Monitoring Results From the First Boston Harbor Navigation Improvement Project Confined Aquatic Disposal Cell

Disposal Area Monitoring System DAMOS

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DISPOSAL AREA MONITORING SYSTEM

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13. ABSTRACT

As part of the overall Boston Harbor Navigation and Improvement Project (BHNIP), shipping berths 11 and 12 at Conley Terminal in South Boston were deepened to -40 ft and -45 ft MLLW, respectively, in June-July 1997. In phase1 of the BHNIP, fine-grained maintenance sediment, classified as unsuitable for open-disposal, was dredged and placed into an in-channel confined aquatic disposal (CAD) cell in Boston Harbor. The cell was extracted into the existing federal channel, below the BHNIP channel depth of -40 ft MLLW. Following placement of maintenance material into the cell, sufficient sand to cover the dredged material with a minimum of 3 ft capping layer was placed using split-hull scows.

A monitoring survey was conducted by SAIC in October 1997 to assess the status of capped CAD cell. Survey methods included one day of vibracoring, and one day of acoustic surveying including bathymetry, subbottom, and side-scan sonar. Results of the survey indicated that most of the CAD cell was covered with a highly variable thickness of sand, while the southern end had little to no cap material. This distribution was consistent with the positioning of the split-hull scows used to dispose the sand. Sand disposal was permitted during the outgoing (southerly) tidal cycle. Prior to the initiation of the project, preliminary modeling of sand transport due to Boston Harbor tidal currents predicted that sand would be transported to the south, so no barge was placed directly over the southern end of the cell. The results suggested that the sand remained in the convective state during placement, so that all the cap material was placed directly below each positioned barge.

The monitoring results also suggested that postcap operations designed to level the sand served to enhance mixing of the cap and underlying dredged material, and resulted in uneven sand coverage. A final videosled survey was conducted by C.R. Environmental in December 1997. These data confirmed the presence of a thick layer of sand covered with tunicates and other organisms in most of the cell, and the flat, fine-grained uncapped mud surface to the south. Overall, the maintenance material was successfully placed in the cell, and capped with sand in all locations where capping barges were located. The results of monitoring of Phase I provided guidance for operational and monitoring modifications for Phase II of the BHNIP in 1998-99.

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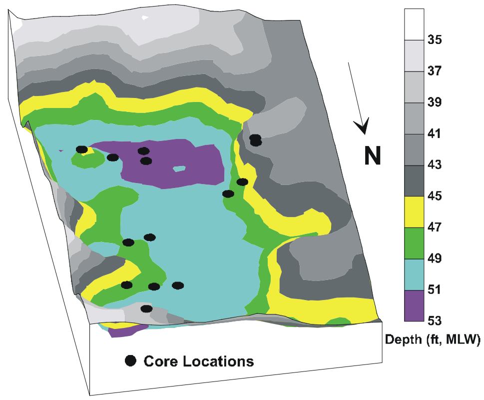

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EXECUTIVE SUMMARY

As part of the overall Boston Harbor Navigation and Improvement Project (BHNIP), shipping berths 11 and 12 at Conley Terminal in South Boston were deepened to –40 ft and –45 ft MLLW, respectively, in June-July 1997. In phase 1 of the BHNIP, fine-grained maintenance sediment, classified as unsuitable for open ocean-disposal, was dredged and placed into an in-channel confined aquatic disposal (CAD) cell in Boston Harbor. The cell was excavated into the existing federal channel, below the BHNIP channel depth of 40 ft MLLW. Following placement of maintenance material into the cell, sufficient sand to cover the dredged material with a minimum of a 3 ft capping layer was placed using split-hull scows.

A monitoring survey was conducted by SAIC in October 1997 to assess the status of capped CAD cell. Survey methods included one day of vibracoring, and one day of acoustic surveying including bathymetry, subbottom, and side-scan sonar. Results of the survey indicated that most of the CAD cell was covered with a highly variable thickness of sand, while the southern end had little to no cap material. This distribution was consistent with the positioning of the split-hull scows used to dispose the sand. Sand disposal was permitted during the outgoing (southerly) tidal cycle. Prior to the initiation of the project, preliminary modeling of sand transport due to Boston Harbor tidal currents predicted that sand would be transported to the south, so no barge was placed directly over the southern end of the cell. The results suggested that the sand remained in the convective state during placement, so that all the cap material was placed directly below each positioned barge.

The monitoring results also suggested that postcap operations designed to level the sand served to enhance mixing of the cap and underlying dredged material, and resulted in uneven sand coverage. A final videosled survey was conducted by C. R. Environmental in December 1997. These data confirmed the presence of a thick layer of sand covered with tunicates and other organisms in most of the cell, and the flat, fine-grained uncapped mud surface to the south. Overall, the maintenance material was successfully placed in the cell, and capped with sand in all locations where capping barges were located. The results of monitoring of Phase I provided guidance for operational and monitoring modifications for Phase 2 of the BHNIP in 1998-99.

1.0 INTRODUCTION

1.1 The Boston Harbor Navigation and Improvement Project

The Boston Harbor Navigation and Improvement Project (BHNIP) involves deepening of the main ship channel (in the Inner Confluence and the mouth of the Reserved Channel), and three tributary channels (Mystic River, Chelsea Creek, and Reserved Channel) in Boston Harbor (Figure 1-1). In addition to the channels, several terminals and berth areas will also be dredged, for a total of 2.1 million yd^3 of material (Table 1-1). All of the channels will be deepened to -40 ft MLLW, except for Chelsea Channel, which will be dredged to -38 ft MLLW. BHNIP is a joint project between the US Army Corps of Engineers, New England District (NAE) and the local sponsor, the Massachusetts Port Authority (MassPort). The first phase of the project, Conley Terminal, was conducted in the summer of 1997.

Following extensive environmental review, the disposal options for both suitable and unsuitable material were described in the Final Environmental Impact Statement/Report (FEIS/R; NAE and MassPort 1995). The plan included disposing the unsuitable material in approximately 50 in-channel confined aquatic disposal (CAD) cells, approximately 1.3 million yds^3 of clean material will be dredged to create the cells averaging 20 feet deep, dredged below the federal navigation channels in the Mystic River, Chelsea River, and the Inner Confluence (Figure 1-2; NAE and MassPort 1995; Demos 1997). Because of concerns over the environmental impact of such a large-scale project, the state of Massachusetts negotiated for intensive environmental monitoring under the auspices of the CWA 401 Water Quality Certificate (WQC; Babb-Brott 1997). The WQC, granted by the Massachusetts Department of Environmental Protection, included the stipulation that the unsuitable material must be dredged using an environmental (closed) clamshell bucket, and capped by at least 3 ft of clean, granular material. One of the goals of the WQC was to monitor the short and long-term integrity of the capped CAD cells, and included review of all monitoring data by a state-sponsored Independent Observer (IO) for the Coastal Zone Management Agency (CZM; ENSR, Acton, MA was selected as IO). Survey results presented in this paper are only part of the extensive monitoring data collected for the Conley Terminal project (ENSR 1997a,b; Section 1.2).

Concerns were raised by the BHNIP Technical Advisory Committee (TAC) prior to capping that the density difference between the fine-grained maintenance sediment and the coarse-grained sand cap would result in displacement of the cap, and that cap coverage would be difficult to verify using bathymetric methods alone (ENSR 1997b). Verification monitoring of the cell, in addition to the required monitoring by the WQC, was initiated in the summer-fall of 1997. The survey data presented in this report were collected in order to address these TAC concerns (Section 1.3).

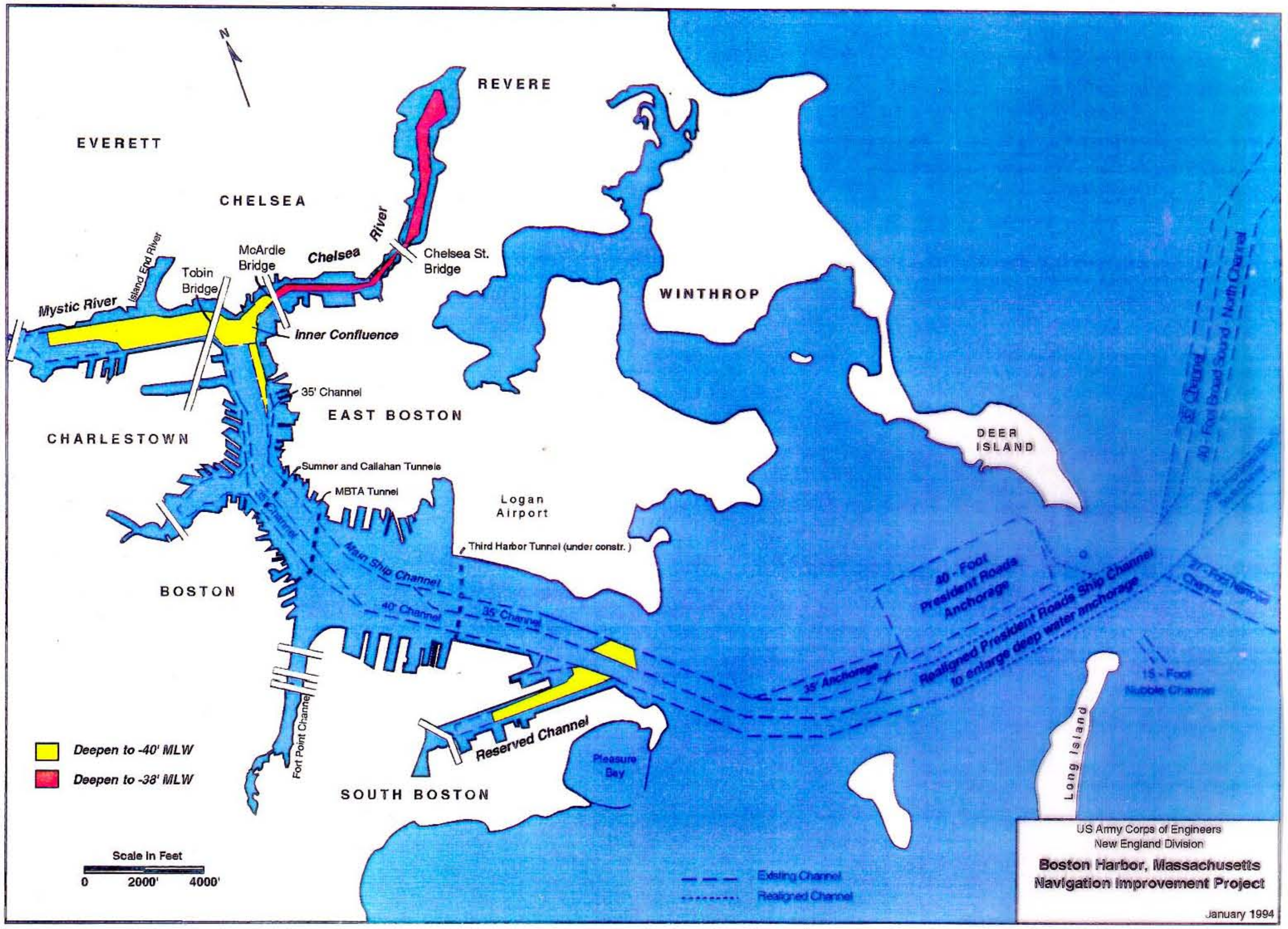


Figure 1-1. Boston Harbor Navigation Improvement Project location of main channels to be dredged (from NAE and Massport 1995).

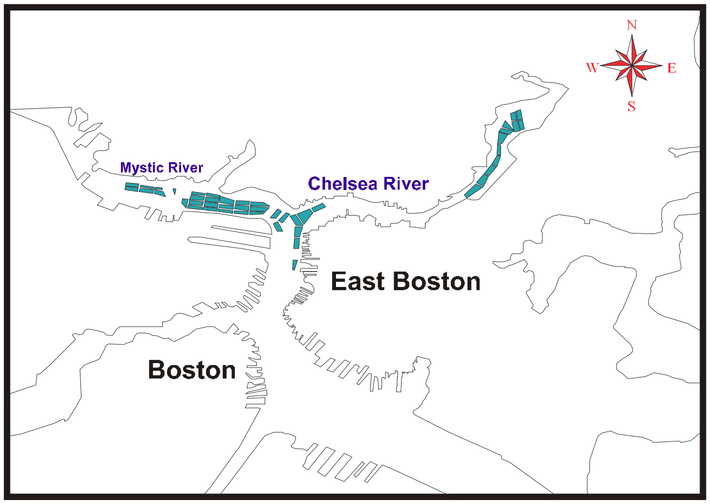


Figure 1-2. Proposed location of in-channel confined aquatic disposal cells

Table 1-1
Volumes of material to be dredged from Boston Harbor

Dredging Area	Suitable for Open-Water Disposal		Unsuitable	Total
	Parent (BBC)	Rock	Silt	
	(cy)	(cy)	(cy)	(cy)
Federal Channels	1,230,000	16,900	612,000	1,858,900
In-channel Cells*	1,300,000			1,300,000
Berths	95,000		181,500	276,500
Total	**2,625,000**	**16,900**	**793,500**	**3,435,400**

*Assumes 54 cells as in Figure 1-2.

1.2 Background to the Conley Terminal Project

For the first phase of the BHNIP, an in-channel CAD cell was constructed for containment of unsuitable dredged material from shipping berths at Conley Container Terminal in South Boston by Weeks Marine (Camden, NJ). The dredged, fine-grained sediments were disposed into the CAD cell and then capped with sufficient sand to cover the deposit with a 3 ft thick layer of clean, granular material. Dredging and disposal operations are summarized in the following sections.

1.2.1 Excavation of the CAD Cell

The CAD cell, located in the main ship channel south of the Inner Confluence near the East Boston shoreline (Figure 1-3), was designated Cell #2 in the FEIR/S for the BHNIP project. The cell was excavated below the maximum channel depth anticipated for Boston Harbor (40 ft MLLW) to an average total depth of 57.5 ft. First, the unsuitable maintenance material from the cell area was removed and stored in a barge. Cell excavation continued into Boston Blue Clay (BBC), a homogeneous, high strength greenish gray clay with low water content and low permeability (CDM 1991). Bathymetric surveys were conducted at all phases of cell construction and fill by the dredging contractor (Weeks Marine; ENSR 1997a). Bathymetric data were provided from a survey conducted by Weeks Marine following the dredging of the cell on 29 June 1997, and processed for graphical purposes by SAIC (Figure 1-4). Results showed an irregular topography, with depths of the cell floor that varied from minimum depths along the edges and in the north central part (54-56 ft), to maximum depths in the SW corner (62-64 ft). The approximate dimensions of the CAD cell were 500 ft long (north-south) by 200 ft wide (east-west).

1.2.2 Dredged Material Disposal Operations

Following the completion of the cell, the unsuitable maintenance material from both the surface of the cell and from Conley terminal was placed in the cell from 29 June to 5 July 1997. Six gravity cores were collected throughout the cell by the NAE on 9 July 1997. The recovered cores ranged from 3.3 - 4.5 ft, and results showed that the majority of the cores consisted of dark gray to black silt with a consistent sand component (13-32%), and were relatively watery (moisture content 80-160%). The bottom 3-10 in of each core consisted of gray clay (approximately 95% silt/clay) with low moisture content (approximately 40%), consistent with the basement BBC.

Four bathymetric surveys were conducted after disposal of the unsuitable material (6, 7, 8, and 14 July). Results from the first postdisposal bathymetry survey (6 July) showed a relatively uniform bottom within the cell with an average depth of 48.5 ft, resulting in an average dredged material thickness of 9 ft (NAE 1997). These results indicated that the material was relatively fluid and settled evenly over the cell floor. By the third survey (8 July),

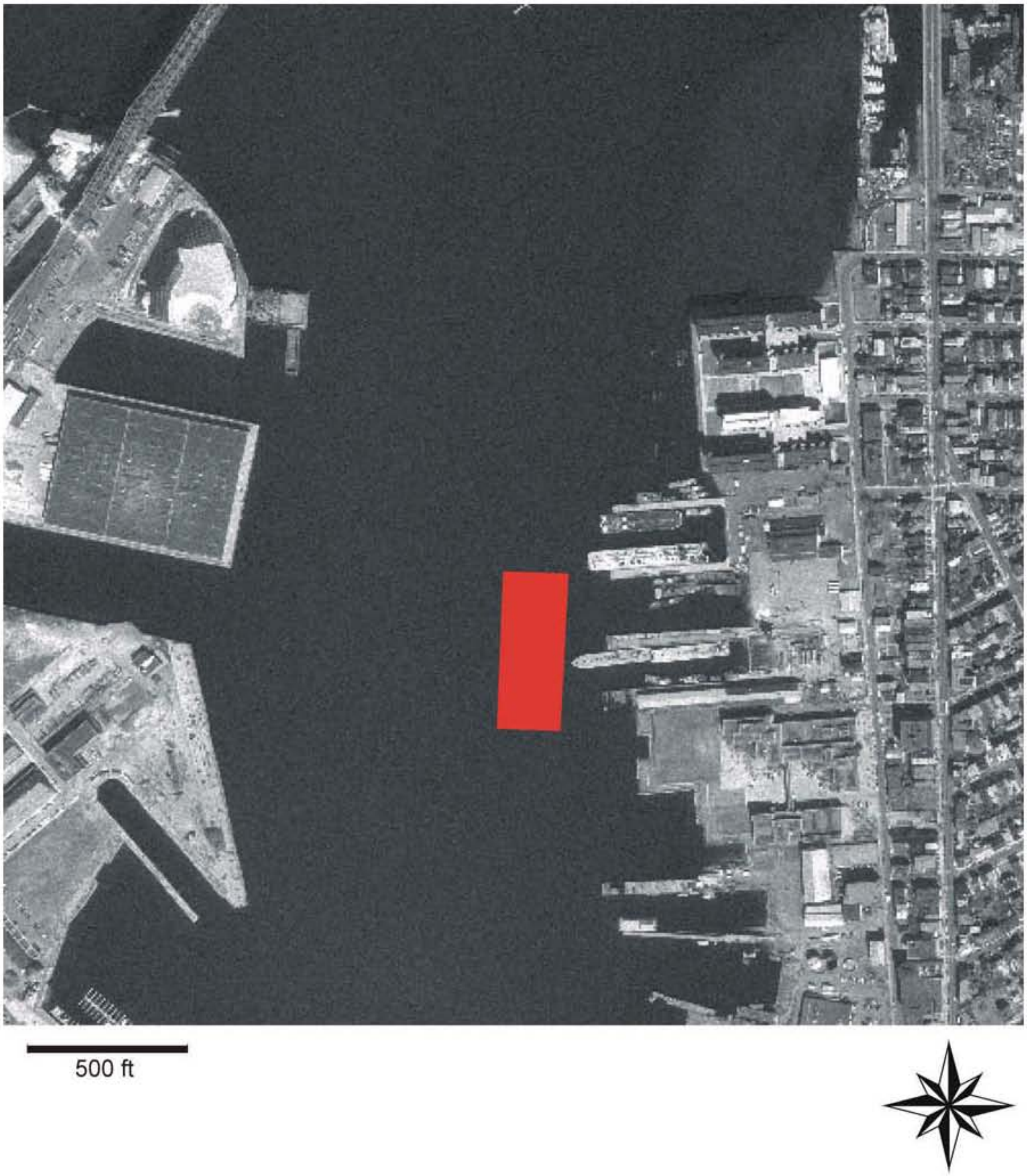


Figure 1-3. Location map of Phase 1 confined aquatic disposal cell.

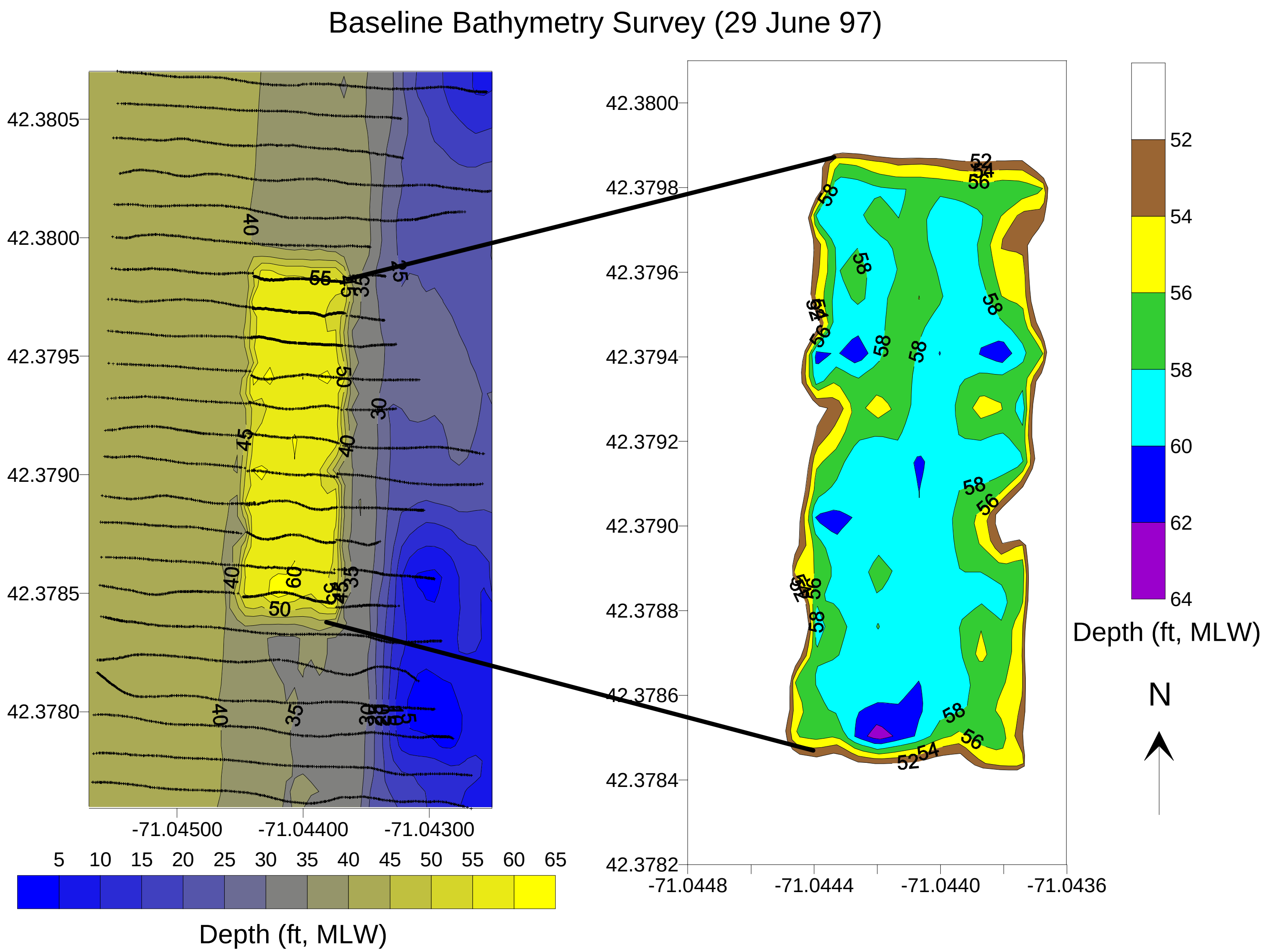


Figure 1-4. Bathymetry of cell area following excavation, prior to disposal (Weeks Marine, NAD 83).

the material had apparently consolidated approximately ½ ft. One week later (14 July), the range of depths in the cell was still relatively narrow (approximately 47.5 - 50 ft), but the deposit showed an average depth of approximately 49.5 ft, indicating an overall consolidation of approximately 1 ft over a period of one week.

1.2.3 Capping Operations

Capping operations were conducted from 14 July to 25 July 1997. Sand was slowly placed in the cell using a split-hull scow that was cracked open to slow the rate of material deposition. Disposal operations were conducted only during the outgoing tidal cycle. The scow was positioned using differential GPS (DGPS) in eight locations over the cell for a total volume of 14,800 yd^3 (Appendix; ENSR 1997a; NAE 1997). The sand was obtained from Ossippee Aggregate. Grain size ranges of the sand were reported as dominated by coarse sand (59%), with smaller fractions of gravel (15%), and fine-medium sand (23%; grain size classifications from Wentworth 1922).

A bathymetric survey was conducted after seven loads of material were placed with the scow oriented in north-south positions around the cell (Appendix). The bathymetric data showed a large mound in the center of the cell. Modeling conducted prior to capping using tidal current data predicted that the sand would spread towards the south (down current) during sand disposal. The preliminary bathymetric data showing a flat, well defined sediment surface was interpreted as indicating that the sand coverage in the southern end was well distributed (resulting from settling from the southerly tidal current), but the northern end of the cell was insufficiently covered. To rectify this, the contractor first unsuccessfully used a sweep bar to even the coverage, and then used a clamshell bucket to redistribute the material. Three 80-ft wide cuts were dredged from the central portion of the cell, and the material was placed in the northern end of the cell. Following this operation, a final barge of sand was placed in the cell; this scow was positioned along an east-west orientation in the northern section of the cell for the final cap disposal event. Weeks Marine conducted a final postcap bathymetric survey at the end of the project on 25 July 1997.

1.3 CAD Cell Monitoring Survey

Following completion of the cell, NAE and MassPort were planning on accelerating part of the monitoring required by the Water Quality Certificate. Coincidentally, samples collected as part of a separate research project suggested that part of the cell contained insufficient cap material (Shull and Fitzgerald 1997). Using this information and recommendations of the technical advisory committee (TAC), NAE planned and implemented an acoustic and coring survey as part of the Water Quality Certificate monitoring to assess the success of capping of the first CAD cell, and to provide a resource for operational and monitoring modifications for application to the remainder of the BHNIP. In addition to the acoustic and coring survey, a follow-up video survey was conducted by C. R. Environmental that confirmed some of the monitoring observations and provided visual evidence of the surface of the CAD cell.

The acoustic and coring survey was planned and implemented to assess the success of capping for two objectives of equal importance:

- to verify coverage of the first CAD cell and locate areas potentially requiring additional cap material;
- to provide a resource for operational and monitoring modifications for application to the remainder of the BHNIP.

The results of the monitoring survey presented here indicated that the majority of the CAD cell was capped with a highly variable thickness of sand, but that the southern end had little or no cap material. Postcap operations designed to level the sand cap appeared to have resulted in highly uneven sand coverage, and potentially served to enhance mixing of the cap and underlying dredged material. The acoustic data suggested that unsupported cell walls had become less steep, and provided evidence that consolidated blocks of material had fallen from the walls and settled on top of the dredged/cap material. Finally, the sediment placed in the cell (maintenance material and cap) had continued to consolidate, resulting in a topography that grossly mimicked the topography of the cell floor.

2.0 SURVEY METHODS

2.1 Navigation

Vessel positioning and data integration were achieved with SAIC's Portable Integrated Navigation Survey System (PINSS) using a Magnavox 4200 GPS receiver. One to 5-m DGPS accuracy was achieved to the GPS signals by applying corrections that were acquired from the U.S. Coast Guard differential beacon located at Portsmouth, NH, using a frequency of 288 kHz. During field operations, PINSS provided the navigator and vessel operator with range and bearing to selected targets (i.e., beginning and end of survey lines), signal quality, time of day, and selected data from environmental sensors including the fathometer, subbottom towfish, and side-scan sonar. Core station and survey lane positioning are discussed under the different survey operation descriptions below.

2.2 Vibracore Survey

2.2.1 Coring Operations

Target locations for the cores were selected in order to meet the goals of the monitoring survey. The primary goal was to collect cores in potential areas of concern as suggested by results of several surface sediment samples collected in the area of the cell (Shull and Fitzgerald 1997), including the southern end and the edges of the cell. In addition, bathymetric data collected during the various phases of the project were used to identify areas of potentially thinner cap. Therefore, the cores were collected beginning from the southern end of the cell, and moving to the central and northern end of the cell as the day progressed.

Long cores were collected with the goal of penetrating to the basement of the cell, which consisted of Boston Blue Clay (BBC). With penetration into the BBC, a complete stratigraphy (cap/dredged material/BBC) could be identified. The complete stratigraphy was essential to determine if cap material had displaced dredged material during operations. The final goal of core collection was to collect material to be used for estimates of speed of sound in the layers of sediment detected by the subbottom data.

The sediment vibracoring survey was conducted on 9 October 1997. Cores were collected using a two-vessel operation. PINSS navigation software and the GPS antenna was configured on a workboat supplied by Boston Line and Service Co., Boston, MA. Cores were obtained using a crane off of a 40 ft barge that was lashed to the workboat, and anchored in a 2-point configuration. Actual core locations were calculated as a distance and offset between the GPS antenna and the coring wireline.

An Aqua Surveys Inc. (ASI) electric motor vibracorer was used to acquire sediment core samples. The corer was deployed off of the barge using the crane, and lowered to the seafloor for vibracore collection. Two types of liners were used, flexible plastic liners that were processed during the survey, and hard Lexane liners (internal diameter of 3.5 in) that were transported to a shore-based core processing facility (Section 2.2.2). Replicate cores (one with a soft liner, one with a hard liner) were collected at each station. A variety of core catchers and nose cones were used throughout the coring day to maximize sediment recovery. In addition to personnel from SAIC, ASI, and Boston Line and Services, two Massachusetts Institute of Technology (MIT) SeaGrant Program students were on-board, as well as the independent observer (IO, ENSR) for the Massachusetts CZM.

2.2.2 Vibracore Collection and Processing

Sediment cores were acquired at a total of seven stations (Table 2-1). Two replicates were collected at each station from CAD-1 through CAD-5. Replicate A from each was collected in a flexible liner and processed on-board, and replicate B was collected in a hard liner and relocated to a shore-based core processing facility. The final two core locations, CAD-6 and CAD-7, were located in areas of thicker sand as suggested by the several feet of sand coating the recovered barrel. Recovery of 6A was low and a loss of material was indicated, so two soft liner cores were collected at this station (CAD-6A, 6B). Two cores became stuck in the sediment, so that no core was recovered at CAD-6C and CAD-7A.

Immediately following retrieval of the vibracore at each station, the flexible core liners were placed in a core cradle that was pre-marked with a scale interval (cm), being careful to keep the core oriented (top to bottom). The soft liner was split open with a utility knife, and the core catcher was placed at the bottom of the core. Cores were described and photographs were collected every 20 cm of the core. Samples were collected by MIT student observers.

The replicate cores collected with a hard liner were removed from the core barrel, carefully capped to prevent loss of sediment and/or water, marked with core numbers, and "top" and "bottom" labels on the core, and stored horizontally for transport back to laboratory coring facilities. Several cores were stored vertically for several hours because the top of the core consisted of very fluid mud, and it was difficult to determine the boundary of the sediment/water interface. After settling, these cores were re-cut at what was determined to be the interface.

Cores were transported to the coring facilities at the Graduate School of Oceanography, University of Rhode Island in Narragansett, RI. They were stored horizontally in a core refrigerator for 4-7 days prior to processing. Cores liners were split longitudinally using the GSO's core splitter which uses two razors to score the outside of the liner. The caps were cut using a utility knife, and then a piano wire was used to split the core into two longitudinal halves. One half was described, and eight samples were

Table 2-1

Core Data Summary

Core Name	Total Length (cm)	Liner Type	Latitude	Longitude	Top (cm)	Bottom (cm)	Unit
CAD-1A	165	soft	42.37904	-71.04436	0	35	DM
					35	60	Sand
					60	80	Mixed
					80	165	DM
CAD-1B	134	hard	42.37902	-71.04442	0	12	DM
					12	22	Sand
					22	37	Mixed
					37	56	DM
					56	73	Mixed
					73	134	DM
CAD-2A	165	soft	42.37893	-71.04449	0	105	DM
					105	165	BBC
CAD-2B	109	hard	42.37895	-71.04448	0	15	DM
					15	29	Mixed
					29	72	DM
					72	109	BBC
CAD-3A	210	soft	42.37863	-71.04383	0	155	DM
					155	210	BBC
CAD-3B	241	hard	42.37869	-71.04395	0	160	DM
					160	241	BBC
CAD-4A	180	soft	42.37863	-71.04408	0	135	DM
					135	180	BBC
CAD-4B	144	hard	42.37869	-71.04408	0	144	DM
CAD-5A	95	soft	42.37927	-71.04391	0	28	Sand
					28	35	DM
					35	50	BBC
					50	95	DM
CAD-5B	210	hard	42.37925	-71.04400	0	26	Sand
					26	184	DM
					184	210	BBC
CAD-6A	45	soft	42.37956	-71.04406	0	30	Mixed
					30	45	DM
CAD-6B	100	soft	42.37958	-71.04385	0	20	Sand
					20	80	Mixed
					80	100	DM
CAD-6C		hard	42.37960	-71.04379	Core not recovered.		
CAD-7A		long core	42.37958	-71.04407	Core not recovered.		

DM = Black silty clay or clayey silt, industrial smell, assumed to be dredged material.

Sand = Brown medium to coarse sand, assumed to be sand cap.

Mixed = Black medium to coarse sand with silt component, assumed to be mix of above.

BBC = Boston Blue Clay.

collected for potential future analysis of grain size. The other half was photographed and archived in a refrigerated coring facility for potential future evaluation.

2.3 Acoustic Survey Operations

Survey operations were conducted aboard the survey vessel *Cyprinodon* (CR Environmental) on 10 October 1997. Those involved in the survey included SAIC, the IO, one MIT student, and two pilots from CR Environmental. The PINSS navigation system was used for all navigation. Survey lanes were designed using the estimated locations for the four corners of the cell (ENSR 1997a). Survey lanes for bathymetry (Section 2.3.1) and subbottom (Section 2.3.2) were planned using the PINSS survey planning module to cover the area of the cell and one survey lane outside in all four directions. PINSS computed towfish position for the subbottom and side-scan sonar fish using a cable layback calculation and provided this position to the data collection system. Side-scan sonar operations were conducted following the bathymetry and subbottom surveys on the same day (Section 2.3.3).

2.3.1 Bathymetric Data Collection and Analysis

Depth soundings were collected with an Odom DF3200 Echotrac® survey echosounder using a 208 kHz transducer with a 3° beam angle. The Odom simultaneously displayed water depth data on a chart recorder and transferred the digital sounding data to the PINSS. The echosounder collected 6-8 soundings per second and transmitted an average value to the PINSS at a rate of one sounding per second. Depth soundings were collected along pre-configured survey lanes with 15 meter spacing in both E-W (14 lanes) and N-S (8 lanes) orientations.

A Seabird Electronics, Inc. Model SBE 19-01 conductivity-temperature-depth (CTD) profiler was used to acquire a vertical profile of sound velocity in the water column during the day. These data were used to correct the bathymetry data for speed of sound during post-processing.

Using SAIC's Hydrographic Data Analysis System (HDAS), bathymetric soundings were edited for outliers and corrected for sound velocity, transducer draft, and tidal variation. Tidal data from the Boston Harbor tide station (station #8443970 located near the Northern Avenue bridge) were obtained from the NOAA Ocean and Lakes Levels Division (OLLD) web-server (http://www.olld.nos.noaa.gov/). Following the application of all correctors, the depth soundings were spatially averaged to produce a grid of cells. The gridded bathymetric data were used to produce the various topographic maps included in this report.

All graphics have been plotted in NAD83 latitude/longitude coordinates. Depth values are relative to Mean Low Water (MLW) in order to compare with data provided by Weeks Marine. Water depths are indicated with specific contour intervals noted on the figures. Both contour plots and three-dimensional relief plots were produced using Golden

Software's Surfer® program; a vertical exaggeration has been added to the 3D plots shaded relief in order to highlight small topographic gradients.

2.3.2 Subbottom Data Collection and Analysis

High resolution subbottom profile data were acquired with an Edgetech X-Star™ Model 216S Full Spectrum Digital Subbottom Profiler. Subbottom profile data were collected simultaneously with bathymetry, and therefore along the same survey lanes (Section 2.3.1). Subbottom seismic profiling is a standard technique for determining the presence of sediment layers below the sediment/water interface. The X-star system emits a swept-frequency pulse; the frequency of the transmitted pulse changes linearly with time, and is therefore called a chirp system. The depth of penetration and the degree of resolution is dependent on the frequency and pulse width of the seismic signal, and the characteristics of the penetrated material.

The narrow beam (13°) transducers of the X-Star system, mounted in a towfish, were lowered using the winch aboard the survey vessel *Cyprinodon*, and trailed the vessel by approximately 15 m. The X-Star system generated a frequency-modulated pulse that was swept over an acoustic range of 2 to 10 kHz during the subbottom survey. The pulse rate was set to 6 pulses per second for optimum performance of the output devices. At 6 pulses per second, traveling at an average vessel speed of 4-5 knots, a subbottom measurement was acquired every 34-43 cm along the vessel track. The return signals were transmitted via a data cable through an analog to digital (A/D) signal converter to an on-board Sun Sparc II Workstation for data display and archive. Data were stored on Exabyte tapes, and continuous profile data were printed on an Alden thermal printer.

Penetration of sound in sediment is both a function of system frequency and the impedance contrast between the water column and sediment. Acoustic impedance, the product of velocity and density of sound in a layer, is also affected by differences in surface roughness, porosity, and grain size, among other factors (Hamilton 1970; LeBlanc et al. 1992). In general, sound penetrates further into fine-grained sediment because the impedance of high-water content silt and clay is closer to that of the water column. The ability to detect subbottom layers is similarly dependent on the acoustic impedance contrast between sediment layers. Subbottom has been used to accurately map the lateral and vertical coverage of a sand cap over dredged material because of the contrast between the sand cap and underlying fine-grained dredged material (e.g., Murray et al. 1994a).

Subbottom layers were not digitized due to the difficulty in identifying continuous reflectors below the surface of the dredged material. The thermal paper printouts were scanned and several representative sections are included in this report. Although depths are shown in the figures, these are not reliable for estimating actual layer thicknesses or water depth. First, the depths are estimated using 1500 m/s as the speed of sound; the speed of sound will be higher in sand and the well-consolidated, homogeneous BBC (approximately 1700 m/s; Hamilton 1971). In addition, one lane was digitized to compare the subbottom depths with bathymetry, and the scale printed on the subbottom cross section was found to be inaccurate.

2.3.3 Side-scan Data Collection and Analysis

A Marine Sonics PC Scan side-scan sonar system was used for side-scan sonar data collection. This system is a single frequency (300 kHz) system that collects digital data directly to a PC-compatible computer. Bottom coverage was 100% for each pass. Several N-S passes were made with the cell on one channel, and the best image was processed using Adobe Photoshop® to enhance the visual resolution and add annotations. The image was not geo-registered, so that the aspect ratio of the cell (width vs. length) has been compressed in the vertical (N - S) direction because of survey vessel speed.

2.4 Videosled Survey

On 3 December 1997, CR Environmental, Inc. (CR) performed a towed video sled survey at the CAD in Boston Harbor to demonstrate the effectiveness of using high resolution underwater video in detecting the coverage of the sand cap. The CR Underwater Video Sled is equipped with a high resolution Sony Hi8 video camera, and two 250 watt Deep Sea Power lights with variable light output. The system has a 100 meter cable, portable monitor and VCR, and isolated power for shock protection.

The operations were performed from CR Environmental's 32-foot survey vessel *Cyprinodon* equipped with a hydraulic winch, A-frame and a large enclosed pilot house for survey equipment. A Northstar DGPS and the Coastal Oceanographics' HYPACK navigation software package were utilized to provide the boundaries of the confined disposal cell and a pre-programmed set of tracklines. The layback of the video sled to the navigation antennae was estimated to be approximately 50 ft. By examining the real-time video display, the vessel captain adjusted the towing speed and the pay out of the tow cable to achieve the best towing angle and bottom coverage. Two north-south transects were made through the disposal cell. Operations were performed at slack low tide and water visibility was estimated as 5 to 10 ft.

3.0 RESULTS

Results from the monitoring surveys are summarized in this section. First, the surface topography and texture of the cell was measured using side-scan sonar (Section 3.1) and bathymetry (Section 3.2). The video data were useful in corroborating the surface sediment topography and recolonization, and are incorporated throughout the presentation of results. Next, the information gathered that documented layer thicknesses within the cell, including core (Section 3.3) and subbottom (Section 3.4) results, is presented.

3.1 Side-scan Sonar Results

The side-scan sonar data over the cell area showed distinct acoustic regions of the cell (Figure 3-1). The southern end of the cell consisted of a uniform low reflectance area interpreted as a flat surface. Strong backscatter from the central and northern portions of the cell indicated a harder bottom, and a rough, uneven topography. Throughout the central portion of the cell, clamshell bucket markings were noted clearly, with dark shadows indicating strong changes in topography that we termed artificial “sand waves” for further discussion. Two of the three dredge cuts (NAE 1997), aligned east-west, showed individual ridges caused by clamshell bucket passes. The third most northern cut was partially obscured because of the sand that was disposed in the northern part of the cell after dredging (Section 1.2). Spud marks from the dredge were noted along the northern edge.

Although the eastern edge of the pit was in shadow, there was a bright spot in the lower southeast corner indicating a topographic feature, consistent with bathymetric results (Section 3.2). This hard acoustic return (dark crescent) suggested that it was present above the ambient sediments to rise above the edge shadow, and hard enough for a strong acoustic return. Further interpretation of this feature is discussed below.

The final distinctive feature of the side-scan sonar results was the scalloped edges of the cell. The shape of the cell walls still appeared to reflect much of the original clamshell markings from the excavation. Although sequential bathymetric surveys indicated some changes in the cell wall orientation, the side-scan results indicated that the BBC was firm enough to retain much of the original dredged topography.

3.2 Bathymetric Results

Weeks Marine provided two bathymetric datasets for evaluation of the survey data, including the survey conducted after the excavation of the cell prior to any disposal (predisposal survey; 29 June 1997), and the final postcap survey conducted at the end of the project (25 July 1997). The surveys were conducted using different survey parameters: the predisposal survey was conducted over a large area with east-west lanes, at 50 ft lane

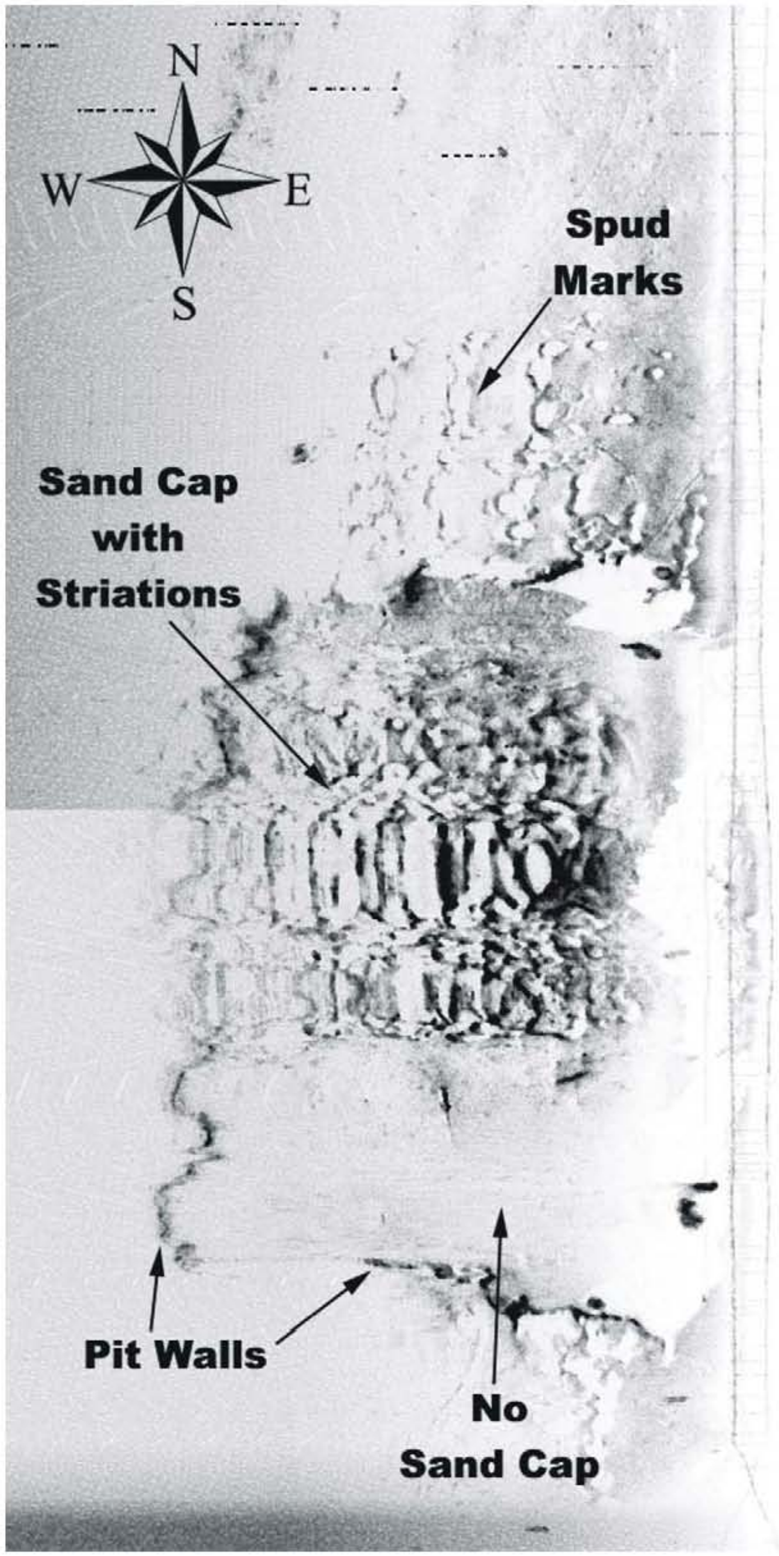


Figure 3-1. Side-scan sonar image of surface of cell.

spacing (Figure 1-4). The postcap survey was conducted at higher spatial resolution (25 ft lane spacing), but over a smaller area. The October bathymetric survey collected by SAIC was conducted using a 15 m lane spacing (approximately 45 ft), and over both east-west and north-south lanes. Because of the different survey parameters, calculating differences in depth by the normal procedure of subtracting equal grids over replicate areas was not reliable, so therefore, qualitative differences between the surveys are discussed below. In addition, comparing the depths collected around the cell (that presumably did not change) showed variation in depth of ±2 ft among all of the surveys. This variability is due to different survey parameters, different vessels (with potentially different depths of the transducer), and potential error due to sea state. These errors would be much reduced, and allow for electronic survey comparison, if the surveys were conducted using exact replicate survey parameters and equipment. All three surveys have been corrected to MLW for comparison purposes.

The predisposal baseline bathymetric survey showed ambient water depths ranging from 5 to 40 ft in the area around where the cell was excavated (Figure 1-4). Water depths in the cell itself prior to disposal ranged from 56-64 ft MLW. The cell walls were fairly irregular, showing scalloping along the edges remnant from the clamshell excavation. The deepest part of the cell was in the southwestern corner, and there were several topographically higher areas along the edges and in the center of the cell.

The postcap survey conducted after completion of the project (Figure 3-2a) showed steep, almost vertical, western and eastern cell walls (lanes were not extended to the southern and northern ends of the cell). Depths ranged between 46-50 ft, with the shallowest depths in the center of the cell consistent with the areas of dredge-induced sand waves shown by the side-scan sonar data. The southern end of the cell was relatively flat (49-50 ft). The average thicknesses of dredged and cap material, therefore, was approximately 10 ft, with a range of thicknesses over the variable topography of the cell floor of approximately 6-14 ft.

The survey conducted in October by SAIC resulted in somewhat less steep cell walls, and a more irregular topography on the floor of the cell (Figure 3-2b). Overall, the bottom of the cell appeared to increase in depth by 1-4 ft (i.e., the bottom of the cell was deeper) over most of the cell during the period between the July and October postcap surveys. Some areas north and south of the sandy peaks from the final postdisposal survey appeared to remain relatively constant between the two surveys (49-51 ft, blue areas). Considering the approximate 1-2 ft of error between the two surveys, the maximum consolidation that could be confidently estimated was at least 2 ft in the far southwestern corner of the cell and in the center of the cell below the thick sandy peaks. Conservatively, this resulted in an overall consolidation of 10-20% since the final postcap survey, concentrated in the dredged material as sand is relatively incompressible. Including the consolidation prior to capping, the total consolidation of the dredged material ranged from 20-40% during the four months past the initial capping. This value was

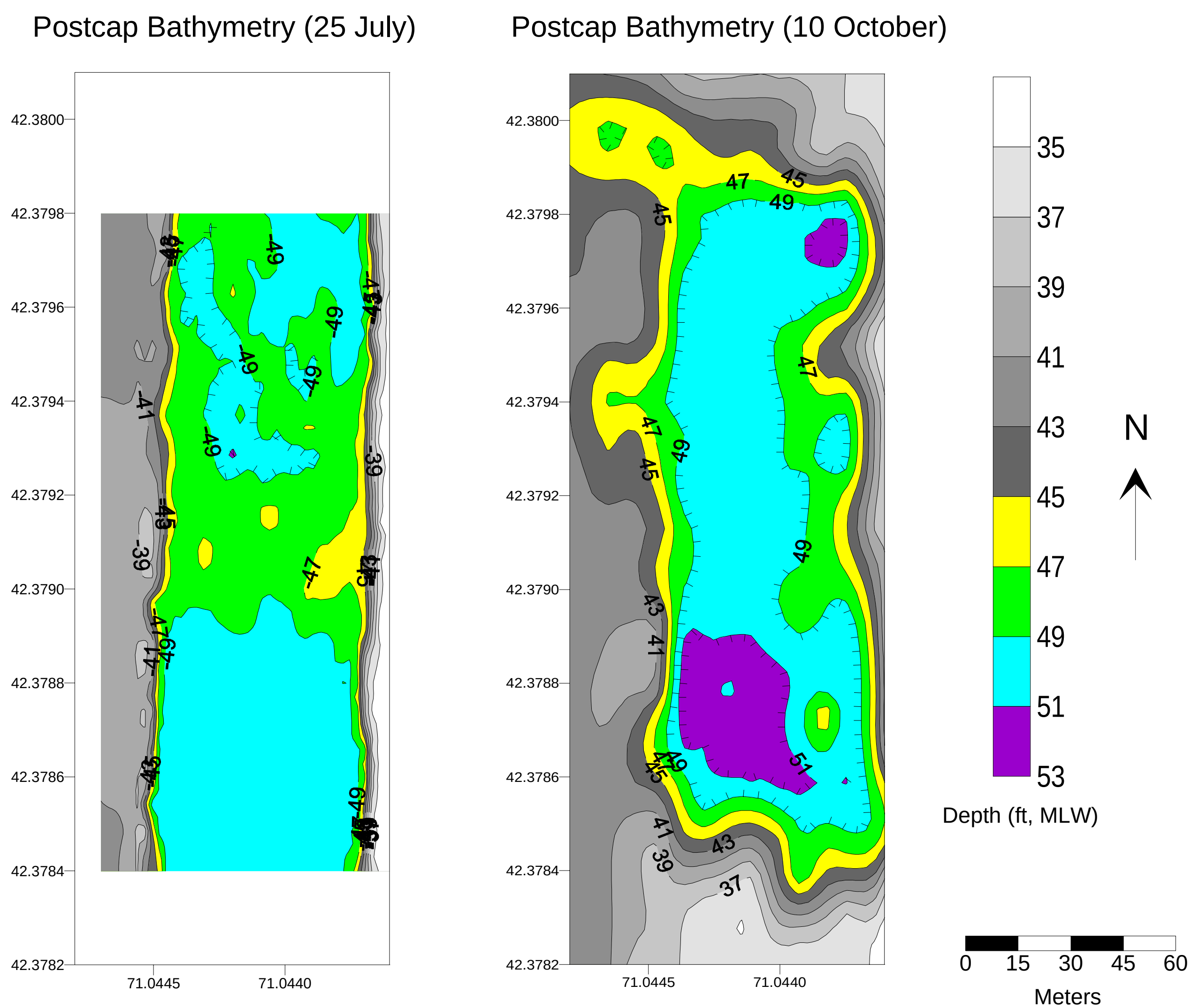


Figure 3-2. Bathymetry of cell area after completion of capping in a) July (Weeks Marine); and b) October 1997 (SAIC; NAD 83)

within a reasonable range, as prior studies of dredged material have shown volume reductions of up to 50% for fine-grained materials attributable to consolidation (e.g., Poindexter-Rollings 1990).

Viewing the data from a three dimensional perspective, the bathymetric data suggested that the slope of the cell walls had become less steep over the 10 weeks between surveys (Figure 3-3). Several areas appeared to show slumping of the wall itself (note far northwestern corner). Sequential side-scan sonar datasets collected during the disposal phase also suggested the outline of the cell wall changed through time (ENSR 1997a). Because the clamshell dredge that was used to create the cell left a sawtooth pattern along the cell walls, it is likely that the dredging process weakened parts of the wall and material sloughed or calved from the walls into the cell. Because Boston Blue Clay is relatively firm (e.g., CDM 1991), this process will likely not continue indefinitely, but until a stable slope for BBC material has been reached. The force of ship propellers along the piers may have also tended to weaken the unsupported walls, especially along the eastern wall of the cell.

An anomalous topographic peak in the southeastern corner of the cell was noted several feet higher than was measured in the previous postcap survey in July (Figure 3-2). The location of the peak was consistent with the hard reflector seen in the side-scan sonar data, and was also seen in the subbottom results (Section 3.4). As discussed below, this deposit may be material that ended up overlying the uncapped dredged material, possibly a remnant of material fallen from the cell wall.

Two N-S transects of raw depth soundings from the October survey (not gridded data) were extracted from the data to produce cross sections of bathymetry. Lanes 6 (central cell) and 7 (eastern cell) were selected (Figure 3-4). The data were plotted to show the transition from the rough surface associated with the re-dredged sand cap to the smooth surface noted in side-scan sonar data. The results showed that the rough, uneven surface slopes down to the smooth surface, and the transition is approximately ¼ of the distance from the southern end of the cell (Figure 3-5). Note that north and south are reversed between Lanes 6 and 7, and are plotted relative to the direction of the boat transit. The difference in topographic expression was investigated further with vibracore data.

3.3 Vibracore Results

A total of 12 cores at six stations were recovered, with core lengths ranging from 45-241 cm (Table 2-1; Figure 3-4). In all, a total of 14 cores were attempted; two core liners became stuck (Cores CAD-6C, 7A; Figure 3-4). Cores collected from CAD-2A and 2B appeared to be outside of the cell. The recovery of 72-105 cm of apparent dredged material, however, suggested that the cores were actually collected in the cell. One of the CAD-2 cores showed evidence of BBC on the top drive motor, indicating the core was

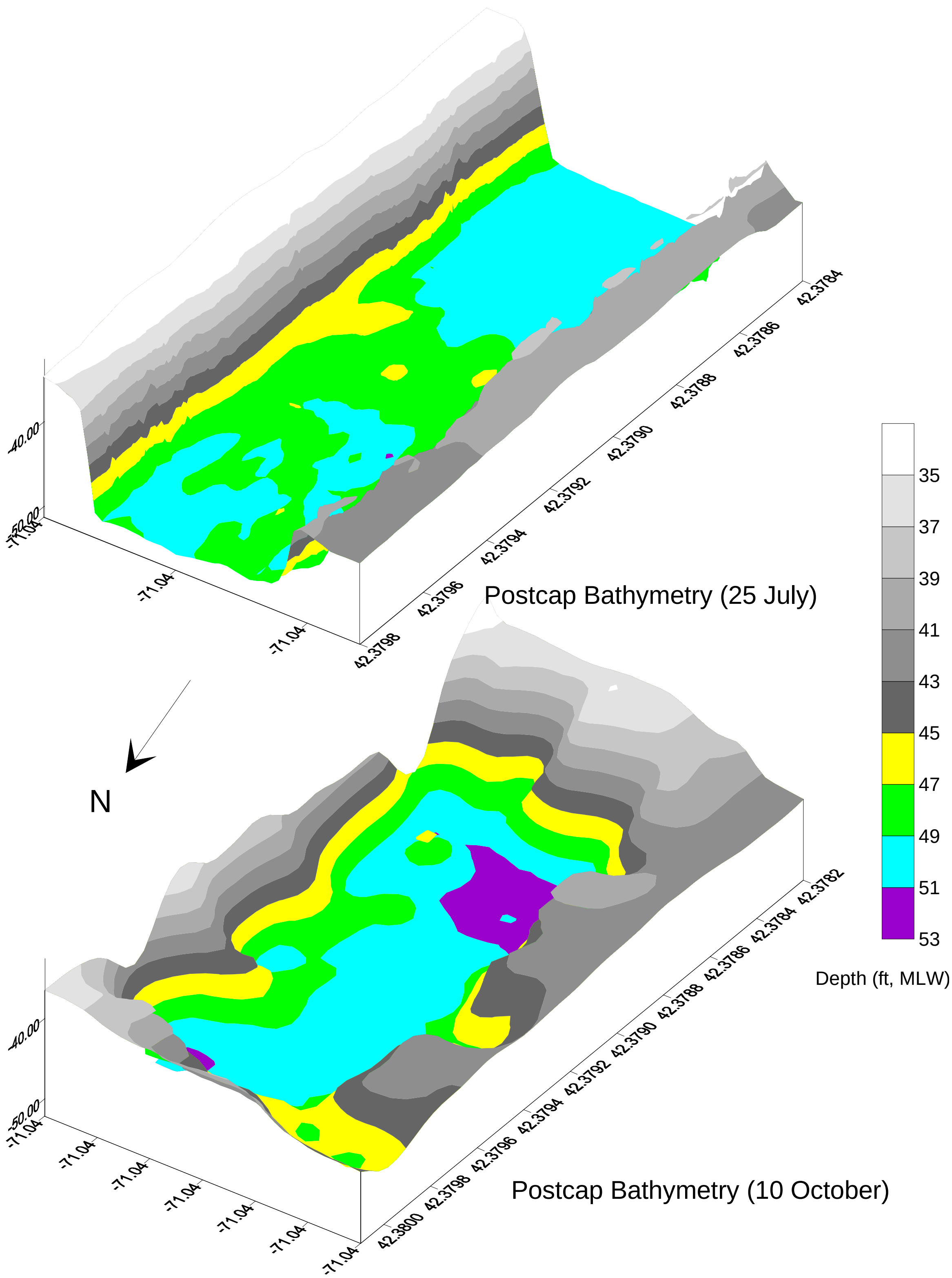


Figure 3-3. Three-dimensional view of postcap cell bathymetry in a) July (Weeks Marine); and b) October 1997 (SAIC); view towards the southern end of the cell.

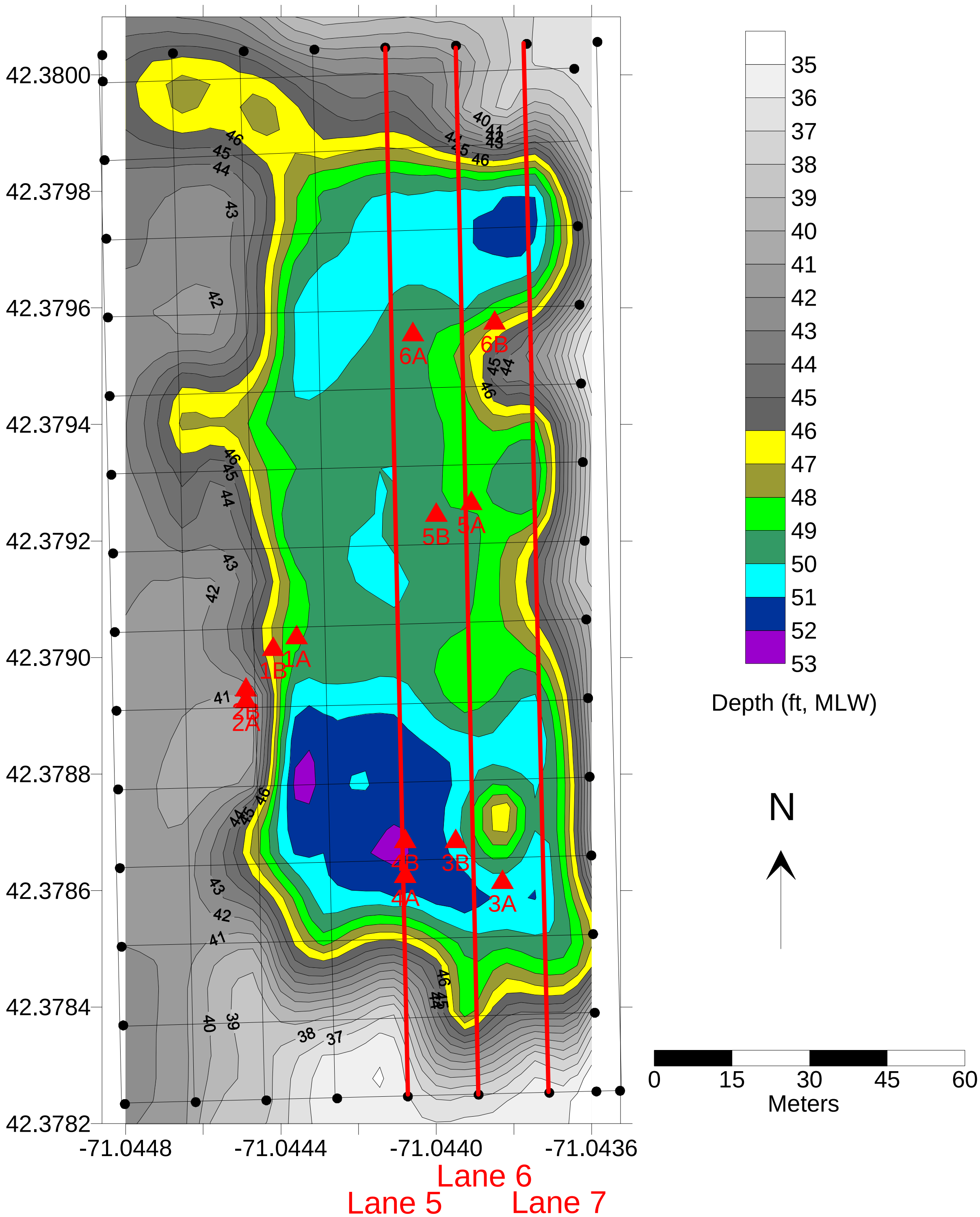
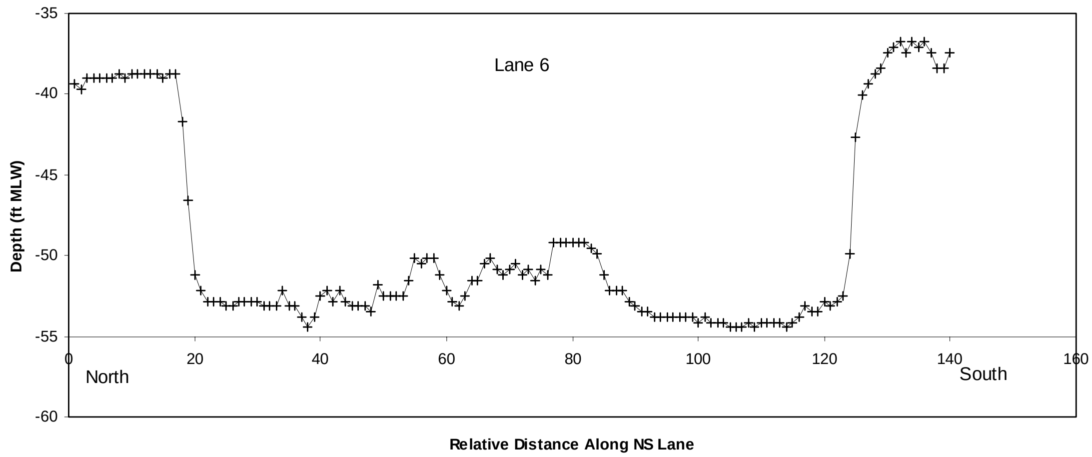


Figure 3-4. Postcap bathymetry of cell collected in October 1997 (NAD 83) showing locations of cores and three cross sections.



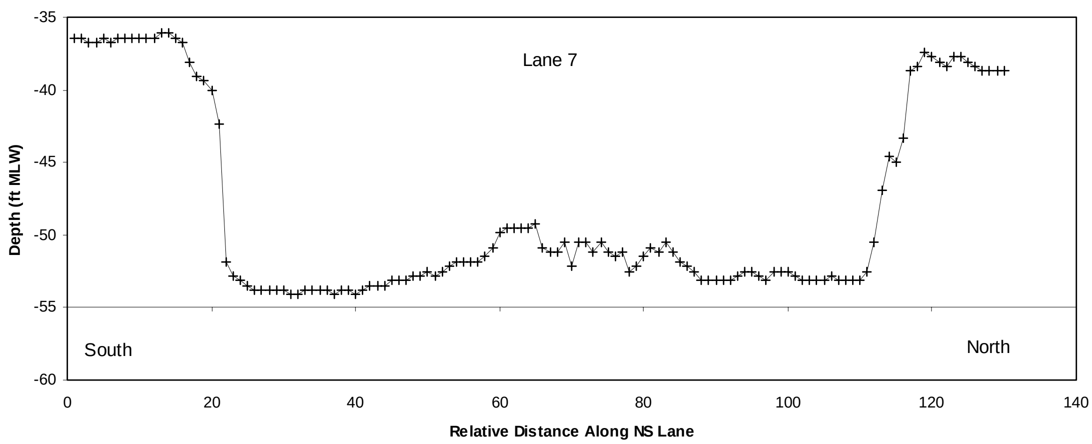


Figure 3-5. Bathymetric transects along north-south lanes 6 and 7 (see Figure 3-4).

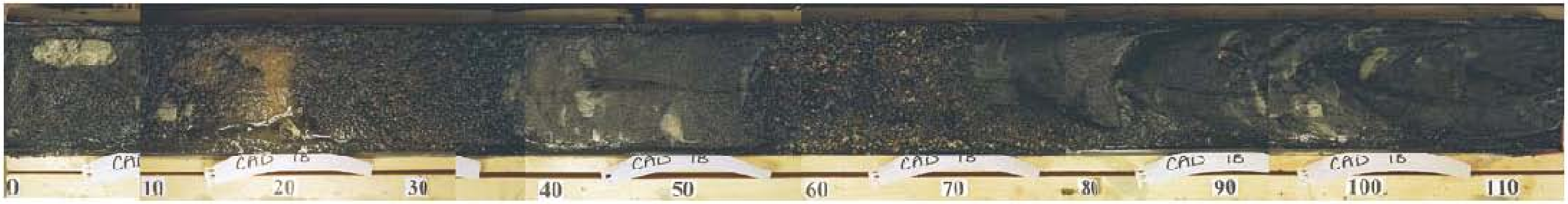
collected very near the cell wall. Core recovery was greater in the cores collected throughout most of the day in the southern area and along the edges where there was little to no sand. The outside of the barrels of the last two cores which were not recovered because of stuck core barrels (6C and 7A) returned covered with sand, indicating that core recovery was hampered by thick sand intervals.

There were three distinct units recovered in the cores. The most common was a black silty clay/clayey silt with a strong hydrocarbon odor. The texture ranged from very watery silt to highly consolidated, low water content firm clay. The second end member unit was a brown medium to coarse sand. Finally, several cores penetrated into a continuous interval of well consolidated BBC. When the core penetrated to refusal into the BBC material, we assumed the core had penetrated into the bottom of the cell. Comparing total dredged material thicknesses as recovered in the cores with bathymetry suggested that core recovery was hampered by loss or compaction of dredged material during the coring process. In Table 2-1, a fourth unit was described as “Mixed,” which was commonly medium to coarse sand with a component of black watery silt material, apparently from the dredged material unit. These units were described in order to estimate the potential magnitude of mixing between sand and dredged material.

The dredged material unit was mottled with BBC in many cores, and in one core (CAD-5A), a solid 15 cm interval of BBC was recovered above the dredged material. The presence of BBC in the dredged material was consistent with reports from on-site inspectors. In addition to BBC, discrete sandier intervals were also noted in the dredged material. Data from cores collected prior to capping indicated that the dredged material consisted of up to 30% sand. For classification purposes, if the sand was a minor component of the dredged material, and disseminated throughout an interval, it was classified as dredged material. If the unit was dominated by medium-coarse sand but was infused with black watery silt material, it was classified as mixed.

The two replicate cores collected at CAD-2, CAD-3, and CAD-4 recovered no sand, and all but CAD-4B were cored to refusal in BBC. These results indicated that no sand was placed in the southern section of the cell. Cores CAD-1A and 1B (Figure 3-6) were collected near the sand/mud boundary, and the results indicated that, near the sand cap boundary, limited mixing of sand and mud resulted in interleaved layers of sand and mud in these cores. The subbottom data also indicated that a wedge of sand near the edge of the sand cap may have been intermixed with the more fluid mud, hampering acoustic differentiation between these lithologies (Section 3.4).

Cap thicknesses among the four cores where sand cap was clearly recovered at the top of the core (CAD-5A, 5B, 6A, and 6B) ranged from 20-28 cm. In cores CAD-5A and 5B, the boundary between the sand cap and the underlying material was sharp and clearly delineated due to the presence of consolidated clays below the sand (Figure 3-6). The stratigraphy was uncertain at core CAD-6A (45 cm of recovery), because material was lost



Core CAD1-B

Core CAD5-A

Core CAD5-B

Figure 3-6. Photographs of selected cores, scale in cm.

from the bottom of the core during operations. Recovery was better for core CAD-6B, where 20 cm of sand overlay 60 cm of mixed sand and dredged material, indicating a maximum recovered thickness of mixed material of almost 2 ft.

The loss of 6C and 7A with evidence of thick sand so close to 6A and 6B indicated a high variability of sand thicknesses. Coring data indicated that mixing of sand and mud of up to 2 out of 3 ft occurred in areas of highly variable sand thickness. This mixing was probably enhanced, and possibly caused, by the force applied to the sand during postcap dredging operations. The consolidation state of the dredged material prior to capping, as shown in Cores CAD-5A and 5B, however, contributed to the presence of a clear sand/dredged material interface. The potential for increasing the consolidation state of the material prior to capping is discussed further in Section 4.0.

3.4 Subbottom Results

Two north-south lanes (Lanes 5 and 7) were selected to show the results of subbottom data (Figure 3-4). Lane 5, through the central portion of the cell, was representative of most of the subbottom results (Figure 3-7). The view is a cross section through the sediment, showing acoustic reflectors below the sediment/water interface where changes in lithology (acoustic impedance) occurred. As discussed in the Methods, the depth markings on the subbottom records do not accurately represent actual depths or thicknesses of the cell lithologies.

Outside of the cell area, a series of horizontal reflectors throughout the harbor resulted from the natural geology of Boston Harbor. These sediments are a combination of BBC and glacial till (material left after a glacier melts) that were deposited in a nearshore marine environment that existed in the Boston area during an interglacial period about 18,000 years ago (CDM 1991 and references therein).

In the area of the cell, much of the subbottom acoustic information reflective of the natural geology of the material was lost, indicating no sound penetration to depths below the dredged and cap material. This result is not surprising, as prior acoustic work over dredged material has indicated that the acoustic signature of dredged material is distinct because of sound loss due to scattering and refraction, indicative of the heterogeneous nature of the deposit (Bokuniewicz et al. 1976; Schock et al. 1992; Murray et al. 1995). Two distinct acoustic regions were consistent with side-scan sonar data. In the southern area of the cell, the top reflector was a strong, smooth reflector indicating a smooth surface with little topography to scatter sound. The high amplitude of the reflector indicated either a harder surface (not borne out by coring data), or a very flat surface. Below this surface reflector, there was a very homogeneous layer as indicated by few internal reflectors, and there is a clear reflector from the base of the cell.

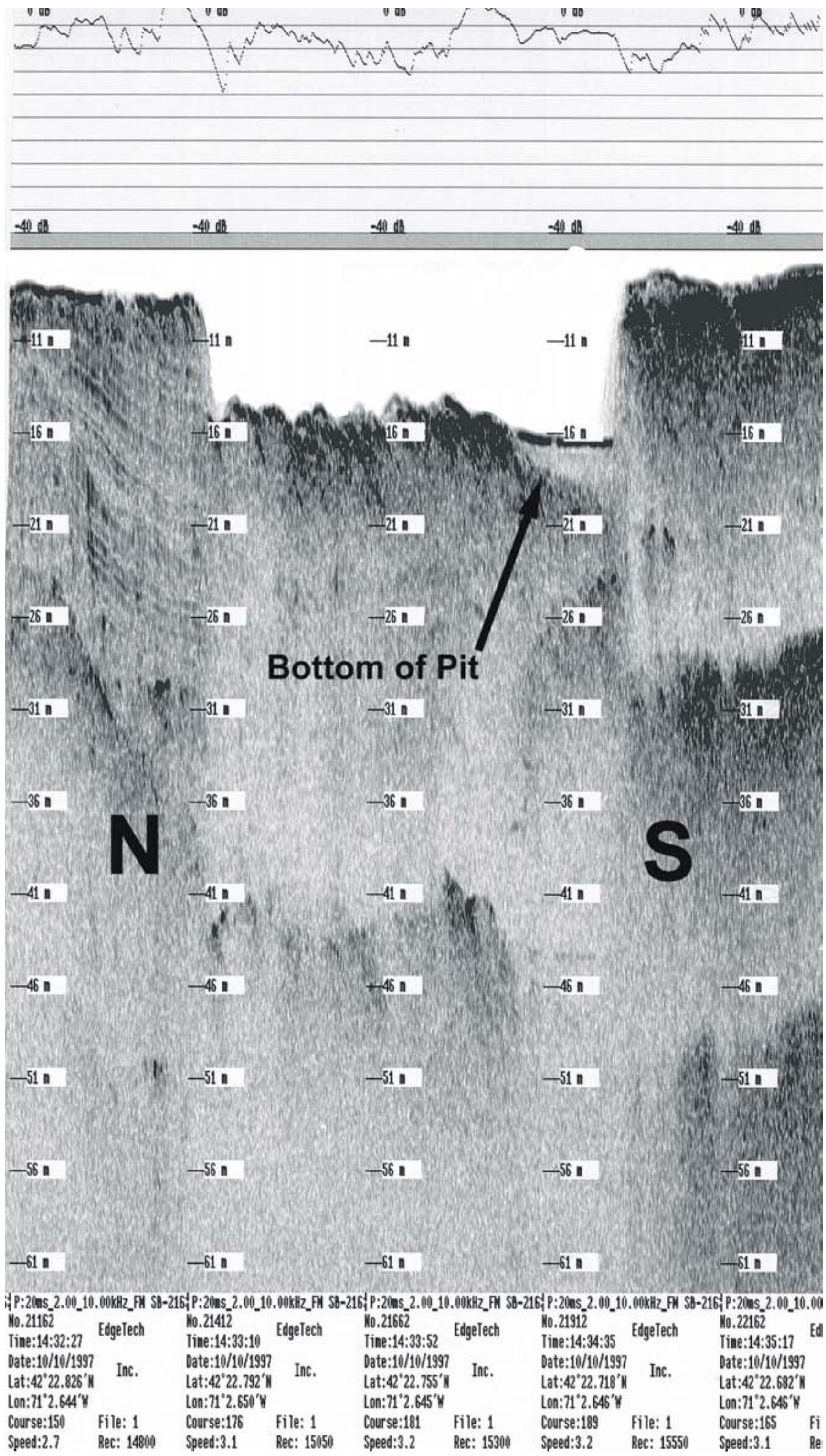


Figure 3-7. Subbottom profile of Lane 5 (see Figure 3-4).

In the central and northern portions of the cell, there was a marked change where the surface became highly irregular as the sound was reflected from the dredge marks shown by side-scan sonar data. Although the surface was very rough and uneven, the amplitude (strength) of the surface reflector was still strong, indicating a relatively hard surface consistent with sand. Below the surface, there was a series of discontinuous internal reflectors indicating a more heterogeneous deposit. Throughout this layer there were u-shaped reflectors that indicated refraction off of irregular deposits. The bottom of the cell was not a continuous reflector, most likely because most or all of the sound was lost in the sand-capped area. This is because at each acoustic boundary where sound was reflected or scattered within the sand deposit itself, less energy was left to continue downward penetration.

The subbottom data indicated that approximately 25% of the cell was uncapped. There was a transition zone between the sand-capped area, and the fine-grained, uncapped area in the south along the N-S cross section (Figure 3-7). Comparing results from cores CAD-1A and 1B near the boundary and the bathymetric transects, it was apparent that there is an interval of transition where sand and mud was interleaved. The reflector along the peak of sand at the southern end of the capped section appeared to dip down towards the south, and was overlain by the mud in that transition. Because the subbottom cross section shown are uncorrected for speed of sound, the transition area between the capped and uncapped portion of the cell should not be interpreted as the actual stratigraphy, as the speed of sound in the sand (and BBC) is faster than in the fine-grained, heterogeneous dredged material. Without digitizing and correcting for speed of sound, the data can still be used to make qualitative conclusions about the interval between the capped and uncapped areas. Because of the weight of the thick sand layer in the central portion of the cell, in combination with the force applied to the central sand cap by the postcap dredging operation, the boundary was most likely characterized by deformed layers of sand and mud.

The farthest eastern N-S lane (Figure 3-4), Lane 7, showed two interesting features (Figure 3-8). First, the cell bottom was a relatively continuous reflector below the cap and dredged material. This indicates that the material was more homogeneous, so that sound could penetrate further to the bottom of the cell. In the sand capped area, however, there was still no sand/mud reflector. Results from cores CAD-6B showed a thick mixed boundary between the sand and mud. These data suggested that the method of delineating cap thickness using subbottom will not be effective if there is a mixed zone that is greater than the depth resolution (wavelength) of the system. If there is a consistent sand/dredged material boundary (as in CAD-5A and 5B, Figure 3-6), subbottom will be more effective in determining cap thickness.

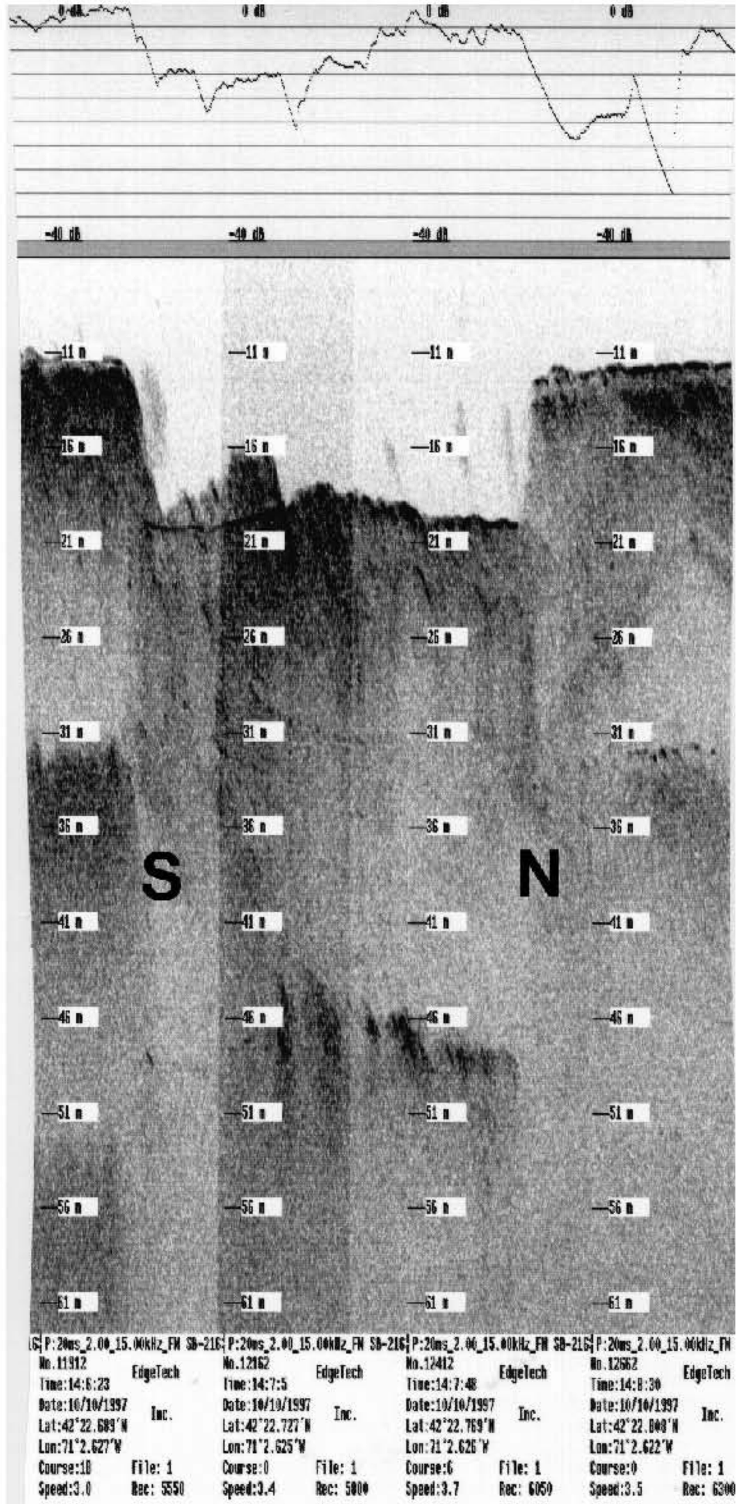


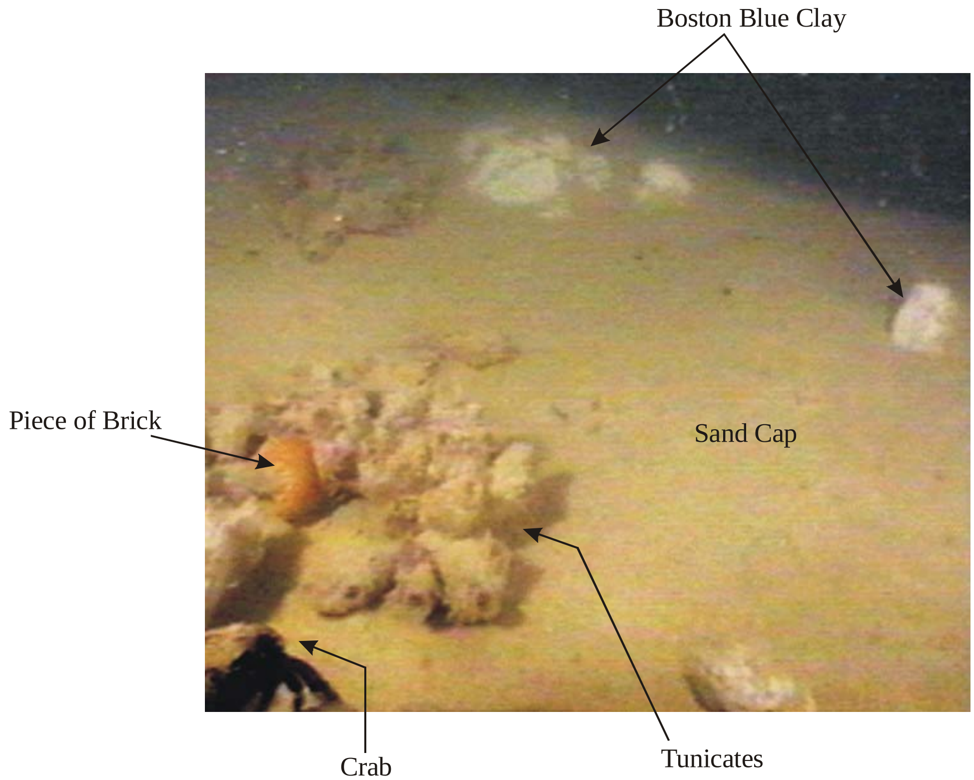
Figure 3-8. Subbottom profile of Lane 7 (see Figure 3-4).

Finally, the southern end of Lane 7 showed an apparent mound of material in the southeast corner of the cell overlying the uncapped mud with a clear acoustic reflector in between. This mound was consistent with the topographic peak that showed up in both the bathymetric and side-scan sonar data. This finding has important implications. The subbottom data were consistent with the bathymetric data that suggested material had settled on top of the dredged material after capping was completed. The fact that the material appeared to have settled on top of the uncapped material suggested that the bearing strength of the material had increased from July to October, and was potentially in an advanced state of consolidation that would increase the success of final capping of the material. Further geotechnical testing of the uncapped material by investigators at MIT will be continuing to address the issues of consolidation and bearing strength.

3.5 Video Results

The videosled survey that was conducted following the monitoring survey confirmed the acoustic data in two north-south transects. The video data provided clear evidence of sand in the north and central portions of the cell, showing tunicate-covered sand waves with dramatic topography (Figure 3-9). Audio data provided additional evidence as the sled was dragged and scraped through the sand. The transition from the sand cap to the uncapped dredged material was apparent primarily from the additional resuspended material associated with the videosled movement through the far southern end of the cell, but also from the change in sound. In general, water clarity was good throughout the cell, contrasting with the suspended sediment present in the ambient Boston Harbor sediments above the edge of the cell. During the second pass of the sled, the tracks from the first pass were noted in both the sand and mud areas, indicating a relatively consolidated surface of the dredged material.

In addition to the surface coverage of sand and mud, the video captured images of *ex situ* material deposited on top of the dredged/cap material deposit, including entrapped debris and blocks of high-reflectance BBC (Figure 3-9). The blocks of BBC probably were remnant from material loosened from the cell walls, similar to the evidence provided by the acoustic data. The presence of debris indicated that material had become entrapped below the ambient current of Boston Harbor and settled on top of the cap. Inferences of the physical environment also could be drawn from the benthic community (tunicates, lobsters, etc.) that inhabited the cell at the time of the video survey. Tunicates, especially, tend to attach to hard bottoms (associated with ship fouling), and are filter feeders. The presence of tunicates on the sand cap indicated that the sand provided sufficiently hard substrate, within a fairly quiescent environment. Finally, video data collected along the cell walls confirmed that the steep walls were scalloped, primarily from the dredging process (Figure 3-10). The BBC walls also had begun to be colonized by a variety of burrowing organisms.



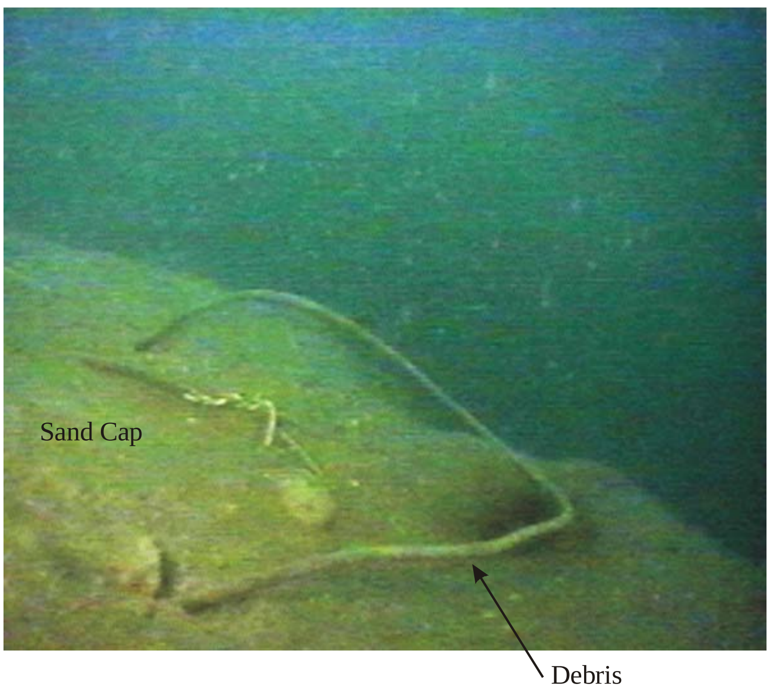
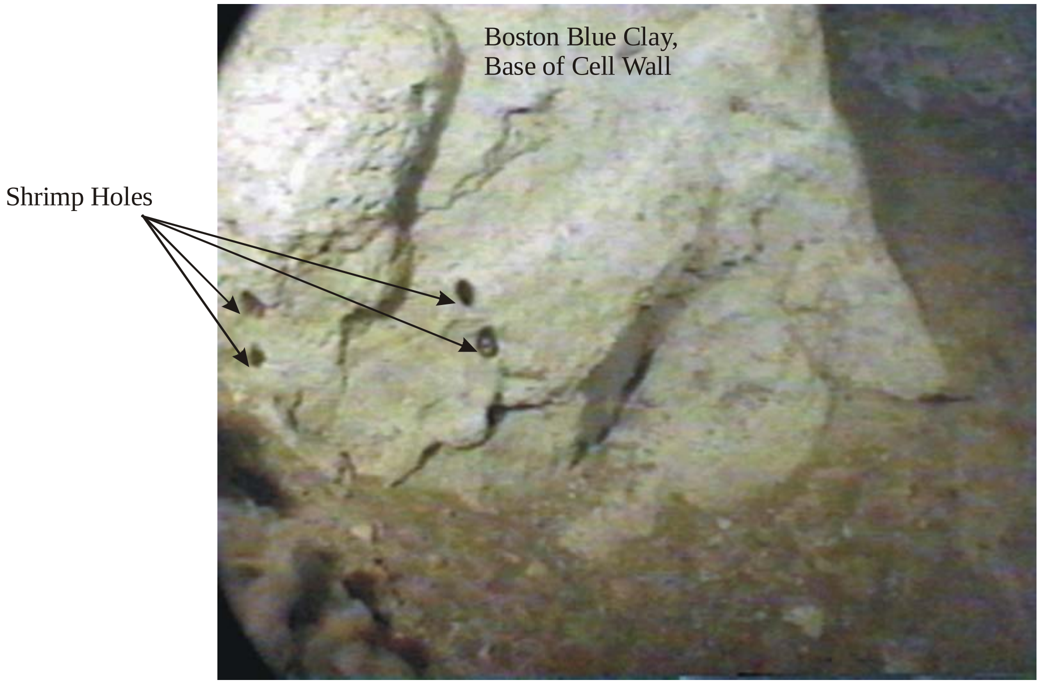


Figure 3-9. Video image of sand cap showing presence of tunicates and other debris



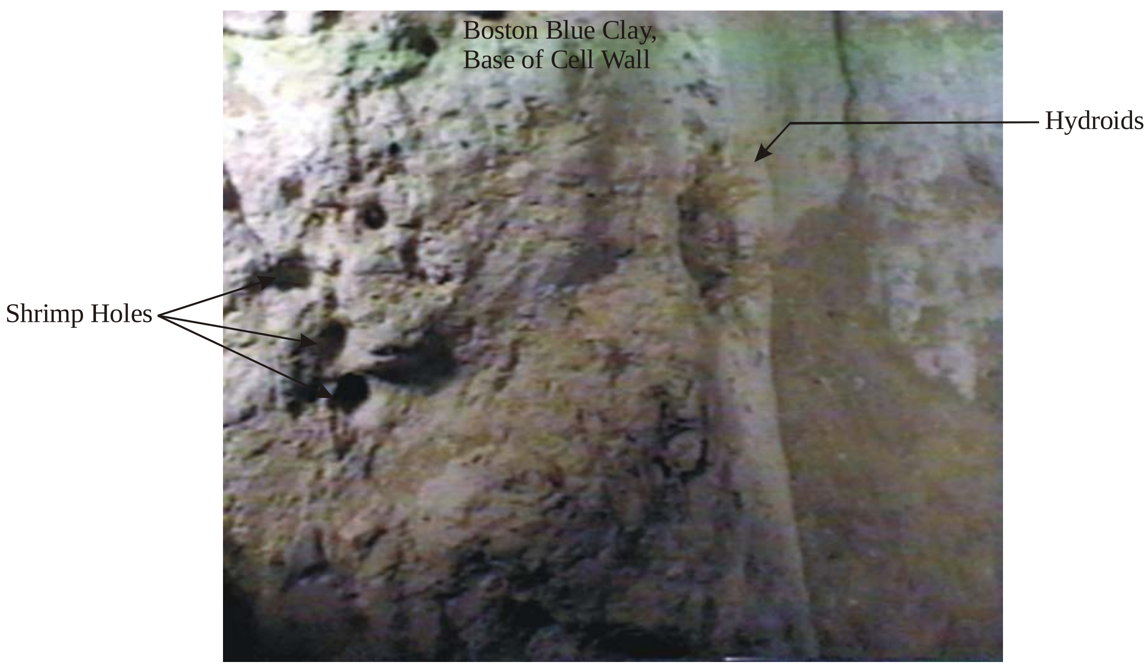


Figure 3-10. Video image of Boston Blue Clay cell wall

4.0 DISCUSSION

4.1 Topography and Texture of the Sediment Surface of the CAD Cell

The presence of two distinct acoustic regions was consistent among all of the data collected within the CAD cell. The acoustic data, in tandem with cores collected throughout the cell, indicated that the northern and central portions of the cell were covered with a coarse sand. Throughout the central portion of the cell, clamshell bucket markings were noted clearly in the side-scan data, resulting in the appearance of sand waves that confounded core recovery in the thicker layers of sand. The distribution of sand across the surface of the cell also was clearly delineated in subbottom data. In that area of the cell, the subbottom reflectors apparent in the ambient Boston Harbor sediments were dissipated, indicating no effective sound penetration to depths below the dredged and cap material. Below the surface of the central and northern portions of the cell, there was a marked change in subbottom penetration, where there was a series of discontinuous internal, u-shaped reflectors that indicated refraction from the heterogeneous sand wave deposit. Clear evidence of sand on the surface was supported by video data, that showed tunicate-covered sand waves with dramatic topography (Figure 3-9), as well as audio evidence as the sled was dragged and scraped through the sand.

In the southern end of the cell, the acoustic and coring data indicated that no sand was present, as all of the cores recovered in the southern end (except CAD-4B) recovered dredged material to refusal in BBC. In the southern area of the cell, the sediment/water interface was a high amplitude reflector in the subbottom data caused by the flat, featureless fine-grained cell surface. Below this surface reflector, there was a very homogeneous layer as indicated by few internal reflectors, and the base of the cell was noted as a continuous subbottom reflector along the southern portion of the cell. In combination, these results indicated that no sand was placed in the southern section of the cell.

The lack of sand in the southernmost area of the CAD cell was attributed to the placement of the split hull scows used for capping. Modeling conducted prior to capping using tidal current data predicted that the sand would spread towards the south (down current). Monitoring data suggested, however, that the majority of the sand, although released slowly from the barge, was released convectively so that the areal coverage was more limited than predicted. The distribution of barges over the cell indicated that no barge was ever placed directly over the southern end, resulting in a lack of sand in this area.

4.2 Thickness of the Sand Cap

The second major result of the monitoring survey was that the central and northern areas of the disposal cell were covered in sand, but the thickness was unevenly distributed. Sand thickness appeared to be most variable in the area impacted by postcap dredging operation. As noted in the side-scan sonar data, clamshell bucket operations resulted in a topography similar to sand waves, so that the resulting cap thicknesses were highly variable.

Sand cap thicknesses among the four cores where sand cap was clearly recovered at the top of the core (CAD-5A, 5B, 6A, and 6B) ranged from 20-80 cm of sand or mixed sand and mud (Table 2-1). The inability to collect cores at 6C and 7A with evidence of thick sand so close to 6A and 6B indicated a high variability of sand thickness. A mass balance approach was used to approximate the variable thicknesses of the deposit. Assuming that the total volume of sand was deposited over, conservatively, 75% of the cell, the average thickness would be 4 ft. The minimum cap thickness measured was approximately 1 ft (26 cm), so the range of cap thicknesses could vary from 1-7 ft.

4.3 Implications of Cap/Dredged Material Mixing

One of the lithological units recovered in the cores was described as mixed, which had the appearance of the sand cap (medium to coarse sand), but with a component of black watery silt material, apparently from the dredged material unit. Coring data indicated that mixing of sand and mud of up to 2 ft occurred in areas of highly variable sand thickness, indicating that mixing was enhanced, and possibly caused, by the force applied to the sand during the postcap dredging operations.

The consolidation state of the dredged material prior to capping, as shown in cores where sand overlay more consolidated clay, contributed to the presence of a clear sand/dredged material interface (Figure 3-6). These data suggested that the more consolidated the dredged material was prior to capping, the less mixing occurred. Maximizing consolidation of the dredged material prior to capping, thereby increasing the bearing strength of the dredged material and reducing the interval over which sand and mud are mixed, therefore, has several advantages, including:

- Increasing the protection of benthic organisms by maximizing the "effective cap" above the zone of advective flux of potentially contaminated pore waters into sand (e.g., Murray et al. 1994b);
- Reducing the volume of sand that has to be placed to ensure 3 ft of coverage;
- Maximizing the efficiency of the subbottom profiling technique to detect the cap/dredged material boundary, which has provided the widest spatial coverage of cap confirmation data to date;
- Increasing the overall long-term stability of the deposit.

The bathymetric results suggested that consolidation has continued throughout the cell, in both the sand-capped and uncapped areas. The critical parameter of consolidation was identified from the monitoring results; specifically, the time necessary to allow for self-weight consolidation of dredged material.

4.4 Consolidation of the Maintenance Material

The overall depth of the cell appeared to increase by 1-4 ft during the 10-week period between the bathymetric data collected immediately after capping in July 1997, and in October 1997. The sequential bathymetric data were used to calculate an overall consolidation of at least 2 ft in the far southwestern corner of the cell, and in the central cell below the sand wave deposits. Conservatively, this resulted in an overall consolidation of the dredged material from initial deposition to 10 weeks after capping of 20-40% . Previous data collected on dredged material consolidation indicated that this value is probably a minimum, considering volume reductions of up to 50% for fine-grained materials have been attributed to consolidation (e.g., Poindexter-Rollings 1990). More accurate estimates of the rate of consolidation within the CAD cells will be useful for the second phase of the BHNIP (Section 5.0).

The acoustic data consistently indicated the presence of a large block of material in the southeast corner of the cell overlying the uncapped dredged material (Figure 3-8). Although no samples were collected from the area of this topographic anomaly, the most logical conclusion is that a large block of BBC fell from the cell wall and settled on top of the dredged material. Although this is highly conjectural, the inference can be drawn that the bearing strength of the uncapped material had increased by the October survey to support the overlying block of material. If this is the case, sometime during the 10-week period between the completion of the dredging project and the October monitoring survey, the material developed sufficient self-weight consolidation to optimize capping.

4.5 Implications of Erosion from the Unsupported Cell Walls

The side-scan sonar data from this report and from prior data collection efforts (ENSR 1997a), as well as the bathymetric and subbottom data, suggested strongly that the slopes of the unsupported cell walls have become less steep, and material has fallen from the walls into the pit. The video captured images of the surface of the cell showing blocks of BBC on top of the CAD cell cap (Figure 3-9). Because the clamshell dredging process that was used to create the cell walls left a sawtooth pattern along the cell walls, it is likely that the dredging process weakened parts of the wall resulting in sloughing or calving from the weakened walls. Video data collected in the cell confirmed that the steep walls are scalloped, potentially increasing the chance for erosion of the cell walls (Figure 3-10).

Boston Blue Clay has a high strength and is relatively firm (CDM 1991), indicating that the erosional process will not continue indefinitely, and may be limited to areas that were weakened during the dredging process by the clamshell bucket. In addition, spud marks on the side-scan image were close to the edge of cell, potentially contributing to sloughing. Because the walls remained unsupported (unfilled cell) at the time of this survey, however, these erosion processes may continue, especially on the eastern side of the pit because of the impact of vessel propeller wash.

For Phase 2 of the BHNIP, the cells will be filled up to ambient seafloor depth (channel depth), so that this result does not affect the dredging and monitoring plans. For the Phase 1 CAD cell, the interesting implication of the monitoring data is that material will continue to settle into the cell, from both weakened cell walls and entrapped sediment and debris. During Phase 2 surrounding areas will be deepened by 5 to 7 feet decreasing unsupported cell wall height. This suggests a sedimentation rate that is more rapid than the surrounding Boston Harbor seafloor, making the estimation of overall sand cap thickness more difficult to assess as time progresses. Ultimately, dependent upon the sedimentation rate and the rapidity of erosion of the remaining cell wall, the dredged material will be covered to ambient depth with sediment. This very thick layer of sediment, be it sand, BBC, or ambient fine-grained sediment, will provide ample containment for the dredged material placed at the bottom of the cell.

5.0 SUMMARY AND RECOMMENDATIONS

5.1 Summary

5.1.1 Side-scan

- The southern end of the cell had low reflectance relative to the rest of cell, indicating a smooth cell bottom and homogenous grain size;
- There was an acoustic bright spot in the southeast corner indicating a topographic peak lying above the shadow created by the edge of the pit;
- The central portion of the cell showed a strong topographic signature from clamshell dredging, resulting in artificial sand waves throughout the center of the cell;
- Rough texture of the surface of the northern end of the cell indicated sand cover, but was less disturbed than central section.

5.1.2 Bathymetry

- Consolidation of at least 1-2 ft in some areas, especially in the southwestern corner and in the center of the cell below the thickest sand layers, continued between the final postcap survey conducted in late July, and the postcap bathymetric survey conducted 10 weeks later in early October;
- Total consolidation of the dredged material since the time of placement was estimated to be 20-40%;
- Evidence for material falling from the unsupported cell walls included the irregular cell outline and flatter slope, as well as the anomalous topographic peak in the southeast corner;
- The dredging process, as well as propeller action along the eastern side and spudding, likely weakened parts of the cell wall, enhancing the potential for material slumping;

5.1.3 Coring

- Cores indicated that the southern end of the cell was uncapped;
- The artificial sand waves in the central portion of the cell resulted in widely varying sand thicknesses over short distances;
- A sharp cap/dredged material boundary was present over consolidated dredged material;
- The estimated range of thickness of the sand in the capped area was estimated to range from 1-7 ft;
- Potential mixing of up to 2 ft of the cap into the dredged material in one core was probably enhanced by the postcap dredging operation, but may also be a result of under consolidated dredged material prior to capping;

- Loss or compaction of dredged material resulted in underestimated total unit thicknesses above BBC.

5.1.4 Subbottom

- In the southern area of the cell, a sharp seafloor reflector indicated a smooth surface with little topography to scatter sound;
- In the central and northern portions of the cell, the surface was highly irregular and very rough, coincident with the sand cap and sand wave area;
- Below the surface in the sand-capped area, a series of discontinuous internal reflectors indicated a more heterogeneous deposit, and most or all of the sound was lost in the upper portion of the deposit;
- The data suggested that delineating cap thickness using the subbottom method will not be effective if there is a mixed zone that is greater than the resolution of the acoustic system;
- New material from the cell wall appeared to have settled on top of the uncapped material, suggesting that the strength of the material has increased and is potentially in a state of consolidation sufficient to support even large sized cap materials with minimal mixing.

5.1.5 Video

- Video data confirmed the presence of thick sand waves in the central and northern parts of the cells, and the transition from the sand cap to the uncapped dredged material was apparent both in audio and video;
- Further evidence of consolidation of the uncapped material was suggested by the presence of sled tracks noted during the second pass of the sled;
- The video captured images of *ex situ* material deposited on top of the dredged/cap material deposit, including entrapped debris and BBC, indicating that material had become entrapped below the ambient current above the cell;
- The presence of tunicates on the sand cap indicated that the sand provided sufficiently hard substrate, within a fairly quiescent environment;
- The video data collected along the cell walls confirmed that the steep walls were scalloped, primarily from the dredging process.

5.2 Recommendations

Results from all of the environmental monitoring surveys were discussed among the project proponents and the BHNIP TAC. Recommendations to modify the requirements for dredging and disposal operations, and potential alterations to the environmental monitoring approach, were considered. The recommendations briefly described below were summarized from the October monitoring survey report (Murray 1997), and preliminary recommendations from the project proponents as summarized by the CZM Independent Observer (ENSR

1997b). The recommendations were designed around the primary concerns raised by the dataset, including lack of spatial coverage of sand, variable thicknesses of sand, and potential mixing between sand and dredged material. The recommendations are intended as practicable methods of improving the CAD capping process for Phase 2 of the BHNIP and other projects.

- **Operational Control During Capping**

The primary source of both uneven spatial coverage and variable cap thicknesses was the method of sand placement in the first CAD cell. For Phase 2, operations will be designed to improve placement of the material, as well as increase the ability to diffuse the sand while capping. In addition, physical disturbance of the sand cap after placement will be minimized.

- **Increase Bearing Capacity of Dredged Material Prior to Capping**

Increasing the consolidation time for the fine-grained maintenance sediments will increase the bearing capacity of the material, increasing the likelihood for a sharp cap/dredged material boundary. The Phase 1 monitoring studies provided no clear guidance for the time required for sufficient consolidation, as there was no hard evidence that the consolidation time for Phase 1 (9 days) was insufficient. The time allowed for consolidation partially will be governed by the potential risk of resuspension of this material. Future geotechnical studies will be conducted to address this issue for further projects.

The most cost-effective method to increase bearing capacity is to allow more time for self-weight consolidation to take place. The subbottom data provided an estimate of the maximum time necessary for the dredged material to be able to support an overlying load, because of the apparent ability of the uncapped dredged material to support the mass of material at the southeast corner of the cell. The topographic peak appeared sometime between the last postcap survey in July and the October survey, providing a maximum waiting period of 10 weeks. The actual waiting period may be shorter (perhaps much shorter depending on when the block fell or could have been supported), and will also depend on the geotechnical character of the actual dredged material as it is placed. This waiting period will be established through careful monitoring of the first few cells.

Another method to increase the bearing capacity of the dredged material is to reduce the water content of the material prior to disposal in the cell. Dewatering, however, is expensive and time-consuming. Use of the environmental clamshell bucket increased the water content of the material, ultimately decreasing the strength of the placed dredged material. The final potential method for increasing the bearing strength of the material prior to placement is to phase the capping process. By adding additional material to the top of the dredged material (additional dredged material, cap material, BBC), the strength of the material will increase and improve the ultimate success of final capping.

- **Confirming Cap Coverage and Thickness**

The basic methods used for this survey can be successful in determining cap spatial coverage and thickness in tandem with improved operational methods. Modifications to these procedures are summarized for the individual types of monitoring.

Bathymetry. Bathymetry proved to be a useful tool to monitor overall consolidation of the project. The advantage of the Boston Harbor project is that the underlying BBC is relatively incompressible, so that any difference in height of the material can be attributed to consolidation of the dredged material itself. It is imperative, especially in small areas like the CAD cells, to replicate survey parameters so that electronic depth differencing between surveys can be conducted. Typically, consolidation will occur rapidly at first, and then slow and become more gradual (e.g., Poindexter Rollings 1990). At the point the consolidation curve begins to flatten is the optimum time to begin capping from a strength perspective. Bathymetry can be used as a tool during dredging, therefore, to allow qualitative analysis of the consolidation state of the material.

Using bathymetry to estimate cap thickness is problematic, however, because of further consolidation of the dredged material after cap placement. Use of subbottom (below) will allow a more comprehensive and accurate acoustic assessment of cap thickness (Murray et al. 1994a).

Coring. Coring has the advantage of actual, visual evidence of the state of the cap. It is limited, however, to measuring in only discrete points so that, with uneven coverage, it may provide an inaccurate picture of the overall cap. Coring can be used to evaluate the boundary between cap and dredged material, so that the ability of subbottom (below) to detect the overall coverage of the cap can be evaluated. Vibracores are required for this type of operation.

Subbottom. As discussed above, if the material is sufficiently consolidated to minimize mixing between the sand and cap, subbottom is the most promising method to evaluate both the spatial coverage and overall thickness of a sand cap. It becomes less useful if the sand is unevenly placed so that sound is lost at the surface, and if the mixed interval exceeds the depth resolution of the subbottom frequencies.

Side-scan. Side-scan data were essential in Phase 1 because of the unique topography of the sand waves. If the sand cap is uniformly placed throughout the cell area, side-scan will show the uniform deposit but will need groundtruth data (cores or video) to document the lithology.

Video. The use of the videosled data proved useful to visually document the status of the cap. Because the area of the cells is small, video can provide relatively good coverage at a reasonable cost.

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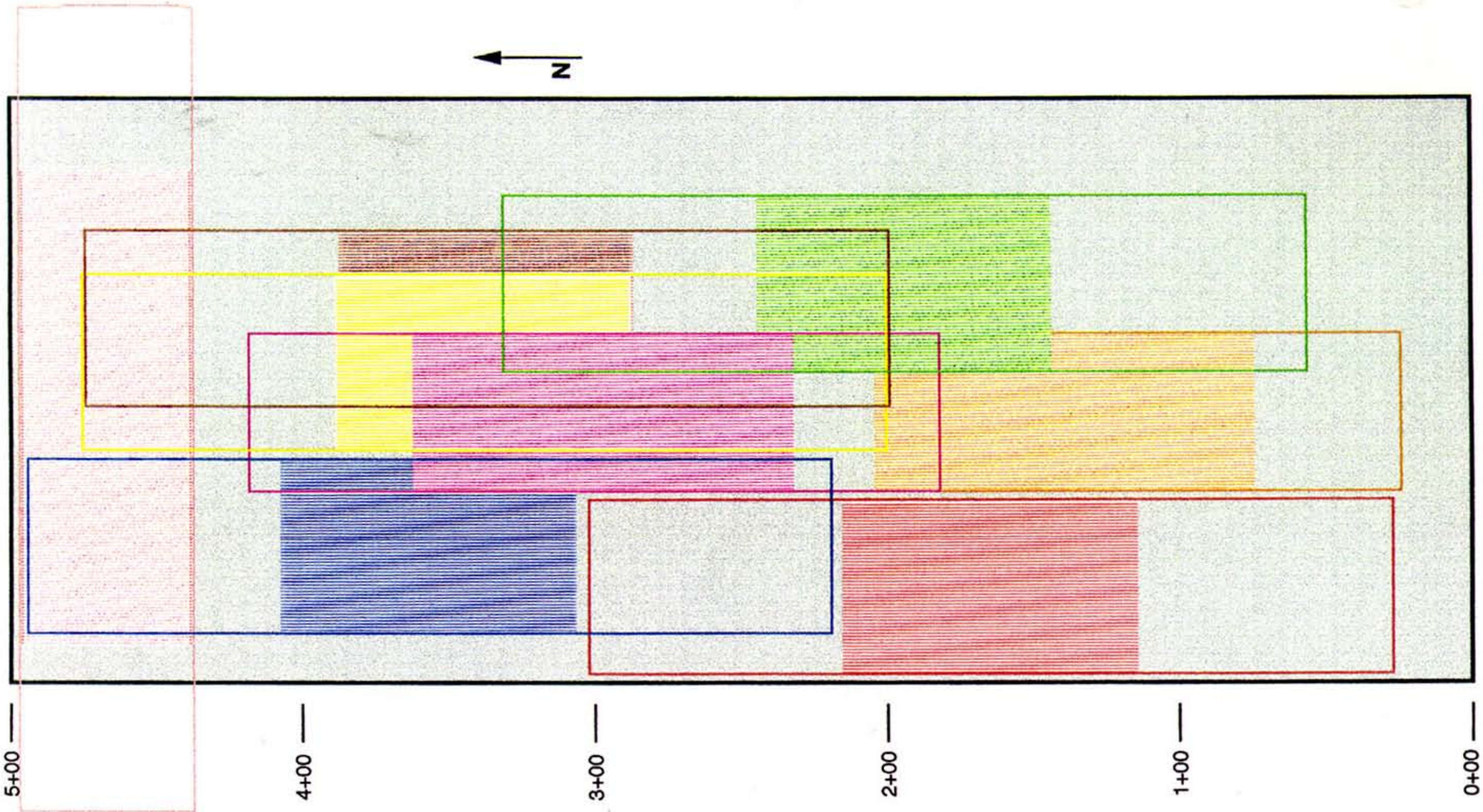
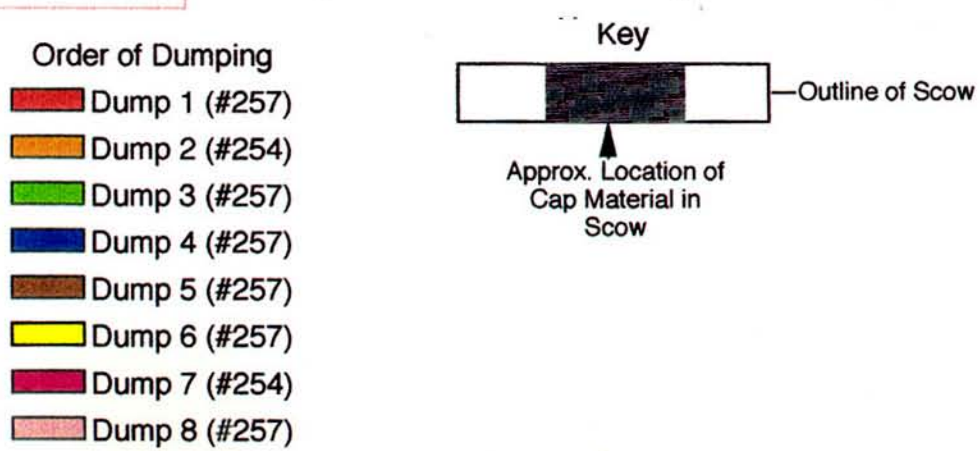
APPENDIX





Location of Scows and Contents During Capping