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Placement, Consolidation, and Erosion Studies at Open-Water Placement Site 92 2009 – 2010

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ABSTRACT

Dredged sediment placement at open-water placement Site 92 occurred between October 25, 2009 and March 21, 2010. Based on scow loads, the contractor estimated that the clamshell-bucket dredge excavated approximately 1.72 million cubic yards (mcy) of clayey-silt sediment from the Chesapeake & Delaware (C&D) Canal approach channel. The cut volume reported by the U.S. Army Corps of Engineers – Philadelphia Distract was reported as 1.39 mcy (1,394,228 cy). The sediment was placed via bottom-release scows into a designated drop zone covering much of Site 92. Water depths across much of the designated drop area ranged from –16 feet to –18 feet (ft.) mean lower low water (MLLW).

The volume of placed sediment identified by Maryland Geological Survey (MGS) at the completion of placement was 1.25 ± 0.16 mcy. This represented a volume deficit of 0.08 mcy, or 6.02% less than the amount identified dredged by the Corps of Engineers channel surveys and using a bulking factor of 0.96 based on sediment water content data. The total area covered by placed sediment was 2.43 million square yards (msy), or approximately 502 acres. The majority of the deposit was 1.0 ft. to 2.0 ft. thick with a maximum thickness between 3 ft. and 4 ft.

The placed sediments underwent elevation and volumetric changes during the following eleven months. The maximum thickness of the placed sediments decreased from nearly 4 ft. at completion to slightly over 3 ft. at eleven months. There was a 52.0 % volume reduction at eleven months following placement. It was estimated that approximately one-fifth of the volume change resulted from consolidation and four-fifths was due to erosion.

In total, Years 1 through 12 placements used 4.75 mcy of the site volume, or 68% of the original site volume of 7.0 mcy. Although open water placement in the Upper Chesapeake Bay has ceased to take place, approximately 1/3 of the original volume estimated to be available at Site 92 remains, assuming an idealized placement configuration with a final authorized depth of –14 ft. MLLW.

PROJECT DESCRIPTION

Routine dredging of the Chesapeake and Delaware (C&D) Canal approach channel in the northern Chesapeake Bay maintains access to the Port of Baltimore. Portions of the dredged sediments are placed overboard on the Bay bottom in designated placement sites known as the Pooles Island Disposal Sites. The designated sites are south and east of Pooles Island, just to the west of the lower reach of the C&D Canal approach channel (Figure 1). Site 92 is presently utilized for placement. The Site 92 Site Management Team (SMT) consisting of representatives from the U.S. Army Corps of Engineers, Philadelphia District (CENAP), Maryland Port Administration (MPA), Maryland Department of the Environment (MDE), Maryland Environmental Service (MES), DMP Services, LLC (DMP), and Maryland Geological Survey (MGS), manages the placement sites.

Site Description

Site 92 is approximately 934 acres (ac) in size (Maryland Environmental Service, 1997). The site initially straddled a trough, oriented in a northeast to southwest direction, between Buoy R "6" to the south and Buoy G "7" to the north. This trough, known as the West Sailing Course, is used principally by tugs running without barges and tugs with empty or light-loaded barges. In the northeast direction, the trough opens to variable bottom topography referred to as the high-relief area. Water depths in the high-relief area range from –10 feet to –40 feet (ft.) mean lower low water (MLLW) over very short distances. The southern end of the high-relief area is east of Site 92. The West Sailing Course trough extends to the southwest into shallower water. The western half of former disposal Area G-South is within Site 92.

Placement History

Prior to its initial use in the winter of 1998-1999, Site 92 had an estimated capacity of 7 million cubic yards (mcy). This estimate is the site volume (space) and assumes an idealized placement configuration when brought to the authorized depth of –14 ft. MLLW. Prior to the 2009-2010 placement operations, ten years of dredged sediment placement have occurred in different designated areas of Site 92 utilizing 4.15 mcy of the site volume.

During the first year of placement, 1998-1999 (Year 1), creation of a sediment berm along the northeastern corner of the site (within the West Sailing Course) minimized the potential for the spread of sediment deposited in subsequent placement operations (Panageotou, 2001). Berm placement utilized 0.70 mcy of the initial capacity. Placements during Years 2 through 9 were designated for filling in the southern three-quarters of Site 92 (Panageotou, 2002, 2003, 2004a, 2004b, 2005, 2006, Offerman and Panageotou, 2007, 2008). The objective was to maximize capacity of the site proceeding from the southern end northward.

The second year of placement, 1999-2000 (Year 2), utilized 0.49 mcy of capacity. This placement filled in the southern end of the site and created an enclosed basin within Site 92. The third year of placement, 2000-2001 (Year 3), utilized 1.23 mcy of capacity. The fourth year of placement, 2001-2002 (Year 4), utilized 0.11 mcy of capacity. The

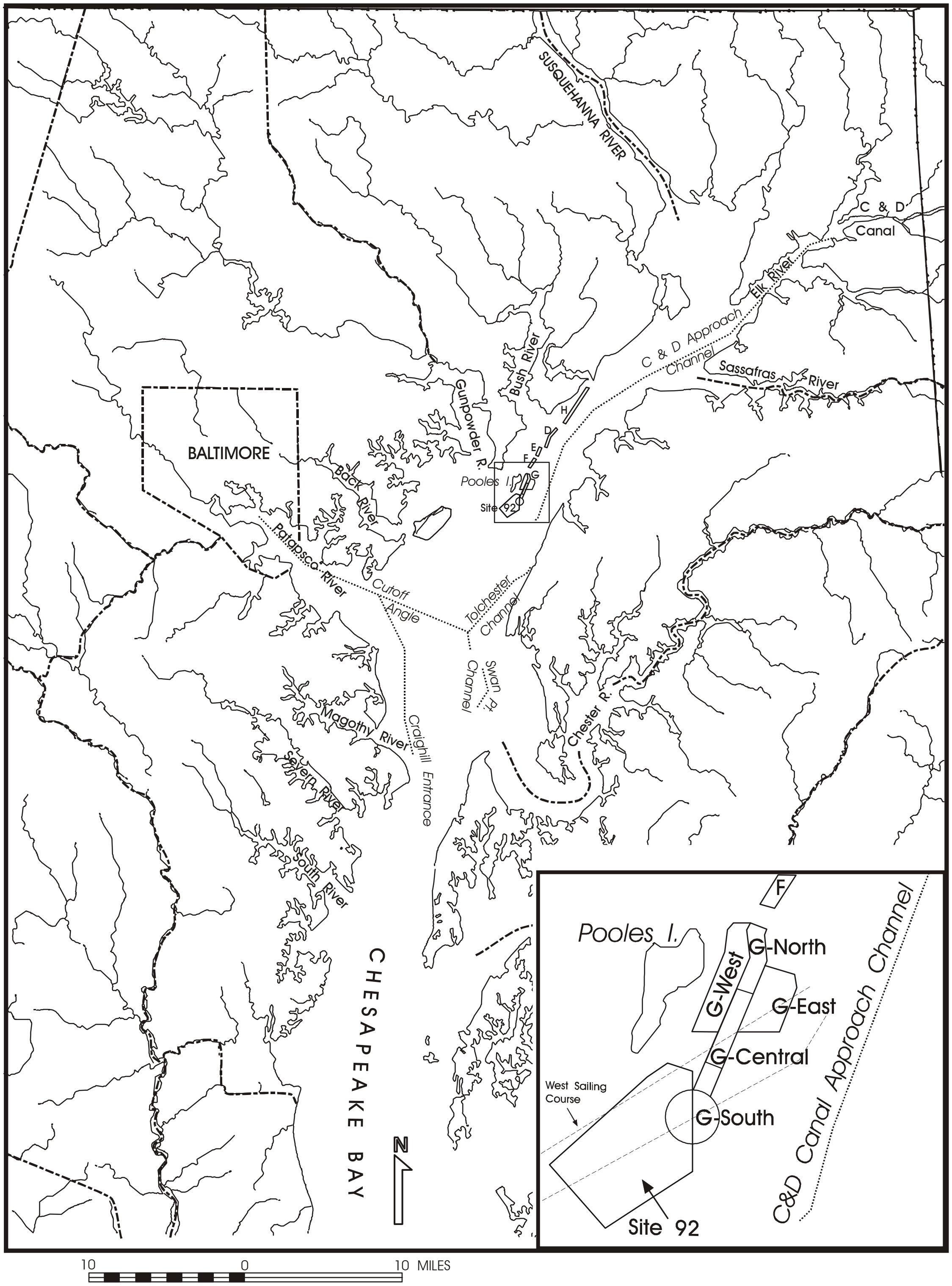

Figure 1. Location of overboard disposal areas in the northern Chesapeake Bay. Site 92 was utilized for sediment placement in 2009-2010. Light dotted lines indicate centerlines of dredged shipping channels.

fifth year of placement, 2002-2003 (Year 5), utilized 0.10 mcy of capacity. However, ten months after completion of placement in Year 5, Hurricane Isabel caused an estimated 0.17 mcy of erosion from the placement site. The erosion resulted in a net capacity gain of 0.07 mcy. The sixth year of placement, 2003-2004 (Year 6), utilized 0.49 mcy of capacity in the center section. Placement during 2004-2005 (Year 7) also took place in the center section of Site 92 and utilized 0.70 mcy of capacity. The eighth year of placement, 2005-2006 (Year 8), utilized 0.33 mcy of capacity in the northern, central portion of Site 92. Placement during 2006-2007 (Year 9) also utilized 0.33 mcy of capacity in the northern portion of Site 92. Placement during 2007-2008 (Year 10) utilized 0.24 mcy of capacity primarily in the southern portion of the site. No maintenance dredging or placement occurred during 2008-2009 (Year 11).

Placement Operations

The eleventh year of placement, 2009-2010 (Year 12), occurred between October 25, 2009 and March 31, 2010. For Year 12 operations, the SMT delineated a drop zones across much of the designated site to accommodate the volume of sediment projected to be dredged. The drop zone perimeter was setback 500 ft. from the site boundary to minimize the potential for the spread of sediment outside the designated site.

Maintenance dredging took place during the winter of 2009-2010 under a CENAP contract with Great Lakes Dredge and Dock Company (GLDD). A clamshell-bucket dredge removed sediments from the channel, and bottom-release scows towed by tugs transported and placed them within the designated drop zone. By the completion of sediment placement, the bottom was not to be shallower than the authorized depth of -14 ft. ±0.5 ft. MLLW.

GLDD submitted a placement operation plan that divided the designated drop zone into cells measuring 200 ft. by 500 ft. The Year 12 Site Management Report (SMR) details the placement operation plan, scow drop locations, and placement-monitoring plan (Maryland Environmental Service, 2010).

GLDD provided an estimate of the quantity of sediment dredged from the channel and placed within Site 92 determined from the quantity of sediment per scow load. The total volume reported was 1.72 mcy transported in 679 scow loads for an average of 2,526 cubic yards per load.

Objectives

As specified in the SMR, placement, consolidation, and erosion studies (PCE) are conducted by MGS on the placed dredged sediments. MPA and CENAP funded the studies, and MES administered the contract. This document reports on the PCE studies. The specific objectives were to:

(1) evaluate pre-placement conditions at the designated placement site;
(2) determine the placement location, thickness, and spatial extent of the deposited dredged sediment and changes in these characteristics through time;

(3) sample the dredged sediments to determine their physical and bulk properties at the placement site;
(4) evaluate foundation settlement underlying the placed sediments during the placement and post-placement periods;
(5) evaluate the quantity of dredged sediment present at the placement site soon after the completion of dredging and placement operations;
(6) evaluate consolidation and erosion of the placed sediments; and
(7) update capacity usage.

METHODS

Chronology of Activities

On-site monitoring activities were conducted aboard the Maryland Department of Natural Resources' Research Vessel *Kerhin*. Table 1 lists the chronology of placement and study activities. The proposed schedule called for 1) bathymetric surveys and 2) bottom sediment coring. Bathymetric surveys were scheduled prior to placement, at the completion of placement, and at one month, three months, six months, and ten months after placement. Bottom sediment coring was scheduled prior to placement, at completion of placement, and ten months after placement. Note from Table 1 that not all the cruises occurred at the scheduled times due to weather conditions or prior vessel commitments. Due to similar reasons, not all coring cruises took place at the preferred dates in close proximity to the bathymetric cruise.

Table 1. Chronology of placement and MGS study activities in Site 92, Year 12.

August 25-26, 2009	Bathymetric survey prior to sediment placement
October 22, 2009	Bottom sediment coring prior to sediment placement
October 25, 2009	Scow placement commences
March 31, 2010	Scow placement completed
April 2, 2010	Bathymetric survey at completion
April 20, 2010	Bottom sediment coring for completion survey
May 5, 2010	Bathymetric survey at one month
July 15, 2010	Bathymetric survey at three months
October 28, 2010	Bathymetric survey at six months
February 23, 2011	Bathymetric survey at eleven months
March 22, 2011	Bottom sediment coring for eleven-month survey

Bathymetric Data Collection

Bathymetric data was collected on tracklines spaced approximately 150 ft. apart across the designated drop zone and immediately adjacent areas. A bathymetric survey was completed prior to placement operations to establish a baseline record of bottom depths. A second survey was completed as soon as possible after placement to establish the initial spatial extent, thickness, and volume of the placed dredged sediment. Subsequent surveys evaluated the bathymetric and volumetric changes of the placed sediments through time.

Raw bathymetric data were collected using Leica 412B survey-grade Differential Global Positioning System (DGPS) and a Furuno FCV-1100L echosounder. DGPS differential corrections broadcast by the United States Coast Guard (USCG) provide a horizontal accuracy of 6.6 ft. to 16.4 ft. Horizontal position was recorded in Maryland State Plane Coordinate System (MSPCS) meters and converted to feet based upon the North American Datum of 1983 (NAD 83).

The Furuno echosounder was calibrated using known vertical measurements before and after each survey. The echosounder generates repetitive acoustic pulses, ten soundings per second, at 200 kilohertz (kHz) for bottom recognition. The acoustic wave reflects off the density gradient differentiating the water column from the bottom sediment. The reflections are then filtered and integrated within the echo-sounder to produce an accurate digital measurement from the transducer to the water/sediment interface every two seconds. A correction for the draft of the vessel was applied by the data logging software, as determined by the “bar check” before the beginning of the survey. At the survey speed of the vessel, a data point was collected approximately every 20 ft. along the survey tracklines. Bathymetry and positioning data were logged to a personal computer at a rate of one point every two seconds.

All depth data presented in this study were referenced to MLLW at the Tolchester Beach location for the 1983-2001 National Tidal Datum Epoch (NTDE). The National Oceanic and Atmospheric Administration/ National Ocean Service (NOAA/NOS) maintains this station. Raw depth data were tidally adjusted by subtracting the Tolchester Beach tide level, recorded at six-minute intervals, from the raw depth data collected on the R/V *Kerhin*. Incorporated into the tidal adjustments was a +20 minute offset from Tolchester Beach to Site 92. The practical resolution of the tidally corrected bathymetric data is ± 2 inches (in.) (Ortt, 1999).

To reduce the error inherent in bathymetric surveys from instrument limitations and from surface modeling interpolation, a controlled reference area was surveyed before and after each survey of the placement area. A secondary adjustment to the tidally corrected data was applied based on the average height measured at the controlled reference area for all of the surveys performed within the study year. Theoretically, this aligns the surfaces to a common plane that might otherwise be offset from the errors inherent in bathymetric surveys. This allows for a higher degree of accuracy when comparing surfaces. Quality Assurance/Quality Control (QA/QC) analyses indicated that the practical resolution of the post-processed bathymetric data after secondary correction application is ± 1 in.

Bathymetric Interpretation and Volumetric Calculations

Interpretation of post-processed bathymetric data utilized Surfer, a commercially available contouring software package (product of Golden Software, Golden, CO). The Triangulation with Linear Interpolation (TIN) method was used to process the adjusted depth data. This method is based on the work of Lawson (1977), Lee and Schachter (1980), and Guibas and Stolfi (1985). Data was gridded to a 100 ft. regularly spaced grid in order to facilitate the calculation of volumes and thicknesses of placed dredged sediments. Isopach maps were created using the gridded surfaces and were used to show bottom changes. The vertical resolution of the isopach maps was estimated to be 0.3 ft. This resolution produces a range of uncertainty in the volume calculations that is a function of the area covered by placed sediments. Gravity cores within and outside the placement area provided ground-truthing of the isopach maps.

Bottom Sediment Sampling

Figure 2 shows the bottom sediment sampling sites. Sampling sites inside Site 92 are labeled 92-13, 92-13A, 92-15, 92-16, 92-30A, 92-31, 92-33, 92-35, 92-36, 92-39, 92-42, 92-43, 92-44, 92-45, 92-46, 92-47, and 92-48. Sampling sites outside Site 92 are labeled 92-G and 92-H.

Bottom sediments were collected in 2.6 in. diameter cellulose acetate butyrate (CAB) core liners inserted into a Benthos open-barrel gravity corer, model 2171, or a Benthos piston corer, model 2450. The recovered cores were trimmed at the sediment-water interface, capped, and returned to the laboratory for bulk property and grain size analyses.

Sediment cores were first X-rayed in their liners using a TORR-MED medical X-ray unit. Prints of the X-ray images were developed using a Xerox 125 xeroradiograph processor. X-rays of cores facilitate recognition of small-scale internal structures, such as clam and worm burrows or tubes, shells, and gas voids. These characteristics were used to evaluate benthic activity and identify the pre-placement bottom. On a negative xeroradiographic print, less dense material, such as burrows or gas voids, appear darker as compared to denser material, such as shells or sand, which appear lighter.

After the cores were X-rayed, the sediment was extruded from the core liner, split along the axis, photographed, and described. The core was carefully examined to identify the pre- and post-placement sedimentary units. Each sedimentary unit was subsequently sub-sampled in equal volumes at 4 in. intervals along the entire core length, homogenized into a single representative sample, and analyzed for water content and grain size. Analyses were conducted according to MGS standard techniques as outlined in Kerhin and others (1988) which have been used in all previous studies of open-water dredged sediment placement in the Northern Chesapeake Bay. Samples used for water content analysis were divided into 0.5 ounce (oz.) to 0.7 oz. portions, dried at 149ºF and then weighed. Water content was calculated as the percentage of water weight to the total weight of wet sediment:

$$\% H_2O = (\frac{W_w}{W_t}) \times 100 \qquad (1)$$

where W_w is the weight of water, and W_t is the weight of wet sediment. The water content, as sub-sampled from the homogenized intervals, was assumed to represent the mean water content present in each pre- and post-placement sedimentary unit.

Loss of water from the sediment in the interval between collection and extrusion of the core may cause an underestimation of the water content. Recently placed

Site 92
2009-2010 (Year 12)
Placement Site & Study Area

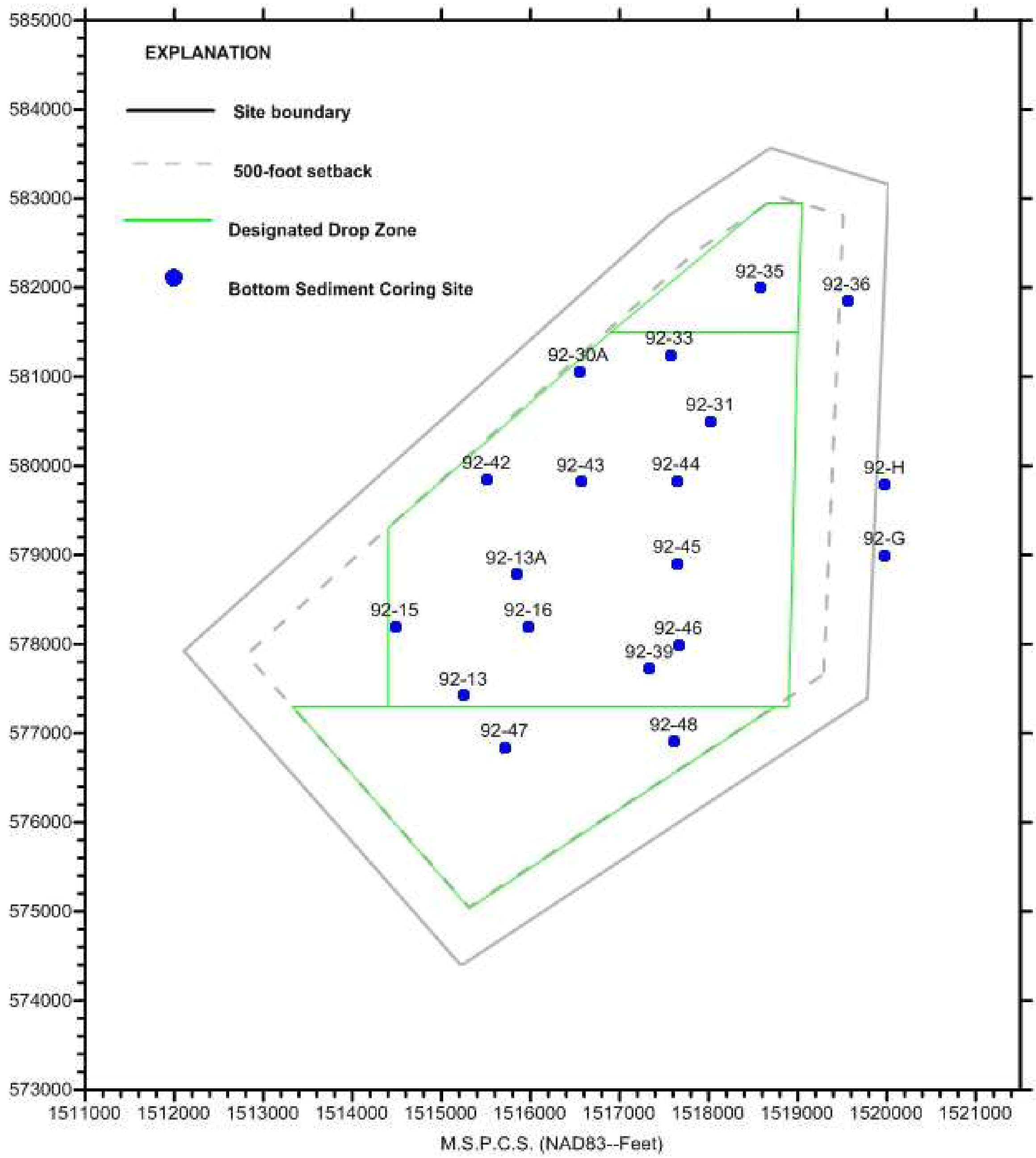

Figure 2: Site 92 showing the site boundary, setback for placement, the designated drop zones for Year 12, and the bottom sediment core sites.

sediments, contained within the core liner, exhibit a measurable amount of dewatering between the time of collection and analysis resulting in compaction. Measuring the change in core length prior to extrusion allows the calculation of the amount of water expressed from the sediment subsequent to collection. Water contents calculated in the laboratory were corrected by assuming that this compaction occurred evenly throughout the thickness of the most recently placed sediment layer. The percent water contents reported for the samples represent corrected values.

During collection of fine-grained sediments via open-barrel gravity coring, a significant but generally variable and indeterminable amount of compression (core shortening) also occurs in the sediment due to frictional forces against the inner wall core liner. The shortening of the collected sediment results from a physical thinning caused by lateral extrusion in front of the core (Weaver and Schultheiss, 1983; Blomqvist, 1985). Lateral thinning of sediment ahead of the retained sediments in the corer does not alter the water content (Halka and Panageotou, 1993).

The precision of water content measurements was determined by calculating the relative standard deviation from replicate measurements made on fine-grained sediments collected at disposal Areas D and F in 1991 (Figure 1). For sediment samples collected and analyzed in this manner, the relative standard deviation for percent water content was 4.46% (Halka and Panageotou, 1993). The standard deviation (σ) for any particular water content is:

$$\sigma H_2O = \frac{\% H_2O}{100} \times 4.46 \qquad (2)$$

This function yields a plus or minus value (±) indicating the general variability in water content for each sediment sample.

Bulk density (ρ_b), porosity (P), and void ratio (e) were calculated from water content utilizing equations (3), (4), and (5) by assuming an average grain density (ρ_s) of 2.65 g/cm^3 and saturation of voids with water density (ρ_w) of 1.0 g/cm^3. This method is an adaptation of the work of Bennett and Lambert (1971):

$$\rho_b = \frac{W_t}{W_d \ / 2.65 + W_w} \qquad (3)$$

where W_d is the weight of dry sediment.

$$P = \rho_s \frac{\% H_2O}{\rho_s \ \% H_2O + \rho_w (100 - \% H_2O)} \qquad (4)$$

$$e = \frac{V_v}{V_s} \qquad (5)$$

where V_v is the volume of voids and V_s is the volume of solids.

The discussion concerning bulk properties focuses on the results of the mean water content analyses. The other properties (bulk density, porosity, and void ratio) – calculated from the water content – are included in Tables 6-10 in the Appendix.

A statistically verifiable change in mean water content over time can be used to definitively quantify volumetric change through time. A t-test compares two water contents at a certain confidence level to determine if the values are statistically different (Davis, 1973; Ott and others, 1978). If the water content values are statistically different, then the percent volume change over a specified time interval can be calculated at the specified confidence level.

The percentage of volumetric change (V_{Δ}) attributable to either bulking (water-loading during dredging and placement) or *in situ* consolidation (dewatering of foundation sediments and post-placement sediments) was determined from the change in porosity over time. Percent volume change can be calculated utilizing equation (6):

$$V_{\Delta} = \frac{1 - P_i}{1 - P_f} \times 100 \qquad (6)$$

where P_i is the initial porosity at time one and P_f is the final porosity at time two. The estimated amount of erosion in placed sediments begins by calculating the total sediment volume change from the bathymetric analyses and then subtracting the volume change due to *in situ* consolidation.

RESULTS

Bathymetric Surveys

Figures 3, 4, 6, 8, 10, and 12 depict the pre- and post-placement bathymetry. The bold, red contour line marks the water depth of –-14 ft. MLLW to facilitate identification of the authorized depth limit. . Figures 5, 7, 9, 11, and 13 depict the bathymetric changes between the pre- and post-placement surveys as isopach maps created from the bathymetric data. The 0.3 ft. contour delineates the minimum change discernable from the bathymetric data.

<u>Pre-placement survey: August 25-26, 2009 (Figure 3)</u>

Water depths over the majority of the site and the designated drop zones were in the -16 ft. to -18 ft. range. Water depths increased slightly to -18 ft. to -20 ft. along the northeastern boundary of the drop zone. The majority of the site was relatively level resulting from numerous previous years of placement operations. Cores were collected at the identified locations three days prior to the initiation of placement.

<u>Completion survey: April 2, 2010 (Figures 4 and 5)</u>

After completion of placement, water depths over the majority of the site were -14 ft. to -16 ft. with depths increasing slightly along the northern portion of the site into the -16 ft. to -18 ft. range. A few small areas in the south-central portion of the site located

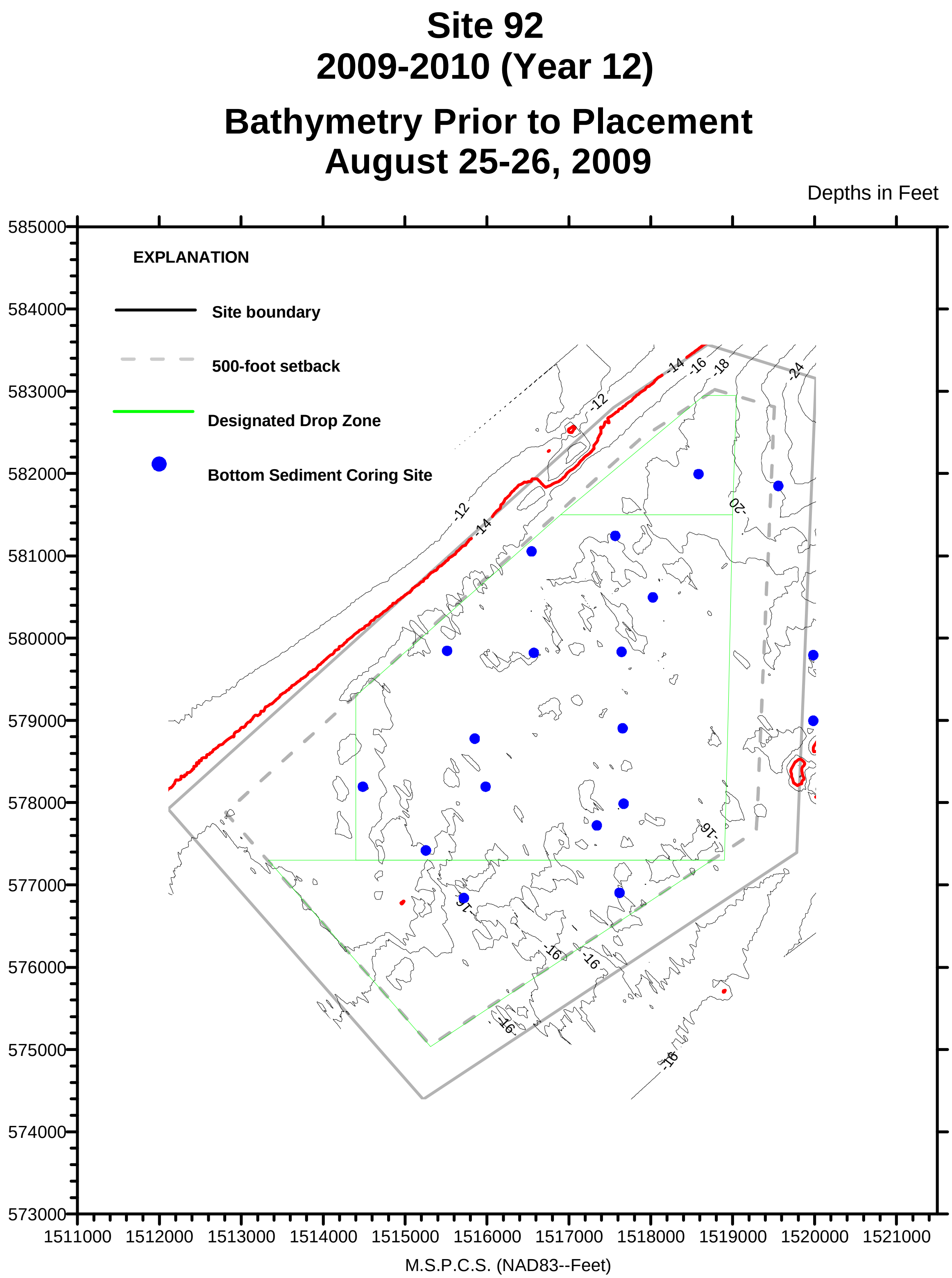

Figure 3: Bathymetry in August 2009 prior to placement, with -14 foot MLLW contour highlighted in red.

Site 92
2009-2010 (Year 12)

Bathymetry at the Completion of Placement
April 2, 2010

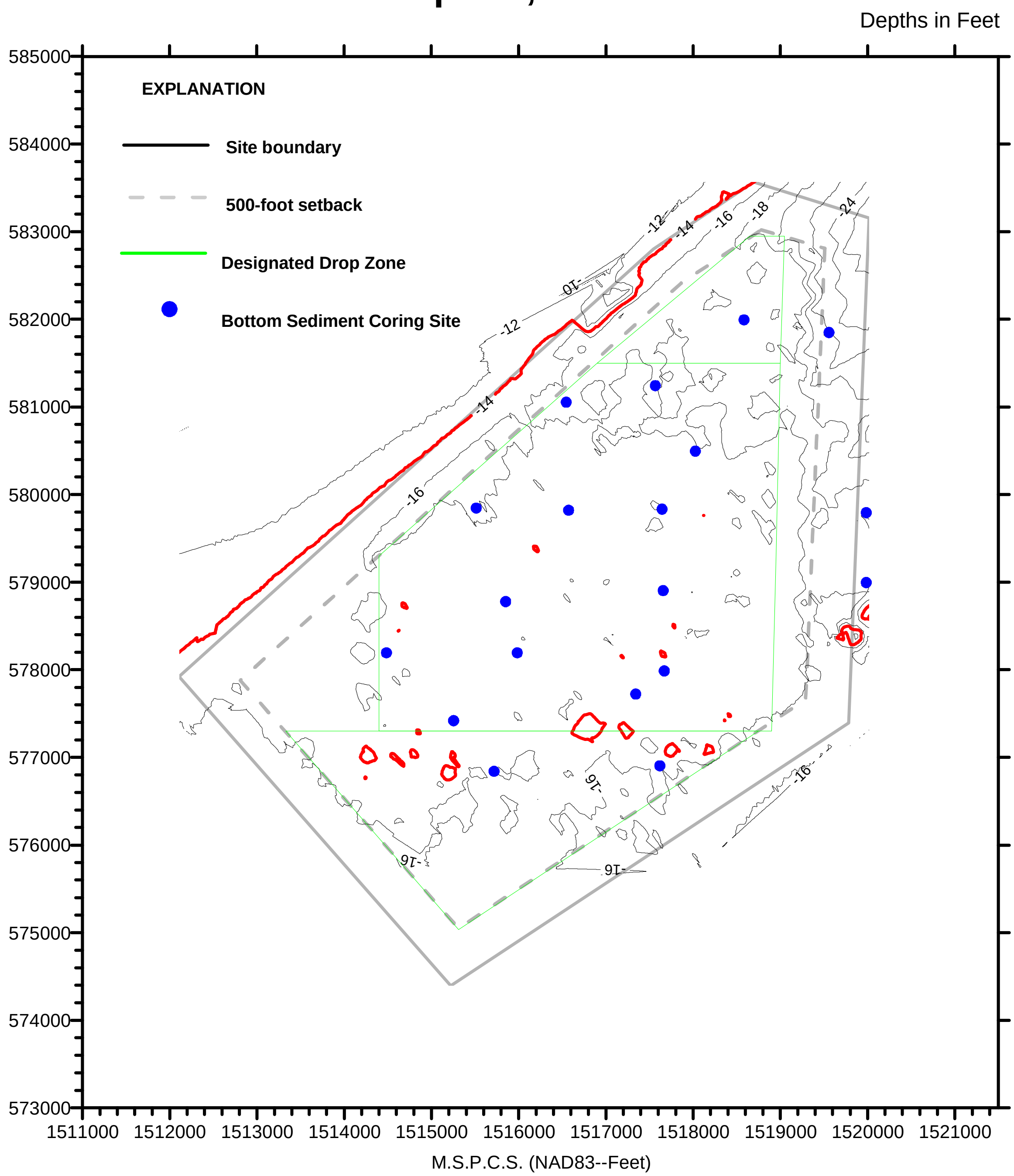

Figure 4: Bathymetry on April 2, 2010 - two days following completion of placement. The -14 foot MLLW contour is highlighted in red.

Site 92
2009-2010 (Year 12)

Change in Elevation
Pre-Placement vs.Completion of Placement

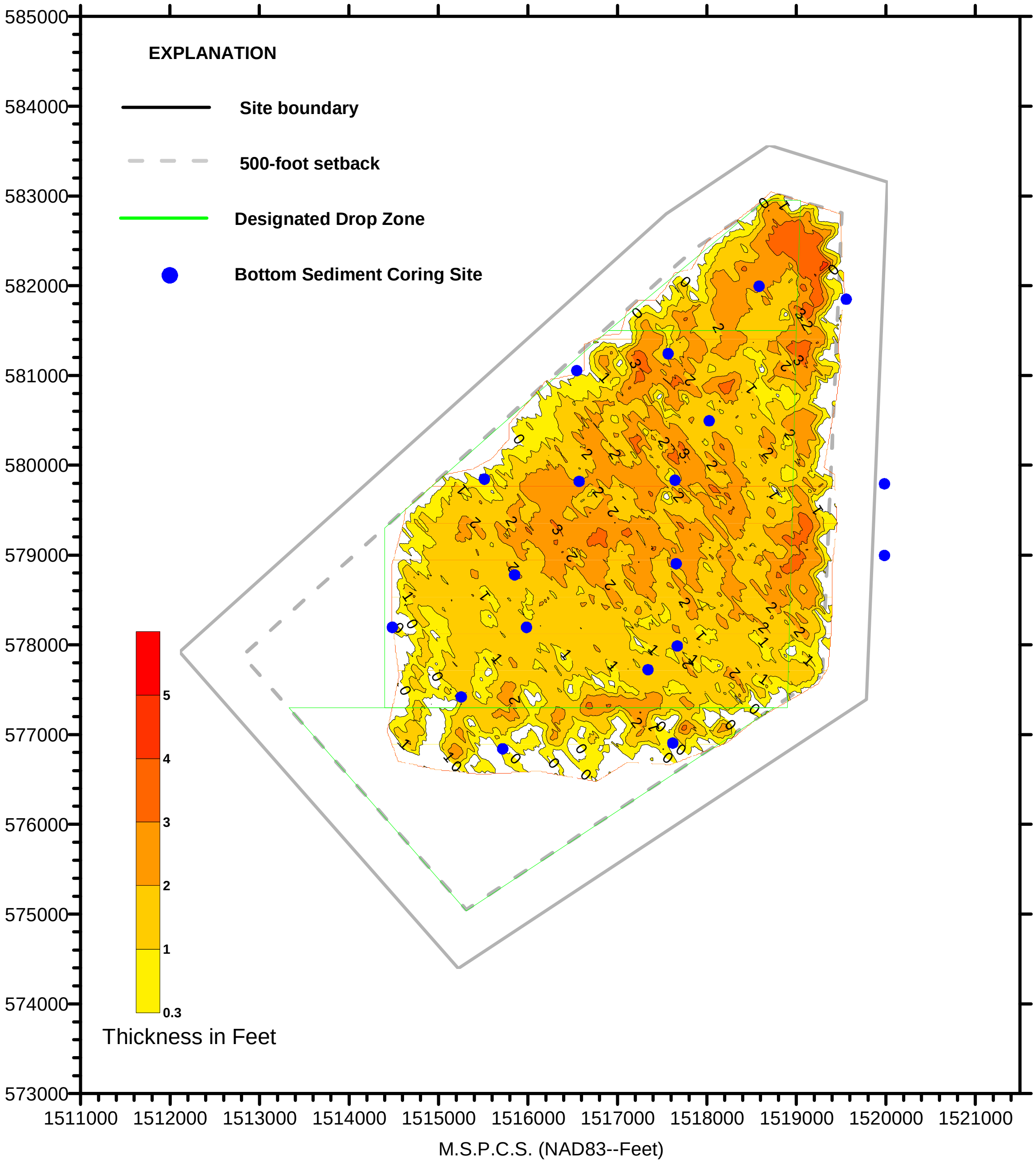

Figure 5: Isopach map showing change in elevation (feet) between pre-placement (August 25-26,2009) and completion of placement (April 2, 2010).

approximately along an east-west line exhibited slight sediment “mounding” and water depths of approximately --14 ft. Bottom relief across most of the site was reduced from the pre-placement conditions and was very flat.

Placed sediments occupied nearly the entire area of the drop zones except for the extreme southern portion of the site. Little sediment extended beyond the drop zones and none was identified beyond the Site 92 boundaries.

The majority of the deposit was 1.0 ft. to 2.0 ft. thick, with slightly greater thicknesses of 3.0 ft. in the center and northern portions of the site. Maximum thicknesses between 3.0 ft. and 4.0 ft. were apparent in some isolated areas in the center of the site and somewhat more extensive along the northern portion of the site. The completion survey identified a placed sediment volume of 1.25 ±0.16 mcy. The total area covered by placed sediment greater than 0.3 ft. thick was 2.43 million square yards (msy) (502 acres), or approximately 54% of the entire Site 92 area.

One-month survey: May 5, 2010 (Figures 6 and 7)

At one month, water depths were very similar to those observed on the completion survey although somewhat deeper overall. Only one small “mounded” area less than -14 ft. depth in the central portion of the drop zone was still evident. The deposit “footprint” was very similar to that observed at completion.

The majority of the deposit exhibited thicknesses of 1.0 ft. to 2.0 ft. with the 3.0 ft. thick areas decreasing in size from the completion survey. The thickest part of the deposit, between 3.0 ft. and 4.0 ft., occurred in a few isolated locations in the central portion of the drop zone and along the northeastern edge of the site. The one-month survey identified a placed sediment volume of 1.02 ±0.16 mcy. The total area covered by placed sediment greater than 0.3 ft. thick was 2.36 msy (487 acres), or approximately 52% of the entire Site 92 area.

Three-month survey: July 15, 2010 (Figures 8 and 9)

Minor changes in water depths occurred in the interval between the one month and three months post-placement period. The remaining -14 ft. deep “mound” in the south central portion of the site was no longer present, but most of the center of the site still exhibited water depths in the -16 ft. range, increasing to -18 ft. depth along the northeastern border of the site. The placed sediment “footprint” was very similar in area to that observed at the completion and the one month post-placement surveys.

The thickness of the majority of the deposit was still in the 1.0 ft. to 2.0 ft. range with the central portion of the site showing thicknesses exceeding 2.0 ft. The small isolated pockets in the center of the area where thicknesses had exceeded 3.0 ft. on the one month survey were no longer present. Only along the extreme northeastern portion of the site did thicknesses exceed 3.0 ft. The three-month survey identified a placed sediment volume of 1.00 ±0.16 mcy. The total area covered by placed sediment greater than 0.3 ft. in thickness was 2.42 msy (500 acres), or 54% of Site 92. Although the thickness and volumes were reduced the overall area covered expanded slightly from the

Site 92
2009-2010 (Year 12)

Bathymetry at 1 Month Post Placement
May 5, 2010

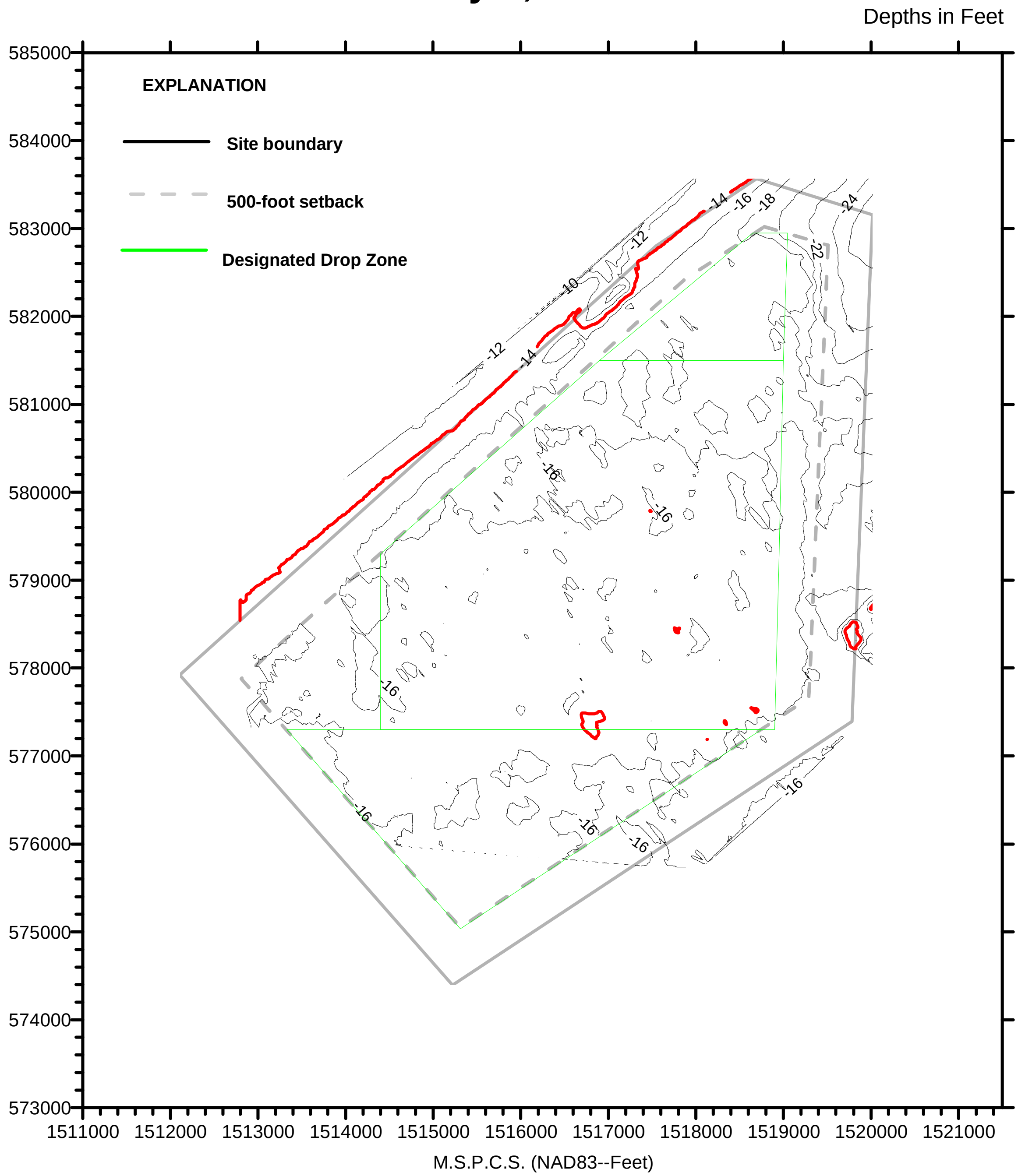

Figure 6: Bathymetry on May 5, 2010 - one month following completion of placement. The -14 foot MLLW contour is highlighted in red.

Site 92
2009-2010 (Year 12)

Change in Elevation
Pre-Placement vs.1 Month Post-Placement

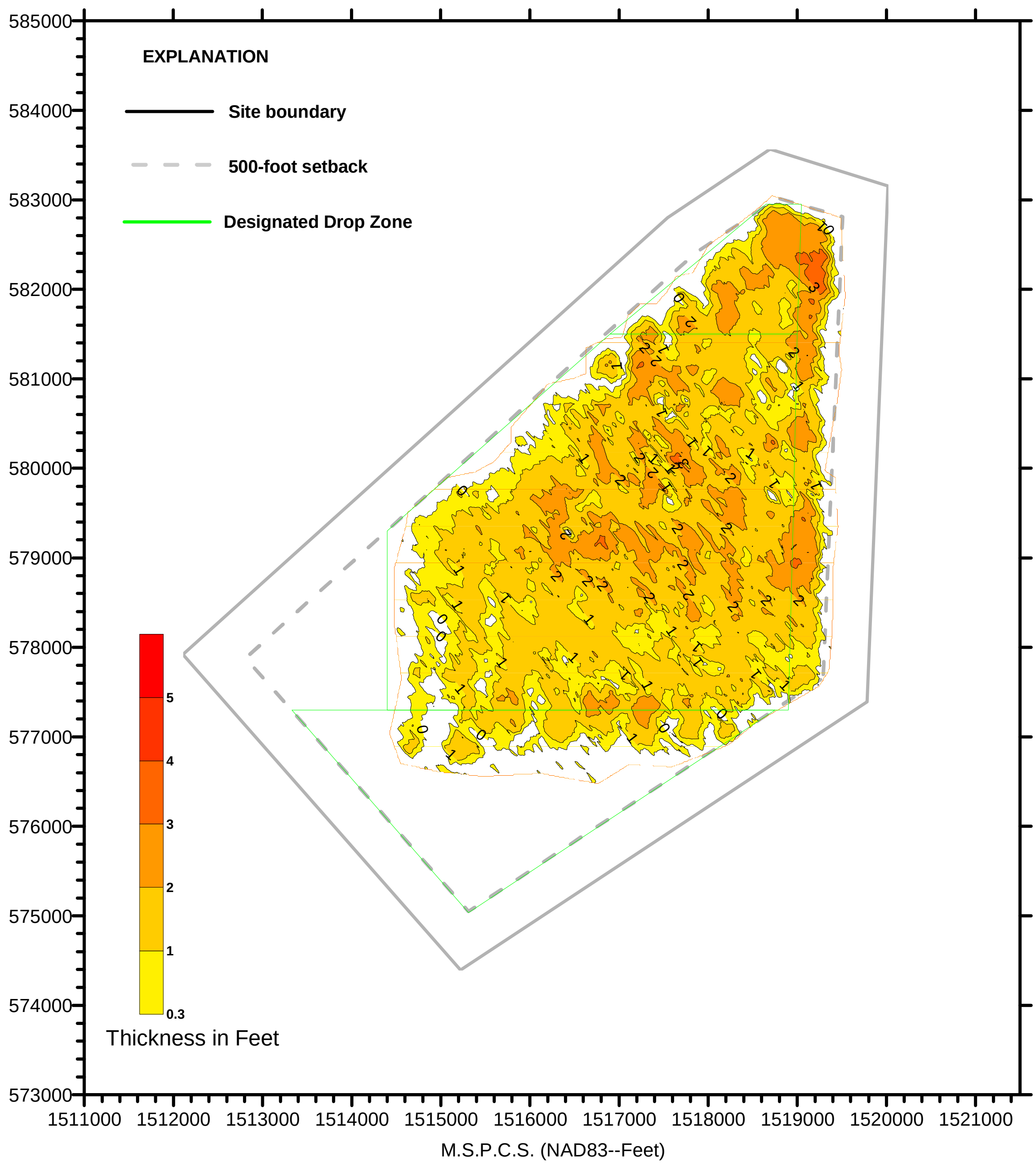

Figure 7: Isopach map showing change in elevation (feet) between pre-placement (August 25-26,2009) and one month post-placement (May 5, 2010).

Site 92
2009-2010 (Year 12)

Bathymetry at 3 Months Post Placement
July 15, 2010

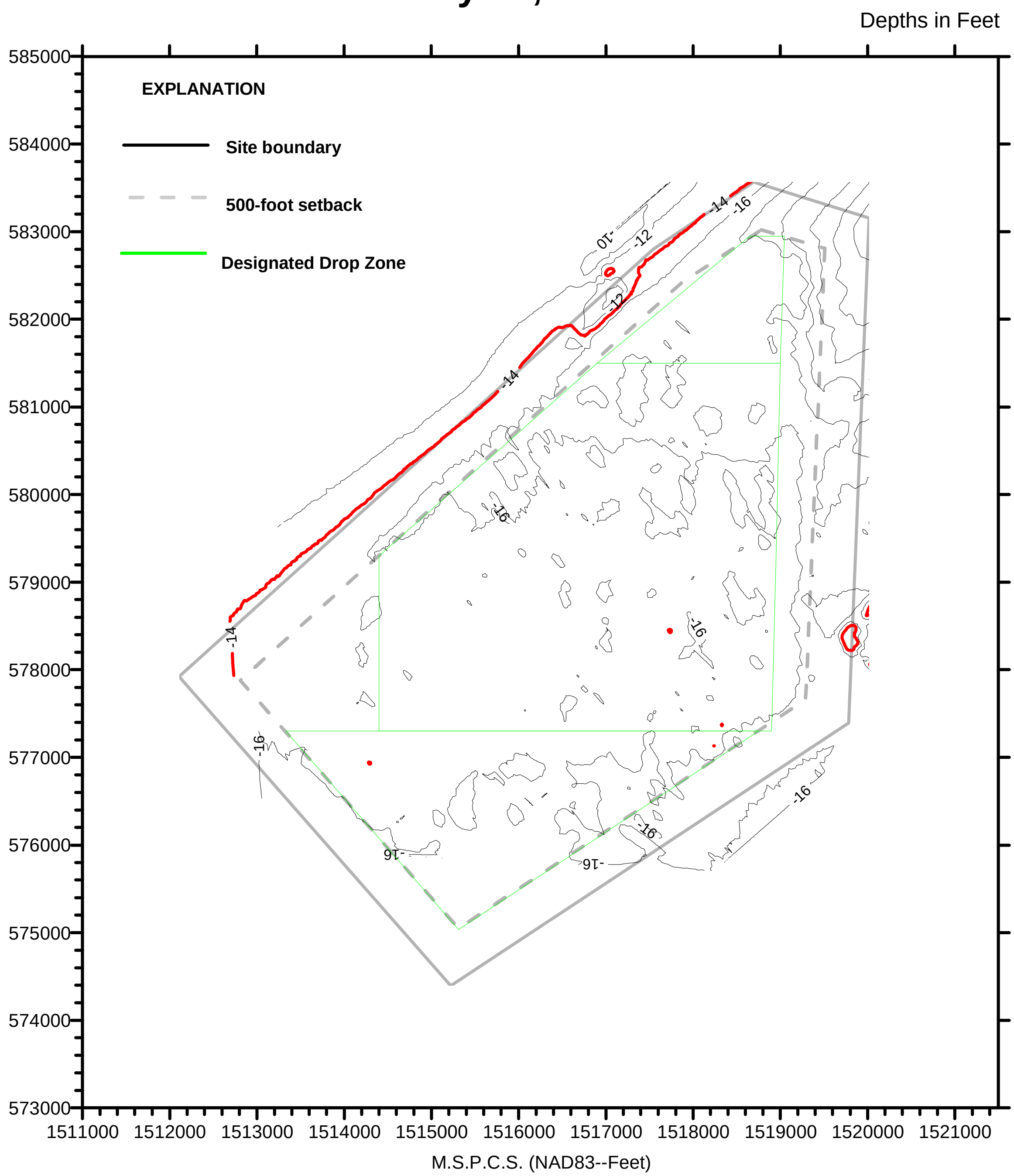

Figure 8: Bathymetry on July 15, 2010 - three months following completion of placement. The -14 foot MLLW contour is highlighted in red.

Site 92
2009-2010 (Year 12)

Change in Elevation
Pre-Placement vs. 3 Months Post-Placement

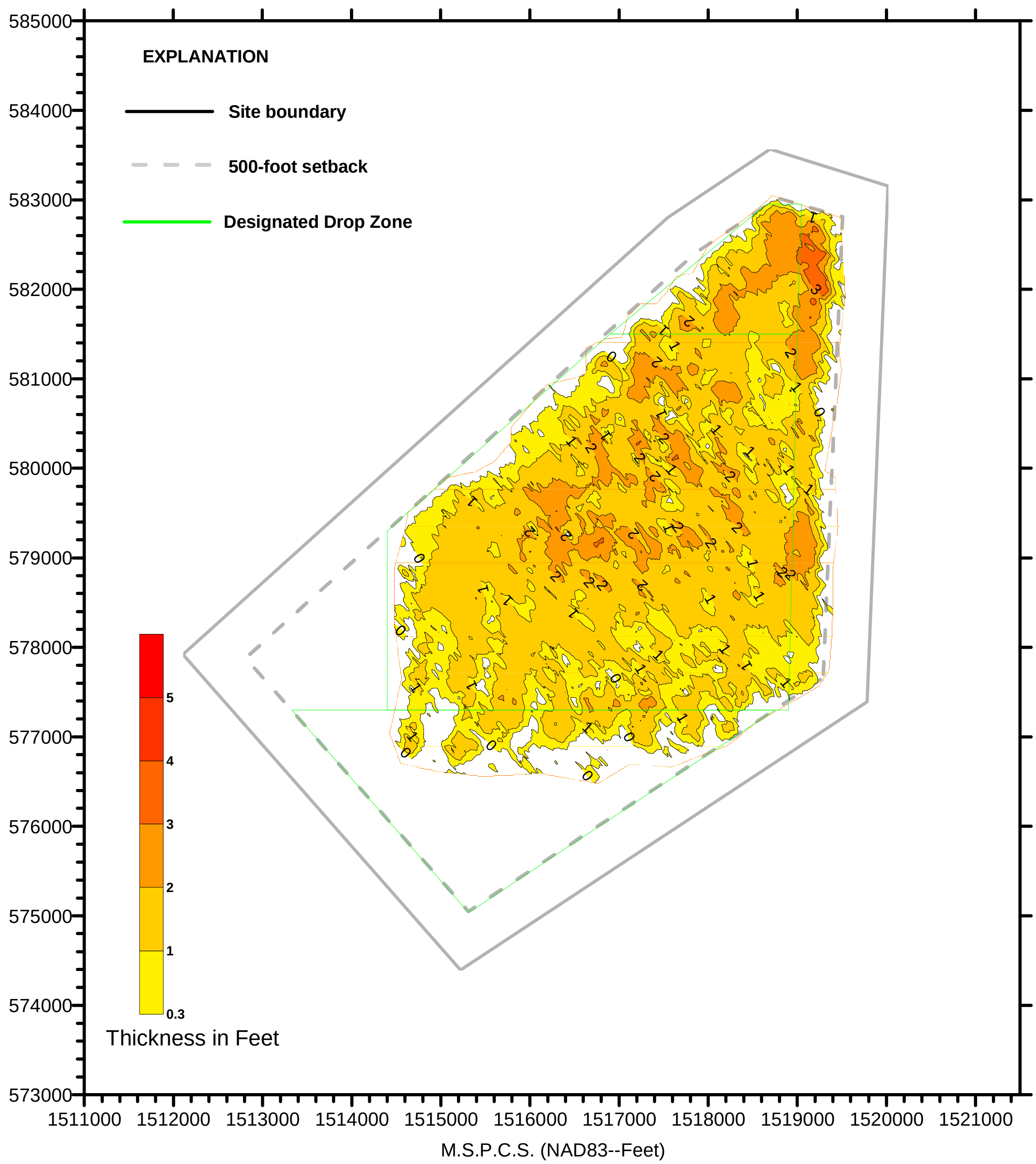

Figure 9: Isopach map showing change in elevation (feet) between pre-placement (August 25-26,2009) and three months post-placement (July 15, 2010).

one-month survey, which may have been due to a minor spreading out of the deposited sediments within the placement site.

Six-month survey: October 28, 2010 (Figures 10 and 11)

At six months, water depths had somewhat uniformly increased from those observed at the three-month post-placement survey. A notable -16 ft. depth contour, oriented east-west, was located across the center of the site. This was displaced to the south of the -16 ft. contour observed on the three-month survey. Along the northeastern portion of the site the -18 ft. depth contour had shifted to the west from the previous survey. Water depths ranged from -15 ft. to -17 ft. across the majority of the site.

The deposit "footprint" was similar to that seen at three months, but the edges retreated toward the center of the site. Only isolated areas in the center exceeded 2 ft. in thickness, and the area exceeding a 3.0 ft. thickness along the northeastern boundary during the three- month survey had a maximum thickness of less than 2.0 ft. The majority of the deposit was less than 2.0 ft. thick, with a maximum thickness of 2.6 ft. in the central portion of the drop zone. The six-month survey identified a placed sediment volume of 0.75 ±0.16 mcy. The total area covered by placed sediment greater than 0.3 ft. in thickness was 2.26 msy (466 acres), or 50% of the Site 92 area.

Eleven-month survey: February 23, 2011 (Figures 12 and 13)

Due to weather conditions and boat scheduling conflicts the cruise intended to take place ten months following placement did not occur until a month later and the coring cruise nearly a month following the bathymetric cruise (Table 1). At eleven months post-placement, water depths across the drop zone were slightly deeper than in the previous survey with the -16 ft. contour becoming more convoluted across most of the south-central portion, and the -18 ft. contour projecting further into the site along the north-eastern side. Water depths over the majority of the site were in the -16 ft. to -17 ft. range.

The majority of the deposit exhibited a thickness of up to 2.0 ft. with only some isolated areas in the center of the deposit and along the northeastern side where the thickness exceeded 3 ft. The eleven-month survey identified a placed sediment volume of 0.60 ±0.16 mcy. The total area covered by placed sediment greater than 0.3 ft. in thickness was 2.13 msy (440 acres), or about 47% of the Site 92 area.

Sediment Properties

Appendix A, Tables 6 through 10 lists the bulk properties for each core collected prior to placement, at completion of placement, and at eleven months after placement. All the coring stations were sampled on each of the coring cruises.

Figures 3, 4, and 12 show the pre-placement, completion, and eleven-month bottom sediment coring site locations overlain on the respective bathymetries. Figures 5 and 13 show the bottom sediment coring sites overlain on the completion and eleven-month isopach maps, respectively. Refer to Figure 2 for identification of the core station numbers. For each core, the placed sediment thickness listed may be less than the *in situ*

Site 92
2009-2010 (Year 12)

Bathymetry at 6 Months Post Placement
October 28, 2010

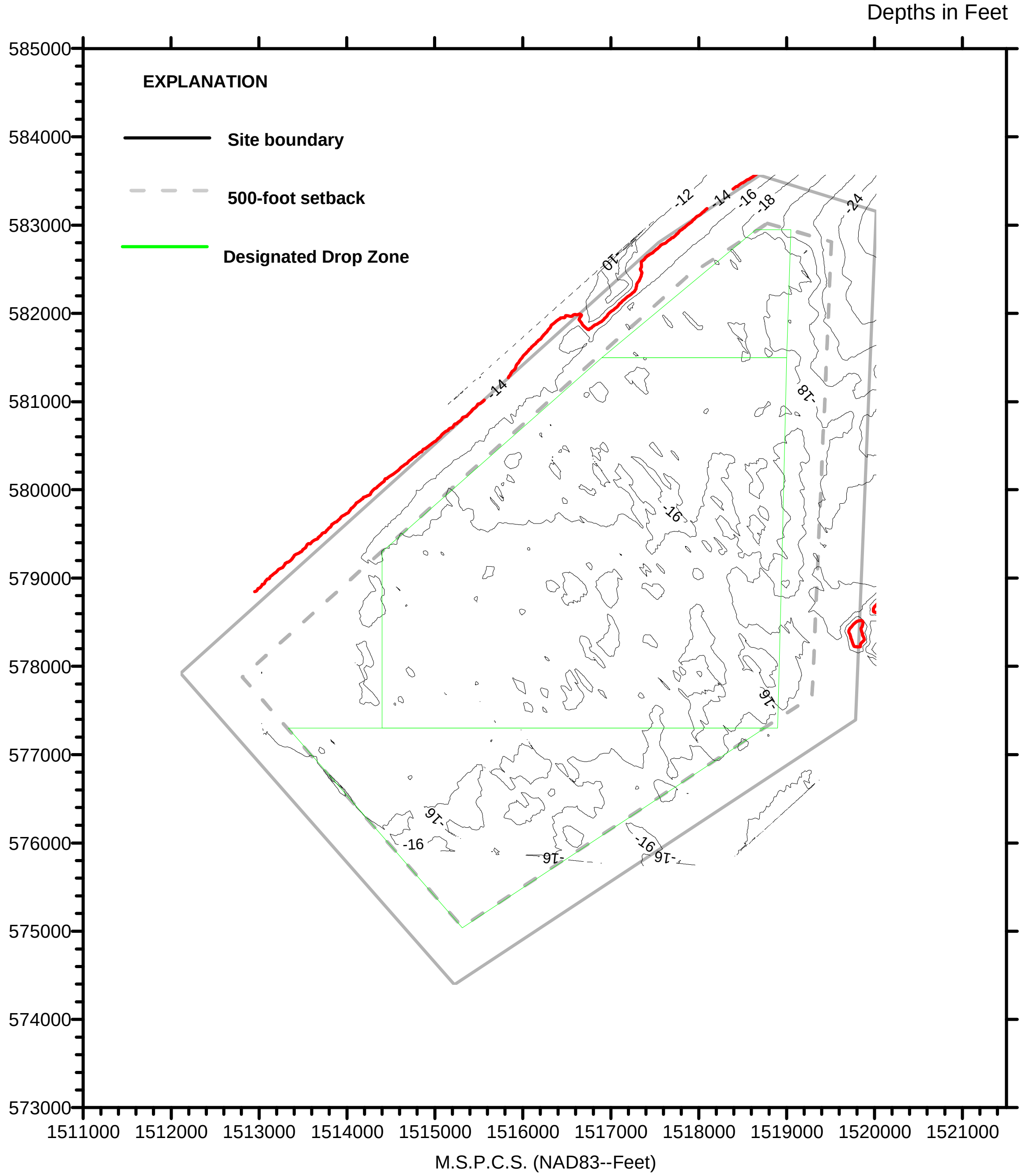

Figure 10: Bathymetry on October 28, 2011 - six months following completion of placement. The -14 foot MLLW contour is highlighted in red.

Site 92
2009-2010 (Year 12)

Change in Elevation
Pre-Placement vs. 6 Months Post-Placement

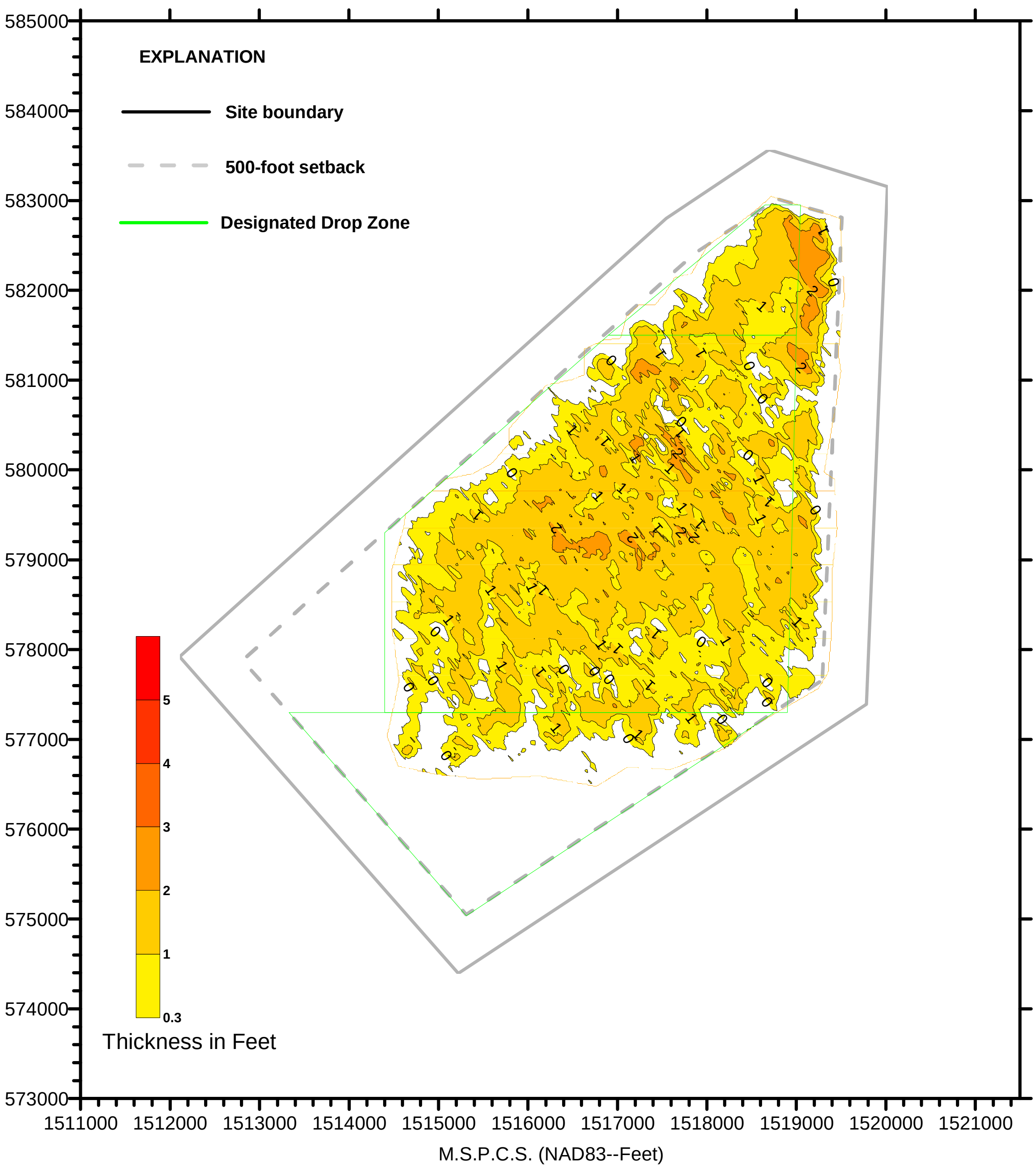

Figure 11: Isopach map showing change in elevation (feet) between pre-placement (August 25-26,2009) and 6 months post-placement (October 28, 2010).

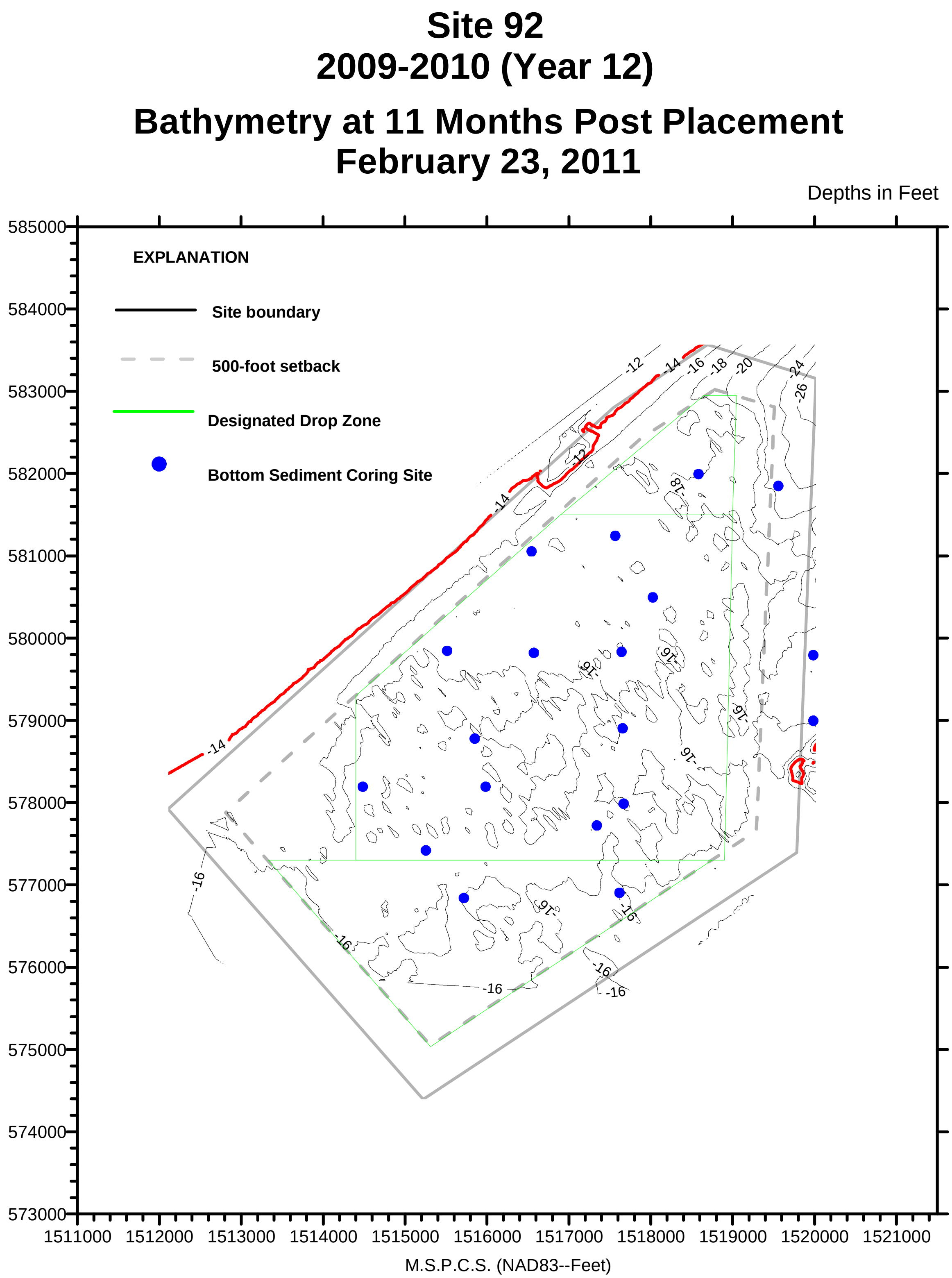

Figure 12: Bathymetry on February 23, 2011 - 11 months following completion of placement. The -14 foot MLLW contour is highlighted in red.

Site 92
2009-2010 (Year 12)

Change in Elevation
Pre-Placement vs. 11 Months Post-Placement

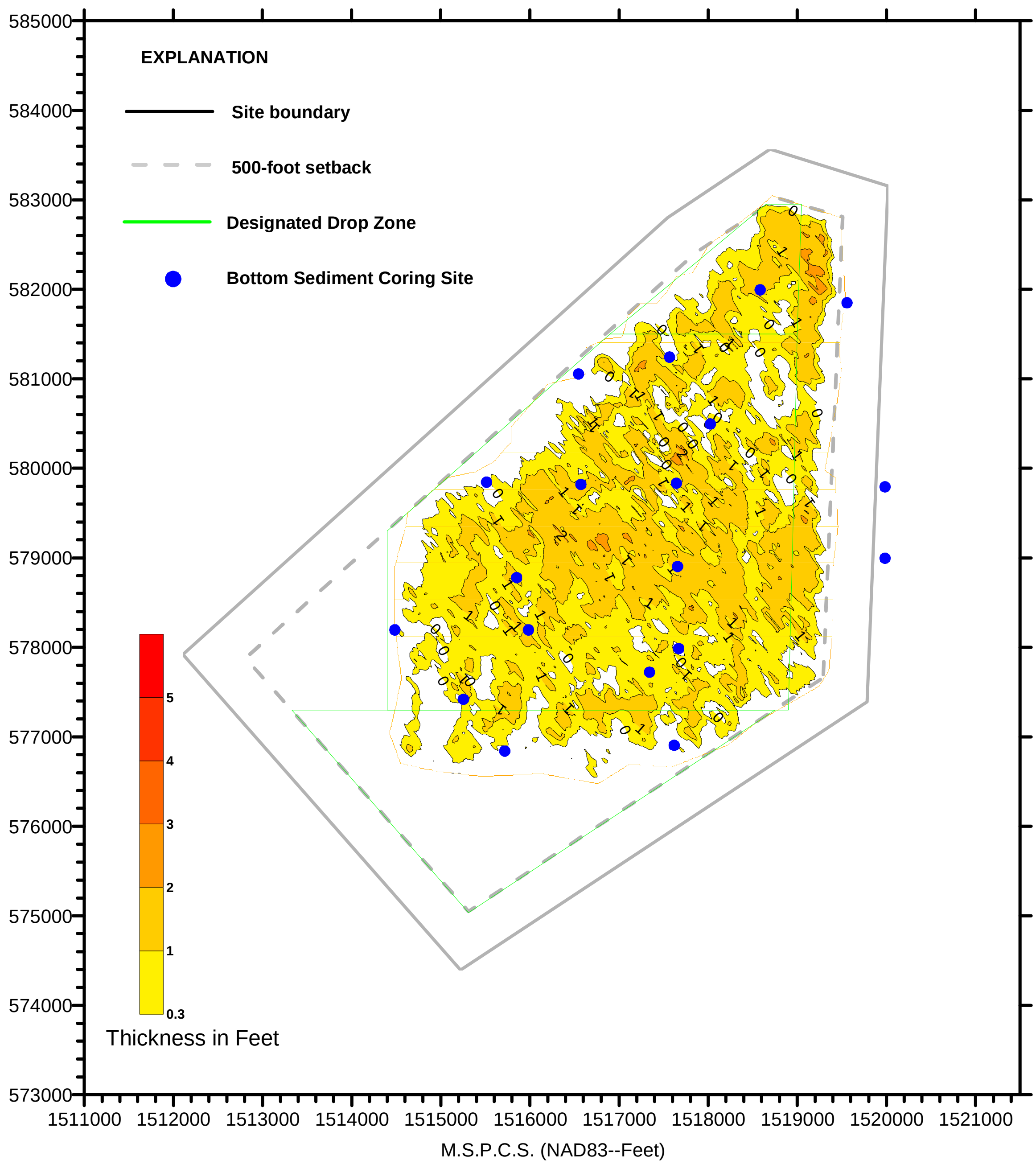

Figure 13: Isopach map showing change in elevation (feet) between pre-placement (August 25-26,2009) and eleven months post-placement (February 23, 2011).

thickness because of core shortening (refer to Methods section). The discussion concerning bulk properties focuses on the results of the mean water content analyses. Bulk density, porosity, and void ratio are also included in the tables for completeness.

Foundation sediments

Bottom sediment coring occurred prior to placement in order to characterize the pre-placement bottom sediments, establish bulk property data to evaluate subsequent foundation consolidation, and facilitate identification of placed dredged sediment. Pre-placement bottom sediments were sampled at 17 locations in Site 92 to ensure adequate coverage in locations where scow placement was likely to occur or potentially spread after placement (Figure 2). Two additional sites were sampled outside of the site boundary to aid in ground-truthing the bathymetric data and confirm the absence or presence of placed sediments beyond the boundary.

Observation of the foundation sediments indicated that they were primarily olive gray fine grained silts and clays similar to sediments obtained at the site in previous years. Sediment water contents within Site 92 varied from 47.7% to 53.4%, a range of 5.7%; and from 41.1% to 49.7% outside the site boundary. The slightly lower water content of the sediments outside the boundary could be attributed to the absence of any dredged sediment previously placed or located in those areas. This would result in a lower overall sedimentation rate and the trapping of lesser quantities of water.

Placed sediments

On the completion sampling date, all of the coring sites within Site 92 except station 36 revealed the presence of Year 12 placed sediments. Station 36 was not located within the drop zone; therefore, the absence of placed sediments at that location was to be expected. Observed thicknesses of placed sediments ranged from 0.1 ft. at stations 92-47 and 92-48 to 2.2 ft. at station 92-35. The water contents of the recently placed sediments spanned a range of 13.9% from 53.0% to 66.9%. The two stations located to the east of the site 92 boundary (92-G and 92-H) did not show the presence of recently placed sediments.

Eleven months after completion of placement, coring recovered placed sediments at all the stations except 13A, 36 and 47. Thicknesses ranged from 0.1 ft. at station 92-48 to 1.8 ft. at station 92-45. Water contents decreased during the period since placement from a low of 47.8 % to a high of 62.7%, a range of 14.9%.

The historical average of the mean water content values for the dredged channel sediments (58.1 ±2.3%), Year 12 completion placed sediments (56.7 ±3.9%), and Year 12 eleven-month placed sediments (53.2 ±4.0%) were utilized to calculate a bulking factor for the completion of placement and consolidation over the post-placement period (Tables 4 and 5).

Analysis of Bathymetric and Sediment Data

This analysis evaluated the QA/QC of the post-processed bathymetric data and the presence of any anomalous trends that would indicate a problematic survey. Gravity cores collected within and outside the placement area provided ground-truth for the isopach maps created from the bathymetric data.

There was a reasonable correlation between the core sediment thickness and the sediment thickness determined from the bathymetric data for both the completion and eleven month cruises. The additional month of time that elapsed between the eleven month bathymetric data cruise (February 23, 2011) and the core collection cruise (March 22, 2011) may have contributed to the differences for that period. At completion, coring recovered placed sediments at sixteen locations (92-13, 92-13A, 92-15, 92-16, 92-30A, 92-31, 92-33, 92-35, 92-39, 92-42, 92-43, 92-44, 92-45, 92-46, 92-47 and 92-48). At eleven months post-placement, coring recovered placed sediments at fourteen locations (92-13, 92-15, 92-16, 92-30A, 92-31, 92-33, 92-35, 92-39, 92-42, 92-43 and 92-44, 92-45, 92-46, and 92-48). Except for location 92-30A, the bathymetric data indicated a sediment deposit greater than 0.3 ft. thick at all these coring stations.

The following core sites were devoid of placed sediments during the completion coring cruise: cores 92-36 (located beyond the designated drop zone) 92-G and 92-H (located outside of the Site 92 boundaries). During the final eleven-month coring cruise, the following core sites were devoid of placed sediments: 92-36, 92-G and 92-H again as well as sites 92-13A and 92-47 which had placed sediment on the completion cruise.

Those cores which exhibited a thin or no deposit present at the time of the eleven month survey were primarily located along the edge of the deposit as determined from the bathymetric survey for that time (Figure 13). These were locations 92-15, 92-30A, 92-47 and 92-48 which all had less than 0.2 ft. of sediment present in the cores except for 92-47 which did not exhibit deposited sediment. The one anomalous coring station was 92-13A which, while located near the center of the deposit where the bathymetric data indicated approximately 1 ft. of sediment should have been present, had no identifiable placed sediment. This anomaly could have been due to a misidentification of the deposited sediment in core 92-13A, or additional sediment may have been moved from the location in the one month that elapsed between the bathymetric and the coring cruises. Given the generally good agreement between the results from the bathymetric data and the core data with no consistent offset in either data set the quality of the data is confirmed.

Consolidation of Foundation Sediments

Foundation consolidation is routinely evaluated to derive the most accurate placement volumes possible. Dewatering of the foundation sediments is expected to occur through time and result in some consolidation after placement. Without accounting for foundation consolidation, the placed sediment volumes determined through the bathymetric surveys may be underestimated. Foundation consolidation lowers the elevation of the overlying placed sediments and increases the water depths. Accounting for the difference in elevation because of foundation consolidation increases the calculated volume of the placed sediment.

The depth to which foundation consolidation is affected by the overburden of placed sediments is unknown. A combination of variables such as the foundation slope, porosity and permeability of the foundation sediments, and the overlying thickness of the placed sediment contributes to the variability measured in previous placement operations. This study evaluated the consolidation of the upper 1.0 ft. to 3.0 ft. of the foundation layer in those areas in which placed sediment was identified in Site 92 (see Tables 7 and 8). This was the maximum thickness that the coring device could penetrate through placed sediments and recover the pre-placement foundation sediments. Poindexter-Rollings (1990) determined that foundation consolidation should be greatest in the upper portion of the underlying sediment column. Based on that research, it was assumed that if minimal foundation consolidation was identified in the uppermost layer, then it was likely consolidation was negligible below this level.

Core sites where placed sediments exceeded 0.5 ft. in thickness at the completion of placement were used in the evaluation of foundation consolidation. Table 2 summarizes the changes in measured water content over the three sampling periods (data taken from Tables 6, 7, and 8).

Table 2. Change in foundation sediment water content through time[1].

placement period	**92-13**	**92-13A**	**92-15**	**92-16**
change in water content (%) between pre-placement (10/22/09) and completion of placement (4/20/10)	-0.3	-0.6	0.2	-1.7
	92-31	**92-33**	**92-35**	**92-39**
	-0.7	1.4	-1.2	2.6
	92-43	**92-44**	**92-45**	
	1.2	5.2	1.4	
post-placement period	**92-13**	**92-15**	**92-16**	**92-31**
change in water content (%) between pre-placement (10/22/09) and eleven months after placement (4/20/10)	-3.3	2.6	-3.7	-1.8
	92-33	**92-35**	**92-39**	**92-43**
	-1.5	-4.2	1.1	1.3
	92-44	**92-45**		
	-8.5	0.8		

[1] Positive values indicate an increase in water content. Negative values indicate a decrease in water content.

No clear trend is evident from Table 2. The change in the foundation sediment water contents over the sampling periods varied from site to site, ranging from –5.2% to +2.6% during the placement period and –8.5% to +2.6% during the post placement period. Over the placement period the water contents of the foundation sediments decreased in 7 core sites and increased in 4, while during the post-placement period the water contents decreased in 6 core sites and increased in the other 4. Ordinarily, it would be expected that the water contents would decrease due to the overburden pressure, but this was clearly not the case at all coring locations. At one core site (92-13A) placed sediment at completion was not present at the eleven month survey. Because the time of removal of that sediment could not be determined the change in foundation water content was included in the determination of the foundation consolidation for the period of sediment placement, but not included in the determination for the post completion consolidation. Therefore, there were eleven sites evaluated for consolidation during the placement period, but only ten for the post placement period.

The average foundation sediment water content at those locations with more than 0.5 ft. of placed sediment was 50.6 ±1.7% prior to placement; 50.1 ±1.4%; by the completion of placement, and 48.7 ±1.8% eleven months after placement. These numbers indicate a slight decrease of 0.5% in foundation sediment water content between pre-placement and completion of placement, and a further decrease of 1.4% between completion of placement and eleven months following placement.

A t-test was run on the data to determine if the observed average decrease in foundation sediment water content was statistically significant. The test demonstrated that the decrease was not significant in either placement or the post-placement period. Therefore, foundation consolidation associated with the apparent loss in average water content was not utilized in determining volumetric changes during the study period.

Dredged and Placement Amounts

The study evaluated the volume of dredged sediment present at the placement site soon after the completion of dredging and placement operations. A volume deficit of sediment is expected at completion of placement operations resulting from processes occurring during the placement period, including: suspension of sediment in turbidity plumes during the dredging and placement of material, sediment removed from the placement site due to the resuspension and erosion, and dewatering (consolidation) of the placed sediment. The reported dredged volumes in conjunction with bulk property and bathymetric data collected by MGS were used to account for the placed sediment volume at completion of operations.

Table 3 summarizes the results of the volume comparisons. The dredged sediment volumes reported by CENAP and GLDD are reported in column *a* as is the average of these two reported numbers. The expected volume at the placement site (column *e*) was determined by multiplying a derived bulking ratio (column *d*) by the reported volume of dredged sediments (column *a*). The bulking ratio is a function of the change in porosities, which is calculated from the mean water contents of the dredged channel sediments (column *b*) and the placed sediments (column *c*). This takes into account the change in volume from both water-loading (bulking) and dewatering (consolidation) of the sediments through time and allows for a more reliable estimation of sediment loss from the placement site. The sediment volume identified at the placement site at the completion of placement operations as determined from the MGS bathymetric data described previously is reported in column *f*. Columns *g* and *h* list the difference between the identified volume at completion and the expected volumes determined from the reported volume dredged and the bulking factor. The possible ranges are due to the limits in vertical resolution inherent in the bathymetric surveys.

Table 3. Comparison of bulk property and volumetric data.							
(*a*) volume dredged (mcy)	(*b*) % water content of channel sediment	(*c*) % water content of placed sediment	(*d*) bulking ratio from water content data	(*e*) expected volume of sediment at placement site (mcy)	(*f*) volume of sediment identified at placement site (mcy)	(*g*) volume difference identified at placement site (mcy)	(*h*) volume difference identified at placement site (%)
<u>CENAP</u> 1.39	58.1 ±2.3	56.7 ±3.9	0.96	1.33	1.25±0.16	–0.08	–6.02%
<u>GLDD</u> 1.72				1.65		–0.40	–24.24%
<u>Average</u> 1.56				1.50		–0.25	–16.67%

The average of the water contents for the channel sediments, 58.1 ±2.3%, was calculated from 13 previous years of data (column *b*). The placed sediments water content (column c) was the average of sixteen water contents from the cores that recovered placed sediments after completion of placement (Appendix, Table 11). The average placed sediment water content, 56.7 ±3.9%, was similar to those observed in previous monitoring of placed sediments at Site 92. A t-test indicated that the decrease in the sediment water content after placement was statistically significant at the 99% confidence level. Therefore, the bulking ratio of 0.96 was utilized in the volumetric analysis to calculate the volume expected at the placement site relative to the observed volumes based on the bathymetric data.

The placed sediment volume identified at Site 92 from the completion bathymetric survey was 1.25 ±0.16 mcy (Table 3, column f). This compares favorably to the volume reported dredged by CENAP with a deficit of only 0.08 mcy or 6.02%, but is significantly less than the volume reported dredged by GLDD (0.40 mcy deficit or 24.24%). While the CENAP volume is expected to be more accurate because it was based on comparisons of channel bathymetry before and after dredging, the deficits identified in previous year's monitoring efforts were generally much greater, and have commonly been in the 30% range. Certainly loss is expected to take place both at the dredging site in the channel and at the placement site during deposition. Additionally, the long dredging and placement period which occurred during this season's operation would have allowed more time for resuspension and erosion as well as consolidation of the placed sediments. Thus, the approximately 6% loss calculated to have occurred is considered low based on previous year's monitoring.

Consolidation and Erosion after Placement

The volumetric reductions that occur after placement result from both consolidation due to dewatering and erosion of sediment from the surface of the deposit. The reduction in sediment volume due to consolidation can be estimated from changes in the water content over time. The amount of erosion can be estimated by first calculating the total sediment volume change from the bathymetric data and then subtracting the volume change determined to be due to consolidation.

Table 4 summarizes the volume changes over time as well as the amount of change attributable to consolidation and erosion at the completion of the study period based on the measured water contents in the core samples. Column *b* summarizes the mean volumes estimated to be present at the completion of placement and at one, three, six, and eleven months after placement, which were discussed above. Column *c* reports the cumulative reduction in sediment volume over time in cubic yards and as a percentage of the originally placed volume. The volumetric change attributed to consolidation (column *f*) is based on change in the average water content of the core samples collected at the completion of placement and the end of the study period. Because water makes up a relatively large proportion of the bottom sediments by volume, relatively small differences in water contents can result in large volume differences. The estimated erosion (column g) was calculated by subtracting the percent volume change that could be attributed to consolidation from the total change in the sediment volume over the eleven month post placement period.

Table 4. Volumetric analyses of placed sediments through time.

Bathymetric analyses and associated volumetric changes.			
(*a*) survey	(*b*) measured volume present (mcy)	(*c*) cumulative volume change (mcy)	(%)
completion	1.25 ±0.16	0	0
one month	1.02 ±0.16	-0.23	-18.4
three month	1.00 ±0.16	–0.25	–20.0
six month	0.75 ±0.16	–0.50	–40.0
eleven month	0.60 ±0.16	–0.65	–52.0

Water content analyses and associated volumetric changes			
(*d*) survey	(*e*) average water content (%)	(*f*) mean volume change due to consolidation (%)	(*g*) mean volume change due to erosion (%)
completion	56.7	-	-
eleven month	53.2	-10.0	-42.0

The in-place volumes identified at one month, three months, six months, and eleven months were 0.23, 0.25, 0.50, and 0.65 mcy less, respectively, than the volume identified on the completion survey. At the end of the eleven-month post-placement period, 48.0% of the original sediment volume remained.

During the post-placement period, the average sediment water content of placed sediments decreased 3.5%, from 56.7% to 53.2%. A t-test indicated that this was a statistically significant change in water content at a 99% confidence level. This equated to a 10% volume reduction due to dewatering and consolidation, or approximately one-fifth of the total volume reduction. The remainder of the volume change attributed to erosion, 42.0%, represented four-fifths of the volume reduction.

The Year 12 percent cumulative volume change (52%) is at the high end of the range observed in previous monitoring at Site 92. For example, in Years 5, 6, 7, 8, 9, and 10 the percent cumulative volume changes were 49%, 38%, 26%, 38.5%, 47.8%, and 46.4%, respectively. The Year 12 volume change due to consolidation and erosion (10.0 % and 42.0%, respectively) are in the ranges observed from previous years. The percent mean volume change due to consolidation ranged from 0% to 13% during Years 5, 6, 7, 8, 9, and 10; and that due to erosion ranged from 19% to 49%.

Capacity Usage

Table 5 summarizes the site volume capacity usage at Site 92. Site volume is the available space for placement usage. The estimates assume an idealized placement configuration when brought to the authorized depth of −14 ft. MLLW. Total site volume was estimated at 7 mcy prior to the placement of any sediment.

In Table 5, of the two reported volume sources (CENAP and contractor), the closest volume to the volume identified by MGS at completion of placement (column *b*) is listed on the top line in column *a* and carried forward to determine the cumulative total cut volume from the channel. The contractor's dredged volume (indicated by +) is based on the quantity of sediment placed per scow load. CENAP dredged volume (indicated by *) is based on the change between pre- and post-dredging bathymetric surveys in the channel (cut volume). Column *c* lists the measured volume reduction over the post-placement period. Column *d* lists the site volume used at the end of the year on a yearly and cumulative cycle. The final bathymetric surveys determined the volumetric usage and the remaining site volume for future placements.

Table 5. Site volume capacity usage at Site 92 (mcy).

NTDE	placement year	Reported (*a*) cut volume from channel: yearly	Reported (*a*) cut volume from channel: cumulative	Measured Site Volume Use at Placement Site (*b*) site volume used at completion of placement: yearly	(*b*) cumulative	(*c*) volume reduction after placement: yearly	(*d*) site volume used at end of year: yearly	(*d*) cumulative	(*e*) remaining site volume at end of year [a]: cumulative
1960-1978	Year 1 1998 1999	1.09+ 0.76*	1.09	1.04	1.04	0.34	0.70	0.70	6.30
1960-1978	Year 2 1999 2000	0.51+ 0.46*	1.60	0.59	1.29	0.10	0.49	1.19	5.81
1960-1978	Year 3 2000 2001	1.78* 0.91+	3.38	1.44	2.63	0.21	1.23	2.42	4.58
1960-1978	Year 4 2001 2002	0.30* 0.18+	3.68	0.19	2.61	0.08	0.11	2.53	4.47
1960-1978	Year 5 2002 2003	0.32+	4.00	0.21	2.34	0.11	0.10	2.63 [b]	4.37 [b]
1983-2001		0.35*						2.23 [c]	4.77 [c]
1983-2001						0.28 [d]	-0.07 [d]	2.06 [d]	4.94 [d]
1983-2001	Year 6 2003 2004	1.07+ 1.08*	5.07	0.74	2.80	0.25	0.49	2.55	4.45
1983-2001	Year 7 2004 2005	1.01+ 1.21*	6.08	0.95	3.50	0.25	0.70	3.25	3.75
1983-2001	Year 8 2005-2006	0.68* 0.87+	6.76	0.53	3.78	0.20	0.33	3.58	3.42
1983-2001	Year 9 2006-2007	0.83+ 0.88*	7.59	0.63	4.21	0.30	0.33	3.91	3.09
1983-2001	Year 10 2007-2008	0.60+ 0.69*	8.19	0.44	4.35	0.20	0.24	4.15	2.85
1983-2001	Year 11 2008 - 2009	0.00 0.00	8.19	0.00	4.15	N/A	0.00	4.15	2.85
1983-2001	Year 12 2009-2010	1.39* 1.72+	9.58	1.25	5.6	0.65	0.60	4.75	2.25

+ denotes contractor's reported dredged volume (cumulative total = 9.11 mcy).

* denotes CENAP reported dredged volume (cumulative total = 9.58 mcy).

a initial site volume 7.00 mcy.

b 1960-1978 National Tidal Datum Epoch (NTDE).

c updated NTDE decreases column *d* cumulative and increases column *e* by 0.40 mcy prior to Hurricane Isabel.

d erosion from Hurricane Isabel decreases column *d* and increases columns *c* and *e* by 0.17 ±0.04 mcy.

Years 1 through 4 placements utilized 2.53 mcy of site volume, or 36%, leaving 4.47 mcy. Prior to Year 5 placement, all bathymetric surveys were referenced to MLLW for 1960-1978 NTDE. During Year 5 placement, the NTDE was updated (1983-2001) to reflect changes in mean sea level along the nation's coast. The updated NTDE increased site volume capacity by 0.40 mcy. Year 5 placement utilized 0.10 mcy of site volume, leaving 4.77 mcy. Subsequently, Hurricane Isabel passed through the mid-Atlantic region (16 days prior to Year 6 placement). After Hurricane Isabel, an estimated 0.17 mcy of sediment eroded from Site 92 resulting in a 0.07 mcy net gain of site volume. Therefore, Year 5 placement had a total net gain of 0.47 mcy, or 6.7% of the site volume, leaving 4.94 mcy. Years 6 utilized 0.49 mcy of site volume, leaving 4.45 mcy. Year 7 placement utilized 0.70 mcy of site volume, leaving 3.75 mcy. Year 8 placement utilized 0.33 mcy, leaving 3.42 mcy of site volume. Year 9 placement also utilized 0.33 mcy of site volume, leaving 3.09 mcy of site volume. Placement in Year 10 utilized 0.24 mcy, leaving 2.85 mcy of site volume, and this remained the same through Year 11 because no dredging and placement took place. Finally, placement in the 2009-2010 dredging operation utilized an additional 0.60 mcy.

In total, Years 1 through 12 placements used 4.75 mcy of the site volume, or 68% of the original site volume of 7.0 mcy. Although open water placement in the Upper Chesapeake Bay has ceased to take place, approximately 1/3 of the original volume estimated to be available at Site 92 remains, assuming an idealized placement configuration with a final authorized depth of –14 ft. MLLW.

CONCLUSIONS

CENAP and GLDD both provided estimates of the quantity of sediment dredged based on different measurement techniques. CENAP reported a total cut volume of 1.39 mcy. GLDD reported 1.72 mcy.

Placement occurred in the designated drop zone in water depths that ranged from –16 ft. to –18 ft. After completion of placement, water depths over the majority of the site were -14 ft. to –16 ft. with some depths in the -16 ft. to -18 ft. range. A few small areas exhibited slight sediment "mounding" and water depths of approximately –14 ft. Bottom relief across most of the site was reduced from the pre-placement conditions and was very flat. Placed sediments occupied nearly the entire area of the drop zones, except the extreme southern portion of the site. Little sediment extended beyond the drop zones, and none was identified beyond the Site 92 boundaries.

The majority of the deposit was 1.0 ft. to 2.0 ft. thick, with slightly greater thicknesses of 3.0 ft. in the center and northern portions of the site. The total area covered by placed sediment greater than 0.3 ft. thick was 2.43 million square yards (msy) (502 acres), or approximately 54% of the entire Site 92 area. The completion survey identified a placed sediment volume of 1.25 ±0.16 mcy, only about 0.8 mcy, or 6.02%, less than the amount reported dredged by CENAP. Consolidation and erosion processes at the placement site reduced the in-place volume by 52.0% in the eleven months following placement.

Water content data indicates that approximately 10%, or one-fifth of the total sediment volume reduction was due to consolidation. The remaining four-fifths was ascribed to erosion of sediment from the site.

This year's cut volume, 1.39 mcy, utilized 1.25 mcy of the site volume at the completion of placement and 0.60 mcy eleven months after placement. In total over the 12 year period since placement began at Site 92, 4.75 mcy, or 68%, of the original site volume was used. Approximately 2.25 mcy, or 32%, of the site volume remains at Site 92.

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APPENDIX

Physical Properties of Sediment Cores

Table 6. Physical properties of foundation sediments prior to sediment placement (collection date October 22, 2009).

Core location	**92-13**	**92-13A**	**92-15**	**92-16**
Sediment thickness in core (ft.)	1.7	1.7	1.5	1.9
Water content (%)	51.5 ±2.3	51.6 ±2.3	47.7 ±2.1	53.4±2.4
Bulk density (g/cm^3)	1.43 ±0.03	1.43 ±0.03	1.48 ±0.03	1.41 ± 0.03
Porosity	0.738 ±0.018	0.738 ±0.018	0.708 ±0.018	0.759 ±0.018
Void ratio	2.8 ±0.3	2.8 ±0.3	2.4 ±0.2	2.9 ±0.3
Core location	**92-30A**	**92-31**	**92-33**	**92-35**
Sediment thickness in core (ft.)	2.0	2.1	1.8	1.6
Water content (%)	52.3 ±2.3	50.9 ±2.3	50.1 ±2.2	51.2 ±2.3
Bulk density (g/cm^3)	1.43 ±0.03	1.44 ±0.03	1.45 ±0.03	1.44 ±0.03
Porosity	0.742 ±0.018	0.733 ±0.018	0.727 ±0.018	0.736 ±0.018
Void ratio	2.9 ±0.3	2.7 ±0.3	2.7 ±0.2	2.8 ±0.3
Core location	**92-36**	**92-39**	**92-42**	**92-43**
Sediment thickness in core (ft.)	1.8	1.6	1.6	1.7
Water content (%)	50.2 ±2.2	48.8 ±2.2	48.8 ±2.2	49.5 ±2.2
Bulk density (g/cm^3)	1.45 ±0.03	1.47 ±0.03	1.47 ±0.03	1.46 ±0.03
Porosity	0.727 ±0.018	0.717 ±0.018	0.716 ±0.018	0.722 ±0.018
Void ratio	2.7 ±0.2	2.5 ±0.2	2.5 ±0.2	2.6 ±0.2
Core location	**92-44**	**92-45**	**92-46**	**92-47**
Sediment thickness in core (ft.)	2.2	1.5	2.1	1.8
Water content (%)	52.8 ±2.4	48.7 ±2.2	49.5 ±2.2	48.0 ±2.1
Bulk density (g/cm3)	1.42 ±0.03	1.47 ±0.03	1.46 ±0.03	1.48 ±0.03
Porosity	0.748 ±0.018	0.715 ±0.018	0.722 ±0.018	0.710 ±0.018
Void ratio	3.0 ±0.3	2.5 ±0.2	2.6 ±0.2	2.4 ±0.2
Core location	**92-48**	**92-G**	**92-H**	
Sediment thickness in core (ft.)	1.8	2.2	2.0	
Water content (%)	52.5 ±2.3	49.7 ±2.2	41.1 ±1.8	
Bulk density (g/cm3)	1.42 ±0.03	1.46 ±0.03	1.58 ±0.03	
Porosity	0.745 ±0.018	0.723 ±0.018	0.649 ±0.018	
Void ratio	2.9 ±0.3	2.6 ±0.2	1.8 ±0.1	

Table 7. Physical properties of foundation sediments at completion of placement (collection date April 20, 2010). Foundation sediments overlain by placed sediments are shaded in the core location and sediment thickness rows.

Core location	**92-13**	**92-13A**	**92-15**	**92-16**
Sediment thickness in core (ft.)	1.4	3.0	1.6	2.2
Water content (%)	51.2 ±2.3	51.0 ±2.3	47.9 ±2.1	51.7 ±2.3
Bulk density (g/cm^3)	1.45 ±0.03	1.44 ±0.03	1.48 ±0.03	1.43 ± 0.03
Porosity	0.736 ±0.018	0.734 ±0.018	0.709 ±0.018	0.739 ±0.018
Void ratio	2.8 ±0.3	2.8 ±0.3	2.4 ±0.2	2.8 ±0.3
Core location	**92-30A**	**92-31**	**92-33**	**92-35**
Sediment thickness in core (ft.)	1.3	1.8	1.9	1.1
Water content (%)	50.8 ±2.3	50.2 ±2.2	51.5 ±2.3	50.0 ±2.2
Bulk density (g/cm^3)	1.44 ±0.03	1.45 ±0.03	1.43 ±0.03	1.45 ±0.03
Porosity	0.732 ±0.018	0.727 ±0.018	0.738 ±0.018	0.726 ±0.018
Void ratio	2.7 ±0.3	2.7 ±0.3	2.8 ±0.3	2.7 ±0.2
Core location	**92-36**	**92-39**	**92-42**	**92-43**
Sediment thickness in core (ft.)	2.0	2.9	2.0	2.5
Water content (%)	50.1 ±2.2	51.4 ±2.3	47.0 ±2.1	48.3 ±2.2
Bulk density (g/cm^3)	1.45 ±0.03	1.43 ±0.03	1.49 ±0.03	1.48 ±0.03
Porosity	0.727 ±0.018	0.737 ±0.018	0.701 ±0.018	0.712 ±0.018
Void ratio	2.7 ±0.2	2.8 ±0.2	2.3 ±0.2	2.5 ±0.2
Core location	**92-44**	**92-45**	**92-46**	**92-47**
Sediment thickness in core (ft.)	1.6	1.3	2.6	1.3
Water content (%)	47.6 ±2.1	50.1 ±2.2	49.4 ±2.2	48.2 ±2.1
Bulk density (g/cm3)	1.48 ±0.03	1.45 ±0.03	1.46 ±0.03	1.48 ±0.03
Porosity	0.706 ±0.018	0.727 ±0.018	0.721 ±0.018	0.711 ±0.018
Void ratio	2.4 ±0.2	2.7 ±0.2	2.6 ±0.2	2.5 ±0.2
Core location	**92-48**	**92-G**	**92-H**	
Sediment thickness in core (ft.)	1.8	3.5	1.8	
Water content (%)	50.7 ±2.3	49.2 ±2.2	47.2 ±2.1	
Bulk density (g/cm3)	1.44 ±0.03	1.46 ±0.03	1.49 ±0.03	
Porosity	0.732 ±0.018	0.720 ±0.018	0.703 ±0.018	
Void ratio	2.7 ±0.3	2.6 ±0.2	2.4 ±0.2	

Table 8. Physical properties of foundation sediments for eleven month survey (collected March 22, 2011). Foundation sediments overlain by placed sediments are shaded in the core location and sediment thickness rows.

Core location	**92-13**	**92-13A**	**92-15**	**92-16**
Sediment thickness in core (ft.)	1.0	1.6	1.9	2.9
Water content (%)	48.2 ±2.2	50.4 ±2.2	50.3 ±2.2	49.7 ±2.2
Bulk density (g/cm^3)	1.48 ±0.03	1.45 ±0.03	1.45 ±0.03	1.46 ± 0.03
Porosity	0.712 ±0.018	0.729 ±0.018	0.729 ±0.018	0.724 ±0.018
Void ratio	2.5 ±0.2	2.7 ±0.3	2.7 ±0.3	2.6 ±0.2
Core location	**92-30A**	**92-31**	**92-33**	**92-35**
Sediment thickness in core (ft.)	1.7	2.2	2.6	2.1
Water content (%)	48.3 ±2.2	49.1 ±2.2	48.6 ±2.2	47.0 ±2.1
Bulk density (g/cm^3)	1.47 ±0.03	1.46 ±0.03	1.47 ±0.03	1.49 ±0.03
Porosity	0.713 ±0.018	0.719 ±0.018	0.715 ±0.018	0.701 ±0.018
Void ratio	2.5 ±0.2	2.6 ±0.2	2.5 ±0.2	2.3 ±0.2
Core location	**92-36**	**92-39**	**92-42**	**92-43**
Sediment thickness in core (ft.)	2.3	1.9	1.6	2.7
Water content (%)	49.0 ±2.2	49.9 ±2.2	46.5 ±2.1	50.8 ±2.3
Bulk density (g/cm^3)	1.46 ±0.03	1.45 ±0.03	1.50 ±0.03	1.44 ±0.03
Porosity	0.718 ±0.018	0.725 ±0.018	0.698 ±0.018	0.732 ±0.018
Void ratio	2.6 ±0.2	2.6 ±0.2	2.3 ±0.2	2.7 ±0.3
Core location	**92-44**	**92-45**	**92-46**	**92-47**
Sediment thickness in core (ft.)	2.5	2.7	1.8	2.2
Water content (%)	44.3 ±2.0	49.5 ±2.2	48.0 ±2.1	51.6 ±2.3
Bulk density (g/cm3)	1.53 ±0.03	1.46 ±0.03	1.48 ±0.03	1.43 ±0.03
Porosity	0.678 ±0.018	0.722 ±0.018	0.710 ±0.018	0.739 ±0.018
Void ratio	2.1 ±0.2	2.6 ±0.2	2.4 ±0.2	2.48±0.3
Core location	**92-48**	**92-G**	**92-H**	
Sediment thickness in core (ft.)	1.6	1.9	2.1	
Water content (%)	47.3 ±2.1	50.4 ±2.2	48.0 ±2.1	
Bulk density (g/cm3)	1.49 ±0.03	1.45 ±0.03	1.48 ±0.03	
Porosity	0.704 ±0.018	0.729 ±0.018	0.709 ±0.018	
Void ratio	2.4 ±0.2	2.7 ±0.3	2.4 ±0.2	

Table 9. Physical properties of placed sediments at completion of placement (April 20, 2010).

Core location	**92-13**	**92-13A**	**92-15**	**92-16**
Sediment thickness in core (ft.)	1.4	0.7	0.5	1.6
Water content (%)	54.7 ±2.4	54.6 ±2.4	56.6 ±2.5	54.8 ±2.4
Bulk density (g/cm^3)	1.39 ±0.03	1.39 ±0.03	1.37 ±0.03	1.39 ± 0.03
Porosity	0.762 ±0.018	0.761 ±0.018	0.776 ±0.018	0.762 ±0.018
Void ratio	3.2 ±0.3	3.2 ±0.3	3.5 ±0.4	3.2 ±0.3
Core location	**92-30A**	**92-31**	**92-33**	**92-35**
Sediment thickness in core (ft.)	0.3	1.0	0.9	2.2
Water content (%)	53.3 ±2.4	56.6 ±2.5	55.6 ±2.5	57.5 ±2.6
Bulk density (g/cm^3)	1.41 ±0.03	1.37 ±0.03	1.38 ±0.03	1.36 ±0.03
Porosity	0.752 ±0.018	0.776 ±0.018	0.769 ±0.018	0.782 ±0.018
Void ratio	3.0 ±0.3	3.5 ±0.4	3.3 ±0.4	3.6 ±0.4
Core location	**92-39**	**92-42**	**92-43**	**92-44**
Sediment thickness in core (ft.)	0.8	0.4	1.7	1.4
Water content (%)	57.8 ±2.6	55.8 ±2.5	53.9 ±2.4	54.2 ±2.4
Bulk density (g/cm3)	1.36 ±0.03	1.38 ±0.03	1.40 ±0.03	1.40 ±0.03
Porosity	0.784 ±0.018	0.770 ±0.018	0.756 ±0.018	0.758 ±0.018
Void ratio	3.6 ±0.4	3.3 ±0.4	3.1 ±0.3	3.1 ±0.3
Core location	**92-45**	**92-46**	**92-47**	**92-48**
Sediment thickness in core (ft.)	2.1	0.3	0.1	0.1
Water content (%)	53.0 ±2.0	56.4 ±2.5	66.9 ±3.0	65.6 ±2.9
Bulk density (g/cm3)	1.41 ±0.03	1.37 ±0.03	1.26 ±0.03	1.27 ±0.03
Porosity	0.749 ±0.018	0.774 ±0.018	0.842 ±0.018	0.835 ±0.018
Void ratio	3.0 ±0.3	3.4 ±0.4	5.3 ±0.8	5.0 ±0.7

Table 10. Physical properties of placed sediments at eleven months (March 22, 2011).				
Core location	**92-13**	**92-15**	**92-16**	**92-30A**
Sediment thickness in core (ft.)	0.9	0.2	1.5	0.2
Water content (%)	52.1 ±2.3	56.3 ±2.5	52.0 ±2.3	56.5 ±2.5
Bulk density (g/cm^3)	1.43 ±0.03	1.37 ±0.03	1.43 ± 0.03	1.37 ±0.03
Porosity	0.742 ±0.018	0.774 ±0.018	0.741 ±0.018	0.775 ±0.018
Void ratio	2.9 ±0.3	3.4 ±0.4	2.9 ±0.3	3.4 ±0.4
Core location	**92-31**	**92-33**	**92-35**	**92-39**
Sediment thickness in core (ft.)	1.0	0.3	1.0	0.5
Water content (%)	47.8 ±2.1	49.0 ±2.2	48.8 ±2.2	54.6 ±2.4
Bulk density (g/cm^3)	1.48 ±0.03	1.47 ±0.03	1.47 ±0.03	1.39 ±0.03
Porosity	0.708 ±0.018	0.718 ±0.018	0.717 ±0.018	0.761 ±0.018
Void ratio	2.4 ±0.2	2.5 ±0.2	2.5 ±0.2	3.62 ±0.3
Core location	**92-42**	**92-43**	**92-44**	**92-45**
Sediment thickness in core (ft.)	0.4	1.1	0.4	1.8
Water content (%)	58.3 ±2.6	51.7 ±2.3	50.1 ±2.2	51.2 ±2.3
Bulk density (g/cm3)	1.35 ±0.03	1.43 ±0.03	1.45 ±0.03	1.44 ±0.03
Porosity	0.788 ±0.018	0.739 ±0.018	0.727 ±0.018	0.735 ±0.018
Void ratio	3.7 ±0.4	2.8 ±0.3	2.7 ±0.2	2.8 ±0.3
Core location	**92-46**	**92-48**		
Sediment thickness in core (ft.)	0.3	0.1		
Water content (%)	54.2 ±2.4	62.7 ±2.8		
Bulk density (g/cm3)	1.40 ±0.03	1.30 ±0.03		
Porosity	0.758 ±0.018	0.817 ±0.018		
Void ratio	3.1 ±0.3	4.5 ±0.6		