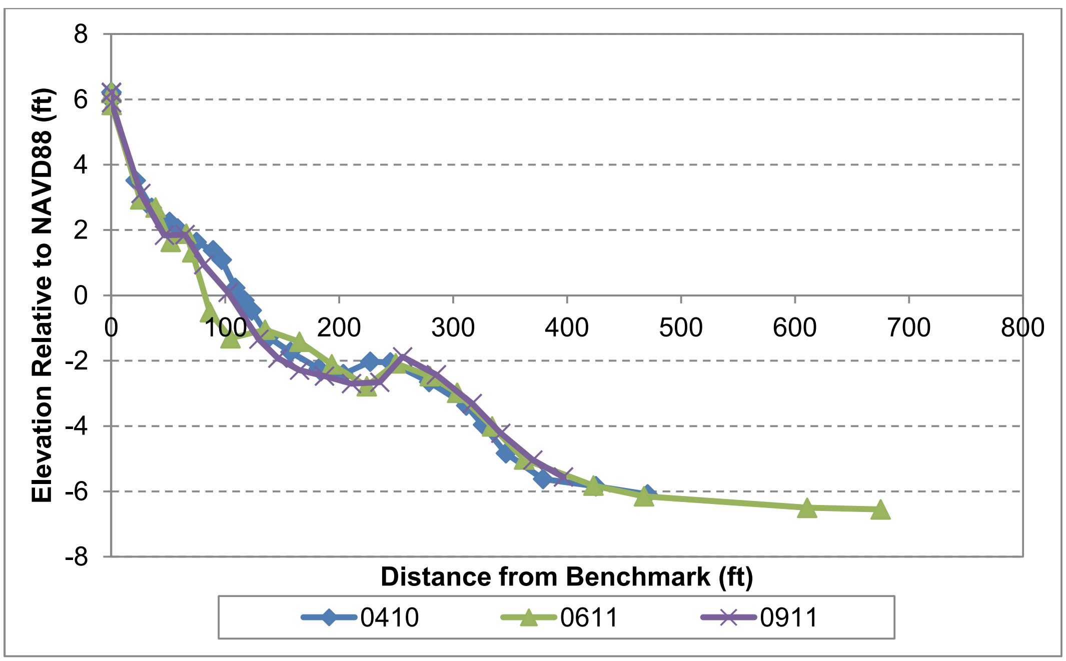


Figure C54. Profile at FMB 54.

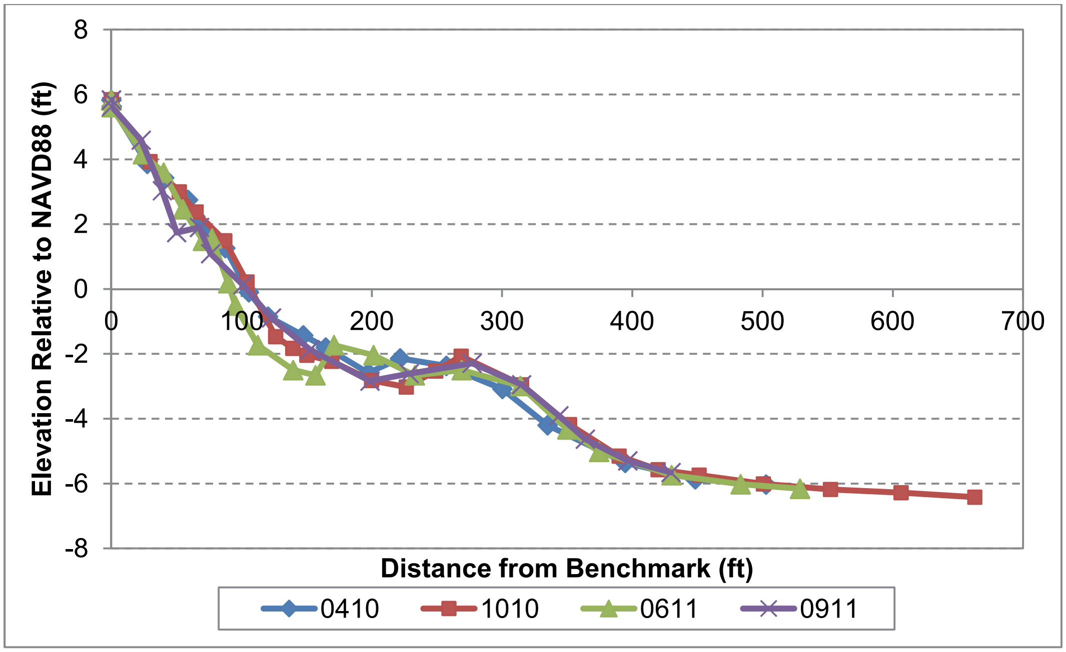


Figure C55. Profile at FMB 55.

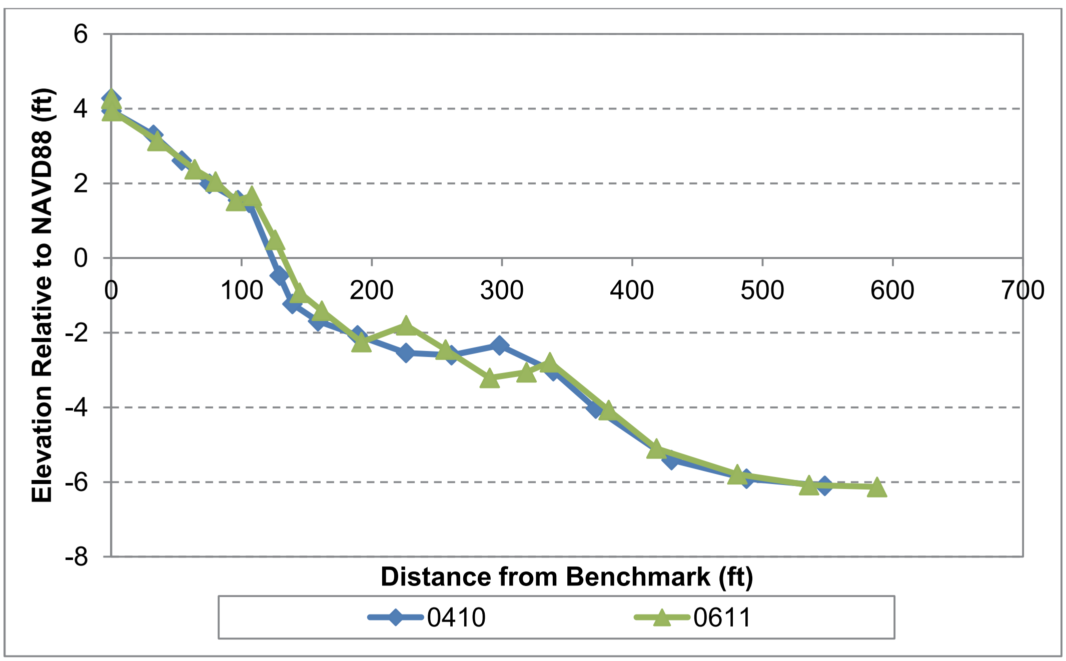


Figure C56. Profile at FMB 56.

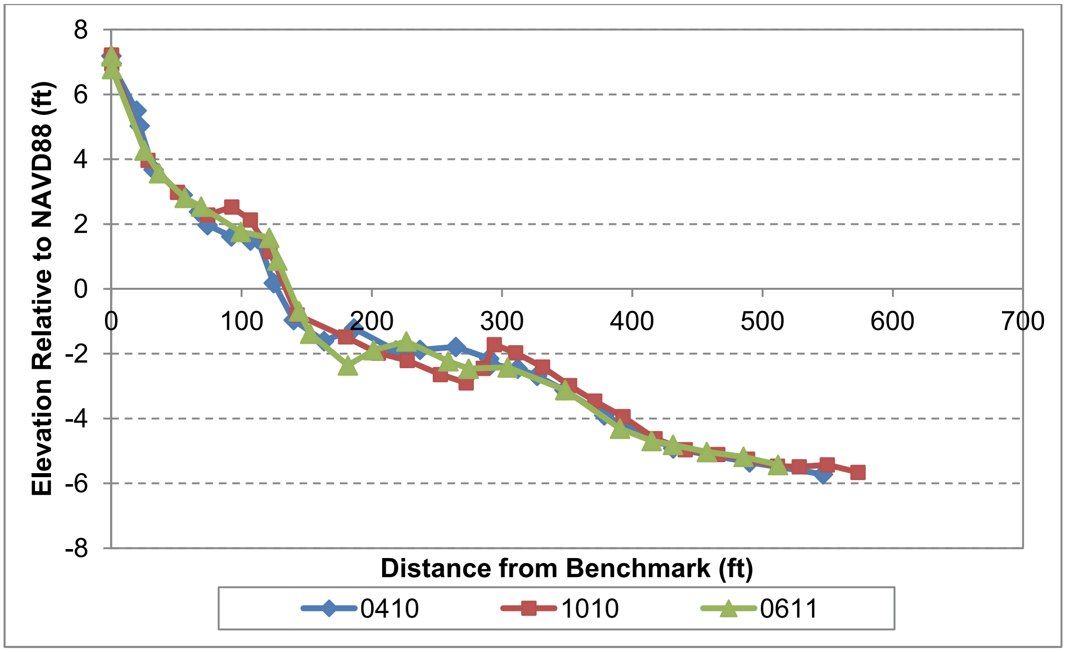
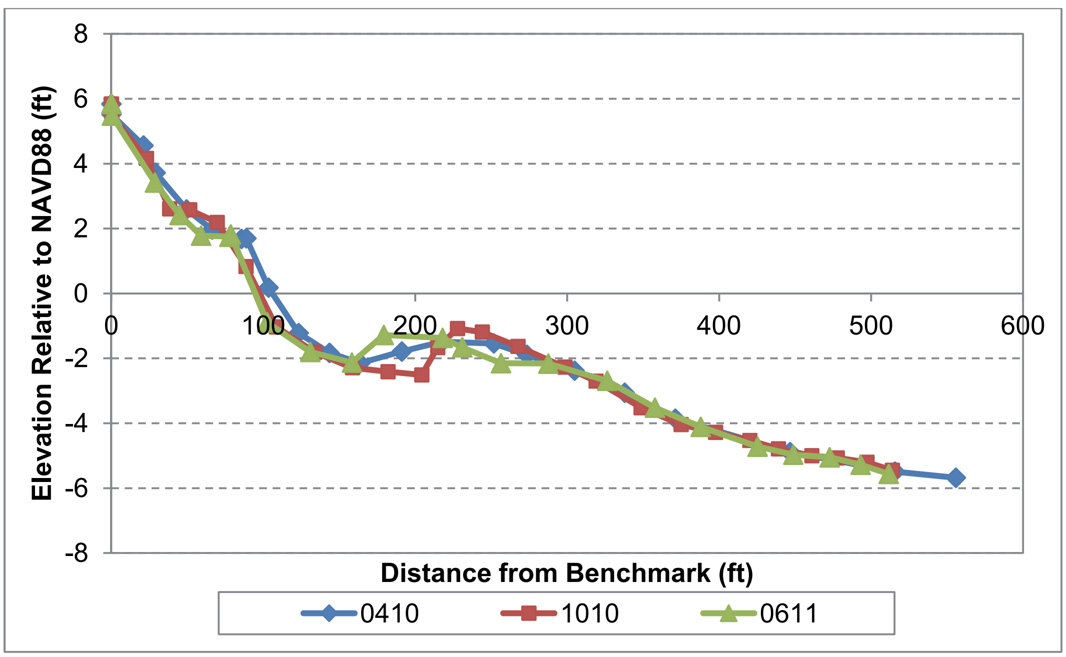


Figure C57. Profile at FMB 57.



Appendix D: Grain-Size Distributions

The follow appendix includes grain-size distribution charts of representative samples from each sample profile. Distributions are shown from 2010 as well as from the corresponding 2011 samples. Grain size is recorded as phi, which can be related to mm as

$$d = 2^{-\phi}$$

where d is the diameter of the grain in mm. Refer to Figure D1 for the sampling transect locations.

Figure D1. Locations of sediment sampling transects

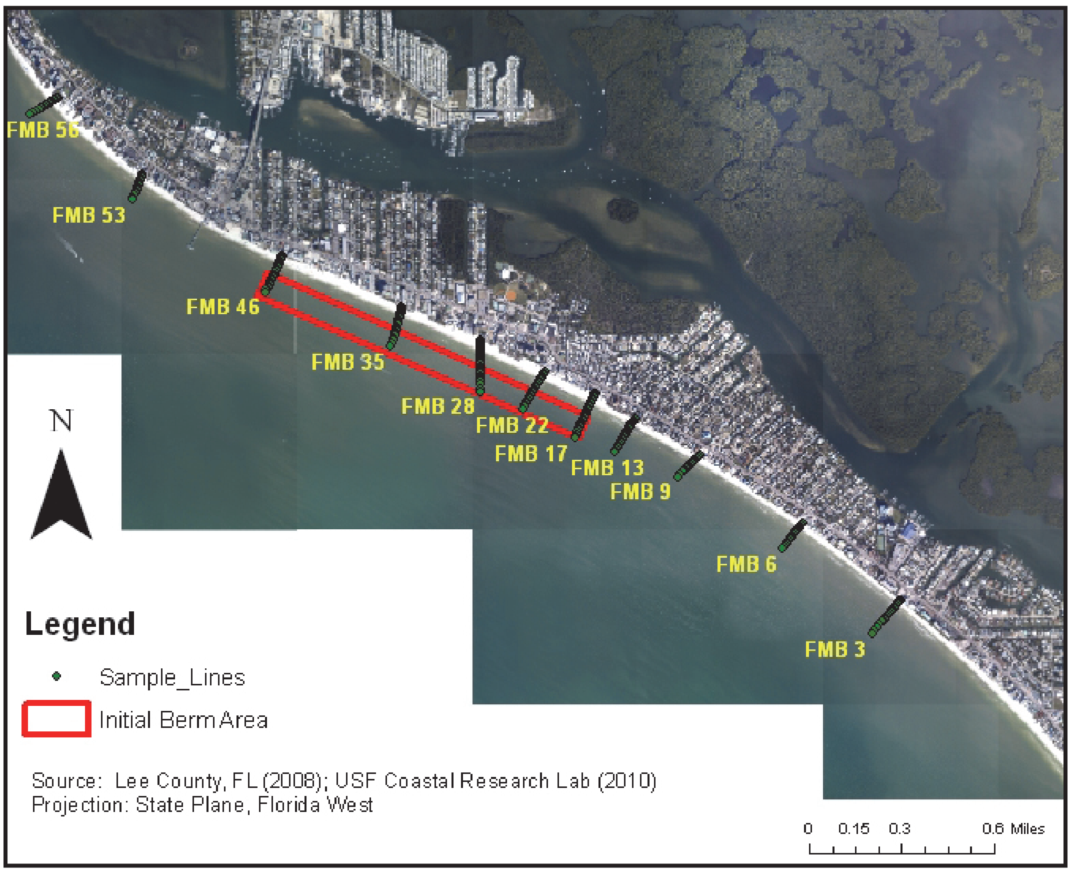


Figure D2. Grain-size distribution at FMB 3 (April 2010).

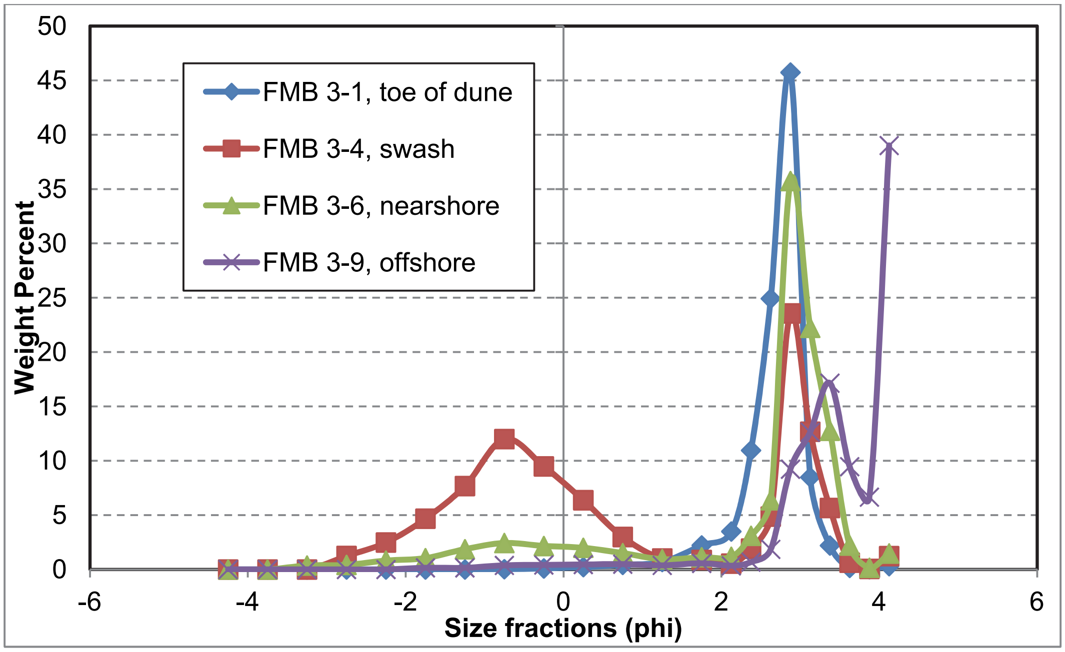


Figure D3. Grain-size distribution at FMB 3 (June 2011).

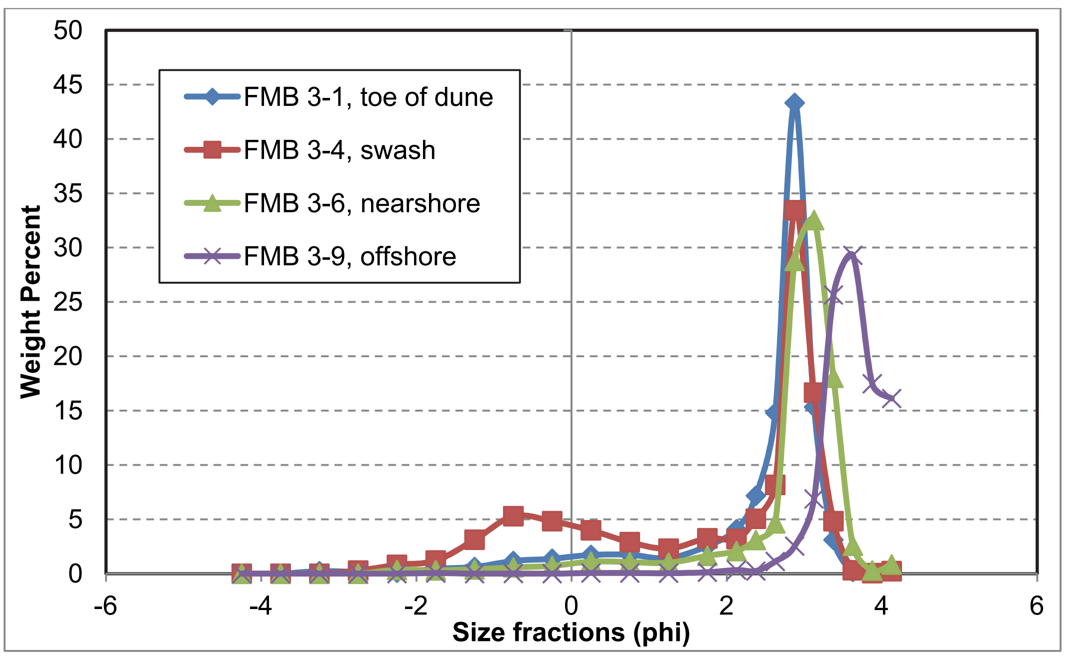


Figure D4. Grain-size distribution at FMB 6 (April 2010).

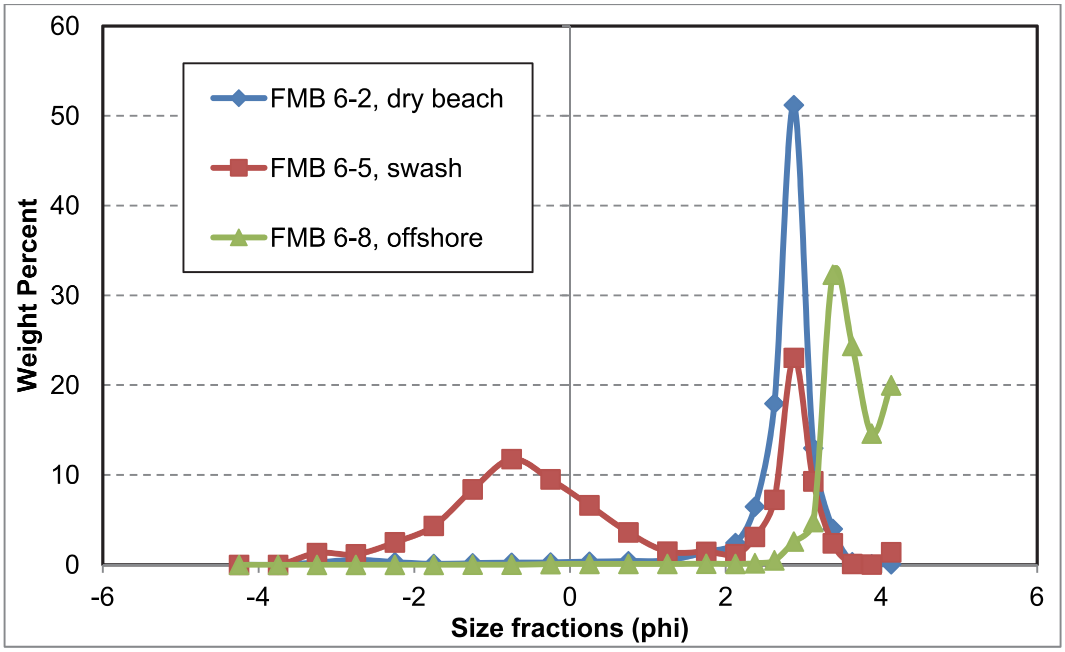


Figure D5. Grain-size distribution at FMB 6 (June 2011).

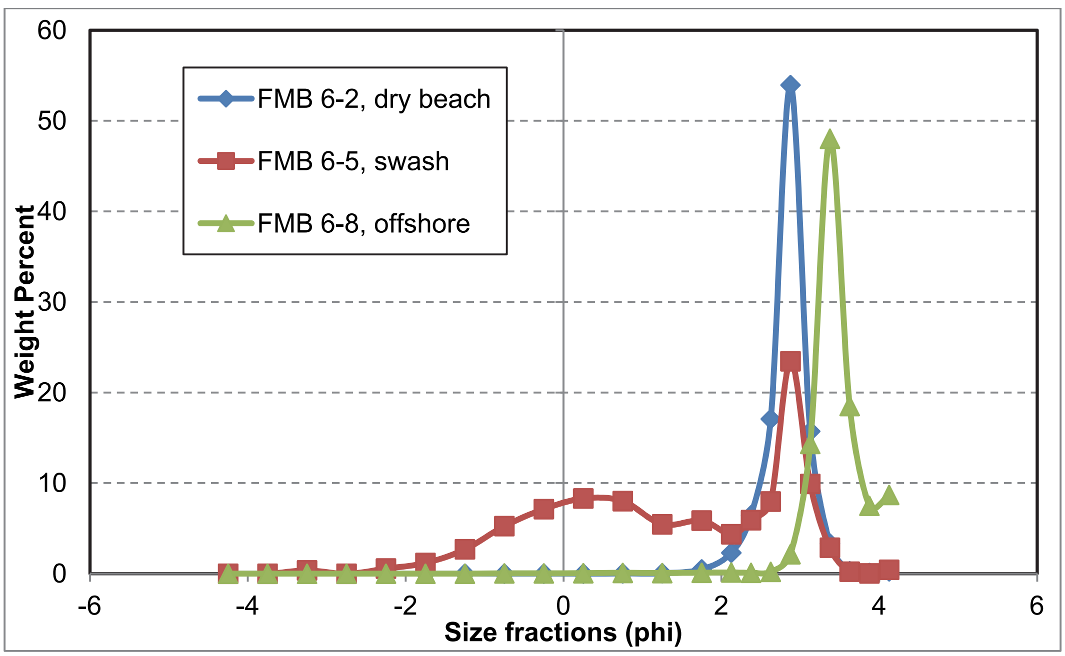


Figure D6. Grain-size distribution at FMB 9 (April 2010).

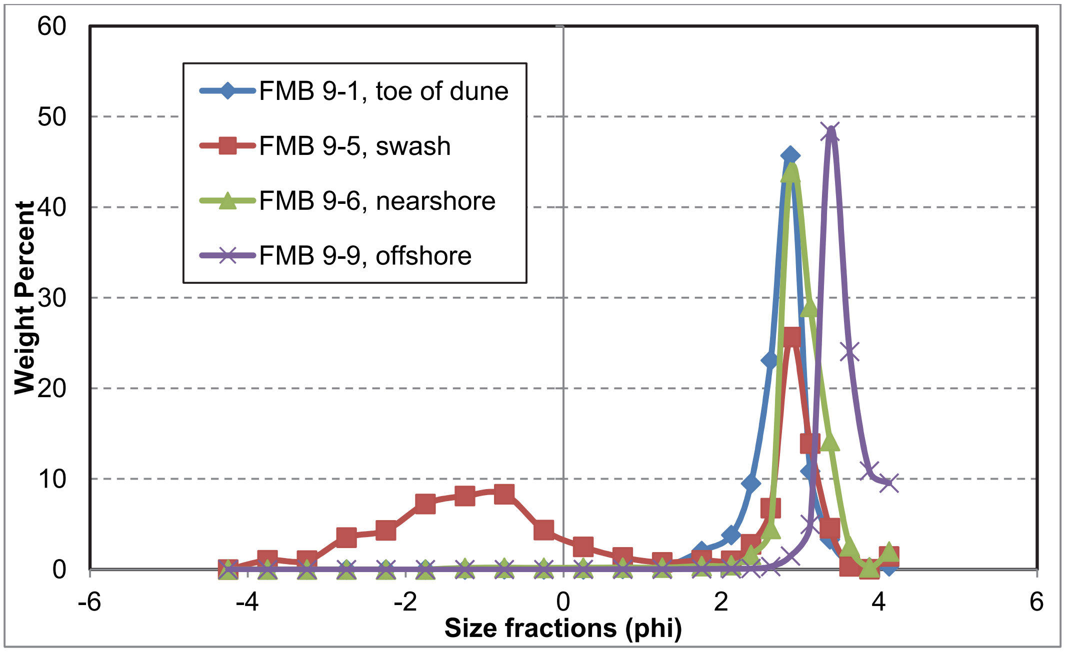


Figure D7. Grain-size distribution at FMB 9 (June 2011).

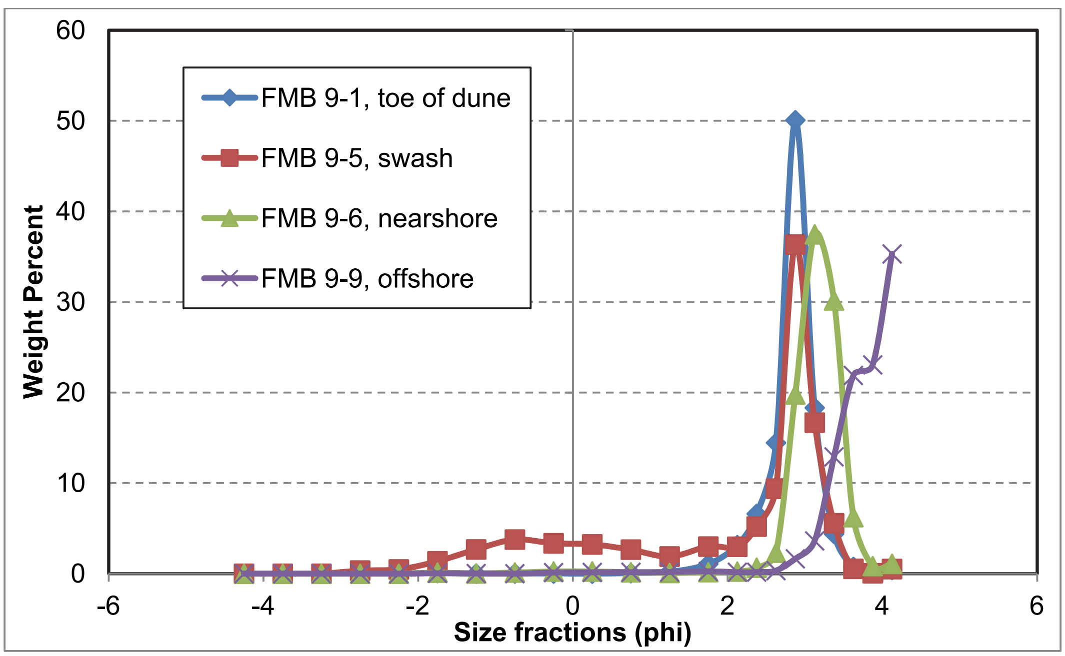


Figure D8. Grain-size distribution at FMB 13 (April 2010).

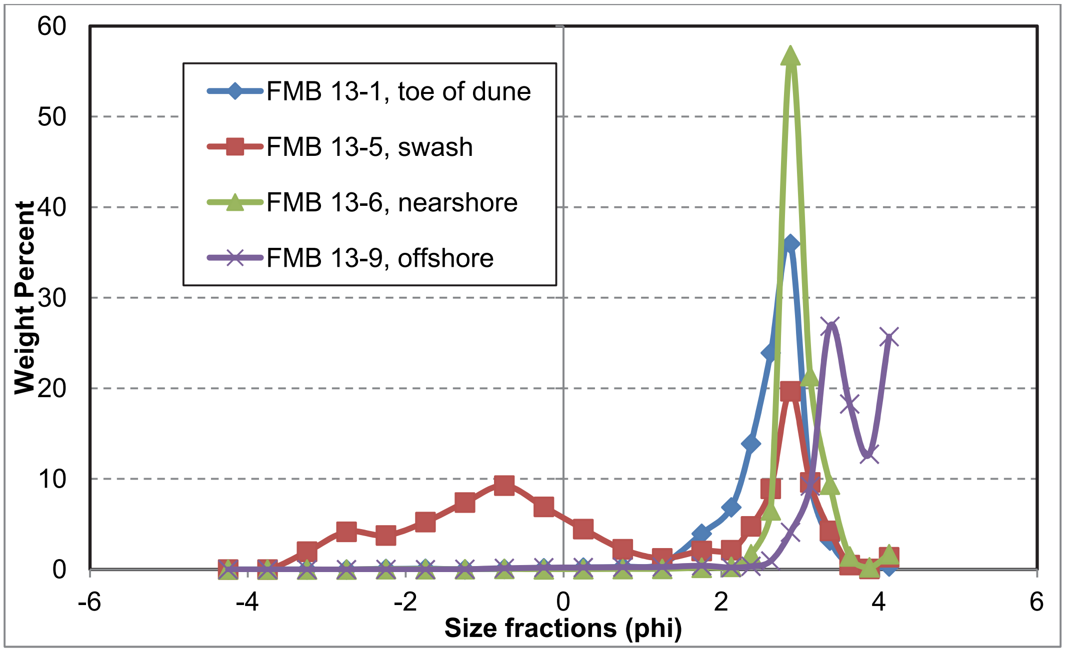


Figure D9. Grain-size distribution at FMB 13 (June 2011).

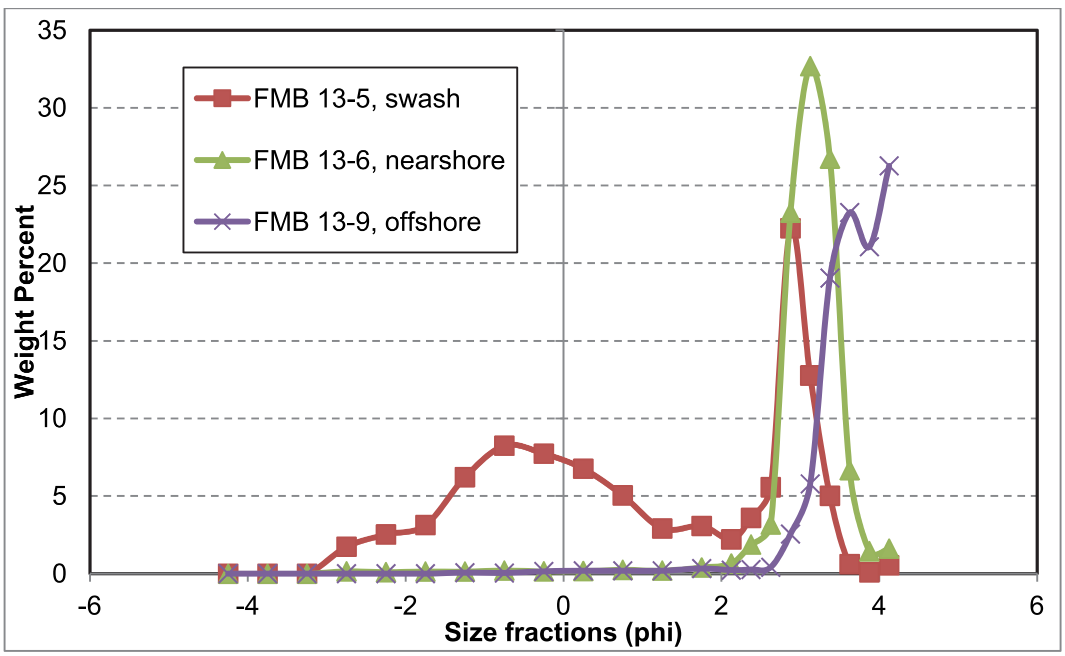


Figure D10. Grain-size distribution at FMB 17 (April 2010).

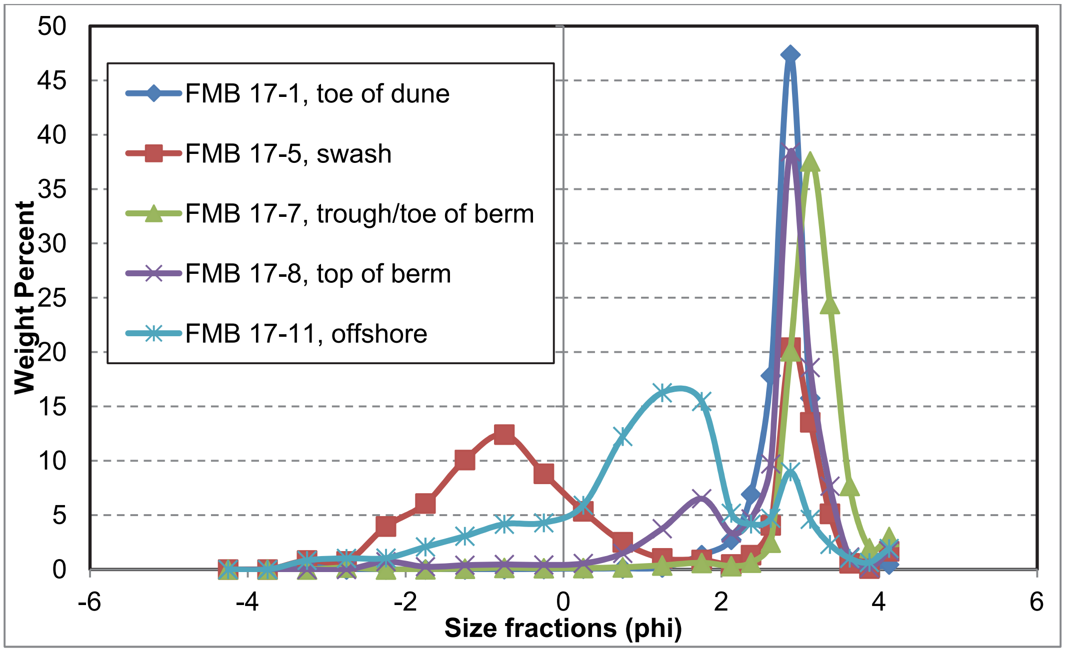


Figure D11. Grain-size distribution at FMB 17 (June 2011).

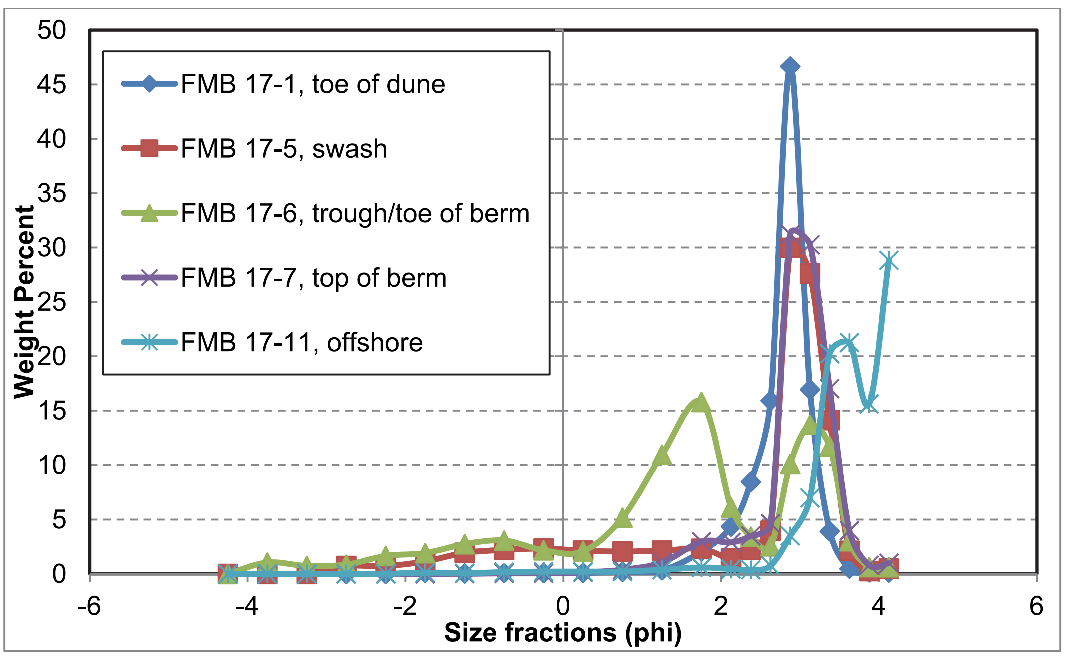


Figure D12. Grain-size distribution at FMB 22 (April 2010).

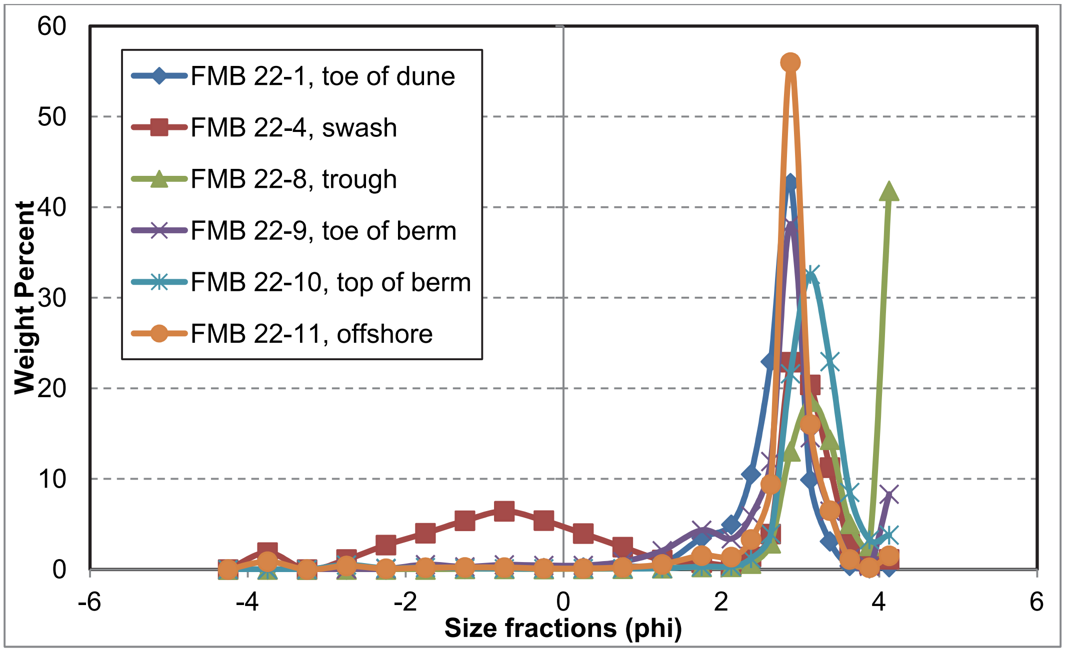


Figure D13. Grain-size distribution at FMB 22 (June 2011).

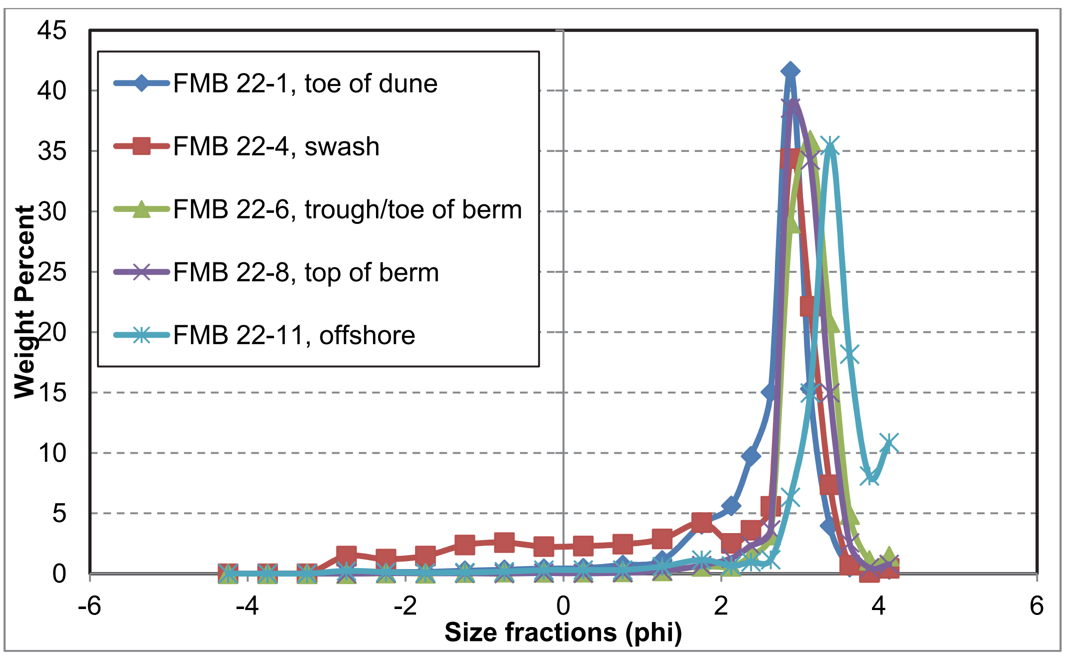


Figure D14. Grain-size distribution at FMB 28 (April 2010).

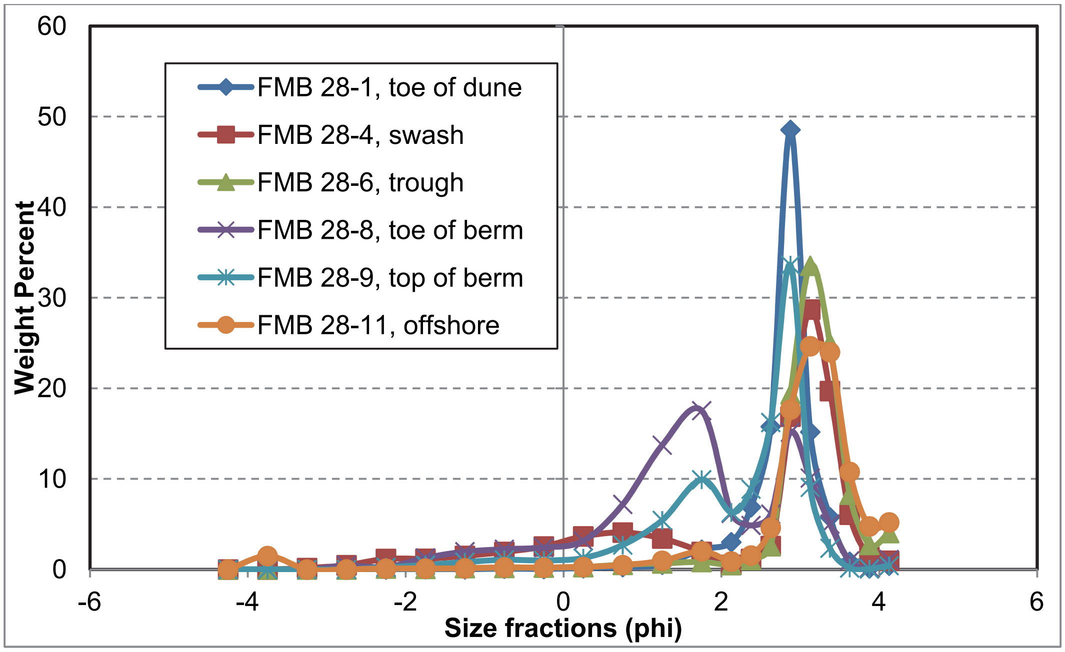


Figure D15. Grain-size distribution at FMB 28 (June 2011).

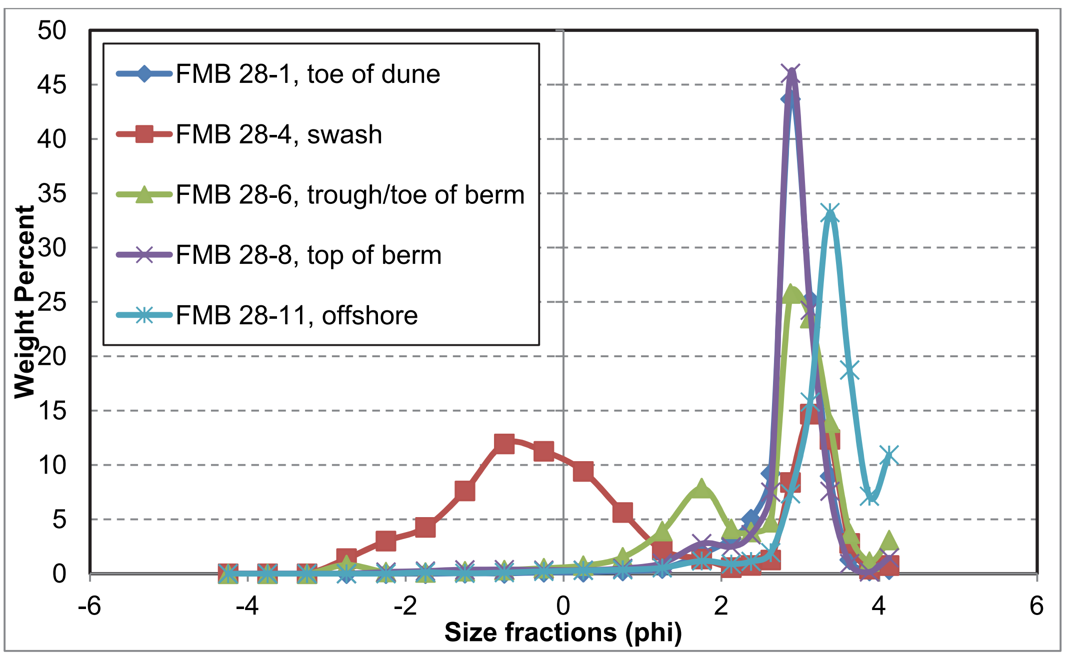


Figure D16. Grain-size distribution at FMB 35 (April 2010).

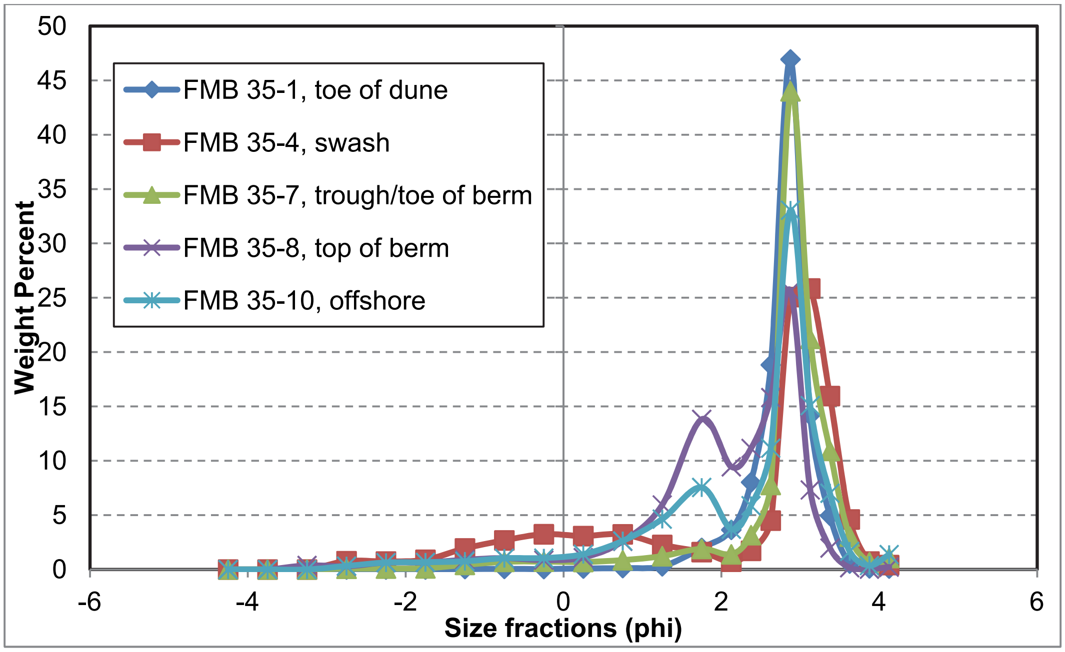


Figure D17. Grain-size distribution at FMB 35 (June 2011).

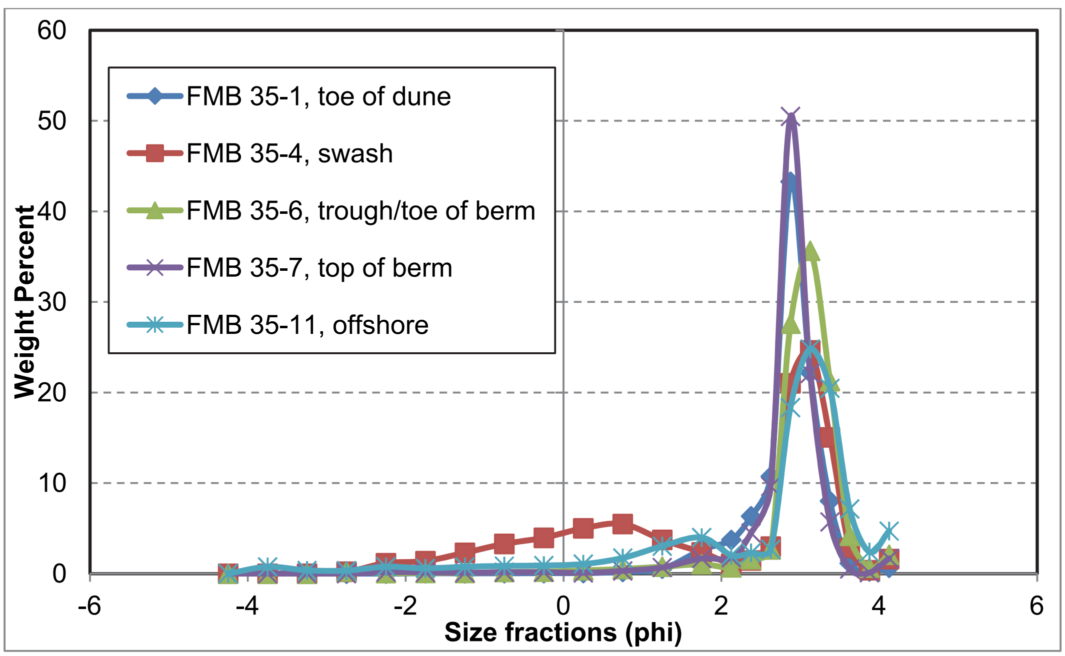


Figure D18. Grain-size distribution at FMB 46 (April 2010).

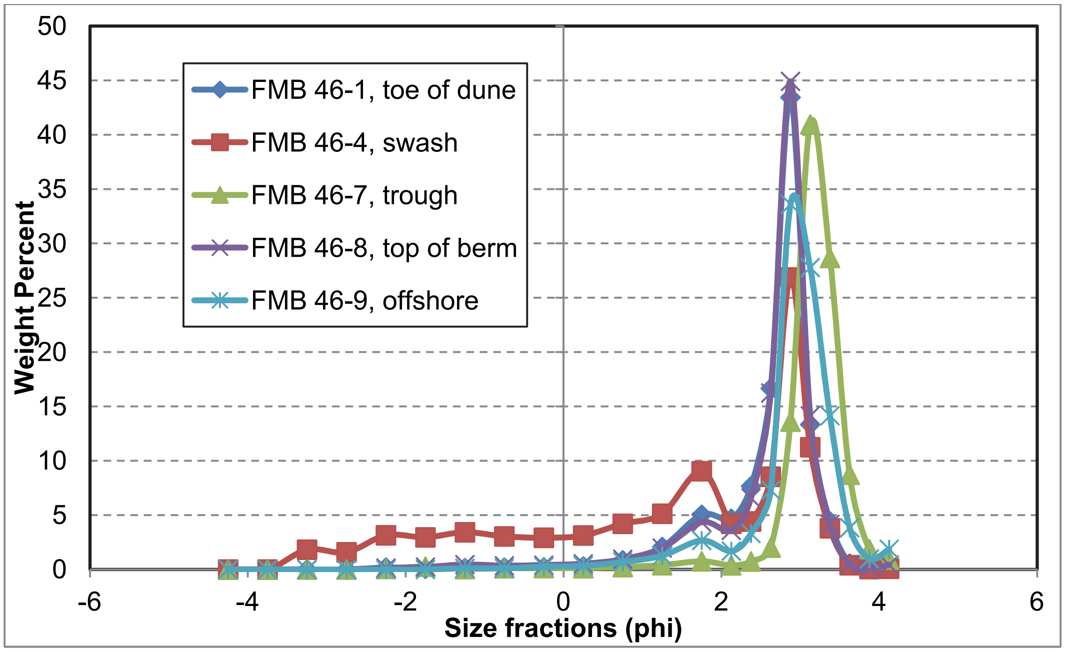


Figure D19. Grain-size distribution at FMB 46 (June 2011).

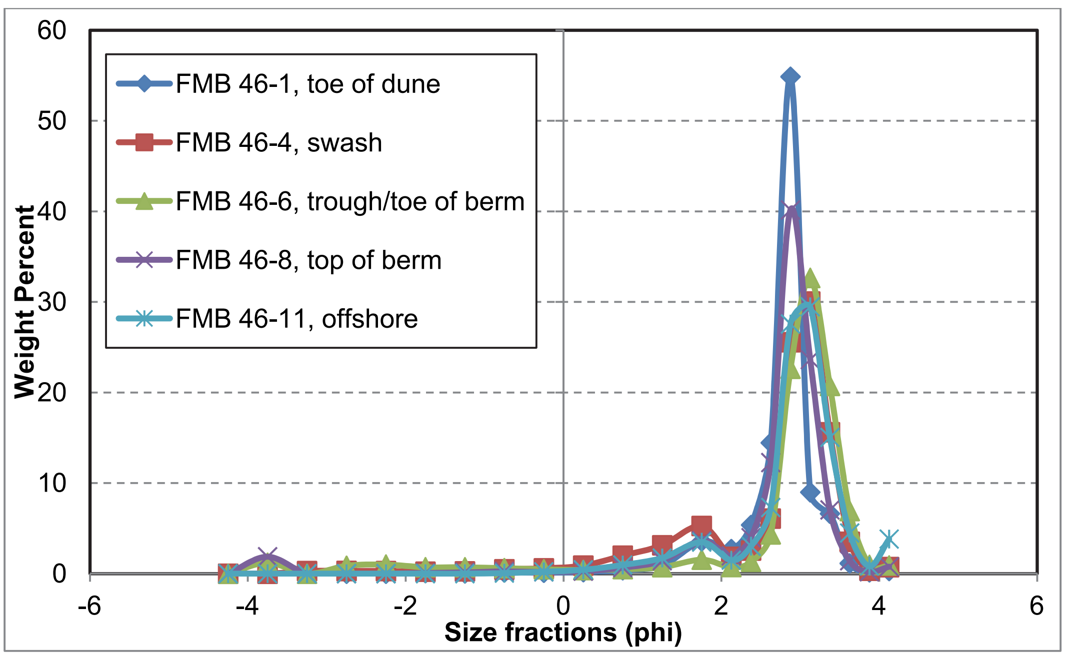


Figure D20. Grain-size distribution at FMB 53 (April 2010).

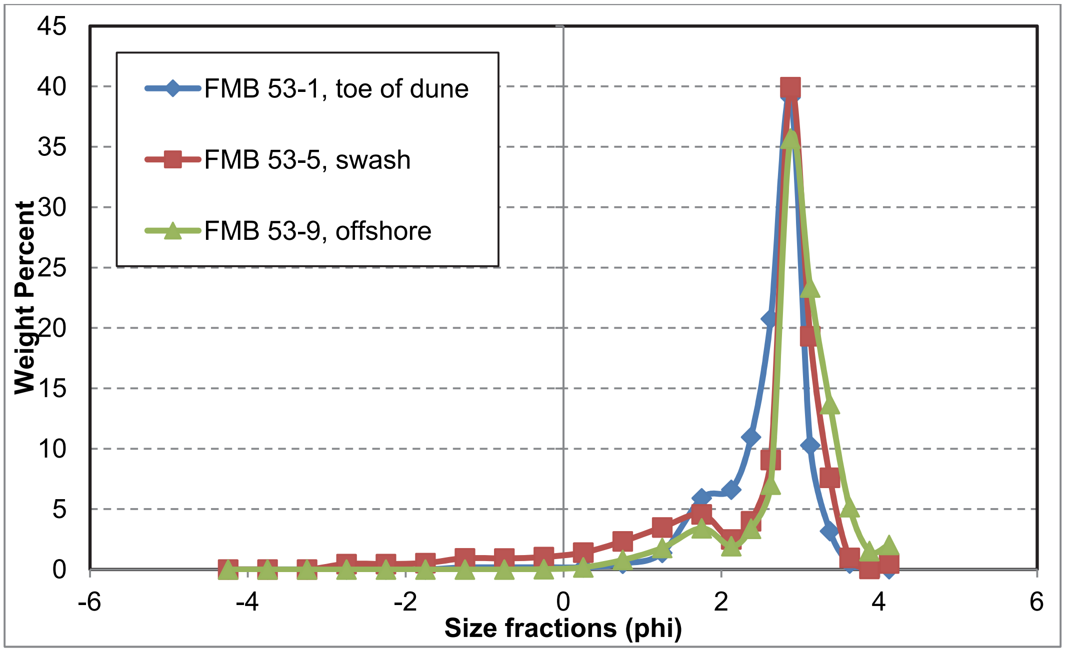


Figure D21. Grain-size distribution at FMB 53 (June 2011).

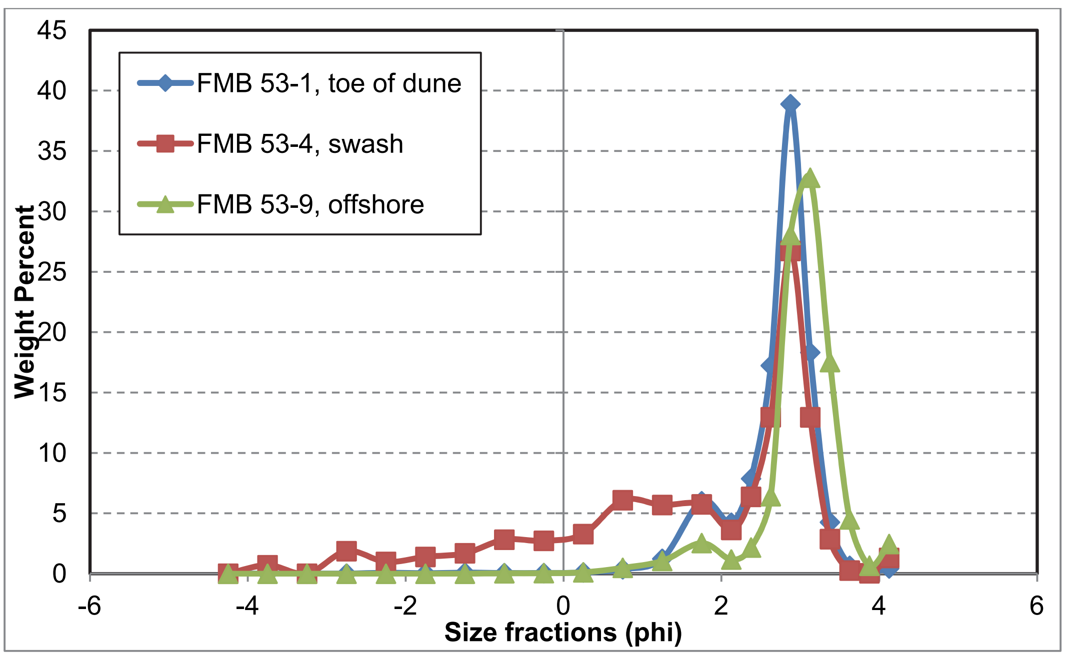


Figure D22. Grain-size distribution at FMB 56 (April 2010).

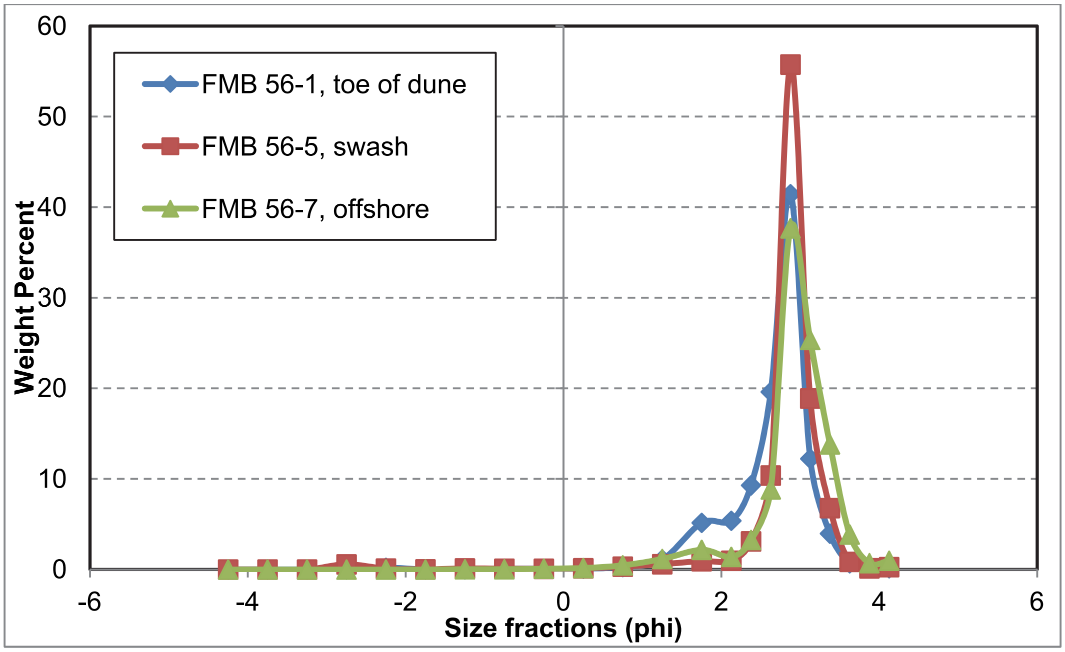
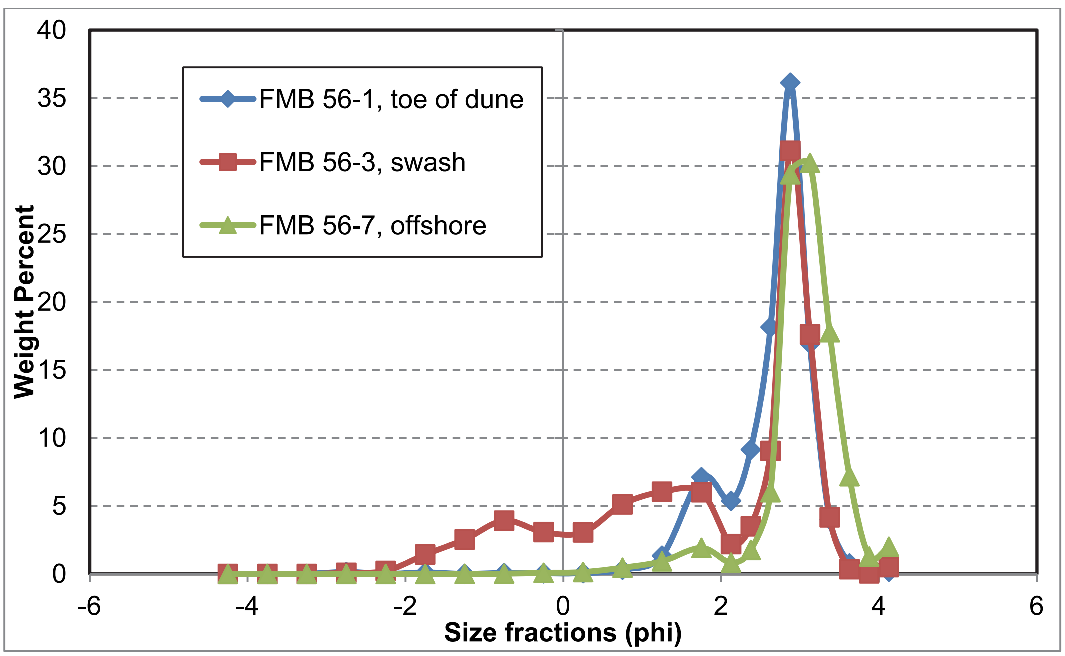


Figure D23. Grain-size distribution at FMB 56 (June 2011).



Appendix E: Mud Content in Surface Sediment Samples

Appendix E illustrates the beach profile of each of the sample lines in both April 2010 and June 2011, with the sample locations indicated by red squares. Percentages of mud in the samples are given next to each sample location. Figure E1 shows the sampling transect locations.

Figure E1. Locations of sediment sampling transects.

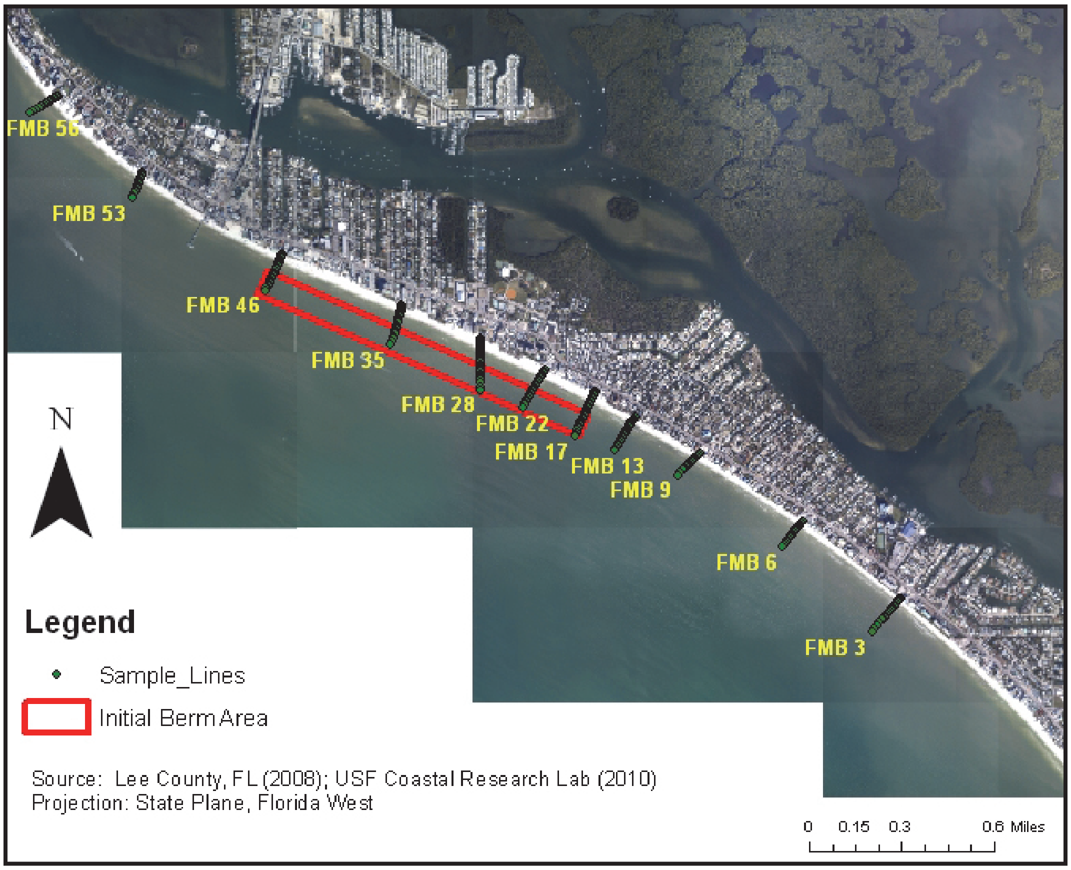


Figure E2. Sample locations with mud percentages at FMB 3 (April 2010).

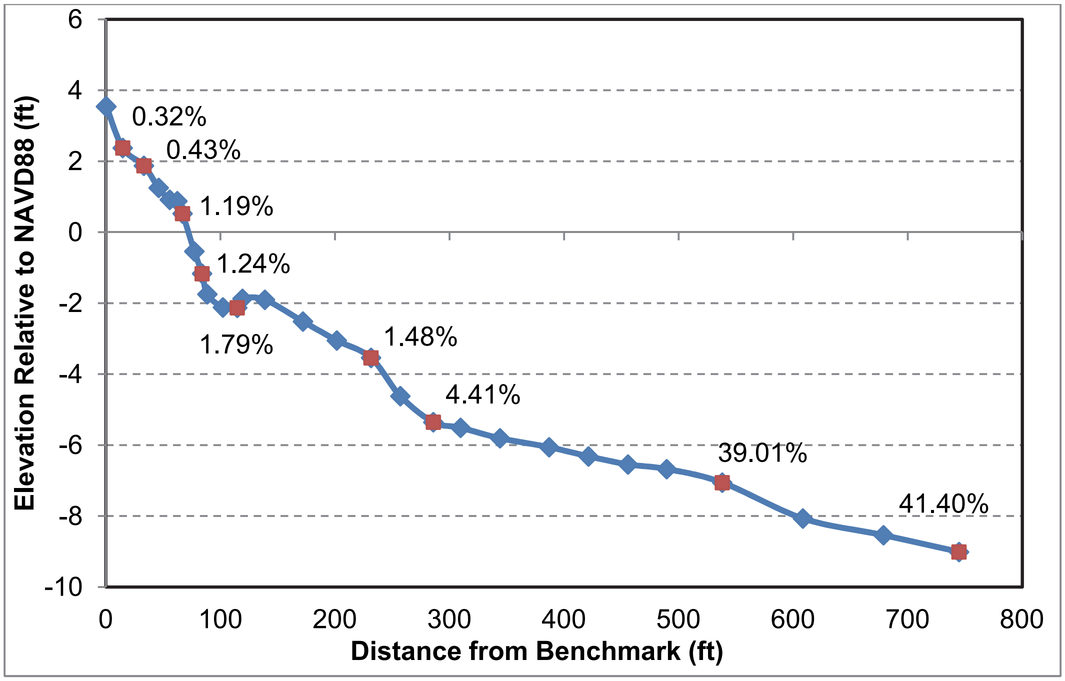


Figure E3. Sample locations with mud percentages at FMB 3 (June 2011).

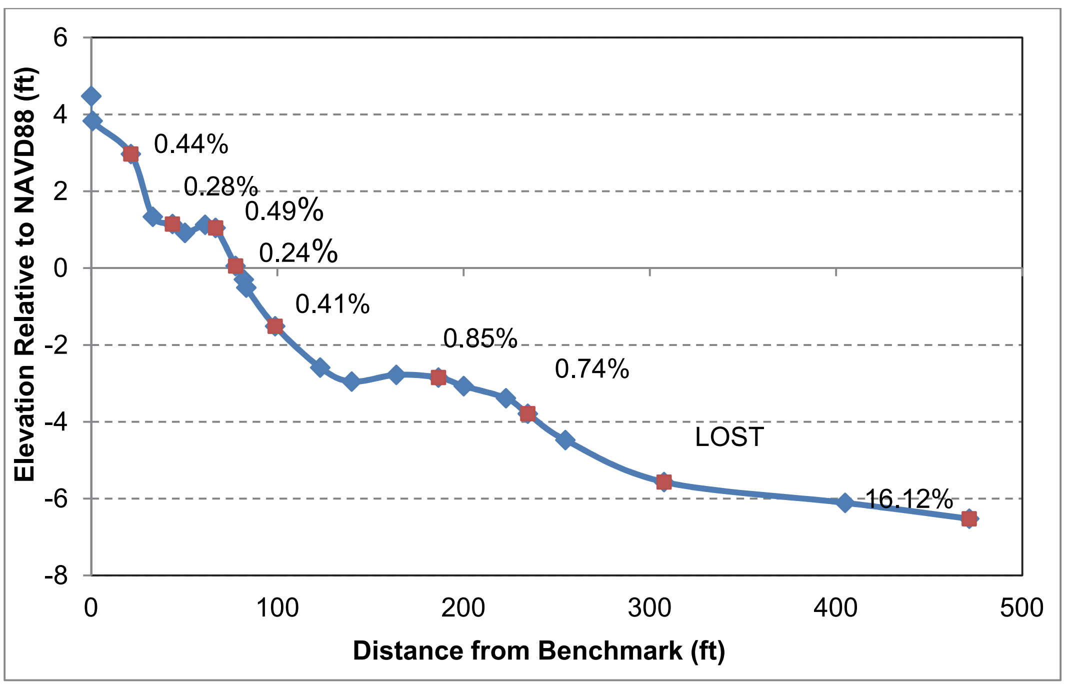


Figure E4. Sample locations with mud percentages at FMB 6 (April 2010).

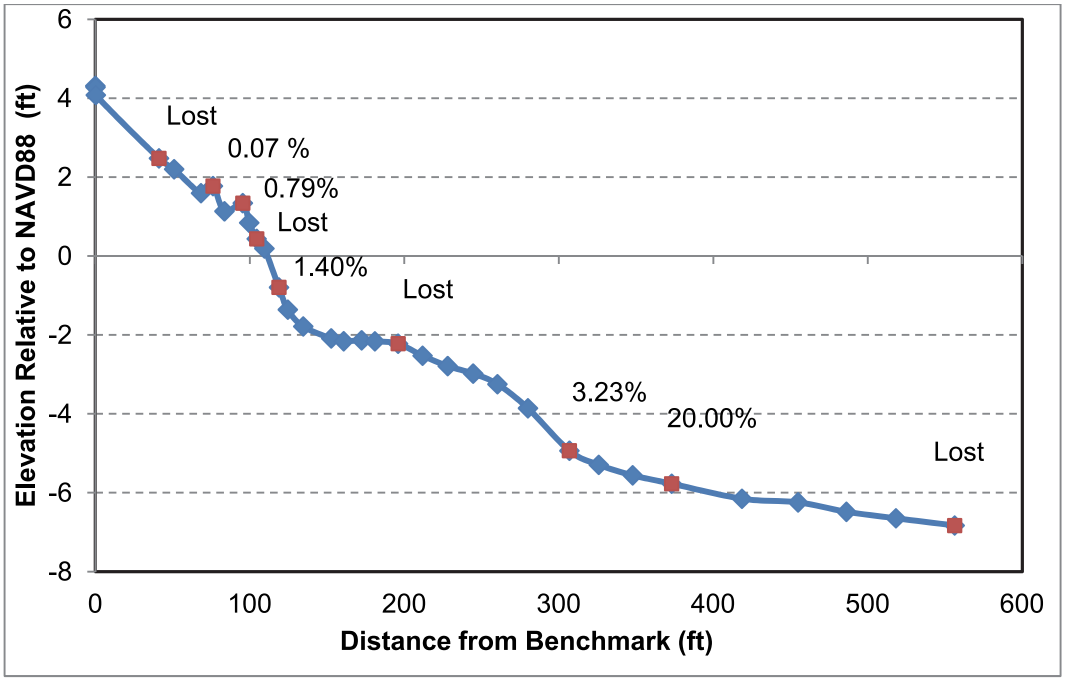


Figure E5. Sample locations with mud percentages at FMB 6 (June 2011).

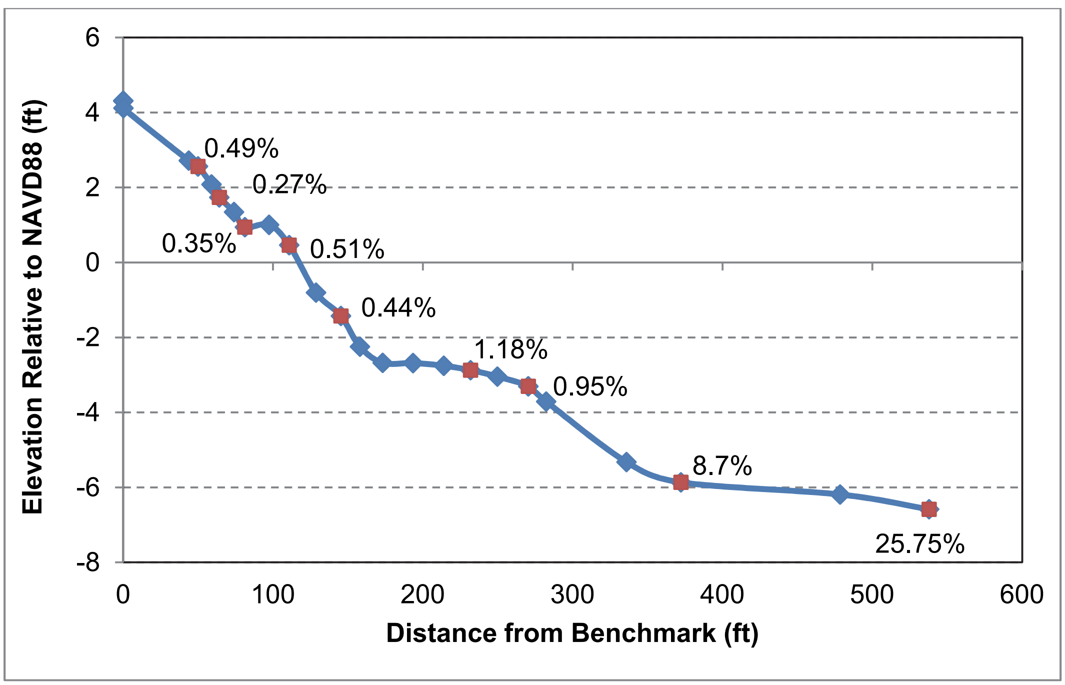


Figure E6. Sample locations with mud percentages at FMB 9 (April 2010).

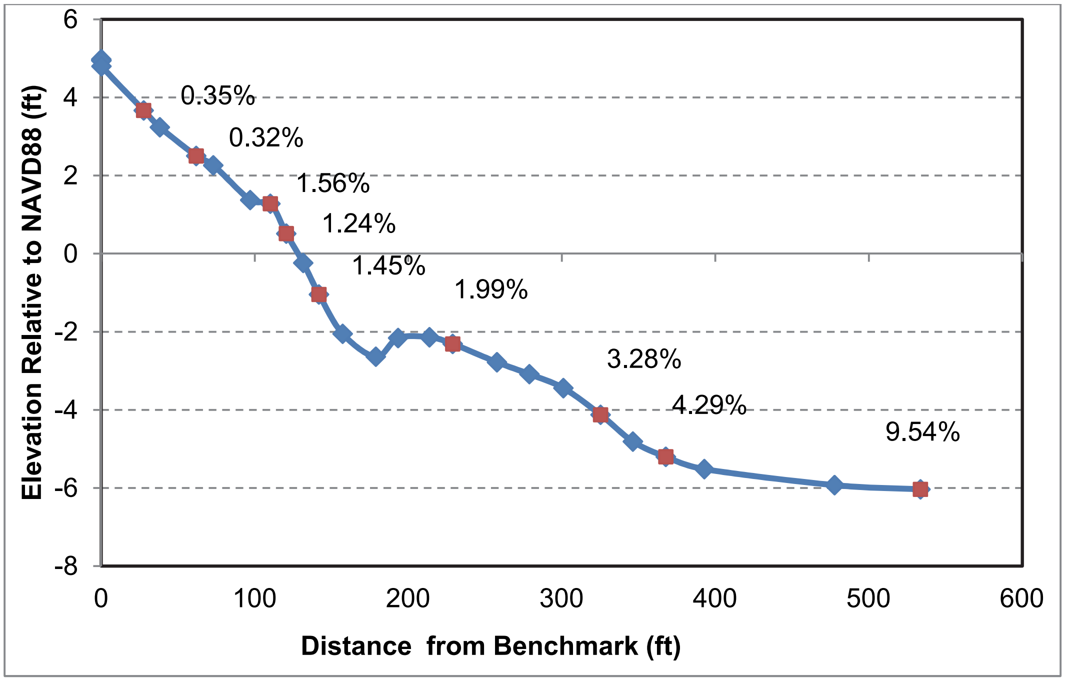


Figure E7. Sample locations with mud percentages at FMB 9 (June 2011).

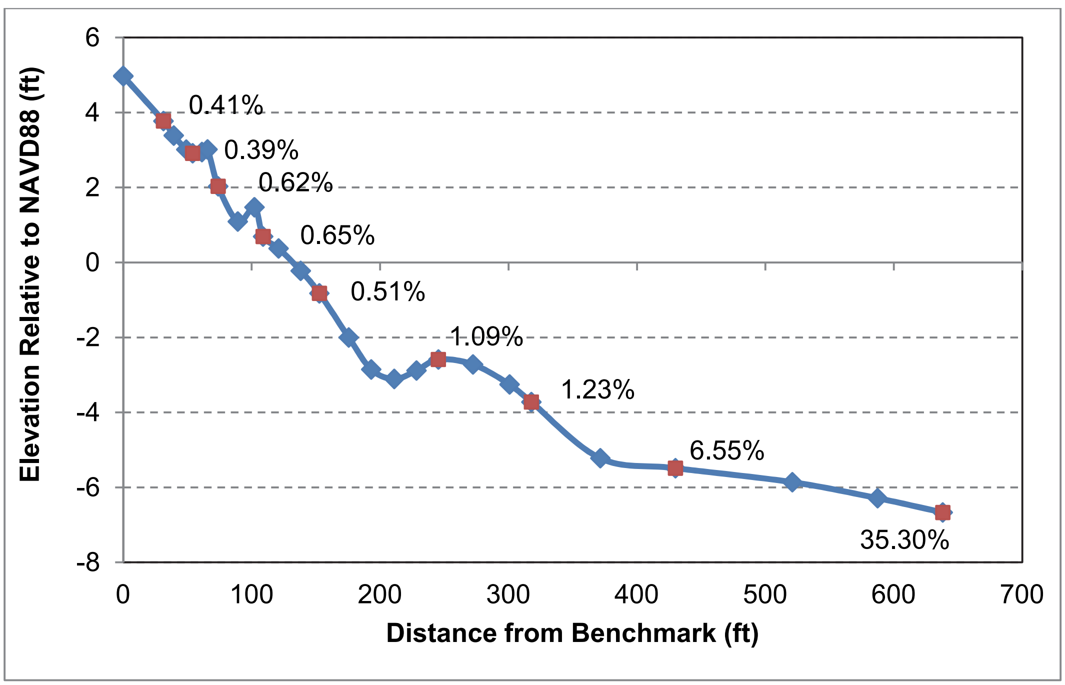


Figure E8. Sample locations with mud percentages at FMB 13 (April 2010).

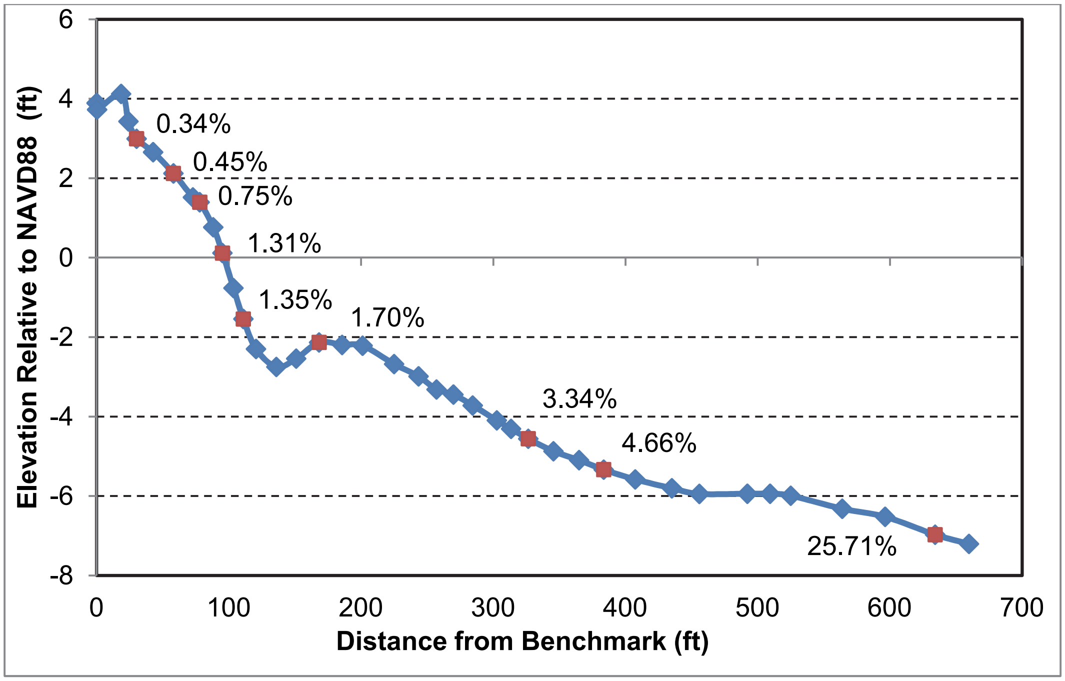


Figure E9. Sample locations with mud percentages at FMB 13 (June 2011).

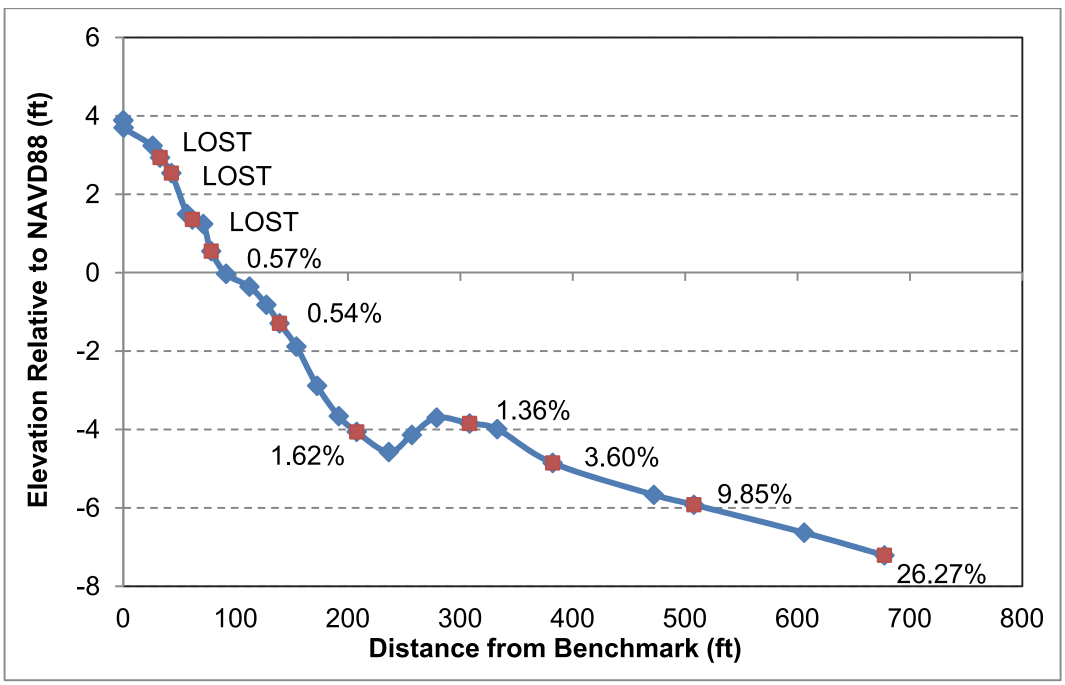


Figure E10. Sample locations with mud percentages at FMB 17 (April 2010).

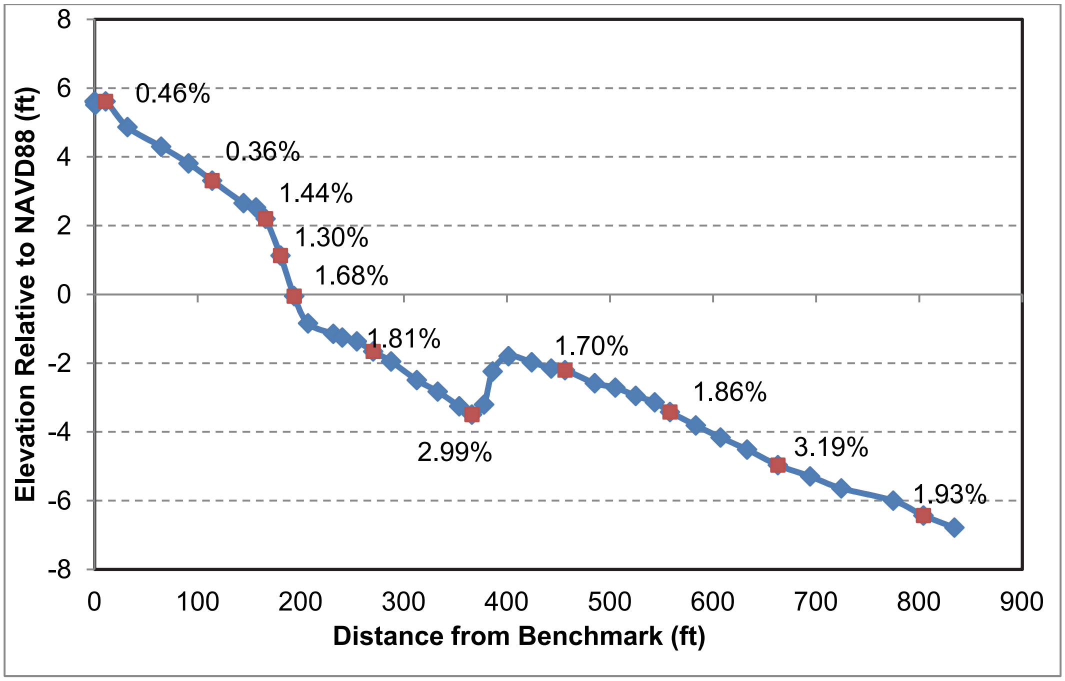


Figure E11. Sample locations with mud percentages at FMB 17 (June 2011).

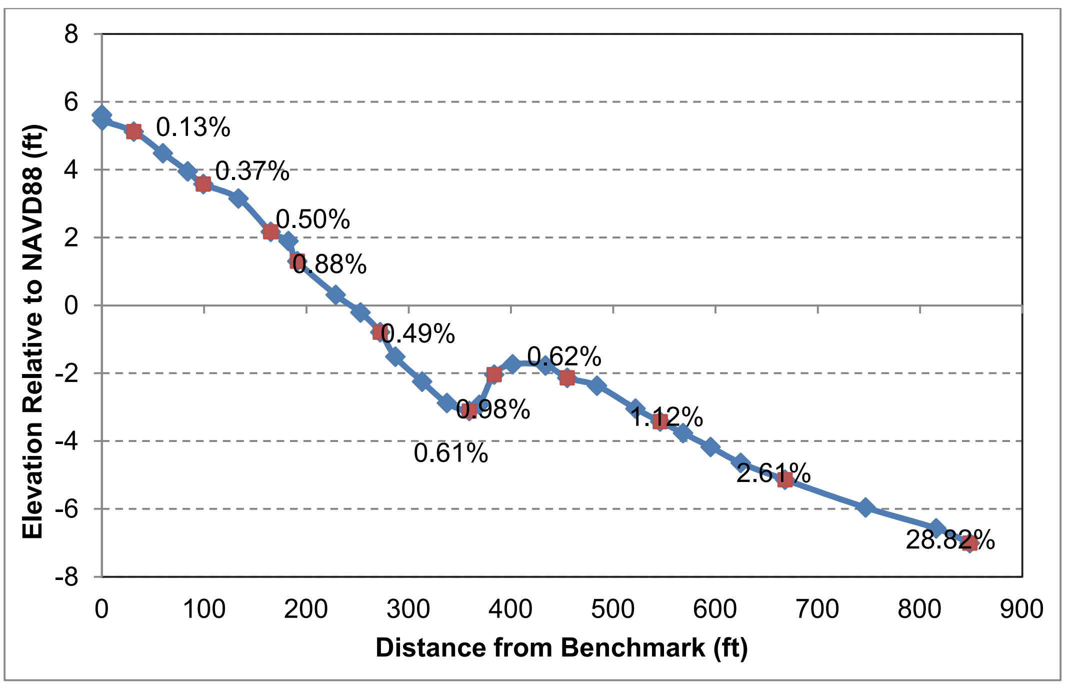


Figure E12. Sample locations with mud percentages at FMB 22 (April 2010).

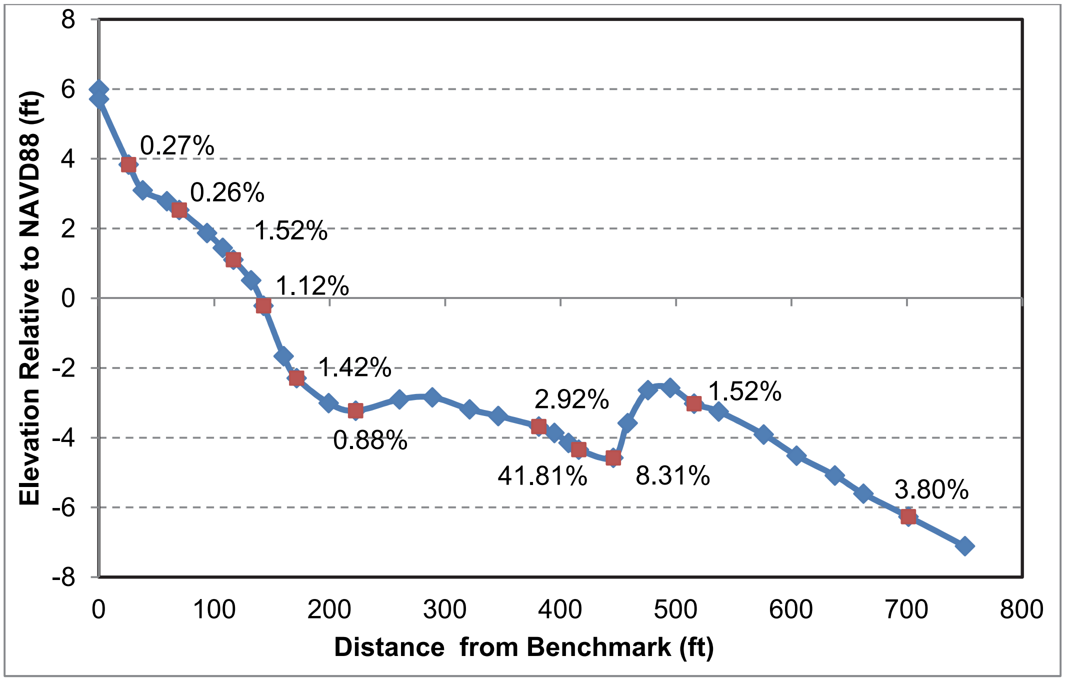


Figure E13. Sample locations with mud percentages at FMB 22 (June 2011).

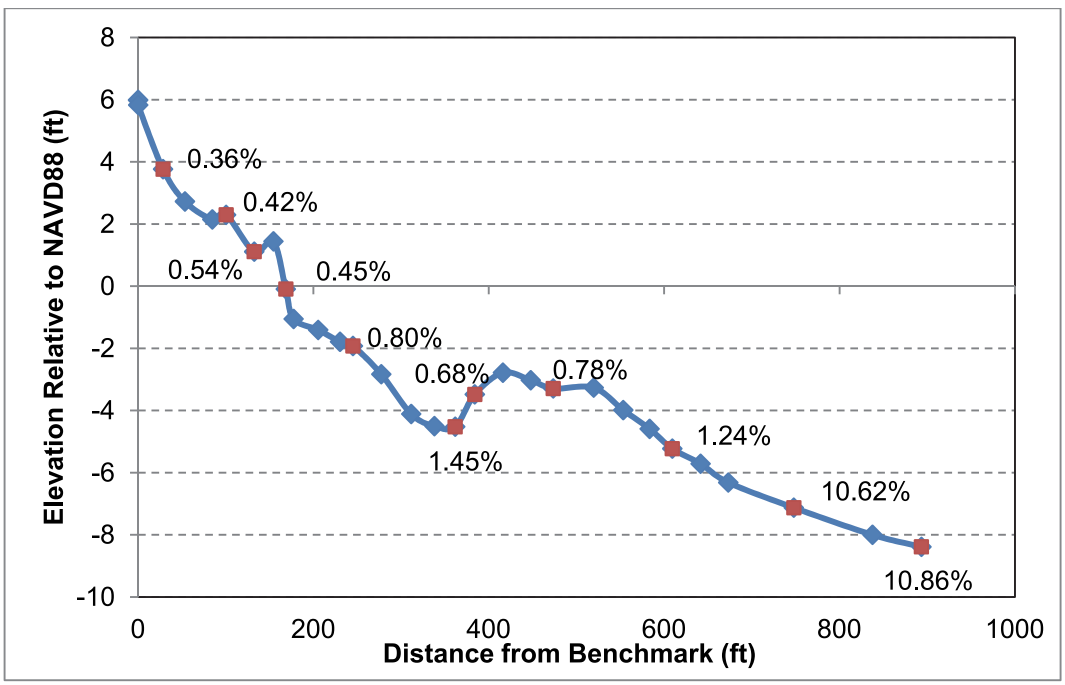


Figure E14. Sample locations with mud percentages at FMB 28 (April 2010).

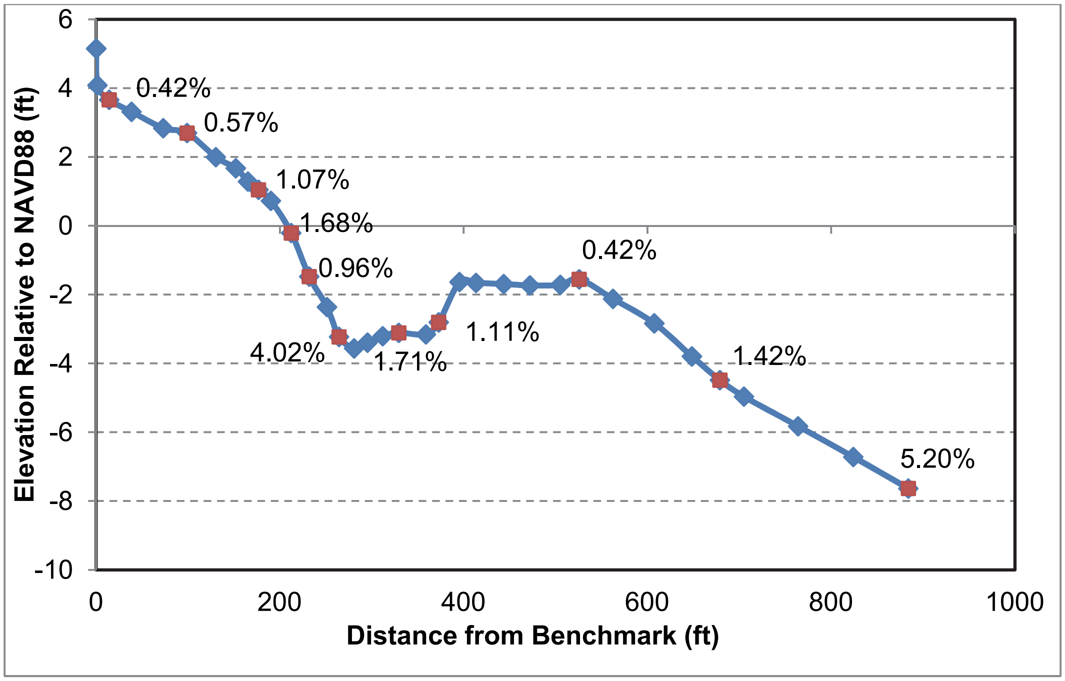


Figure E15. Sample locations with mud percentages at FMB 28 (June 2011).

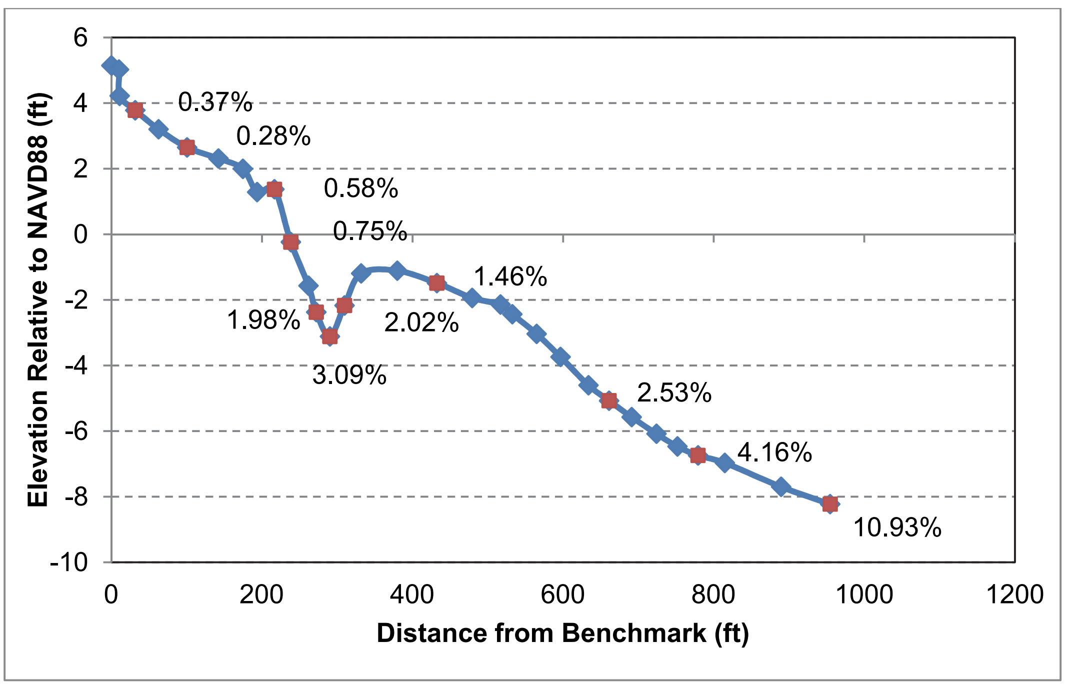


Figure E16. Sample Locations with mud percentages at FMB 35 (April 2010).

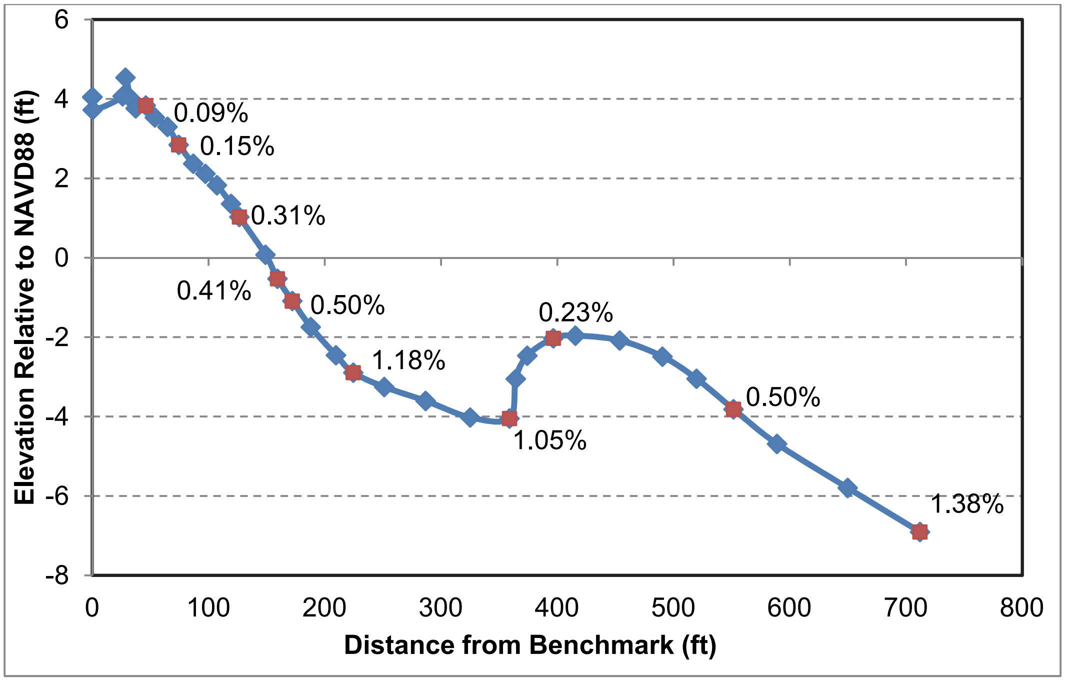


Figure E17. Sample Locations with mud percentages at FMB 35 (June 2011).

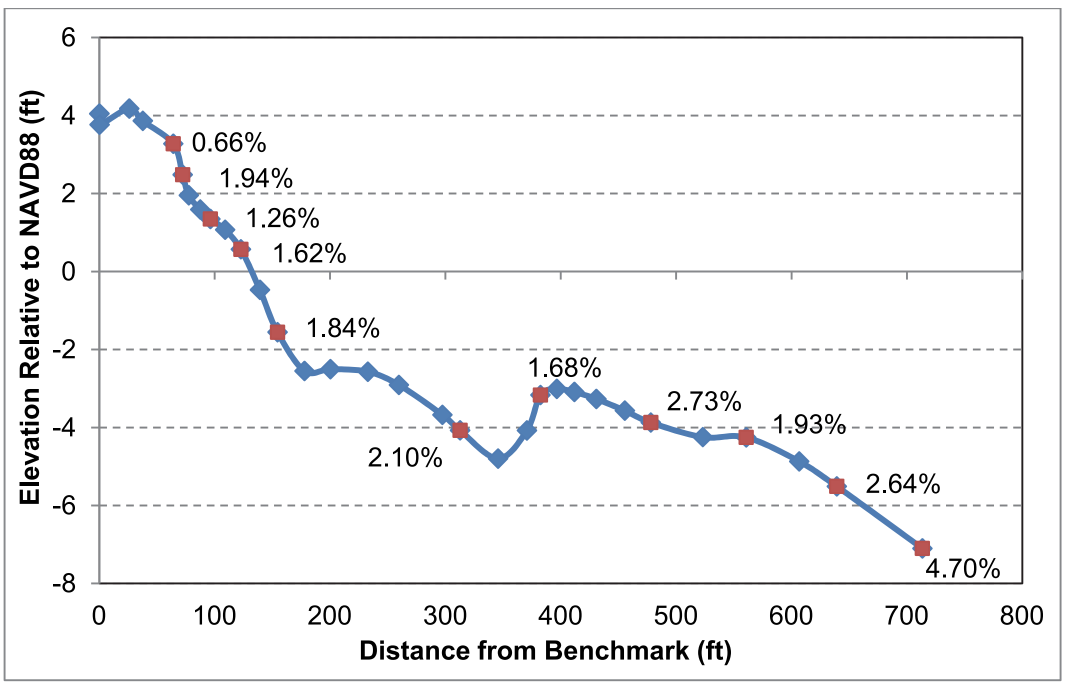


Figure E18. Sample Locations with mud percentages at FMB 46 (April 2010).

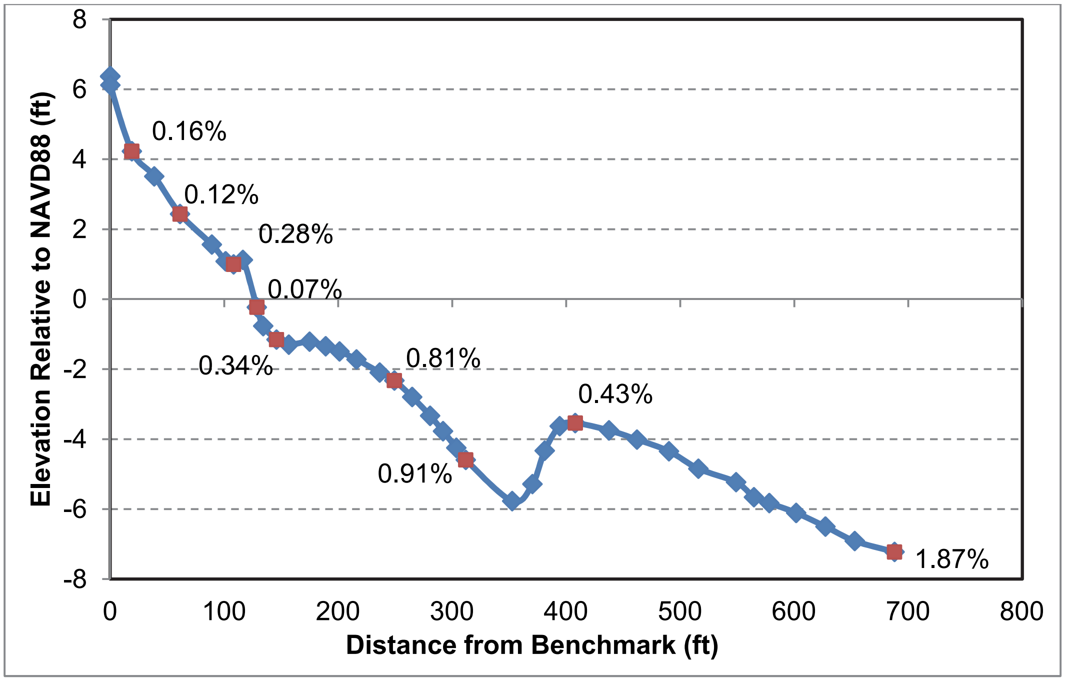


Figure E19. Sample Locations with mud percentages at FMB 46 (June 2011).

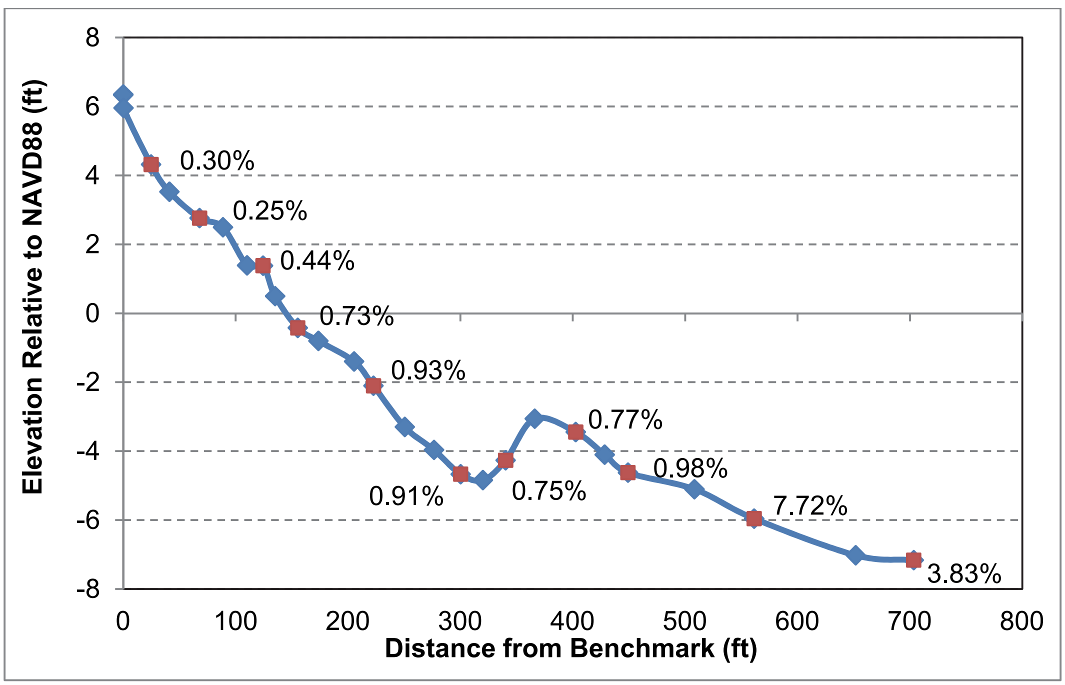


Figure E20. Sample Locations with mud percentages at FMB 53 (April 2010).

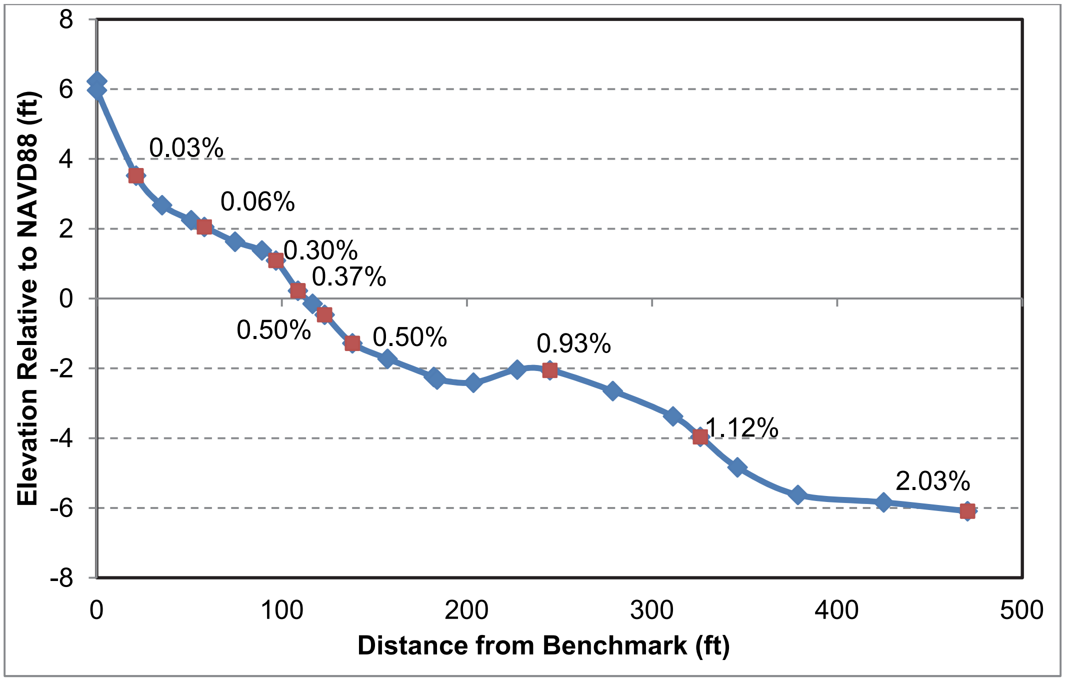


Figure E21. Sample Locations with mud percentages at FMB 53 (June 2011).

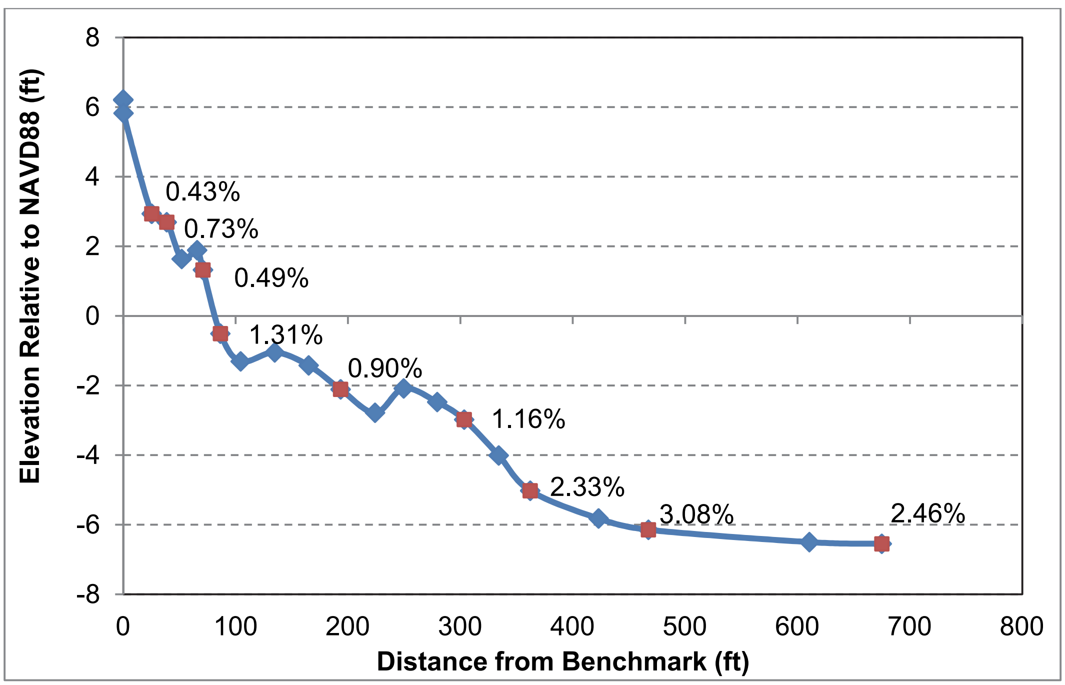


Figure E22. Sample Locations with mud percentages at FMB 56 (April 2010).

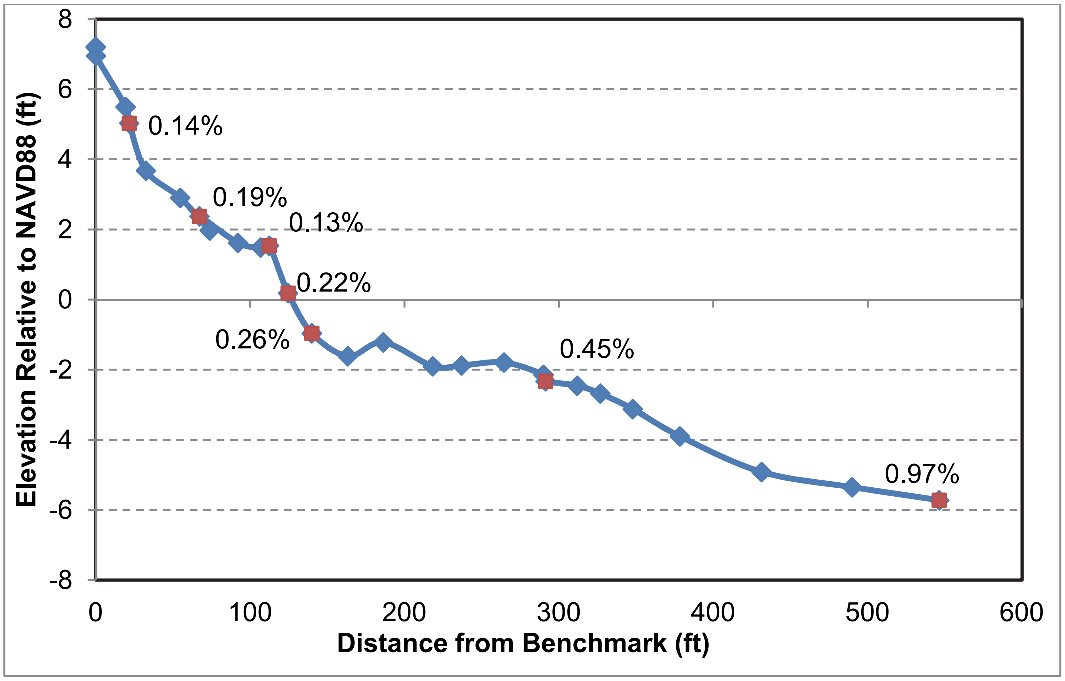
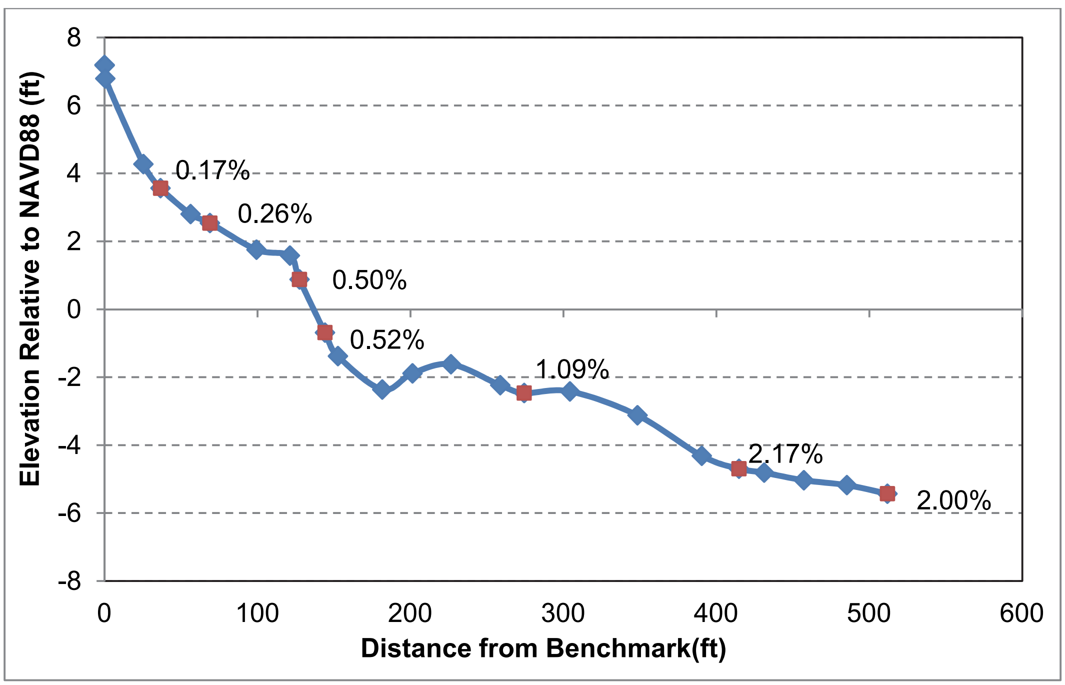


Figure E23. Sample Locations with mud percentages at FMB 56 (June 2011).



Appendix F: Carbonate Content in Surface Sediment Samples

The figures in Appendix F illustrate the beach profile of each of the sample lines in both April 2010 and June 2011, with the sample locations indicated by red squares. Percentages of carbonates in the samples are given next to each sample location. Figure F1 shows the sampling transect locations.

Figure F1. Locations of sediment sampling transects.

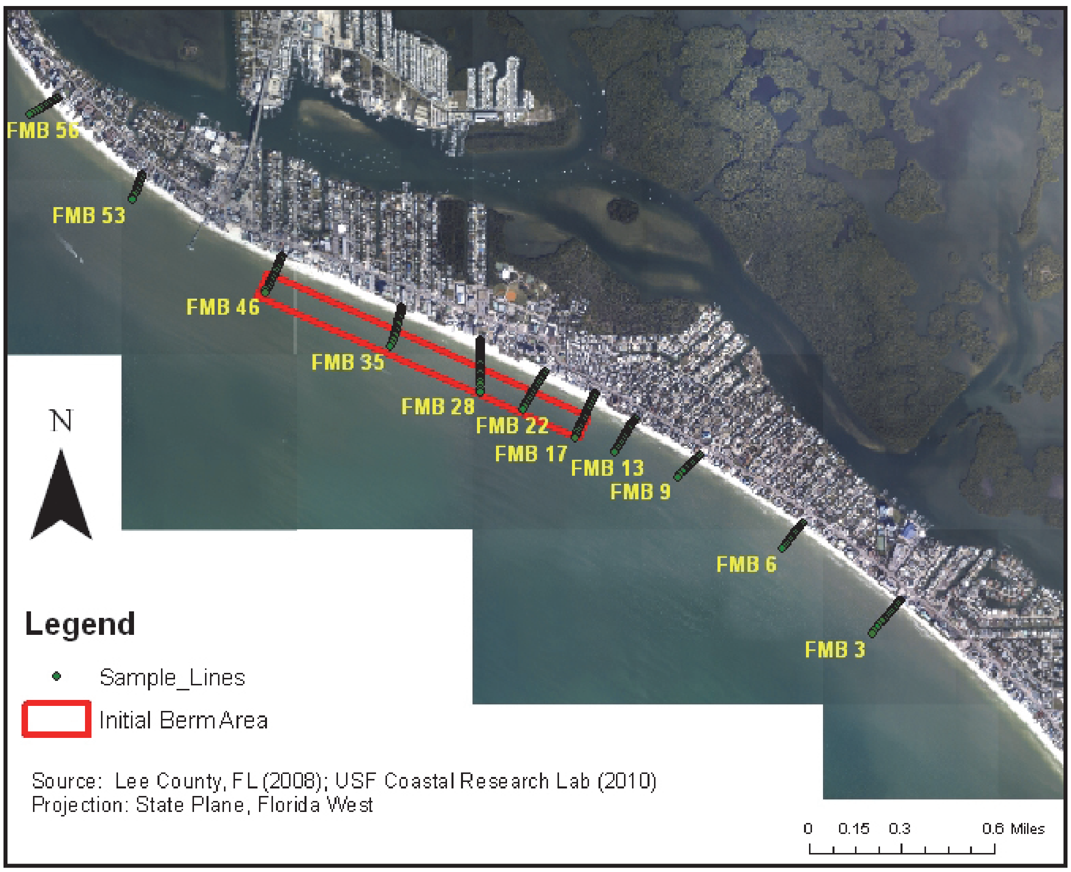


Figure F2. Sample Locations with carbonate percentages at FMB 3 (April 2010).

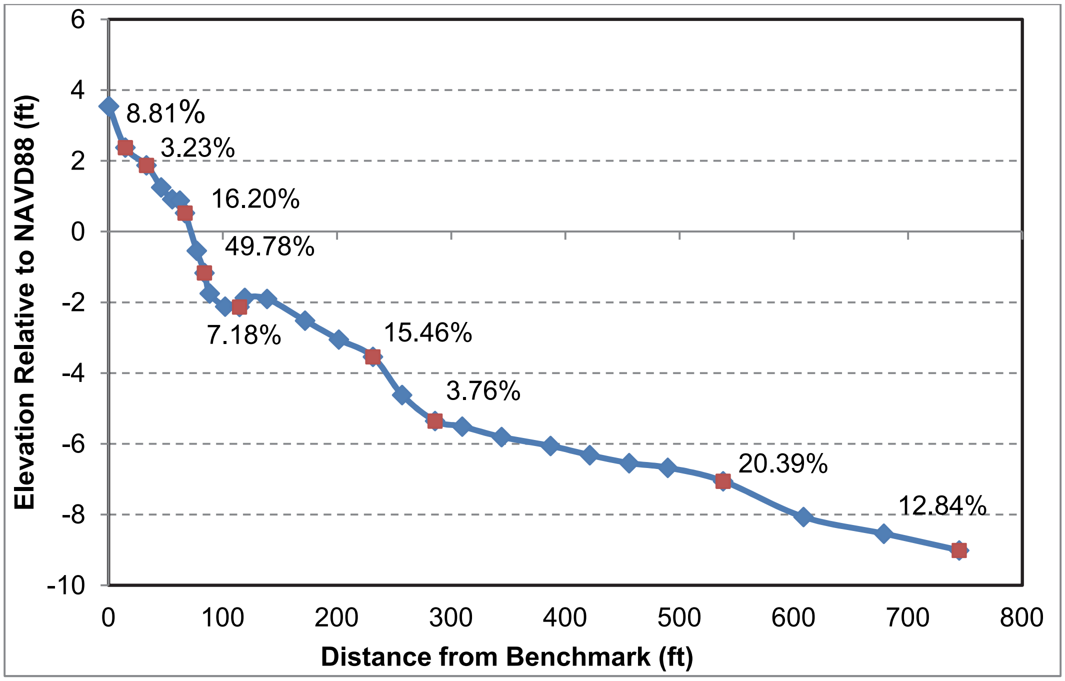


Figure F3. Sample Locations with carbonate percentages at FMB 3 (June 2011).

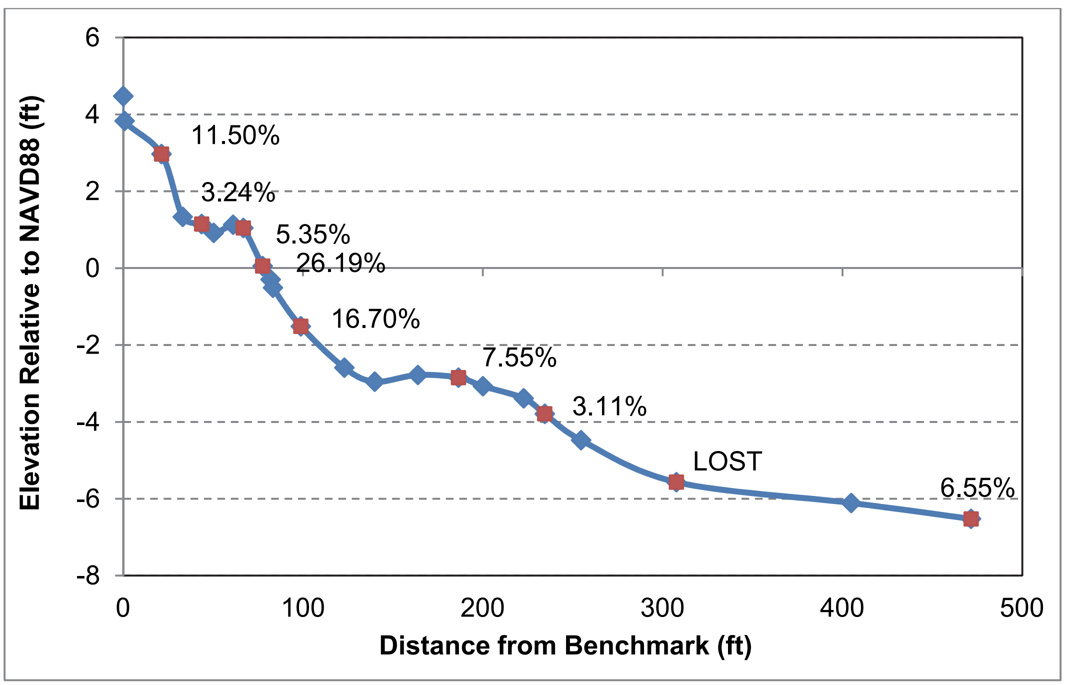


Figure F4. Sample Locations with carbonate percentages at FMB 6 (April 2010).

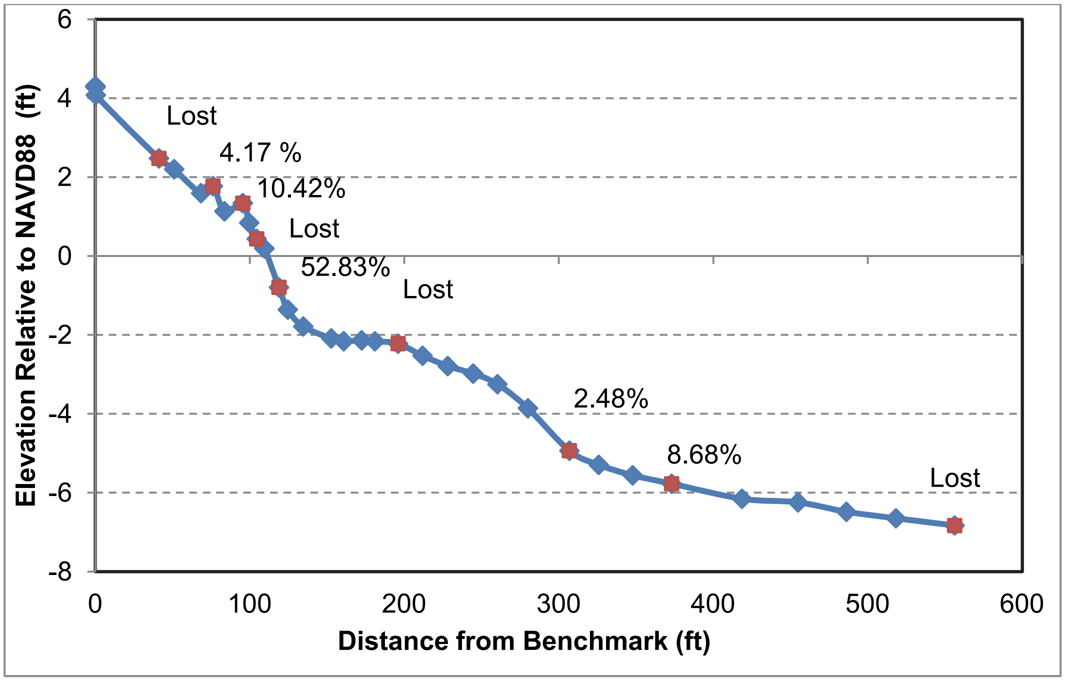


Figure F5. Sample Locations with carbonate percentages at FMB 6 (June 2011).

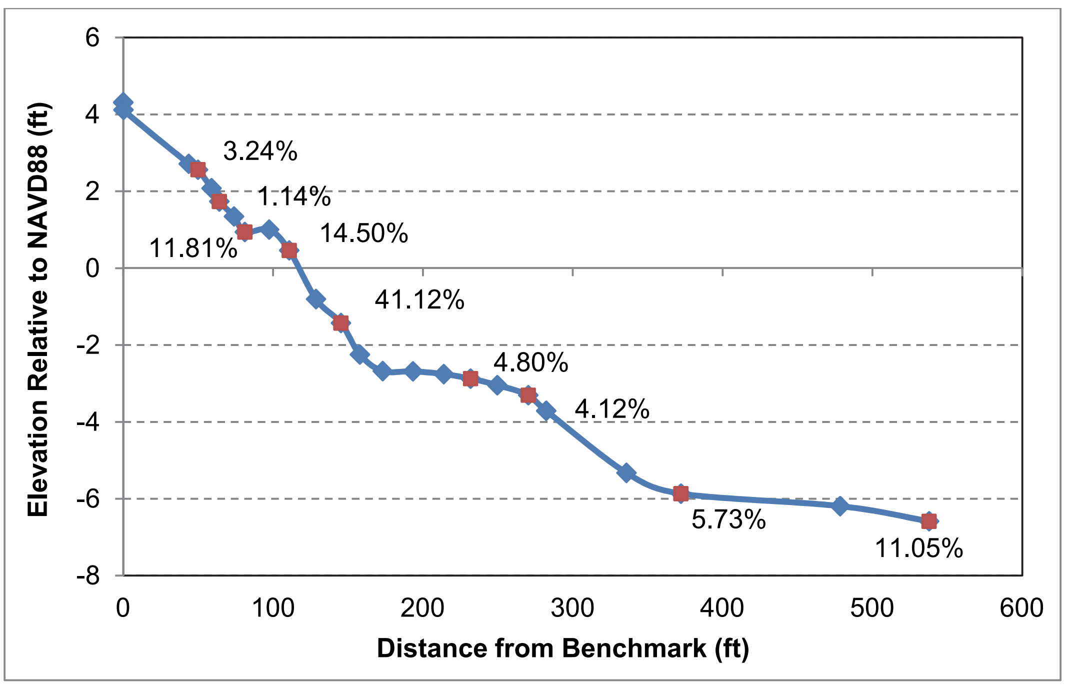


Figure F6. Sample Locations with carbonate percentages at FMB 9 (April 2010).

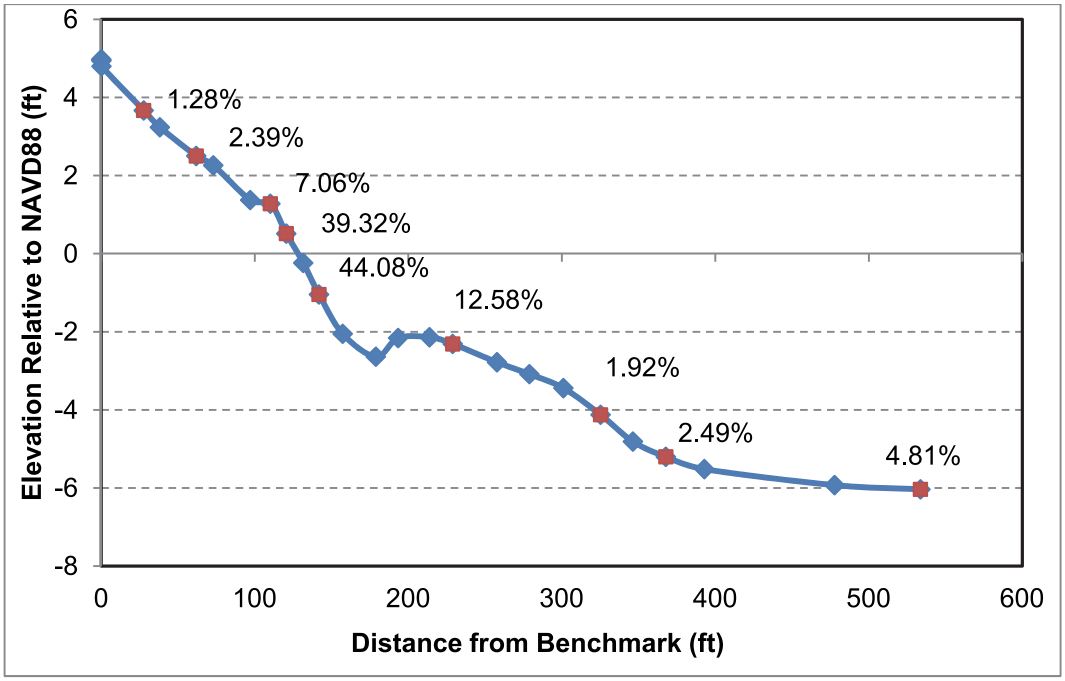


Figure F7. Sample Locations with carbonate percentages at FMB 9 (June 2011).

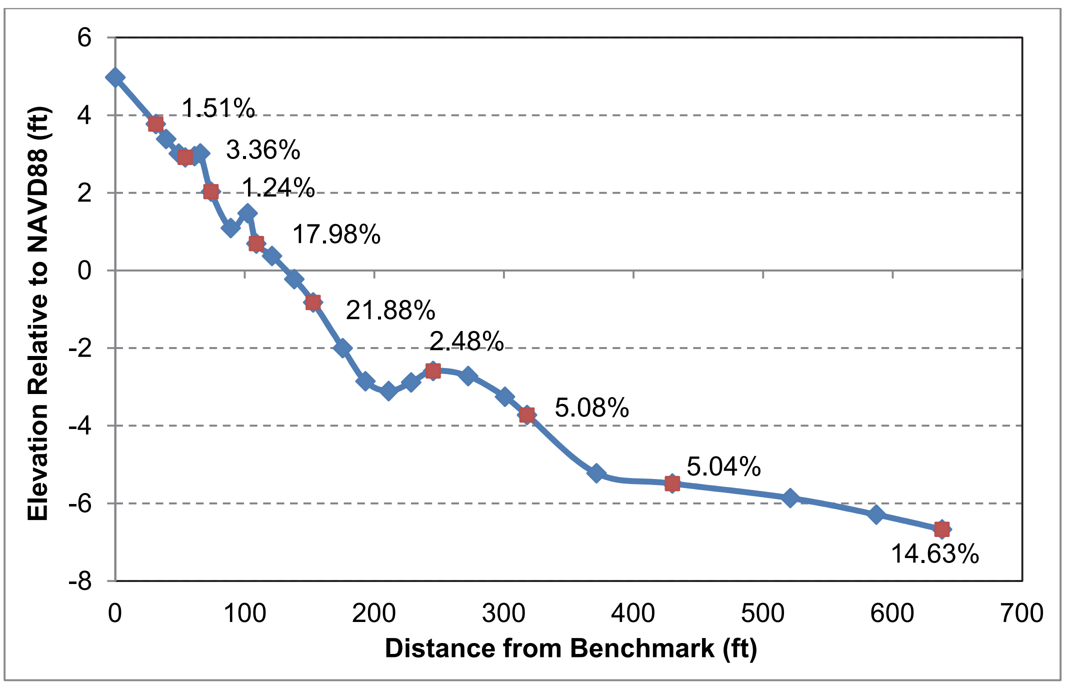


Figure F8. Sample Locations with carbonate percentages at FMB 13 (April 2010).

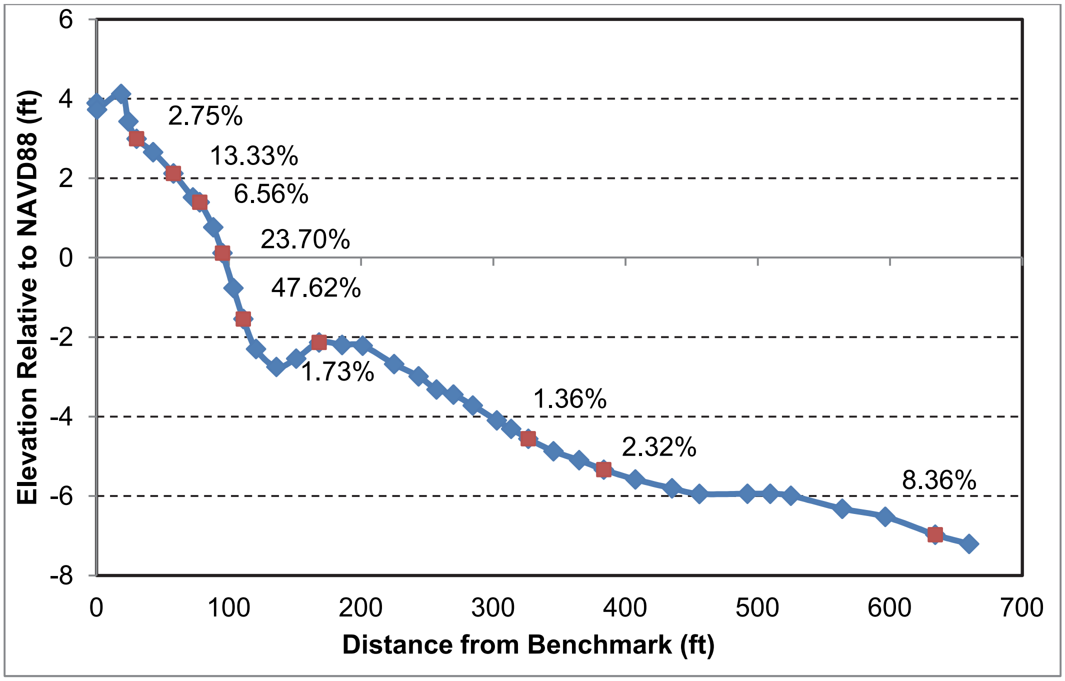


Figure F9. Sample Locations with carbonate percentages at FMB 13 (June 2011).

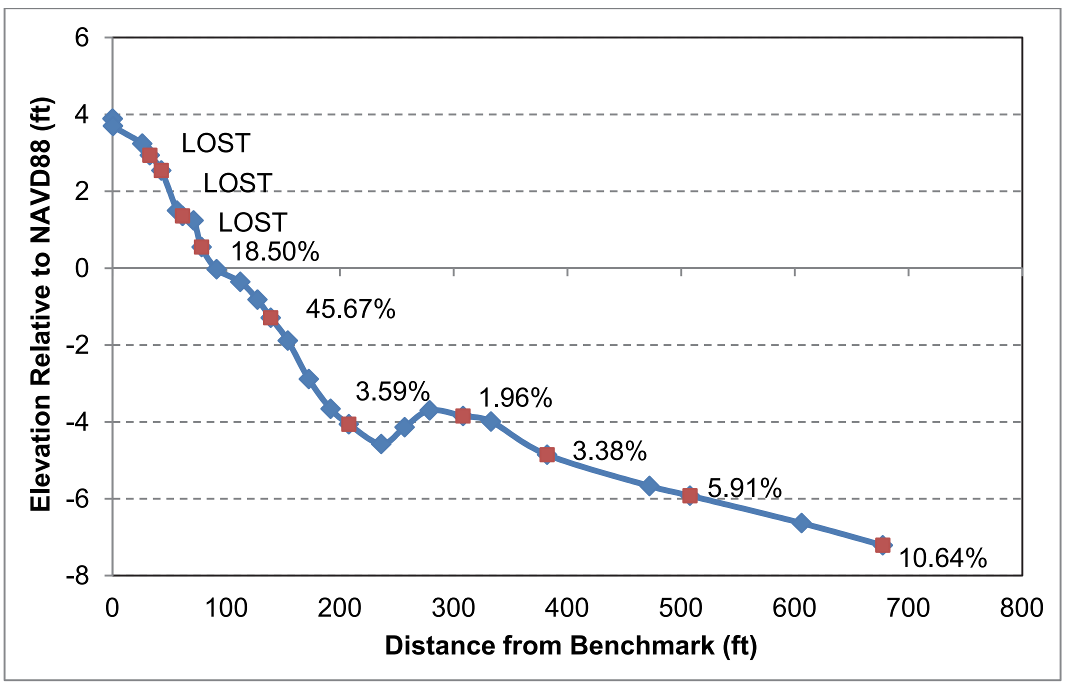


Figure F10. Sample Locations with carbonate percentages at FMB 17 (April 2010).

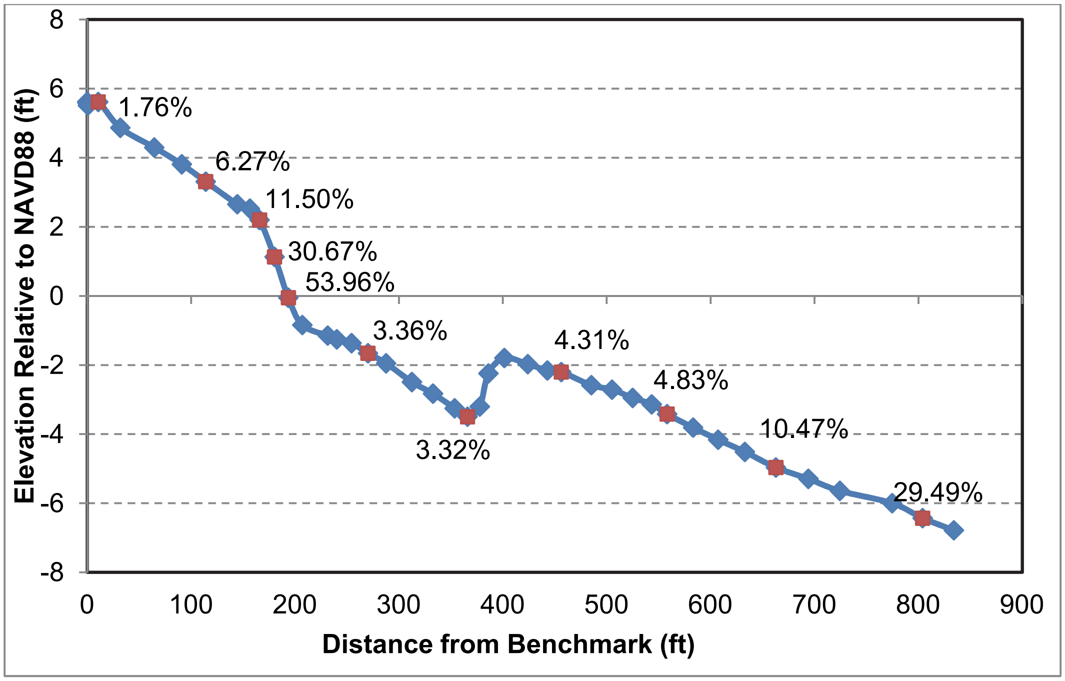


Figure F11. Sample Locations with carbonate percentages at FMB 17 (June 2011).

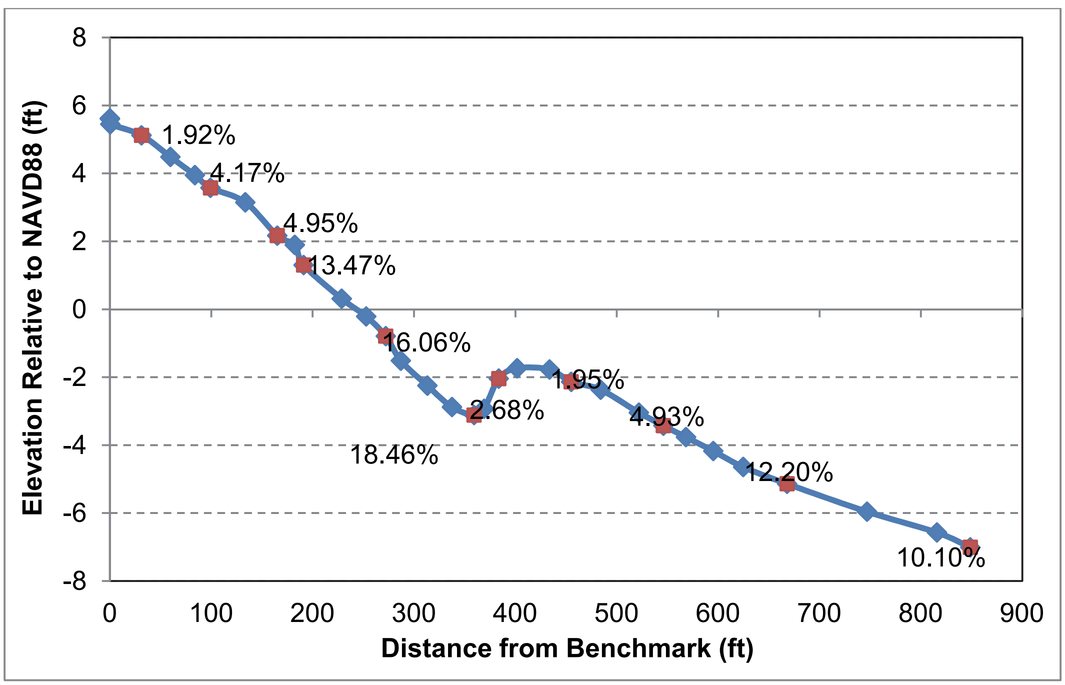


Figure F12. Sample Locations with carbonate percentages at FMB 22 (Aprile 2010).

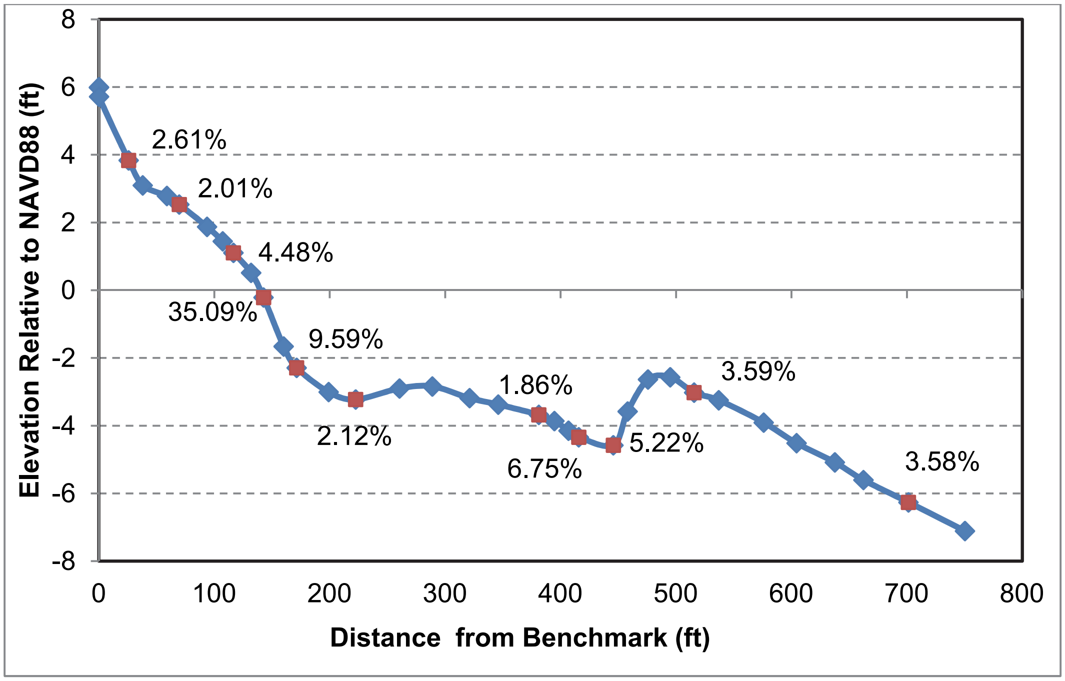


Figure F13. Sample Locations with carbonate percentages at FMB 22 (June 2011).

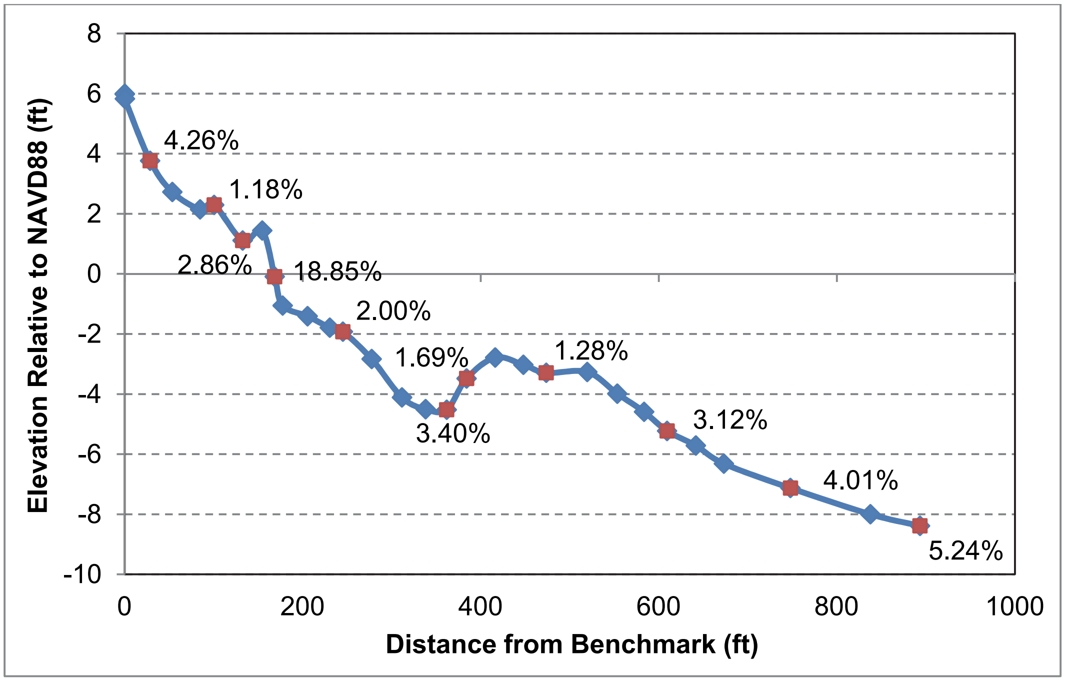


Figure F14. Sample Locations with carbonate percentages at FMB 28 (April 2010).

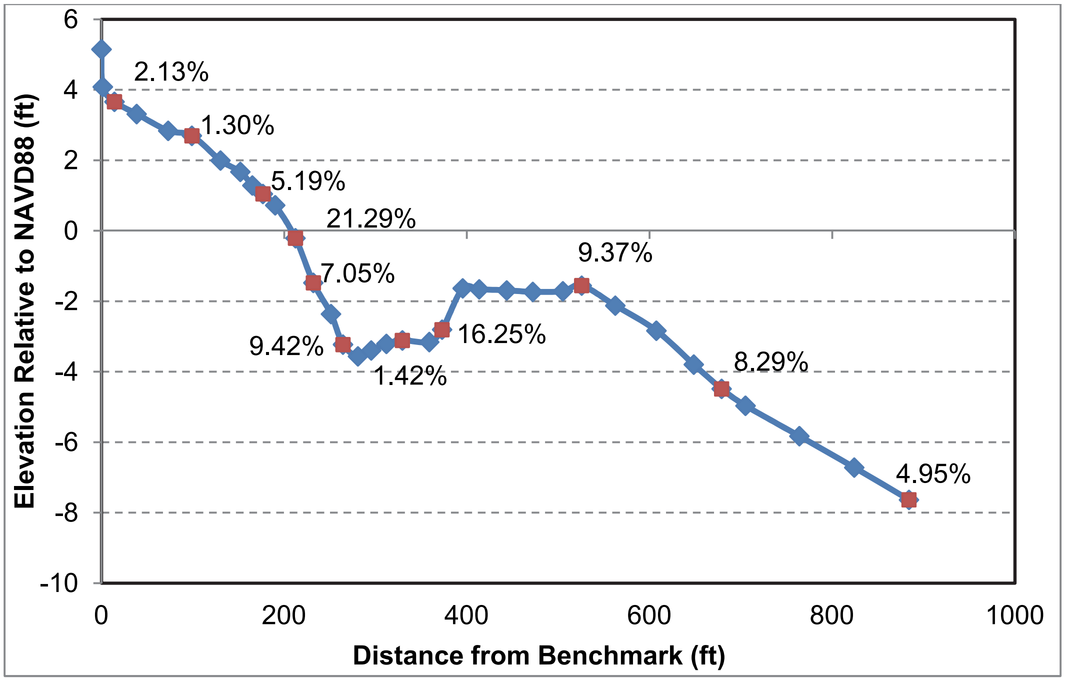


Figure F15. Sample Locations with carbonate percentages at FMB 28 (June 2011).

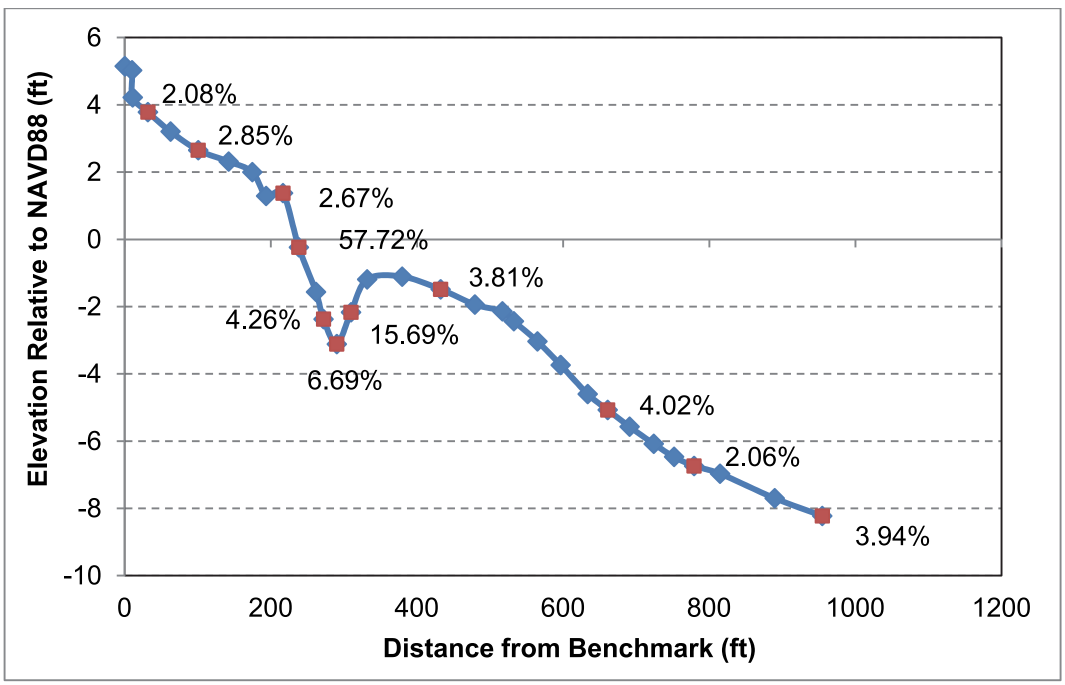


Figure F16. Sample Locations with carbonate percentages at FMB 35 (April 2010).

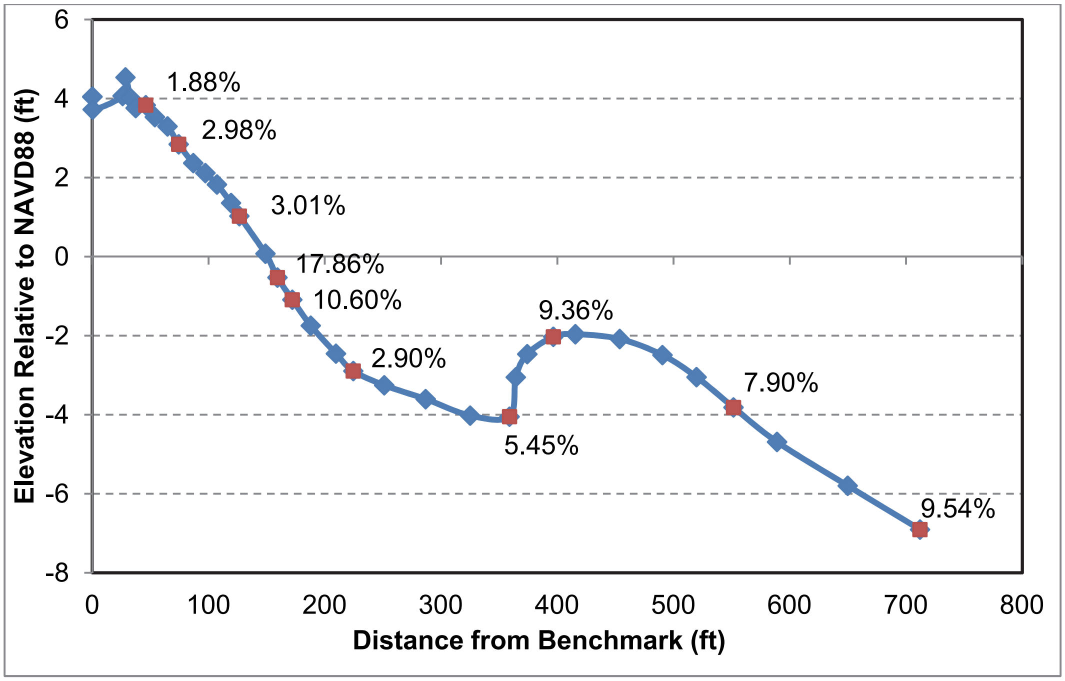


Figure F17. Sample Locations with carbonate percentages at FMB 35 (June 2011).

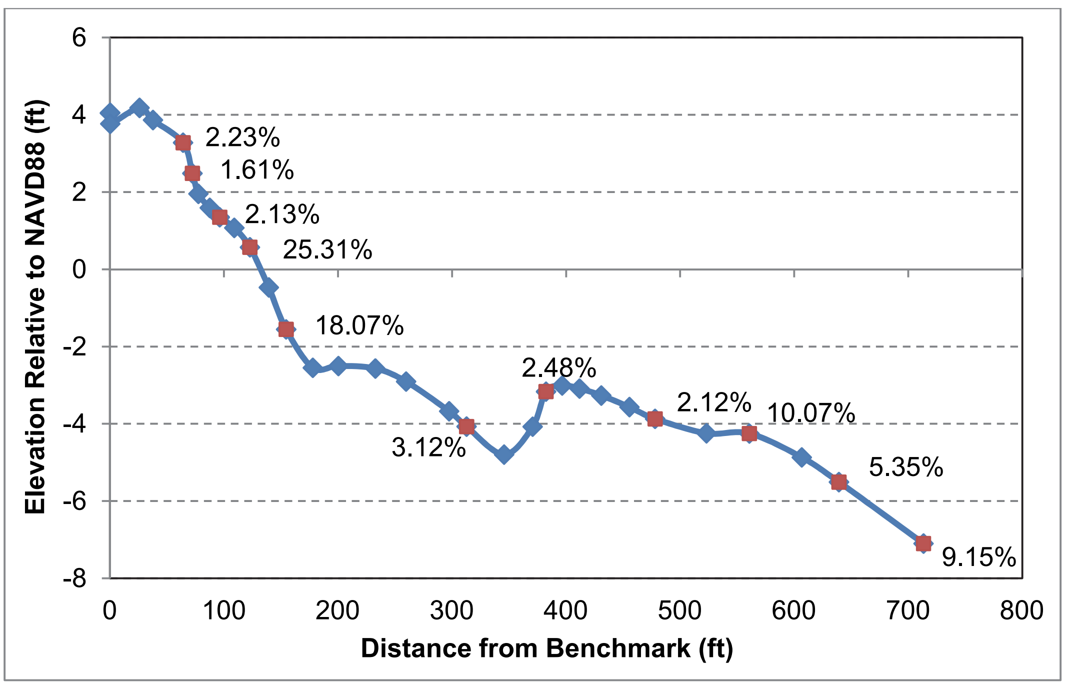


Figure F18. Sample Locations with carbonate percentages at FMB 46 (April 2010).

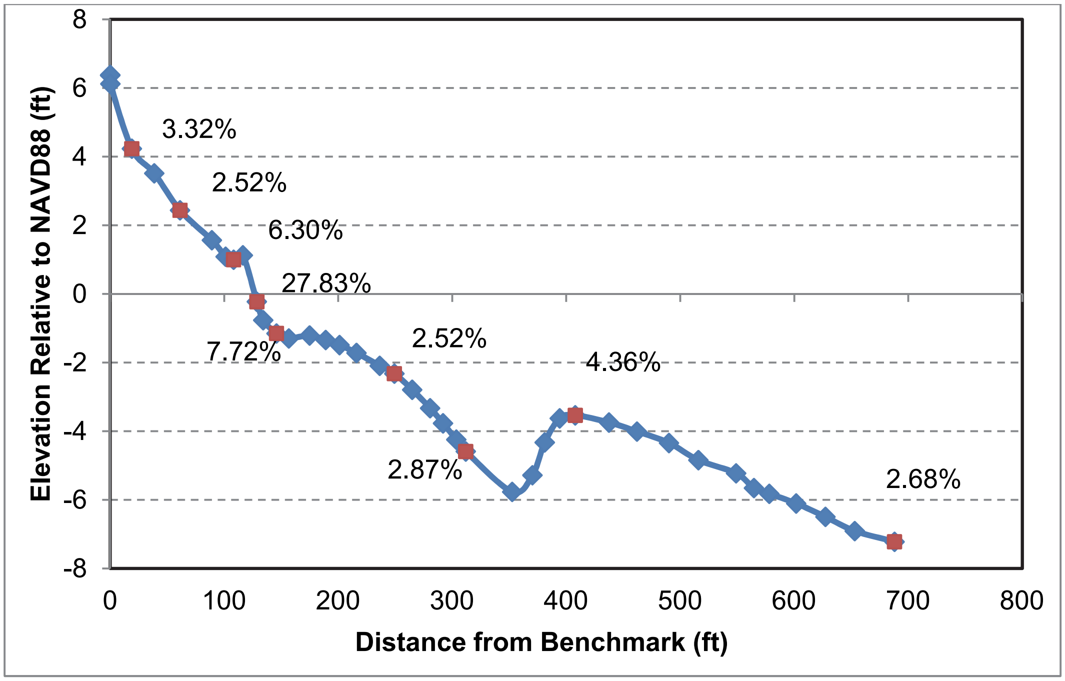


Figure F19. Sample Locations with carbonate percentages at FMB 46 (June 2011).

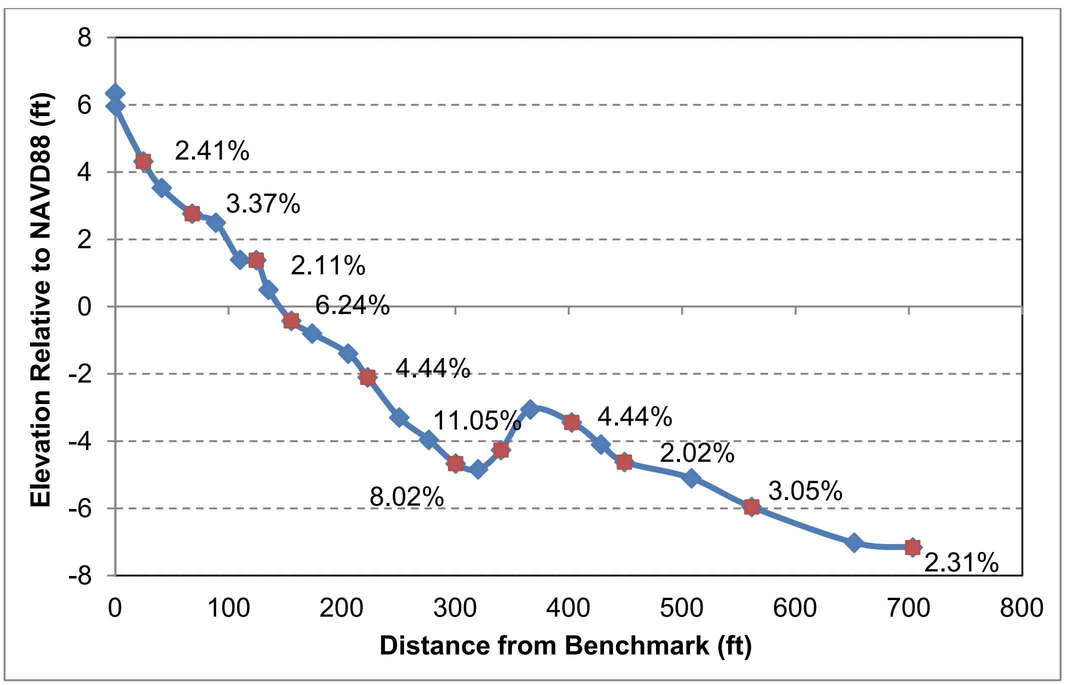


Figure F20. Sample Locations with carbonate percentages at FMB 53 (April 2010).

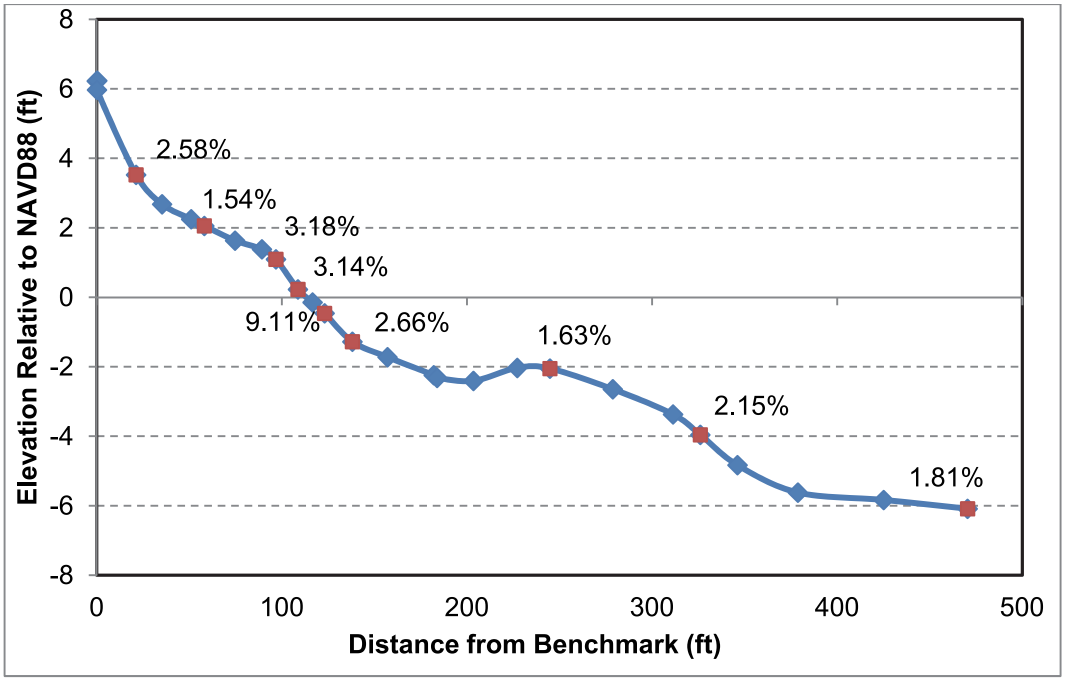


Figure F21. Sample Locations with carbonate percentages at FMB 53 (June 2011).

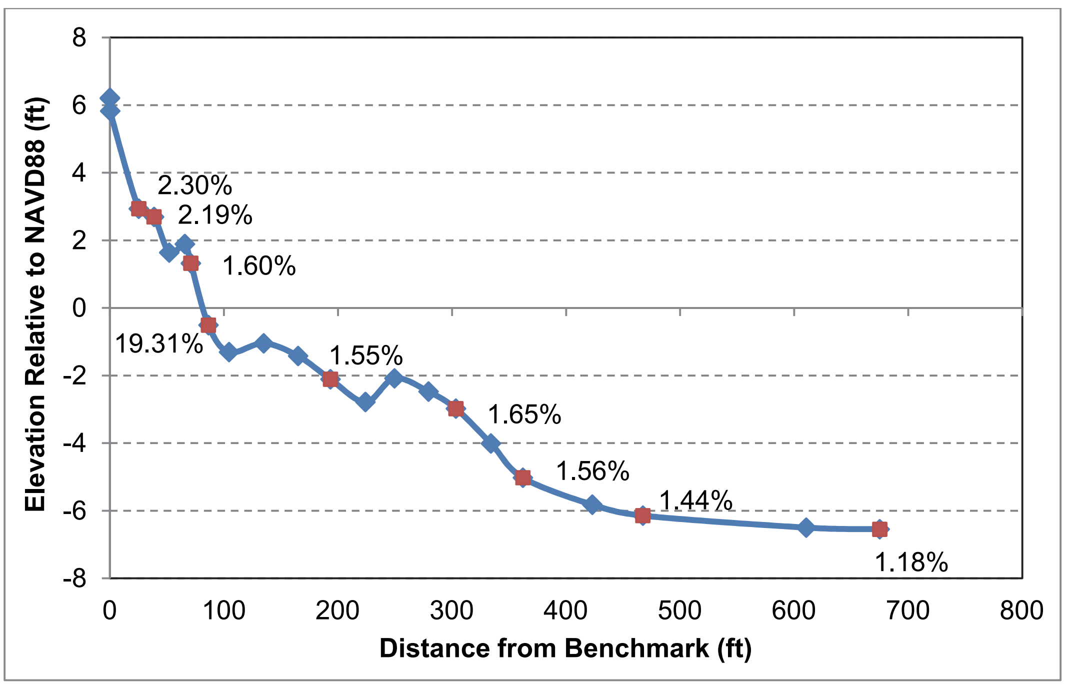


Figure F22. Sample Locations with carbonate percentages at FMB 56 (April 2010).

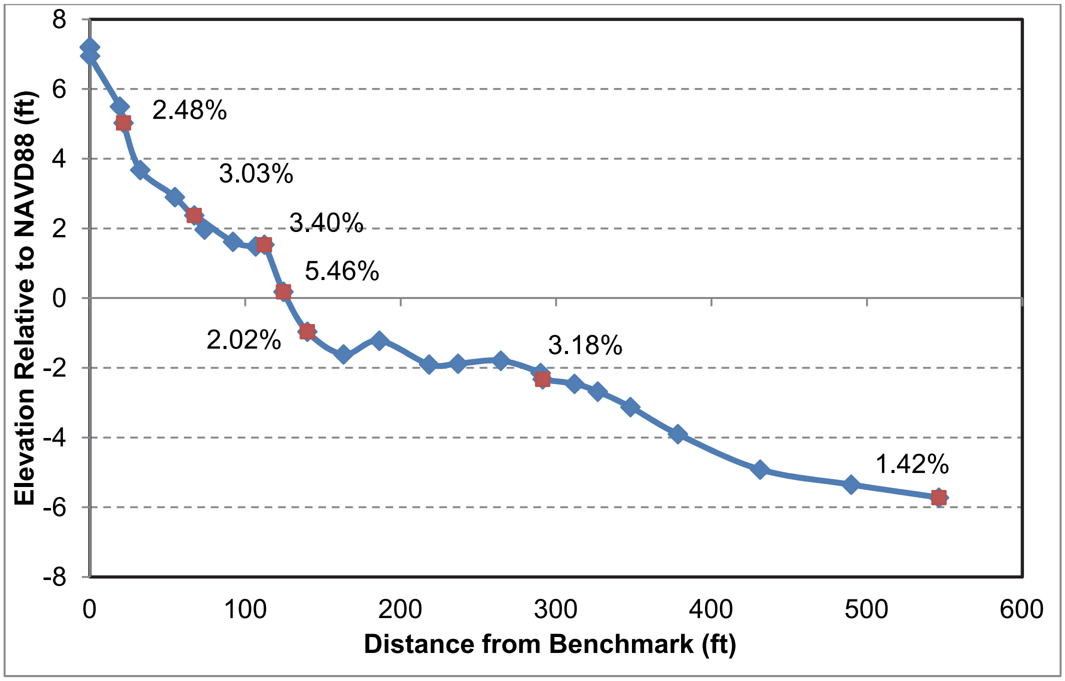
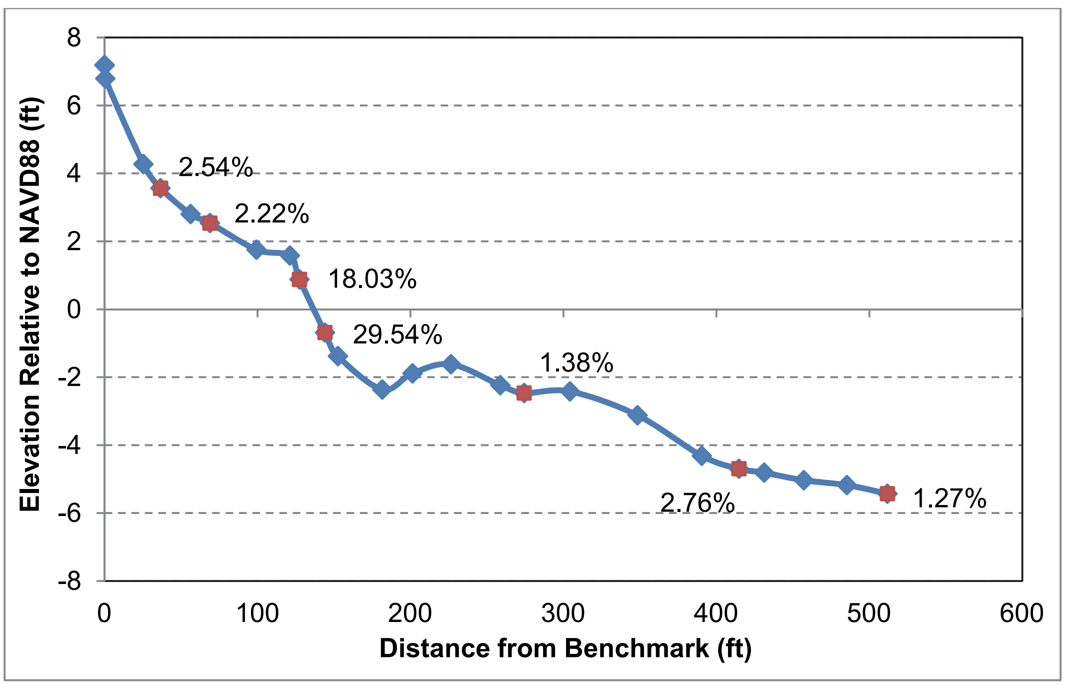


Figure F23. Sample Locations with carbonate percentages at FMB 56 (June 2011).



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14. ABSTRACT

This report documents the placement and monitoring of an active nearshore berm at Ft. Myers Beach, Florida. From May to July 2009, mixed sand and finer sediment dredged from a nearby inlet was were placed in the active littoral zone in the form of a bar-shaped nearshore berm. Six sets of beach-nearshore profile surveys and two periods of sediment sampling along profiles were collected. The Ft. Myers Beach nearshore berm migrated onshore roughly 300 ft during the first two years. The elevation of the berm crest increased up to 2.0 ft. Nearly half of the onshore migration occurred during the first nine months post-construction. Greater distances of onshore migration were measured during the more energetic winter seasons than during calmer summer seasons. No offshore migration was measured during the entire 2two-year study period. The shape of the nearshore berm evolved from a roughly symmetrical bell-shaped bar to a highly asymmetrical shape with a steep landward slope, typical of a landward migrating bar. At the end of the 2two-year period, the berm migrated to roughly 150 to 200 ft from mean sea level shoreline. The dry beach landward of the berm and along the adjacent beaches remained stable over the 2two-year period. A primary concern of this project was the dispersion of fine sediment fol-lowing placement. Results of sediment sampling indicated that some of the fine material initially migrated into the nearshore trough, and was then dispersed further offshore after several months. Onshore-directed transport and deposition of coarser sand fractions, and offshore-directed transport and deposition of fine fractions were observed. The nearshore berm had negligible influence on the characteristics of the dry beach sediment, which remained to be well- sorted, fine sand. The constructed berm showed considerable longshore variation in mor-phology, including several gaps/depressions. These gaps were maintained over the 2two-year period, although longshore and cross-shore migrations were measured. Future studies should include continued monitoring to document potential attachment of the nearshore berm to the dry beach.

15. SUBJECT TERMS
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