Monitoring Cruise at the Massachusetts Bay Disposal Site, August 1990

Disposal Area Monitoring System DAMOS

Contribution 92
November 1994

US Army Corps of Engineers
New England Division

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
November 1994

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Monitoring Cruise at the Massachusetts Bay Disposal Site, August 1990

5. FUNDING NUMBERS

6. AUTHOR(S)
J. Germano, J. Parker, and J. Charles

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Science Applications International Corporation
221 Third Street
Newport, RI 02840

8. PERFORMING ORGANIZATION REPORT NUMBER
SAIC-90/7599&C90

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers - New England Division
424 Trapelo Road
Waltham, MA 02254-9149

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DAMOS Contribution No. 92

11. SUPPLEMENTARY NOTES
Available from DAMOS Program Manager, Regulatory Division
USACE-NED, 424 Trapelo Road, Waltham, MA 02254-9149

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Our knowledge of the physical factors that control the deposition of dredged material suggested that, in deep water, most deposits will cover a relatively large area with only minor vertical relief. From this argument and barge log volume calculations, it was presumed that material disposed in MBDS at the "MDA" buoy since November 1988 would not provide a vertical signature large enough to be observed with precision bathymetric equipment. This study, conducted from 13 to 17 August 1990, set out to test the supposition through bathymetric and REMOTS surveys. Since the last survey in November 1988, an estimated 260,300 m^3 of dredged material had been deposited at this site. The thickness and extent of dredged material surrounding the "MDA" disposal buoy were mapped and compared to data collected in 1988 and 1987. Against expectation, the bathymetric survey did indeed detect a mound measuring 0.8 m in height and 420 m in diameter, when the 1990 survey was compared to 1988.

When compared to previous bathymetric data collected over the same area from 1987, the dredged material had formed a mound 1 m high and 450 m in diameter. This demonstrated the successful formation of a well-defined dredged material mound at MBDS.

14. SUBJECT TERMS
MBDS
dredged material
sediments
bathymetry
REMOTS
sediment profile photography

15. NUMBER OF PAGES
51

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified			

MONITORING CRUISE AT THE MASSACHUSETTS BAY DISPOSAL SITE, AUGUST 1990

CONTRIBUTION #92

November 1994

Report No.
SAIC-90/7599&C90

Submitted to:

Regulatory Branch
New England Division
U.S. Army Corps of Engineers
424 Trapelo Road
Waltham, MA 02254-9149

Submitted by:

J. Germano
J. Parker
J. Charles
Science Applications International Corporation
Admiral's Gate, 221 Third Street
Newport, RI 02840
(401) 847-4210

US Army Corps
of Engineers
New England Division

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Our knowledge of the physical factors that control the deposition of dredged material suggested that in deep water most deposits will cover a relatively large area with only minor vertical relief. From this argument and barge log volume calculations, it was presumed that material disposed in MBDS at the "MDA" buoy since November 1988 would not provide a vertical signature large enough to be observed with precision bathymetric equipment. This study, conducted from 13 to 17 August 1990, set out to test the supposition through bathymetric and REMOTS® surveys. The thickness and extent of dredged material surrounding the "MDA" disposal buoy were mapped and compared to data collected in 1988 and 1987. Against expectation, the bathymetric survey did indeed detect a mound measuring 0.8 m in height and 420 m in diameter.

The site boundaries for the interim Massachusetts Bay Disposal Site (MBDS) were established in 1977, but the area has been used for the disposal of dredged material at least since the 1960s. The disposal area during this study was a 2 nmi diameter circle centered at 42° 25.700′ N and 70° 34.000′ W. The MBDS received a great deal of public and private scrutiny during consideration as a permanent Ocean Dredged Material Disposal Site (as part of the final site designation by the EPA in 1993, the disposal site center was moved approximately 0.95 nmi southwest). Since the last survey in November 1988, an estimated 260,300 m^3 of dredged material has been deposited at this site. The MBDS is expected to receive large volumes of material over the next several years due to the major construction projects underway in the Boston area.

The August 1990 bathymetric data around the "MDA" disposal buoy was compared to bathymetric data collected over the same area in 1988 and 1987. From 1987 to 1990, the dredged material had formed a mound 1 m high and 450 m in diameter. The portion of the deposit formed between 1988 and 1990 was 0.8 m high and 420 m in diameter. This demonstrated the successful formation of a well-defined dredged material mound at MBDS. The ability to form well-defined dredged material mounds is essential, if capping operations are planned to isolate contaminated dredged material at MBDS, should the need arise in the future.

"Fresh" dredged material, as indicated by chaotic sedimentary fabrics and anomalous grain size distributions, was detected in REMOTS® sediment-profile photographs out to 800 m west, 500 m south, 400 m east, and 500 m north of the center of the disposal site. These results showed an area of the seafloor affected by disposal activity 83% larger than that indicated by bathymetry. The REMOTS® photographs also indicated a steady recovery in the benthic ecosystem since the 1989 REMOTS® survey as indicated by an increase in Stage III taxa.

The bathymetric and REMOTS® sediment-profile surveys conducted at MBDS in August 1990 confirmed that dredged material released at this site forms a deposit 1 m high at the mound center. The flanks of the dredged material deposit extended from 400 m to 800 m from the disposal point.

The detection of the dredged material on the seafloor at MBDS, and the steady recovery of the benthic ecosystem while the site is being used for disposal, support the conclusion that dredged material released at MBDS has remained within the site, and that the benthic community has not been adversely affected by disposal.

1.0 INTRODUCTION

The Massachusetts Bay Disposal Site (MBDS) is located in the northeast portion of Massachusetts Bay, approximately 18 nmi east-northeast of the entrance to Boston Harbor and 10 nmi south-southeast of Gloucester, Massachusetts. The site described in this report refers to an interim location prior to final designation in 1993. This interim disposal site consisted of a 2 nmi diameter circle centered at 42° 25.700′ N and 70° 34.000′ W. The MBDS boundary overlaps a portion of the old Industrial Waste Site which had been in use since the 1940s for the disposal of dredged material as well as other waste. The Industrial Waste Site, a 2 nmi diameter circle centered approximately 1 nmi west of the present site, was the recipient of many types of matter not limited to dredged material, including building debris, canisters of industrial waste, and encapsulated low-level nuclear waste. Environmental Protection Agency (EPA) records show no permitted use of the industrial waste site after 1976, and it was formally dedesignated on February 2, 1990 (Wiley 1991). The MBDS has been used for the disposal of dredged material since 1977.

SAIC has conducted five monitoring surveys at MBDS from 1985 to 1990. An extensive survey was conducted in 1985 to determine if the existing site should receive final designation while more recent studies were designed to monitor the site (SAIC 1987a, 1989b). These studies determined the extent of dredged materials, monitored the formation of the disposal mound, evaluated the benthic environment, provided information on the physical parameters of the site, and determined the extent of chemical contamination. Assessment techniques for the surveys have utilized precision bathymetry, side-scan sonar, REMOTS® sediment-profile photography, current meter and transmissometer deployments, CTD/DO monitoring, and sediment and benthic faunal sampling for physical and chemical analysis. The 1985 survey also included observational cruises utilizing manned submersibles, fish collections, and the implementation of the Benthic Resources Assessment Technique (BRAT).

Major construction projects underway in the Boston area (the Central Artery/Third Harbor Tunnel project and the relocation of the Deer Island outfall) will likely create a substantial increase in disposal activity at MBDS over the next several years. MBDS received an estimated 260,300 m^3 of dredged sediments since the last bathymetric survey in November 1988. The sediments deposited at MBDS have been a mix of sands, silts, and clays which have met regulatory requirements for open water dredged material disposal (Table 1-1). Barge logs indicated that most of this material was deposited within 400 m of the "MDA" (formerly the "FDA") buoy, centered at 42° 25.086′ N and 70° 34.457′ W.

The oceanography of MBDS is influenced, in part, by the circulation of the Gulf of Maine. The Gulf of Maine circulation patterns in the vicinity of MBDS are modified to a large extent by the presence of Stellwagen Bank on the eastern margin of Massachusetts Bay

Table 1-1

Grain Size Analysis of Dredged Material Source Areas Deposited at MBDS during 1988-1990

Source/Sample #	Date Sampled	% Coarse Material	% Sand	% Silt	% Clay
Scituate Harbor	12/86-7/89	0	14	58	28
		0	35	51	14
		0	37	50	13
		0	45	40	15

Source/Sample #	Date Sampled	% Coarse Material	% Sand	% Silt/Clay
Plymouth Harbor	9/87-12/89	3	34	63
		0	19	81
Boston Harbor/ Chelsea Creek	10/87-4/90	12	53	35
		43	43	14
		5	51	44
		36	41	23
		36	46	19
Squantum Channel Dorchester Bay	10/87-12/89	0	64	36
Pines-Saugus River	10/88-4/90	15	64	21
		0.6	90	9.4
		0.5	84	15.5
		0.6	93	6.4
Pines River	12/88-12/89	24	62	14
Manchester Harbor	1/89-7/89	0	37	63
		0	45	55
		0.3	85	14.7
		0	58	42
		0	59	41
		0.4	85	14.6

(SAIC 1988). The bank blocks the exchange of water at depth with the Gulf and the shelf beyond. Stellwagen Bank is a popular fishing and whale watching area that has been designated as a national marine sanctuary. One major concern raised by regulatory agencies and environmental groups is the proximity of marine mammals (specifically, humpback and finback whales) on Stellwagen Bank and the potential harmful effects on their feeding activities from suspended sediment transport during disposal activities at MBDS (SAIC 1988).

Dredged material which settles on the bottom at MBDS can be expected to remain in place for extended periods of time (EPA 1989). Physical oceanographic studies conducted under the DAMOS Program as well as those by other investigators have shown that the bottom current velocities at the disposal site are quite low, averaging less than 7 $cm \cdot s^{-1}$ (Butman 1977, Gilbert 1975, SAIC 1987a). Occasional higher velocities, near 20 $cm \cdot s^{-1}$ in a westerly direction, have been observed in near-bottom waters in response to easterly storm events that occurred in fall and winter. Near-bottom currents of this magnitude were not predicted to be strong enough to resuspend sediments at MBDS (EPA 1989). However, surficial sediments may be resuspended by wave action on rare occasions of severe easterly storm events. Waves of sufficient height and period to cause resuspension can be generated by easterly storms with winds in excess of 40 mph for a period of more than 12 hours, an event estimated to occur approximately once every four years (EPA 1989). Based on data obtained from the National Weather Service, such a storm occurred only once during the period between 1978 and 1986. Resuspension events such as these are rare and typically result in resuspension of only 4% of the surface material (EPA 1989). Transport of the resuspended dredged material in combination with resuspended natural sediments would be to the west and southwest during these events.

The prevailing low current velocities minimize the possibility of resuspension of deposited material at this site, and the water depth tends to isolate the bottom from the effects of all but the severest of storm events (SAIC 1988). The wave conditions in the vicinity of MBDS normally result from both local sine wave formation and propagation of long period waves generated on the adjoining continental shelf. The sheltering provided by the coastline severely limits wave generation from the westerly direction; waves from the westerly quadrants larger than 1.8 m occur rarely, and waves over 3.7 m are virtually nonexistent (EPA 1989).

The temperature/salinity cycle of Massachusetts Bay is characterized by seasonal variability, with maximum temperatures (18° C at surface) typically occurring in a stratified water column during August and September, and minimum temperatures (5° C) typically occurring in an essentially isothermal water column in January and February (SAIC 1987a). Salinity values range from 31 to 33 ppt (SAIC 1987a).

A plume study was conducted at MBDS during 1982-1983 to assess the potential impact of dredged material disposal on the surrounding environment. Plume behavior was examined through a combination of acoustic tracking and *in situ* sampling which involved measurements of salinity and suspended particulate matter (SAIC 1984). Acoustic results indicated a rapid, convective descent of dredged material to the bottom. Based on the calibration provided by the water samples, a concentration of 750 $mg \cdot l^{-1}$ of sediment was observed in the upper layer of the plume immediately after disposal. This concentration decreased rapidly to 39 $mg \cdot l^{-1}$ within 20 minutes after disposal and to 5 $mg \cdot l^{-1}$ approximately 40 minutes after disposal. The ambient concentration of suspended material averaged approximately 1 $mg \cdot l^{-1}$ (SAIC 1984). The concentration and distribution of suspended material in the plume 40 minutes after disposal varied only slightly (from 5 to 12 $mg \cdot l^{-1}$), and represented 3% of the total load of dredged material (100,000 kg). Although the plume tracked in this study moved in a southeasterly direction, the dominant near-surface tidal currents at MBDS are NNE-SSW with velocities of 15 to 20 $cm \cdot s^{-1}$ (EPA 1989). These currents decrease with depth to lower velocity, less periodic currents near the bottom (generally < 10 $cm \cdot s^{-1}$; EPA 1989).

A similar study was conducted in May 1985 at the Rockland Disposal Site (RDS) located in West Penobscot Bay, Maine (SAIC 1987b). Within two hours, 90% of the material was on the bottom (mostly within the disposal site), and suspended sediment concentrations were similar to background levels of 3-5 $mg \cdot l^{-1}$. If disposal occurred on maximum flood tide, it was estimated that approximately 6% of the dredged material may be transported out of the disposal site while if disposal occurred evenly at all stages of the tide, this estimate was reduced to 1%. Results of current measurements at 10 m depth and 60 m depth (SAIC 1984) showed that the dominant flow at RDS was to the N-NE and that the maximum current velocities occurred on the flood tide (40 $cm \cdot s^{-1}$). The average current speed at RDS was approximately 13 $cm \cdot s^{-1}$. Based on these measurements, once outside the disposal site, the dredged material would be so widely distributed (via current transport and physical mixing in the water column) as to be undetectable (SAIC 1984).

From 13 to 17 August 1990, SAIC conducted field operations at MBDS to provide information on the effects of disposal operations since the November 1988 bathymetric and January 1989 REMOTS® surveys. Field operations included a precision bathymetric survey and REMOTS® sediment-profile photography. The benthic community around the "MDA" buoy was predicted to be similar to that observed during January 1989. In 1989, infaunal successional stages at the disposal site included Stage I (small pioneering polychaetes), Stage III (larger burrowing deposit feeders), and Stage I on Stage III communities, with 75% of the stations showing evidence of Stage III taxa. Stage III taxa represent high-order successional stages typically found in low disturbance habitats. The influx of Stage I species represents a response to disturbance due to disposal activities.

The volume of sediments deposited from November 1988 to August 1990 was expected to add to the existing disposal mound without increasing the height and size of the mound detectable with bathymetry. This prediction was based on results from a bathymetric and REMOTS® survey conducted in January 1987 which suggested that material may spread more in a deeper site such as MBDS in comparison to shallow water sites (Bajek et al. 1987). It was also felt that positioning problems during the disposal operations may have caused inaccurate and widely spaced placement of dredged material inhibiting the formation of a dredged material mound. While this was the expected result, there was some anticipation that a mound may have been successfully formed since the 1988 survey. The formation of a mound at a deep water site such as MBDS (depths >25 m and <150 m) would mean capping of dredged material is also feasible.

2.0 METHODS

2.1 Navigation and Bathymetry

The SAIC Integrated Navigation and Data Acquisition System (INDAS) provided the precise navigation required for all field operations. A complete description of this system can be found in DAMOS Contribution No. 48 (SAIC 1985). Shore stations for the 1990 field operations have been used in previous MBDS surveys and were established at Marblehead Neck Light (42° 30.320′ N and 70° 50.051′ W) in Marblehead, and Eastern Point Light (42° 34.809′ N and 70° 39.899′ W) in Gloucester, Massachusetts (Figure 2-1). Repeated use of these stations allows accurate comparisons of past and present surveys.

An Odom DF3200 Echotrac® Survey Recorder with a narrow-beam 208 kHz transducer recorded depth. This particular fathometer was rented to temporarily replace identical equipment used in 1988 because of a malfunction in the in-house fathometer. Analysis of the data and comparison with the 1988 results indicated that the gridded depths were reliable, in general, but the raw data contained a higher variance. This higher variance was due most likely to lower maintenance standards on the rental equipment. The result is an apparent higher level of "noise" in the contoured bathymetric chart in comparison to the 1988 survey. It is important to note that this variance does not obscure the general correspondence of contours between the two surveys.

The fathometer recorded depth to a resolution of 3 cm (0.1 ft). However, the acoustic records could reliably detect changes in depth on the order of 20 cm due to the accumulation of errors introduced by the positioning system, tidal corrections, the calibration of the fathometer (speed of sound through the water column), the slope of the bottom, and the vertical motion of the vessel. The speed of sound is determined from the water temperature and salinity data measured by an Applied Microsystems CTD probe. However, for this survey the correction factor was calculated based on historic depth/temperature profiles obtained for August 1985 (SAIC 1987a) due to a malfunction of the CTD probe. Depth/temperature profiles for August 1985 were obtained at the "A" buoy, 42° 25.671′ N, 70° 35.004′ W. Any discrepancy with the actual speed of sound during the bathymetric analysis for 1990 was resolved when the 1990 survey was corrected to areas in the 1988 survey unaffected by disposal (an accepted method for normalizing to a benchmark survey).

The bathymetric survey conducted on 13 and 14 August 1990 encompassed a 1200 × 1200 m grid centered around the "MDA" buoy at coordinates 42° 25.086′ N and 70° 34.457′ W. Forty-nine lanes were run east to west at 25 m spacing. The bathymetric survey on 4 November 1988 utilized this same grid. This configuration provided adequate coverage to assess the distribution of dredged material at the site. The stated objective of the 1990 survey was to map areas of the dredged material mound exceeding 1 m in thickness. This objective assumed a substantial decrease in bathymetric measurements in deeper water

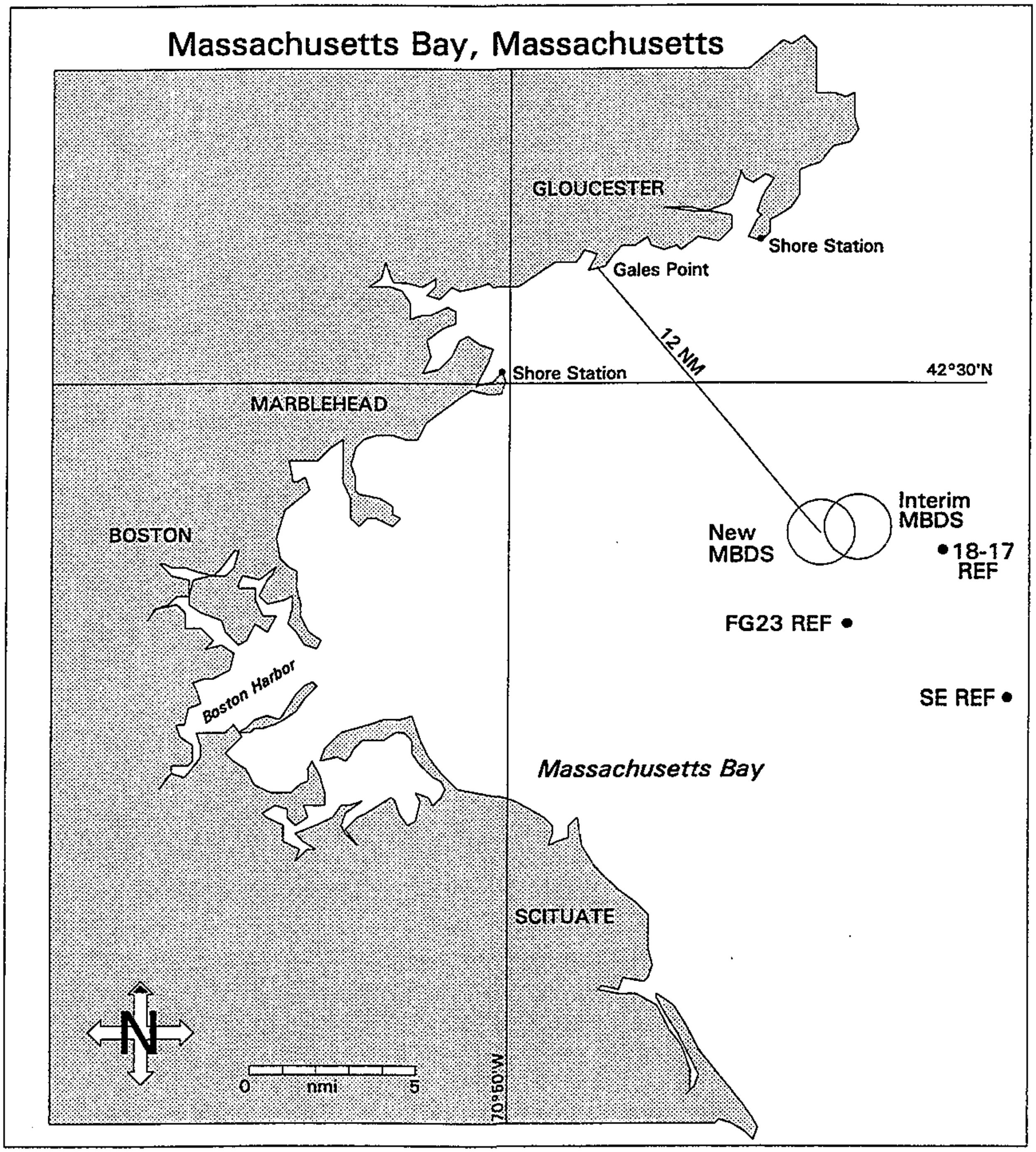


Figure 2-1. Location of MBDS and reference stations in relation to Gloucester, Massachusetts

compared to shallow water surveys. However, the equipment used in 1988 and 1990 was able to discriminate 20 cm changes at 90 m depth. Raw depth values were corrected to Mean Low Water during analysis of the bathymetric data by adjusting for the ship draft, tidal changes during the survey, and the speed of sound. The tidal changes used during SAIC surveys are predicted tidal changes. Because disposal sites are located so far offshore, actual tidal ranges (based on shoreline measurements) are not necessarily correct for a boat's location during a survey. The correction method for normalizing to a benchmark survey also corrects for tidal changes.

2.2 REMOTS® Sediment-Profile Photography

REMOTS® photography was used to detect the distribution of thin (1 to 20 cm) dredged material layers, map benthic disturbance gradients, and monitor the progress of infaunal recolonization on and adjacent to the disposal mound. A detailed description of REMOTS® photograph acquisition, analysis, and interpretative rationale is presented in DAMOS Contribution No. 60 (SAIC 1989a).

A REMOTS® survey, performed 14, 15, and 16 August 1990, generated triplicate photographs for each of the 41 disposal site stations surrounding the "MDA" buoy (Figure 2-2). The objective of the survey was to map that portion of the recently deposited dredged material not detectable with bathymetry. REMOTS® stations, spaced 100 m apart, extended 700 m to the north, 800 m to the south, 900 m to the east, and 800 m to the west of the disposal site center. The 13 REMOTS® stations established at each of the three reference areas allowed comparisons between ambient and on-mound conditions. These reference area stations were arranged in a cross-shaped pattern similar to the disposal site sampling grid and spaced 100 m apart. Photographs were taken in triplicate at each station with the exception of 200S and 300S at SE-REF (due to difficulties with the camera). Disposal site and reference area station locations were the same as those analyzed in January 1989. Reference area locations, depths, and distances from the "MDA" buoy are summarized in Table 2-1.

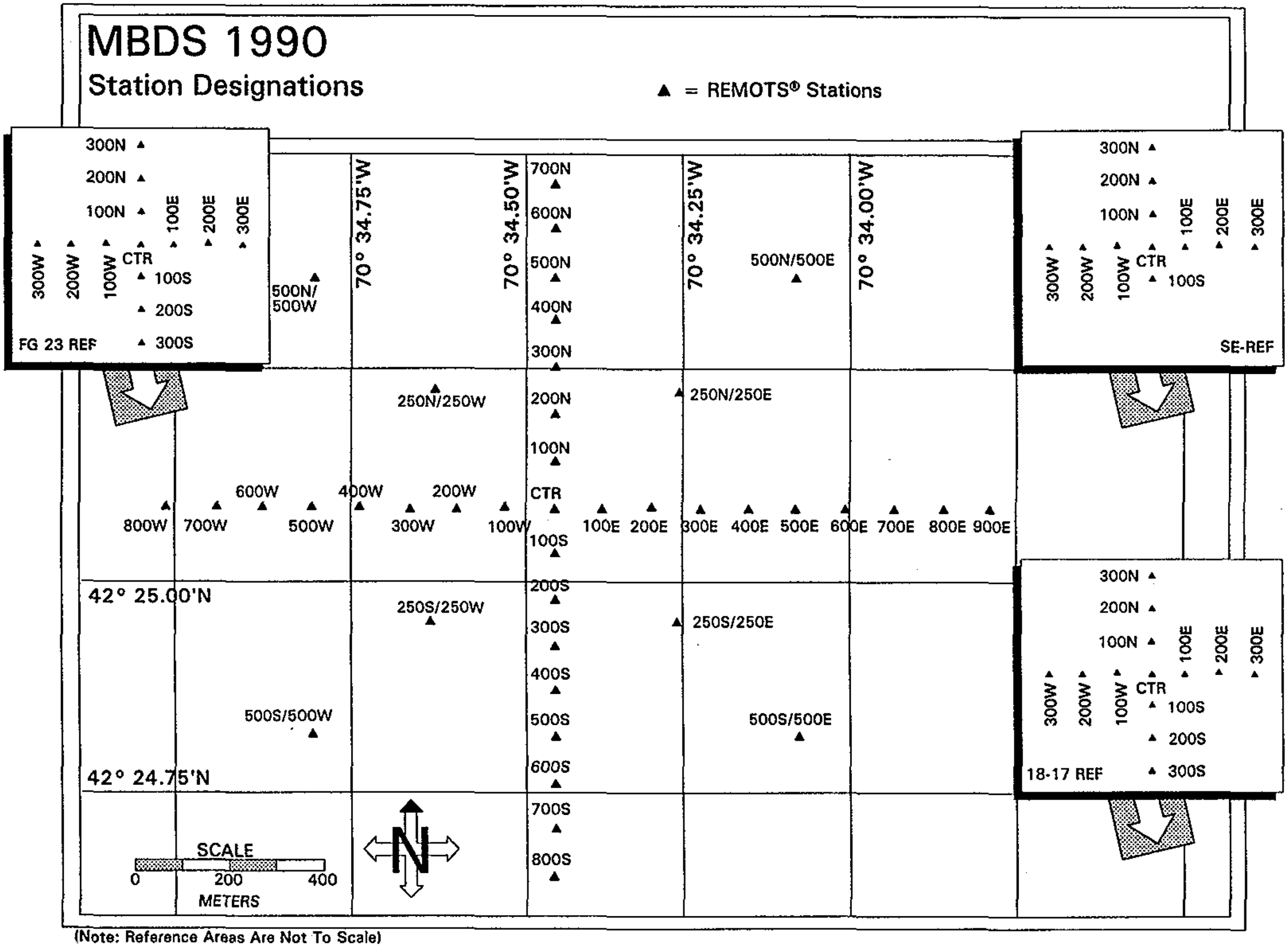


Figure 2-2. REMOTS® station locations at MBDS, August 1990

Table 2-1

Summary of Reference Areas

	LOCATION	DISTANCE FROM "MDA" BUOY	DEPTH
FG 23	42° 22.700′ N latitude 70° 34.600′ W longitude	4421 m South	85 m
SE	42° 20.000′ N latitude 70° 28.000′ W longitude	12932 m Southeast	90 m
18-17	42° 24.686′ N latitude 70° 32.814′ W longitude	2373 m East-Southeast	85 m

3.0 RESULTS

3.1 Bathymetry

A comparison of the August 1990 and November 1988 precision bathymetric surveys showed that a distinct mound was formed at the "MDA" buoy between these two surveys. In August 1990, the minimum depth at the disposal point was approximately 88.50 m (Figure 3-1), compared to a depth of 89.25 m in November 1988 (Figure 3-2). A depth difference contour chart (Figure 3-3) indicated that the deposit had a maximum thickness of 0.8 m and was centered slightly east of the buoy. The average diameter of the deposit was 420 meters. Depth differences on the order of 20 cm (i.e., approaching the limits of detection in this comparison of the 1990 and 1988 surveys) occurred within 400 m of the disposal mound center. Depths within the surveyed area ranged from 87.25 m in the southwest to 92.25 m in the northwest.

A depth matrix comparison of the 1988 and 1990 bathymetric surveys resulted in a volume calculation of 78,075 m^3 (95% confidence limits; 55,500 m^3 to 100,650 m^3) of material deposited since the November 1988 survey. Total volume estimates, including an estimate based on dredged material detected with REMOTS®, are discussed in the next section.

3.2 REMOTS® Sediment-Profile Photography

The major modal grain size over the surveyed area ranged from fine sand (3-2 phi) to silt-clay ($\geq$ 4 phi; Figure 3-4). For most of the disposal site stations and the three reference areas the major mode was $\geq$ 4 phi (Figure 3-5). Coarser sediments, consisting of patches of fine (4-2 phi) to medium (2-1 phi) sands intermixed with some silt-clay, were located within 200 m north, 200 m south, 300 m east, and at the center of the disposal site (Figure 3-6).

Small-scale surface boundary roughness values at the disposal site stations were significantly greater than those for the reference areas ($p<0.05$, Mann-Whitney U-test). Frequency distributions for small-scale surface boundary roughness indicated a major mode at 0.6-1.0 cm (class 2) for disposal site stations and at 0.0-0.6 cm (class 1) for the reference areas (Figure 3-7). Values for the disposal site stations reflected the physical disturbance related to disposal operations.

Dredged material layers presumed to be recently deposited (i.e., since the January 1989 survey) were evident in the REMOTS® photographs from stations surrounding the disposal buoy (Figure 3-8). The presence of "relic" dredged material at most of these same stations made the precise boundaries of this deposit difficult to determine. This "relic" material was presumed to be the result of disposal operations which have been conducted at

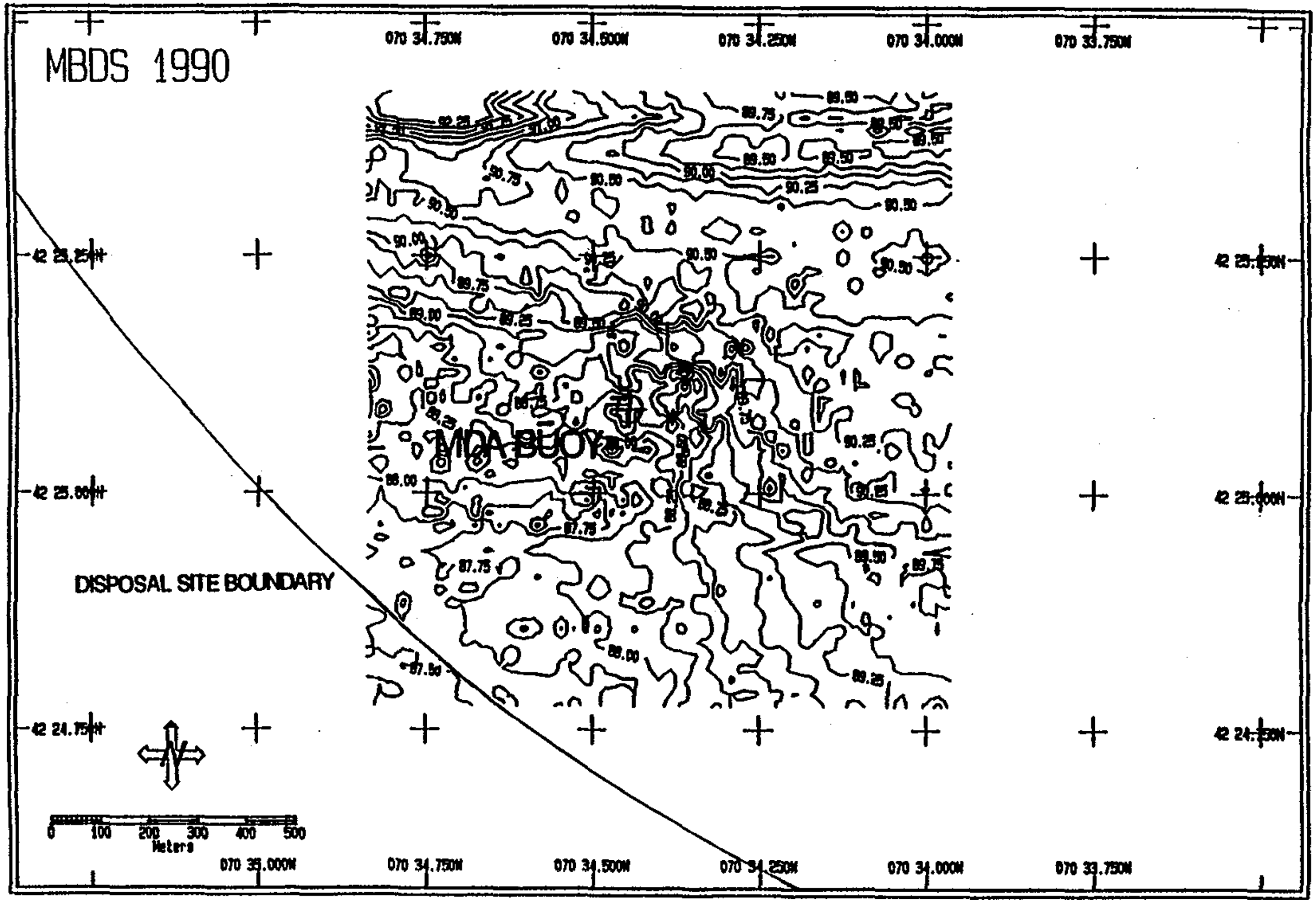


Figure 3-1. Contoured bathymetric chart (in meters) of the area surrounding the "MDA" buoy (former "FDA" buoy) at MBDS, August 1990

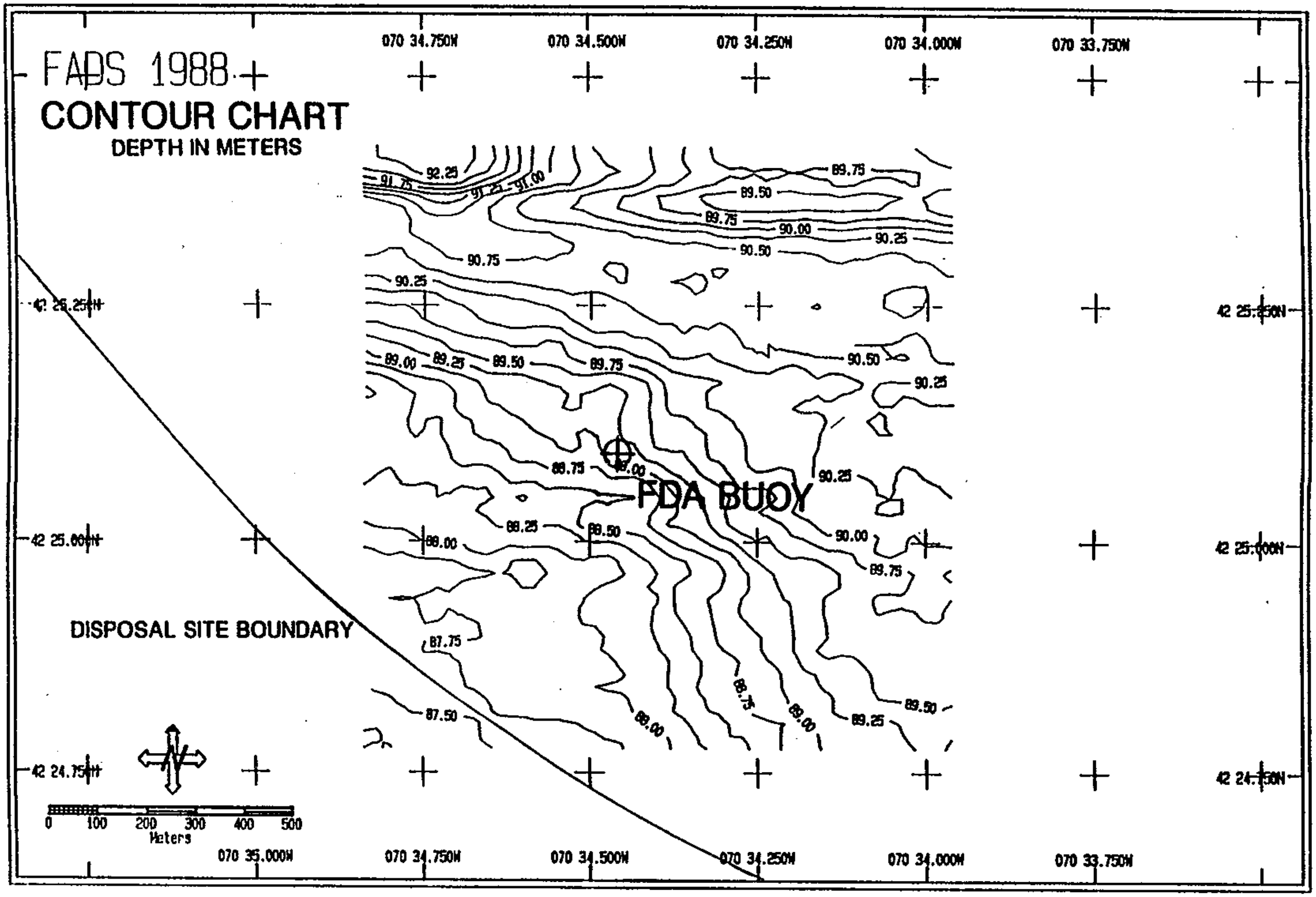


Figure 3-2. Contoured bathymetric chart (in meters) of the area surrounding the "FDA" buoy at MBDS, November 1988

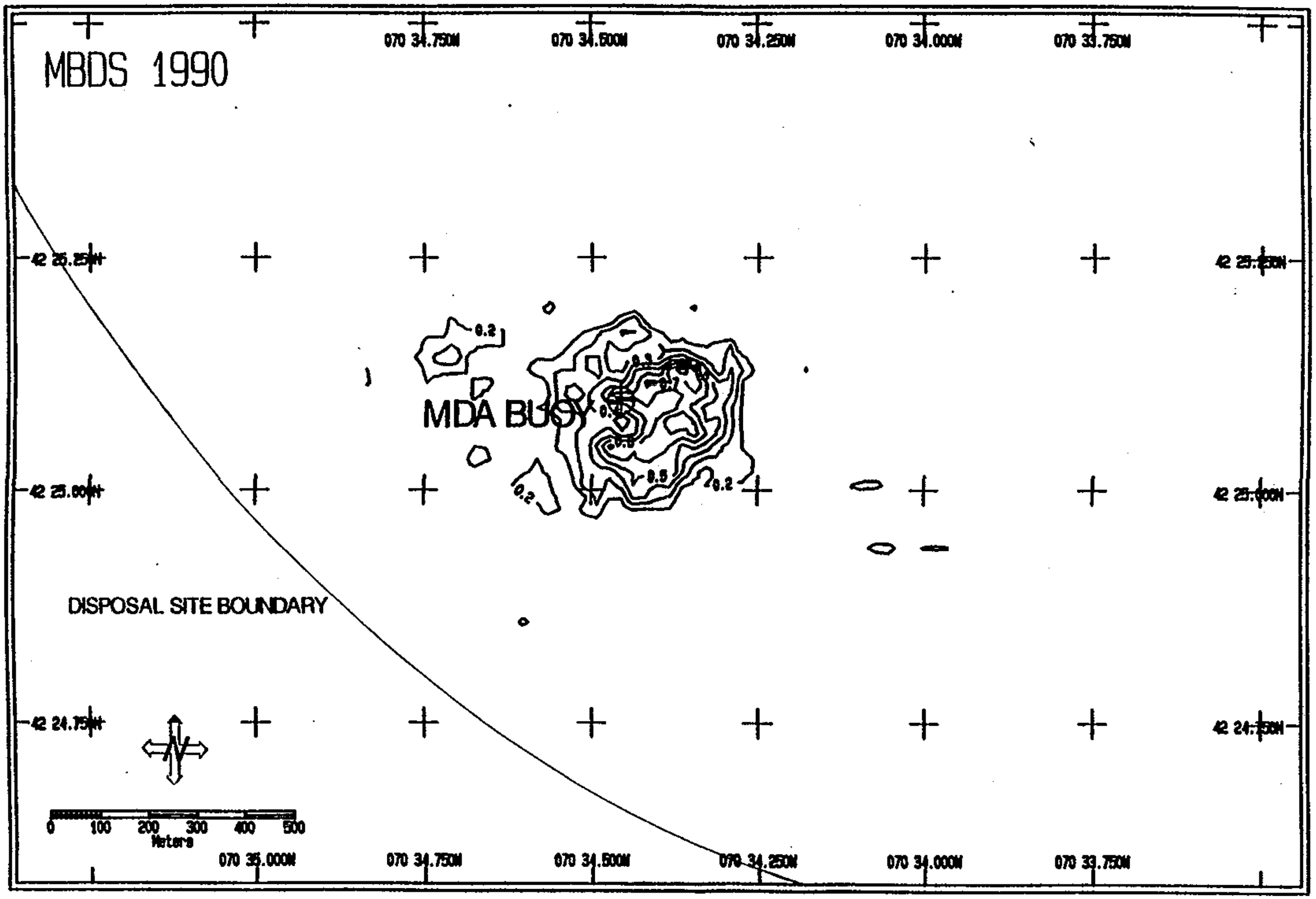
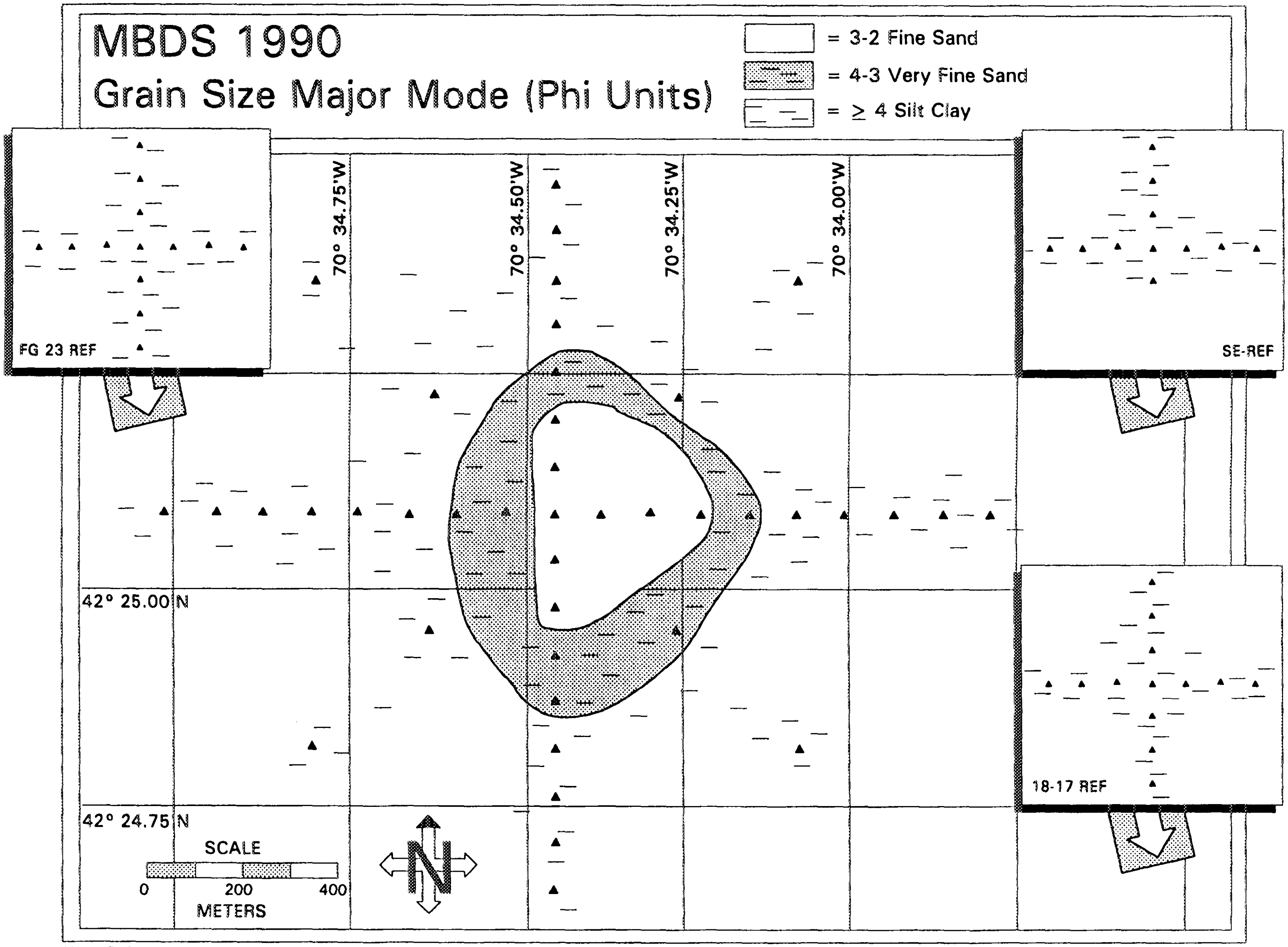


Figure 3-3. Depth difference (in meters) contour map based on comparison of the November 1988 and August 1990 precision bathymetric surveys at the "MDA" buoy



(Note: Reference Areas Are Not To Scale)

Figure 3-4. Map of sediment grain size major mode for MBDS, August 1990

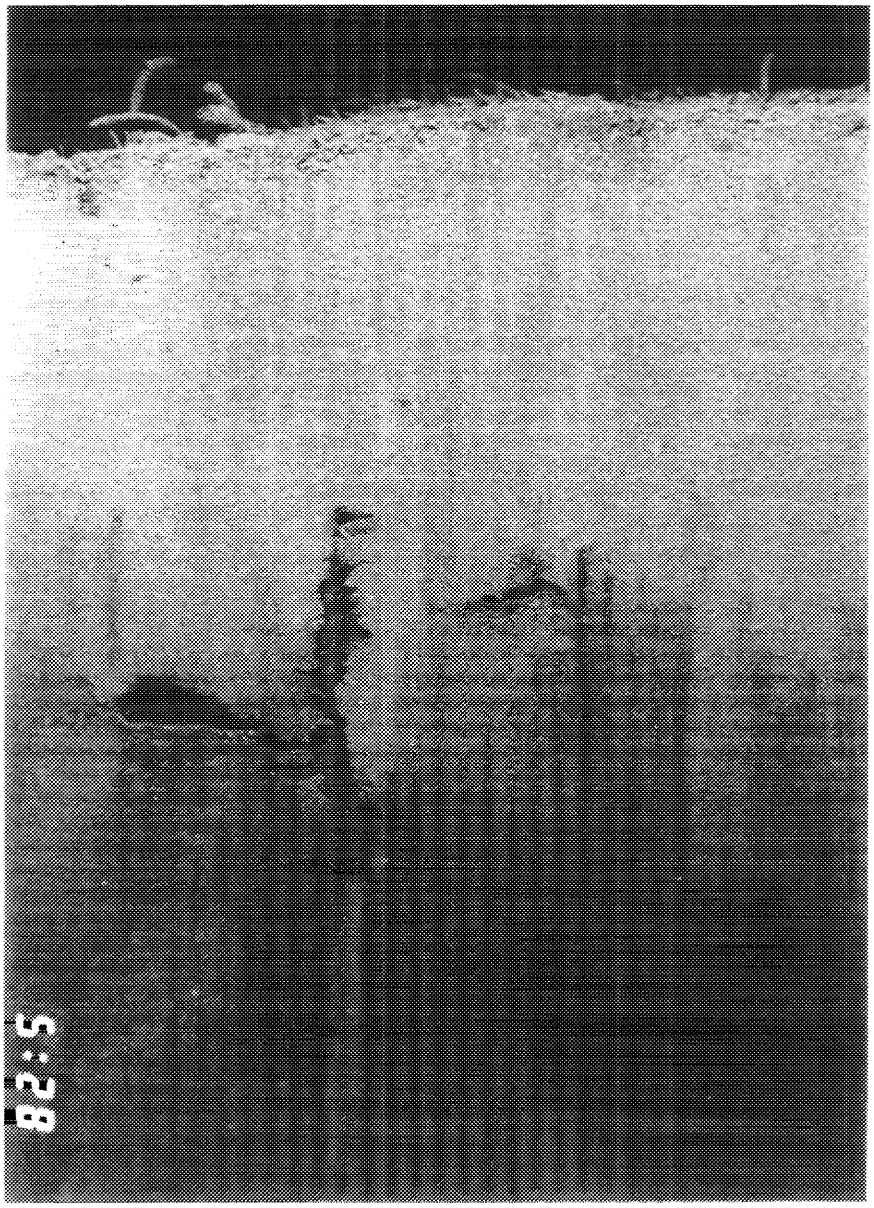
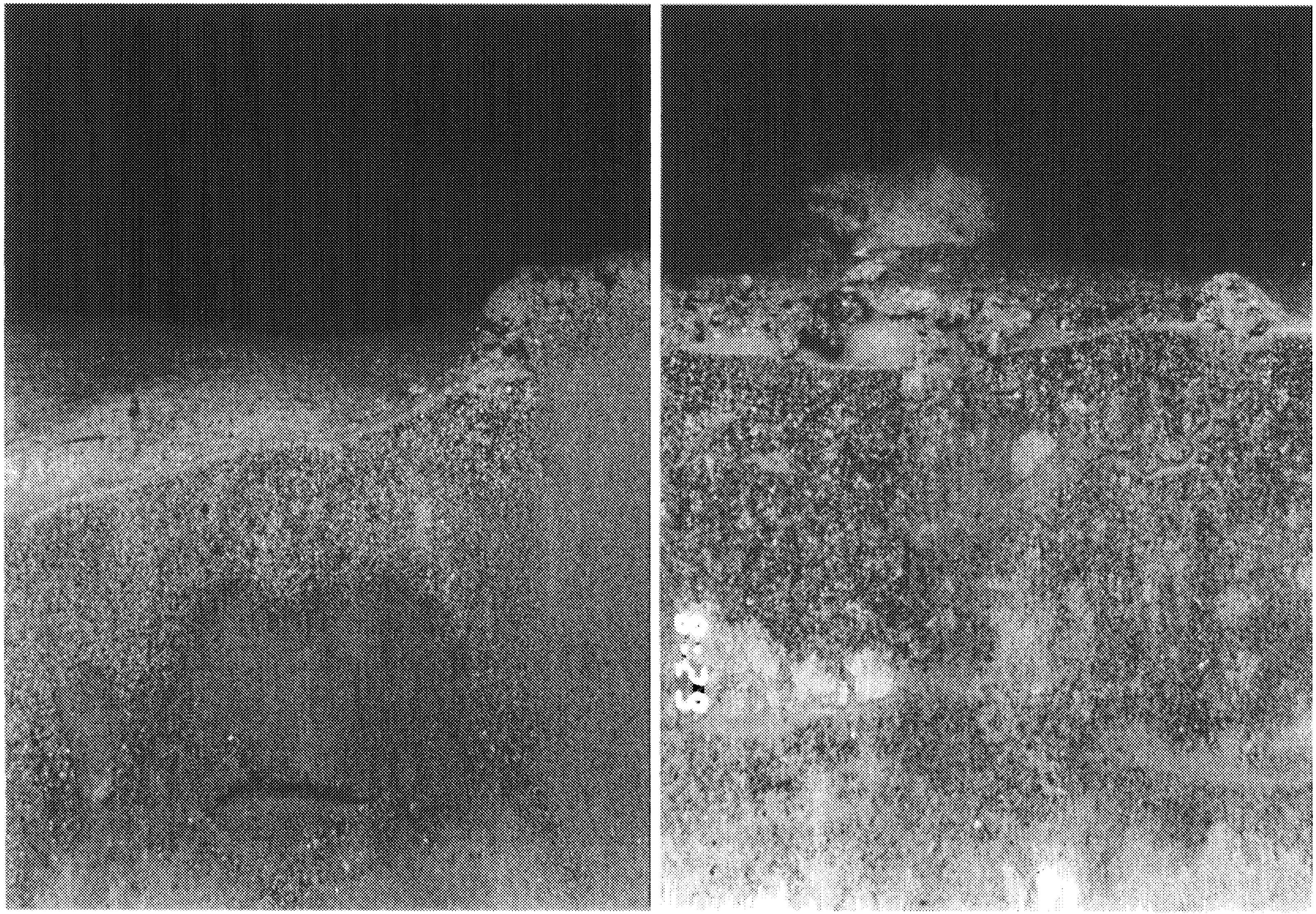


Figure 3-5. REMOTS® photograph from the SE reference area showing an ambient bottom of fine-grained material and a Stage I on III assemblage (magnification 1×)



A B

Figure 3-6. REMOTS® photographs from station 300E (A) and the disposal site center (B); anomalous grain sizes indicated the presence of dredged sediments (magnification 1×)

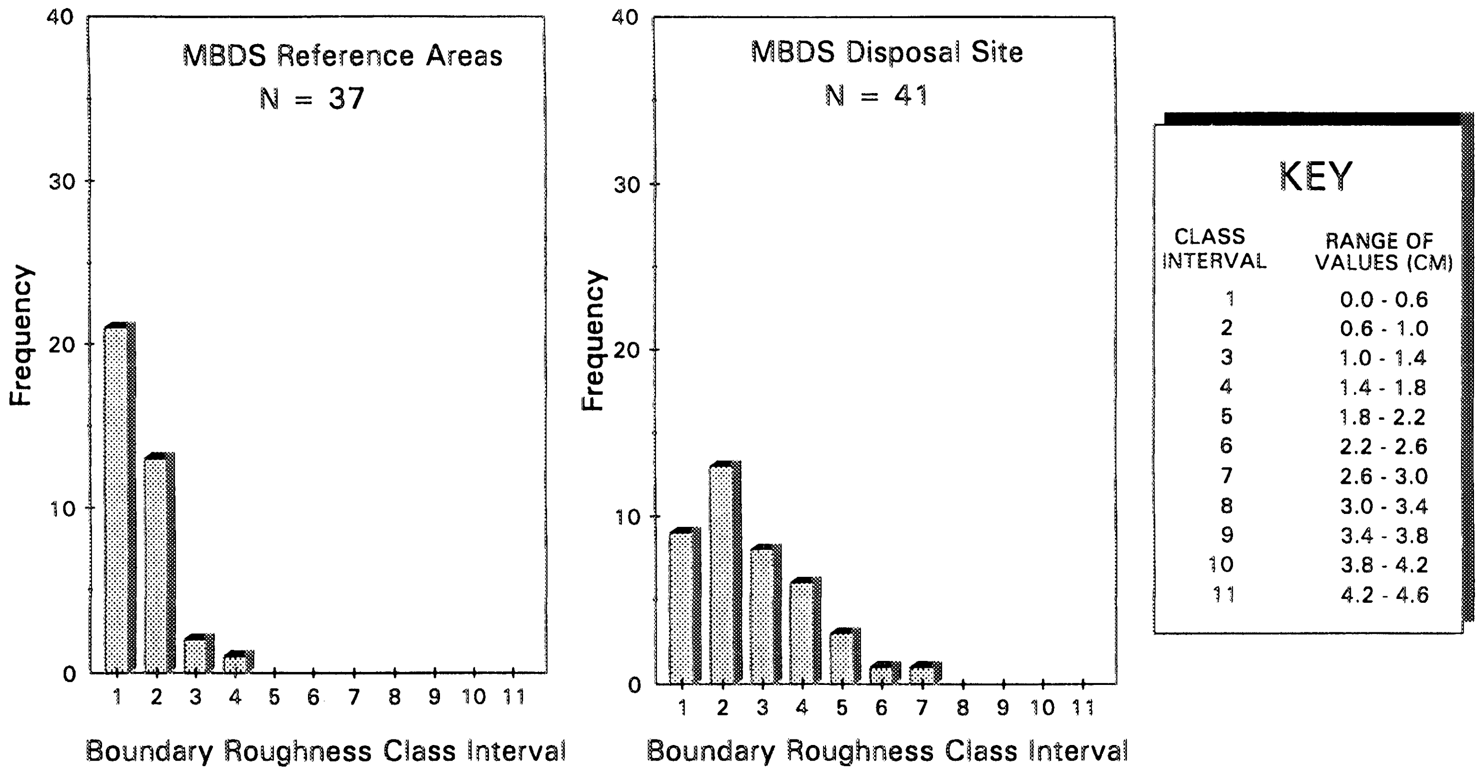
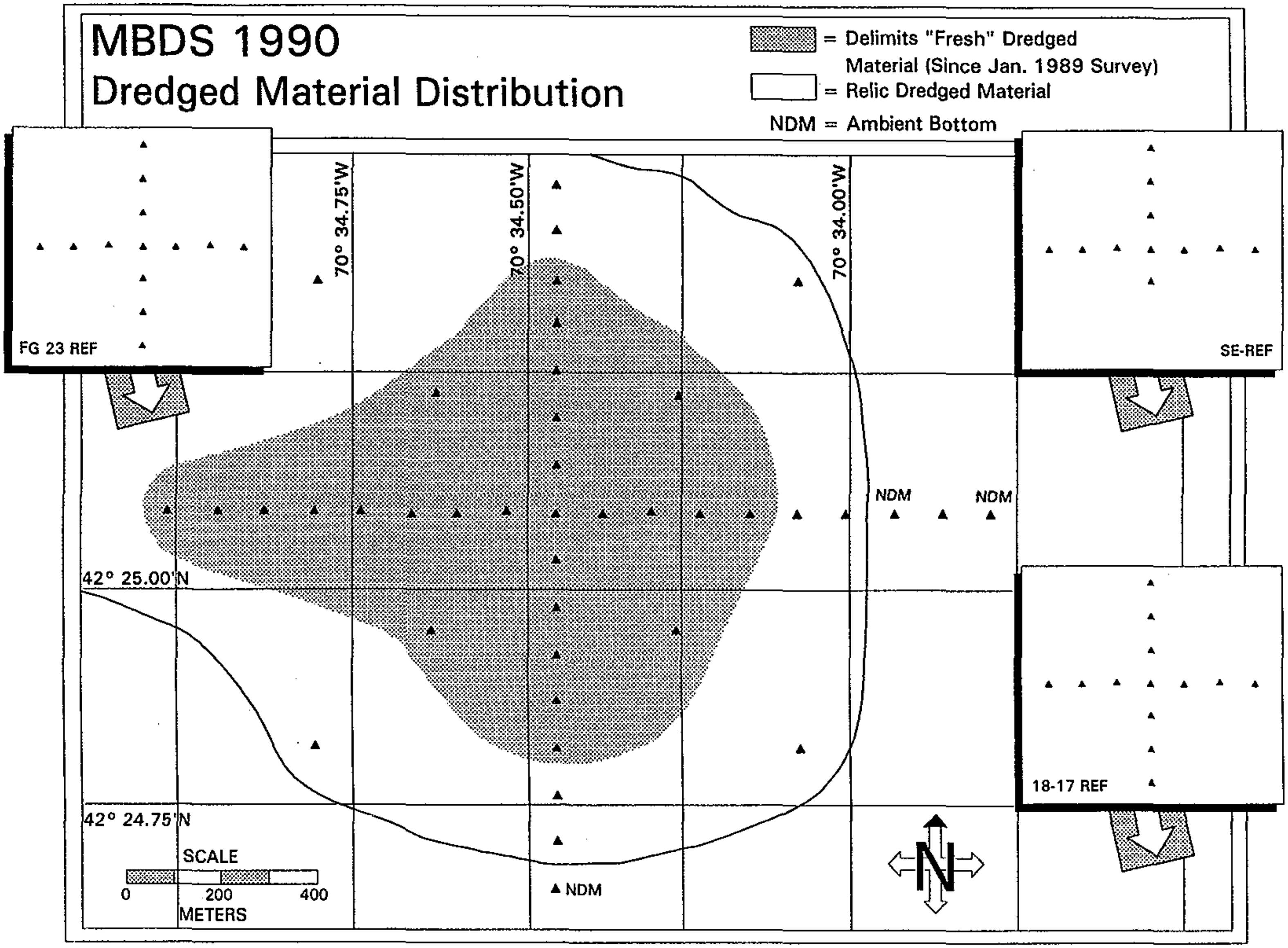


Figure 3-7. Frequency distribution of small-scale surface boundary roughness values for disposal site stations and reference stations at MBDS, August 1990



(Note: Reference Areas Are Not To Scale)

Figure 3-8. Distribution of dredged material based on REMOTS® photography at the "MDA" buoy, August 1990. No dredged material was found at any of the reference stations.

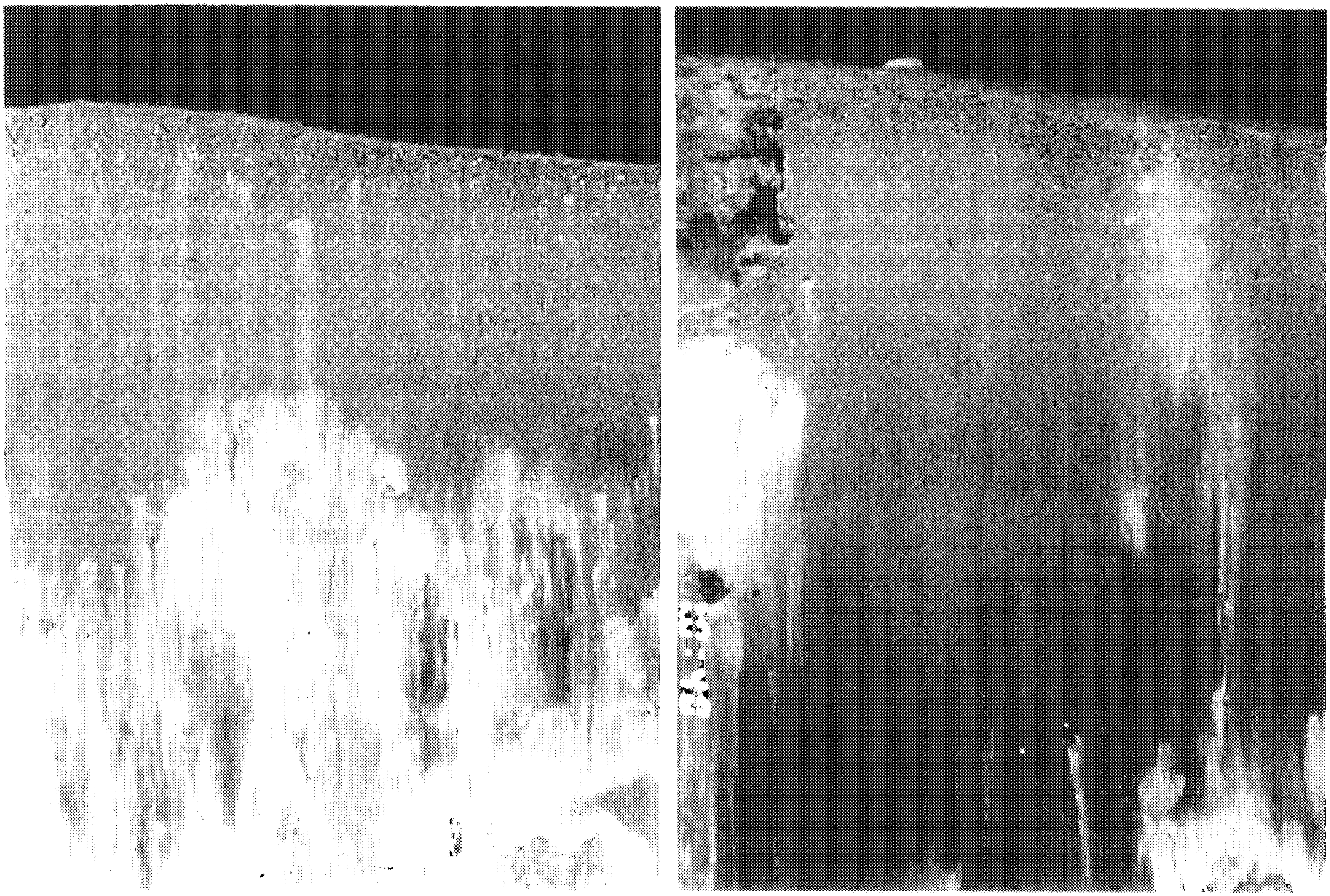
this location since November 1985. "Fresh" dredged material appeared to be present within 800 m west, 500 m south, 400 m east, and 500 m north of the center of the disposal site.

The apparent "fresh" dredged material contained chaotic sedimentary fabrics and anomalous grain size distributions (Figures 3-6, 3-9). Gravel, very coarse, and coarse sands (< 1 phi) were present at the center of the disposal site and within 200 m of the center. Penetration by the camera was limited at stations 200N, 200S, and 100E due to over-consolidated clay clasts and occasional rock rubble at the sediment surface (Figure 3-10). At other stations, the dredged material consisted of sand over mud and appeared to be less consolidated, exhibited more stratification, and allowed deeper penetration by the camera (Figure 3-9). Dredged material was not apparent at the reference stations.

Steep gradients in the depth of the RPD were measured between the disposal site, where most RPD values fell between 2 and 4 cm, and the three reference areas, where most values were ≥ 5 cm (Figure 3-11). The frequency distribution of mean apparent RPD depths for the disposal site stations indicated a major mode of 3.0 cm while the distribution of RPD depths for the reference areas showed a major mode at 6 cm (Figure 3-12). Reference area RPD values were significantly deeper (Mann-Whitney U-test, $p < 0.05$).

The spatial distribution of infaunal successional stages, as inferred from REMOTS® photographs, showed that all reference stations and all disposal site stations (with the exception of station 100 E) supported Stage III taxa (Figure 3-13). In general, the dominant infaunal successional stage was Stage I on Stage III at both reference and disposal site stations. Only 75% of the January 1989 disposal site stations showed evidence of Stage III taxa. Reference station replicate photographs indicated the presence of Stage I, Stage II on Stage III, and Stage III communities.

Past mapping experience has shown that Organism-Sediment Index (OSI) values ≤ +6 indicate bottom disturbance by either chemical or physical means. Only 3 stations had median OSI values ≤ +6 and included 500SW, 400W, and 300N (Figure 3-14). This indicated an improvement in benthic conditions in comparison with results from the 1989 REMOTS® survey in which 9 stations immediately surrounding the disposal site center had mean (vs. median) OSI values of ≤ +6. OSI values were greater generally in August 1990 and ranged from 6 to 11 compared with November 1988 values of 2 to 11. These higher values (≥ +6) are indicative of undisturbed, high-diversity benthic communities. Reference station (1990) OSI values were significantly greater than values at disposal site stations (Mann-Whitney U-test, $p<0.05$). The OSI frequency distribution for the disposal site stations showed a major mode of 10 and 11 at the reference stations (Figure 3-15).



A B

Figure 3-9. REMOTS® photographs from stations 300W (A) and 800W (B) showing a "chaotic" mixture of silts, fine sands, and sands intermixed with clay in the recently disposed dredged material (magnification 1×)

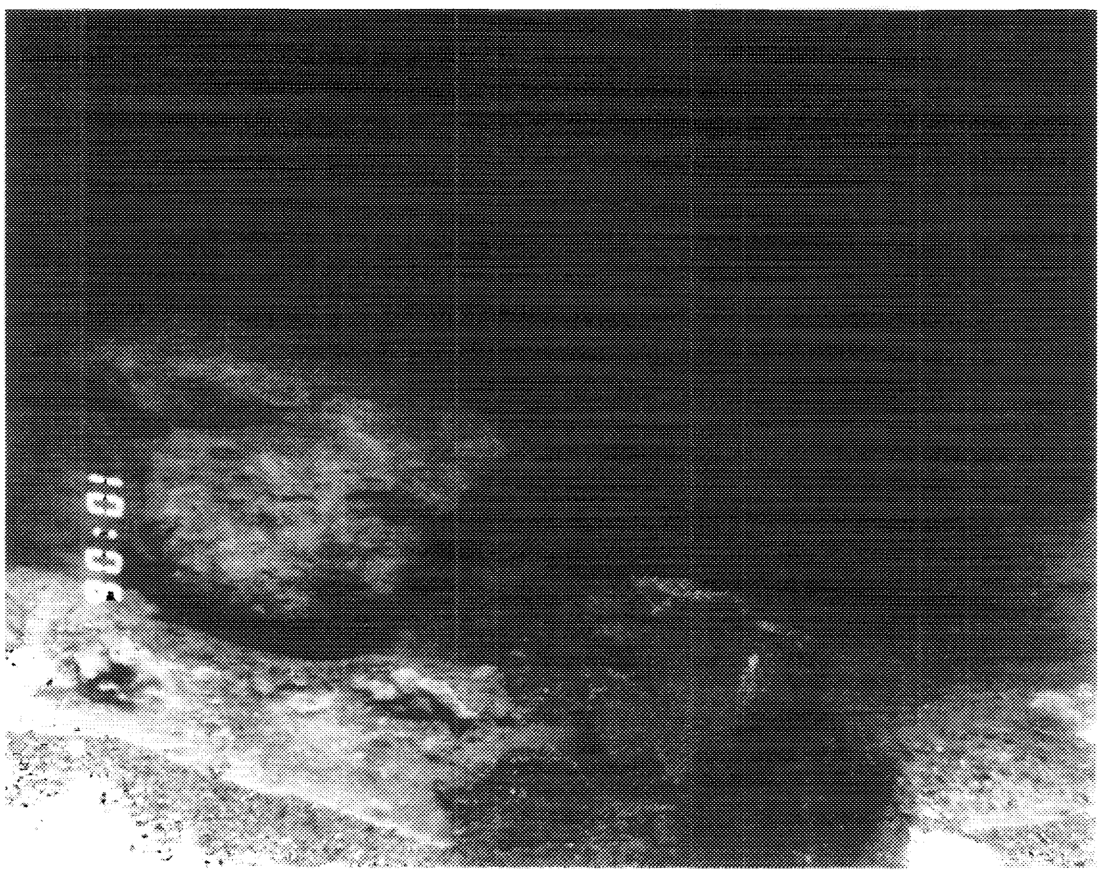
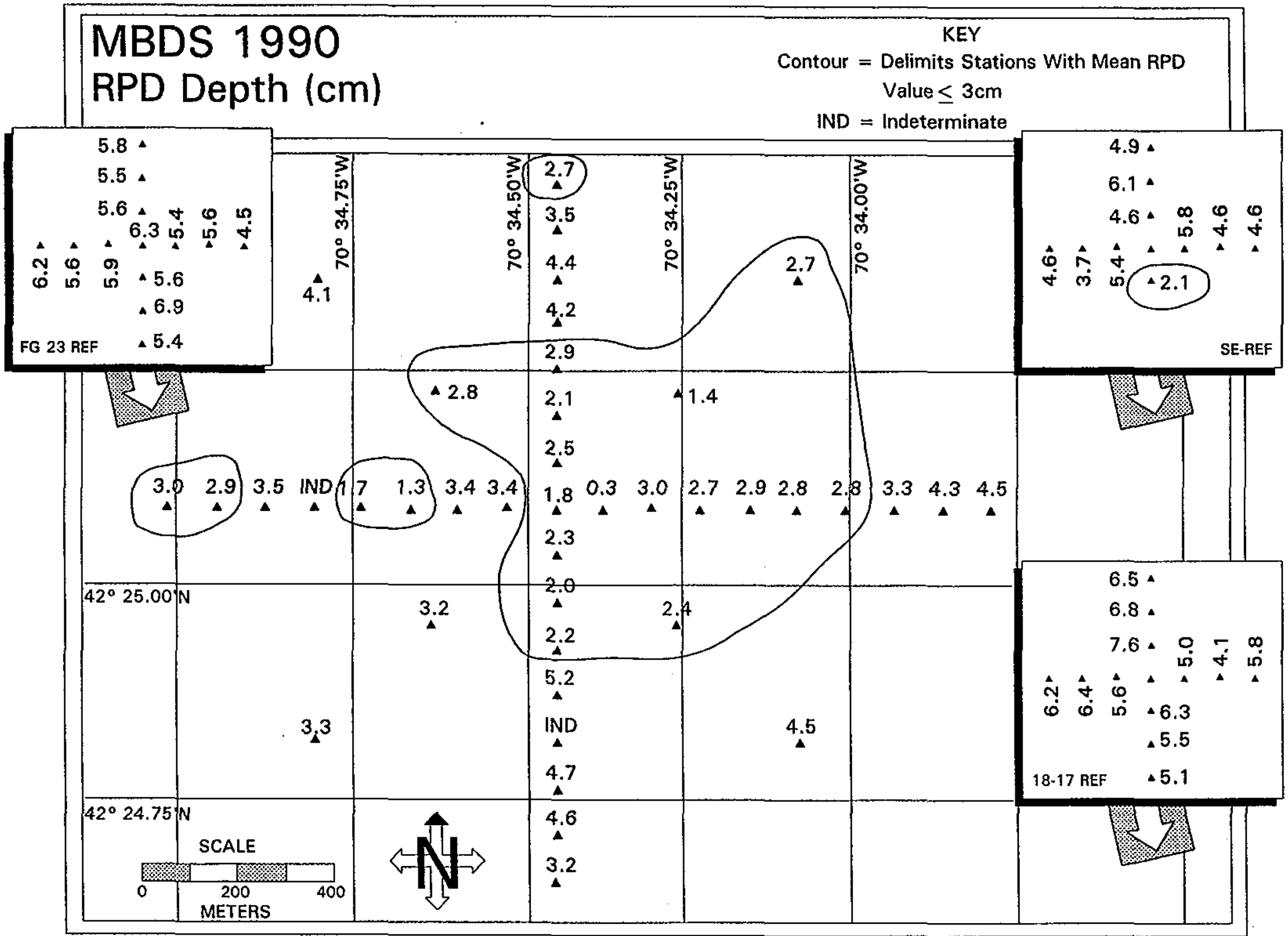


Figure 3-10. A REMOTS® photograph from station 100E where over-consolidated clay clasts and rock rubble limited penetration by the camera (magnification 1×)



(Note: Reference Areas Are Not To Scale)

Figure 3-11. Mean apparent RPD depths (cm) for MBDS, August 1990

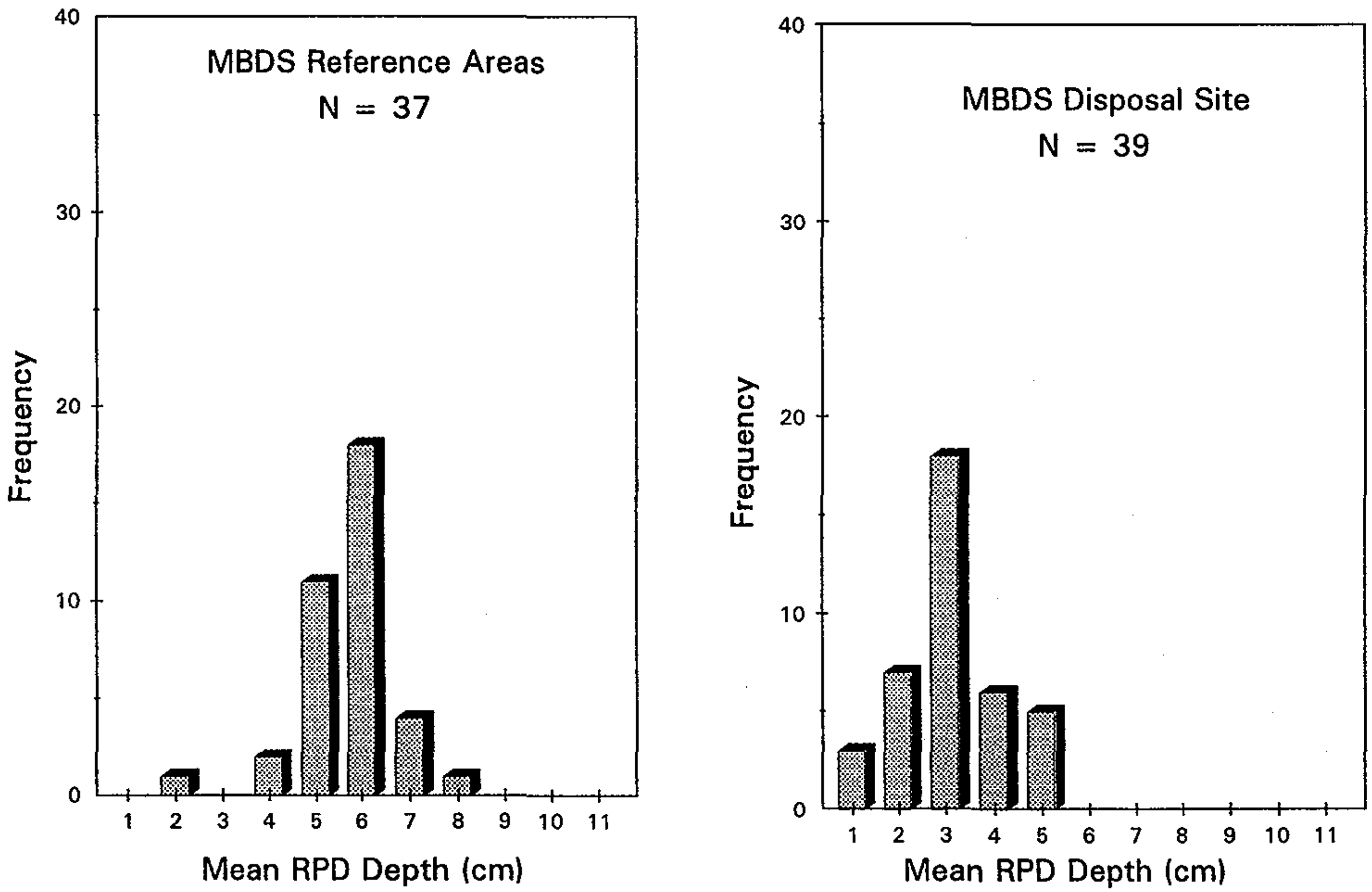


Figure 3-12. Frequency distributions for mean apparent RPD depths for on-site and off-site locations at MBDS, August 1990

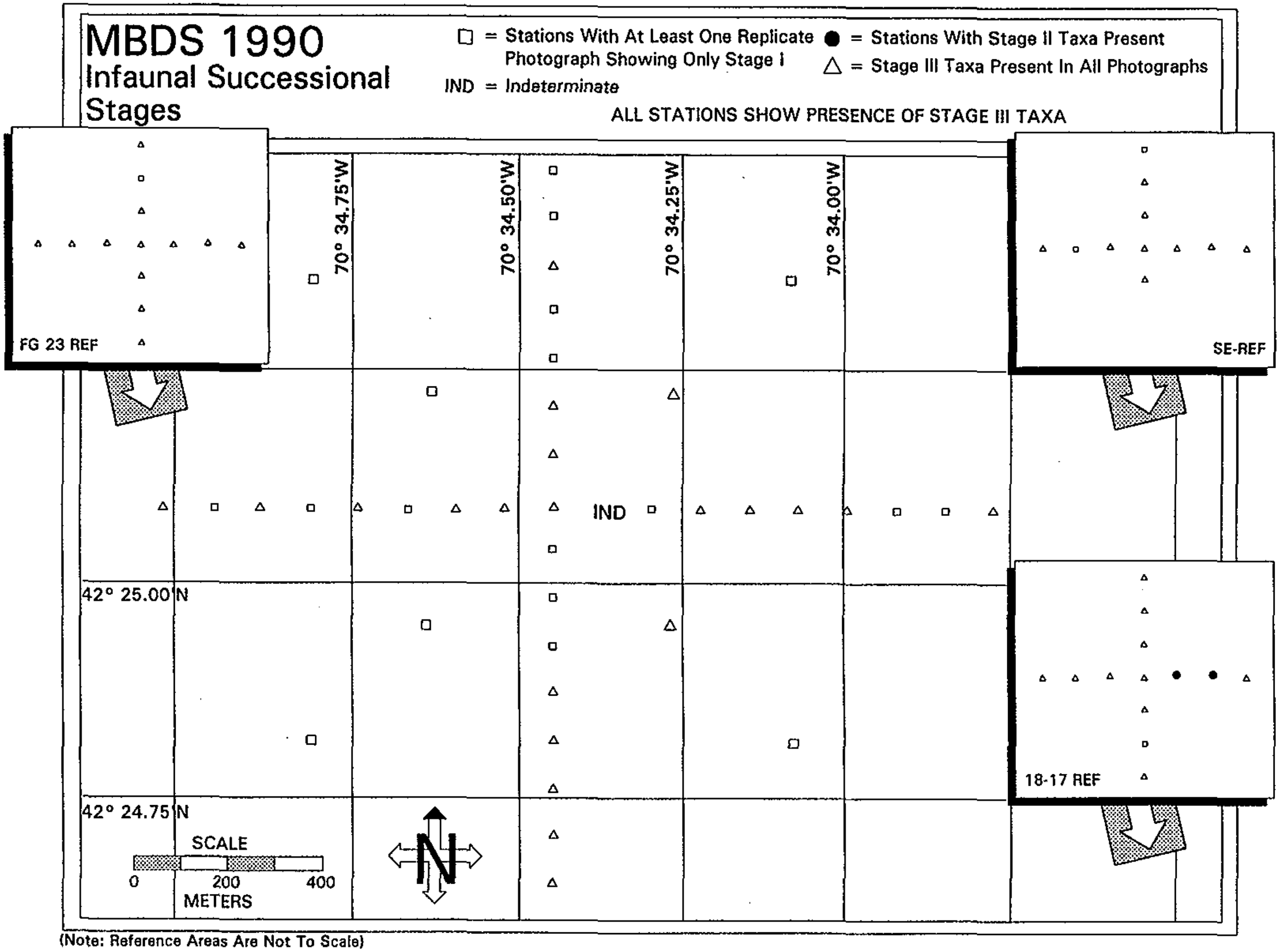
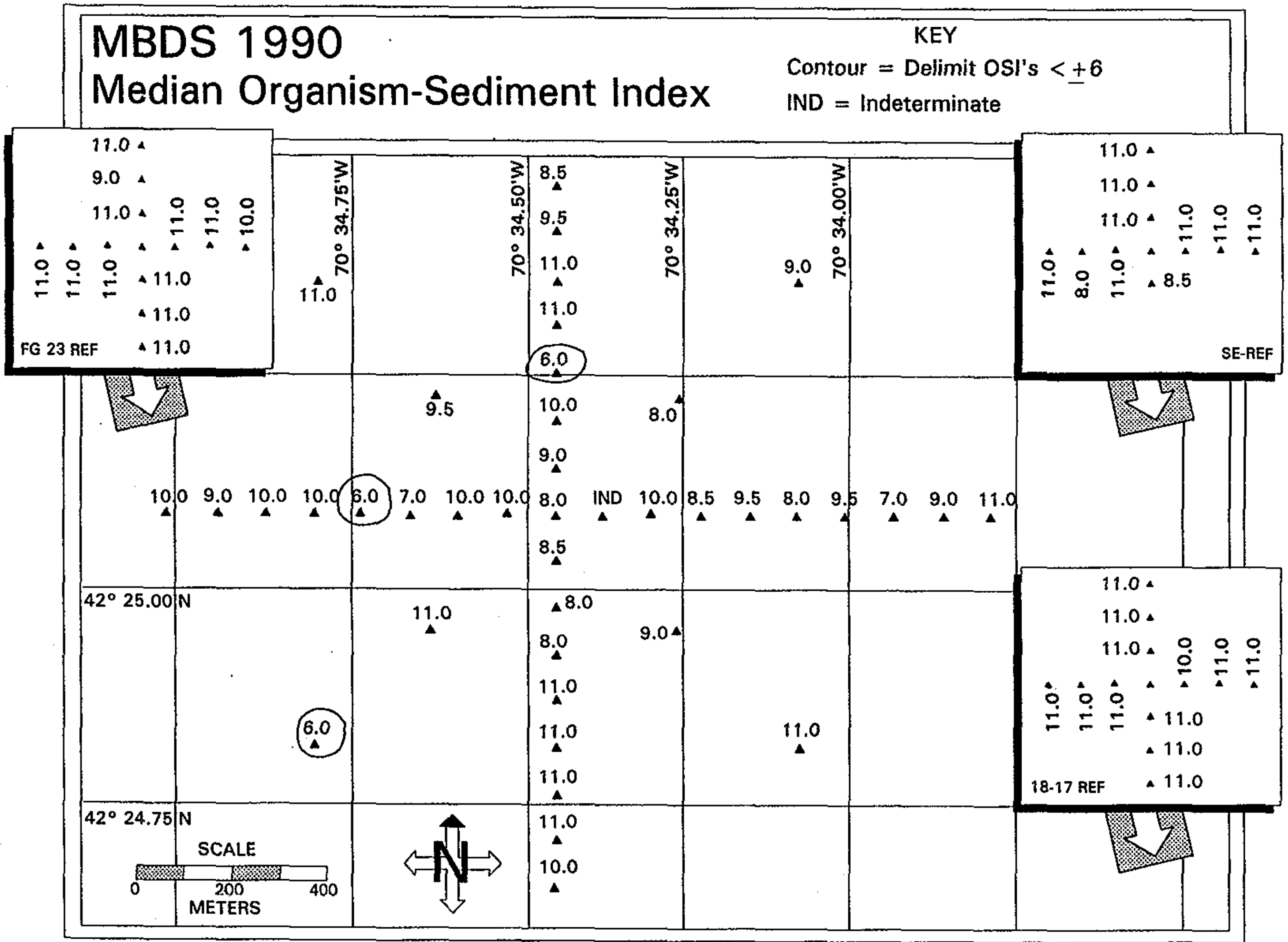


Figure 3-13. The spatial distribution of infaunal successional seres for MBDS, August 1990



(Note: Reference Areas Are Not To Scale)

Figure 3-14. The median Organism-Sediment Index (OSI) values for MBDS, August 1990

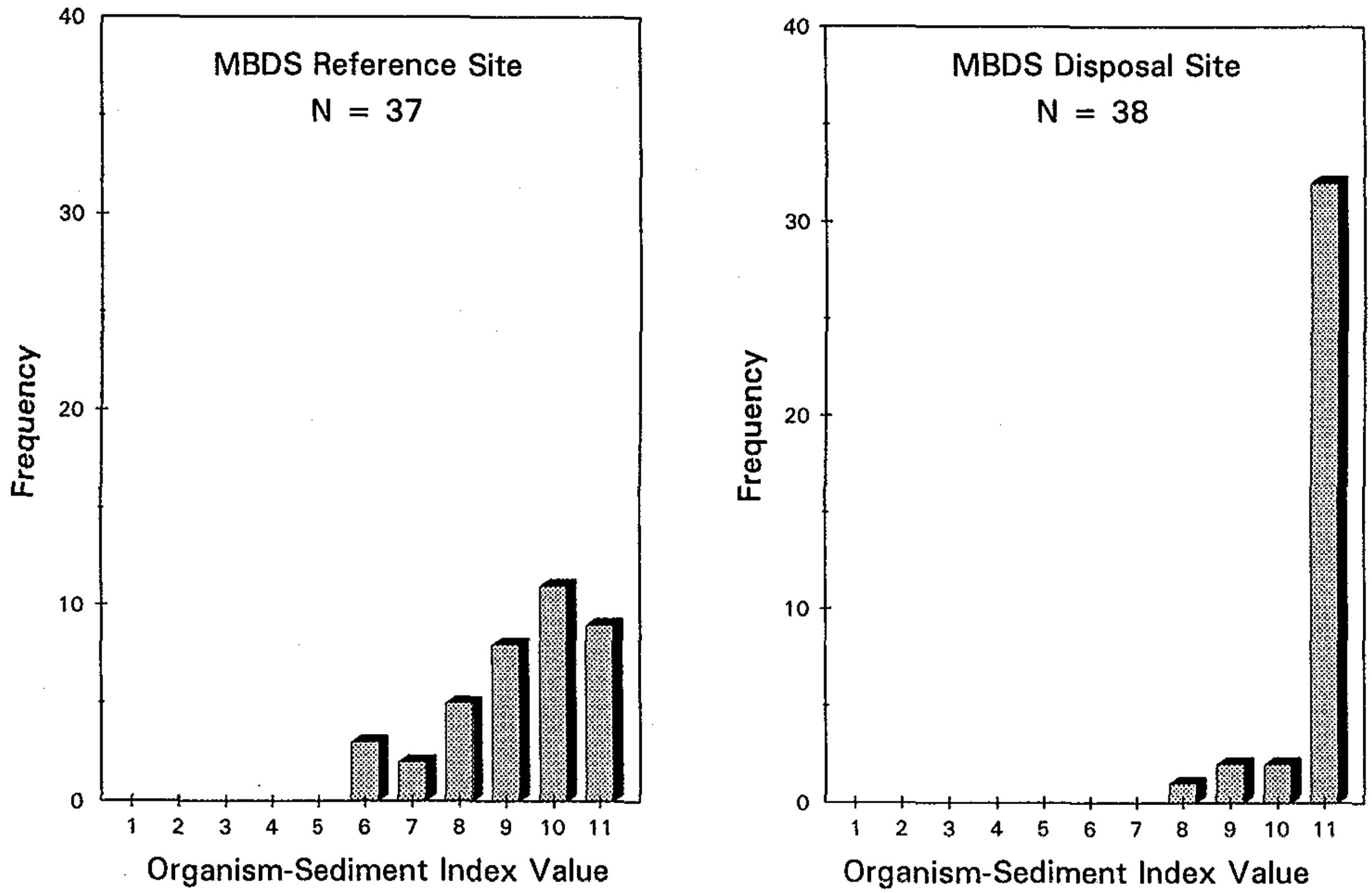


Figure 3-15. Frequency distribution of OSI values for on-site and off-site locations at MBDS, August 1990

4.0 DISCUSSION

The bathymetric analysis showed significant accumulations of dredged material in the vicinity of the disposal buoy since 1988, which contradicted the prediction that changes in mound height and diameter would not be detectable with bathymetry. Plots of barge release points over the 1988-1990 disposal seasons (Figure 4-1) indicated that the majority of barges released near the designated location. Barge release points that are further than average from the buoy location may be due to fluctuations in the LORAN readings or weather conditions. The successful formation of a mound from these disposal activities demonstrated that a distinct mound can be formed with dredged material at this site providing that tight control is exercised over disposal operations (Wiley 1991).

Barge log estimates indicated that 260,300 m^3 of dredged material was deposited within 400 m of the "MDA" buoy at MBDS from November 1988 to August 1990. Tavolaro (1980) showed that volume estimates based on barge logs overestimate considerably the amount of dredged material because of the significant amount of interstitial water associated with the material in the barges. He calculated "depth difference" volume estimates based on successive bathymetric surveys to be as much as 41% less than the barge log volume estimates. The discrepancy was attributed not only to the barge log inaccuracies, but also to the compaction of the dredged material on the bottom following disposal and the significant volume of material deposited at the flanks of the mounds in layers too thin to be detected acoustically. Applying Tavolaro's maximum 41% correction factor to the barge log estimate of 260,300 m^3 resulted in a corrected volume of 153,600 m^3. The volume calculation from the comparison of the 1988 and 1990 bathymetric surveys was 78,100 m^3, or 50.9% of the corrected volume of released material. Consolidation of underlying sediments (disposal sediments from 1985 to 1988, and base material) may have contributed to the apparent "loss" of material. As these sediments consolidated, the elevation measured in 1988 (which was used as a reference plane) was reduced. For every 1 cm of consolidation over a 400 m diameter mound, an apparent loss of 1256 m^3 can occur. Inaccurate positioning of some barges at the time of disposal may have also contributed to the apparent loss of material; dredged material disposed on the flanks of the mound would have been undetected by bathymetry.

REMOTS® photographs confirmed the existence of dredged material layers beyond the boundaries determined by bathymetry, a result which is consistent with results at other disposal sites. The precise boundaries of the new mound were difficult to determine at some stations (particularly 500E and 250NW) due to the presence of "fresh" and "relic" dredged material layers. This difficulty in distinguishing between "fresh" and "relic" dredged material was also found with REMOTS® results from January 1989. In the previous survey, the radius of "fresh" material was determined to be approximately 300 to 350 m while relic material extended the radius to approximately 500 m. The current survey indicated an

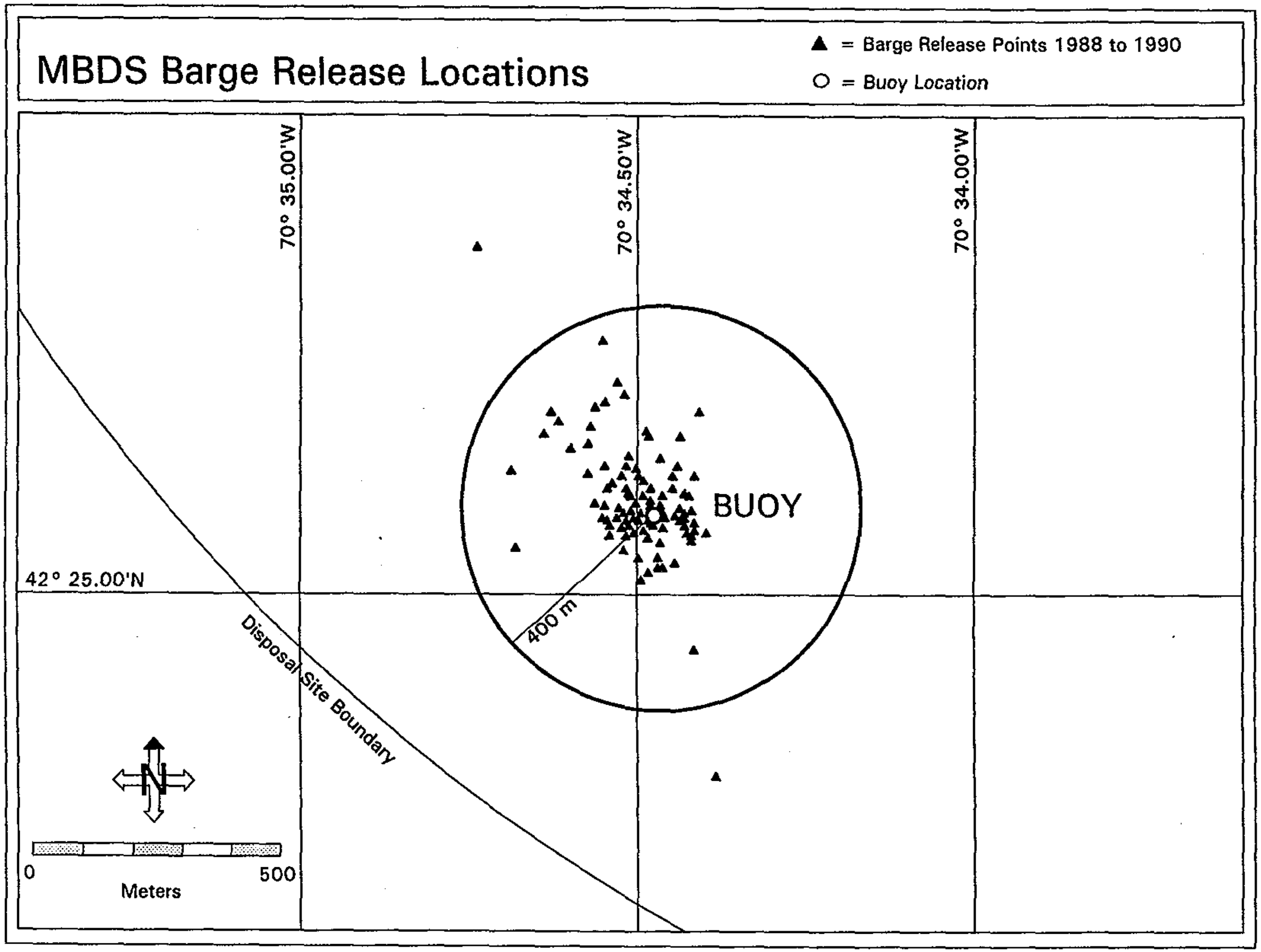


Figure 4-1. A plot of the barge release points for 1988-1990. The plot indicates that the majority of barges released dredged sediments within 400 m of the buoy location.

elliptical shaped mound extending 500 m to the north and south, 400 m east, and 800 m west of the disposal site center.

Dredged material deposited on the flanks of the mound was deposited in layers too thin to be detected reliably by precision bathymetry (the acoustical limit for this survey was approximately 20 cm). Therefore, this material was not included in the bathymetric volume calculation. It can, however, be measured with REMOTS® photography which can detect dredged material layers in the range of 1 mm to 20 cm. When the area representing the flanks of the mound was digitized and measured, it was found to occupy 661,000 m^2 and increased the area of the seafloor affected by dredged material an additional 83% beyond that detected by bathymetry.

A conservative estimate for the average thickness of the fresh dredged material layers in this area was 10 cm. This was based on the actual thickness of dredged material layers measured in photographs obtained from several flank REMOTS® stations. This estimated depth, applied over the entire 661,000 m^2 area, resulted in an estimated volume of 66,100 m^3 of dredged material on the mound flanks not included in the bathymetric volume calculation (78,075 m^3). When combined, the two surveys total 144,175 m^3 (Table 4-1).

The measurements of dredged material thickness were underestimated due to limited camera penetration. It is likely that the layers of dredged material as determined by REMOTS® are deeper than the average camera penetration depth for this survey (10-12 cm). A more reasonable estimate for the depth of dredged material layers on the mound flanks in this case would be 20 cm, the maximum penetration depth of the REMOTS® camera. The volume of dredged material on the mound flanks based on an average depth of 20 cm is 132,200 m^3. This volume, combined with the bathymetric volume calculation, accounts for a total volume of dredged material at the "MDA" buoy of 210,275 m^3 (Table 4-1).

Since the dredged material volume calculated from REMOTS® includes material occurring in thin (10-20 cm) layers, comparisons were not made with the barge log volume corrected to Tavolaro's 41% factor, but with barge log volumes corrected to 15.4%. Tavolaro's 15.4% factor (1980) accounts for loss of interstitial pore water during disposal and initial self-compaction of the disposed material. When the combined volumes for bathymetry and REMOTS® at 10 cm (144,175 m^3) and 20 cm (210,275 m^3) depths are compared to 15.4% of the barge log volume (220,214 m^3; Table 4-1), they account for 65.5% and 95.5% of the corrected volume, respectively.

The presence of dredged material in a large number of REMOTS® stations away from the disposal buoy is primarily related to vessel positioning at the time of disposal. The expected radius of an individual disposal event (2,000 m^3 at a 90 m depth) as calculated by the DAMOS capping model for MBDS indicates that material would spread a distance of 300 meters (Figure 4-2) from the point of impact. A plot of the barge release points (Figure 4-1) indicates that this would account for material deposited to the north, south, and east of the buoy. Barge release points do not, however, account for the dredged material deposited out to 800 m west.

Table 4-1

Comparison of Barge Log Volumes and Volume Estimates from Bathymetric and REMOTS® Surveys

Average Penetration Depth of REMOTS® Camera	Estimated Volume of Dredged Material on Mound Flanks (m^3) from REMOTS®	Combined Volumes (m^3) from REMOTS® and Bathymetric Surveys**	% of Corrected+ Barge Log Estimate (220,214 m^3)
10	66,100	144,175	65.5
20	132,200	210,275	95.5

** The bathymetric volume calculation resulted in 78,075 m^3 of material (95% confidence limits; 55,000 m^3 to 100,650 m^3).

+ Assuming in-place volume is 15% less than barge estimates due to consolidation purposes.

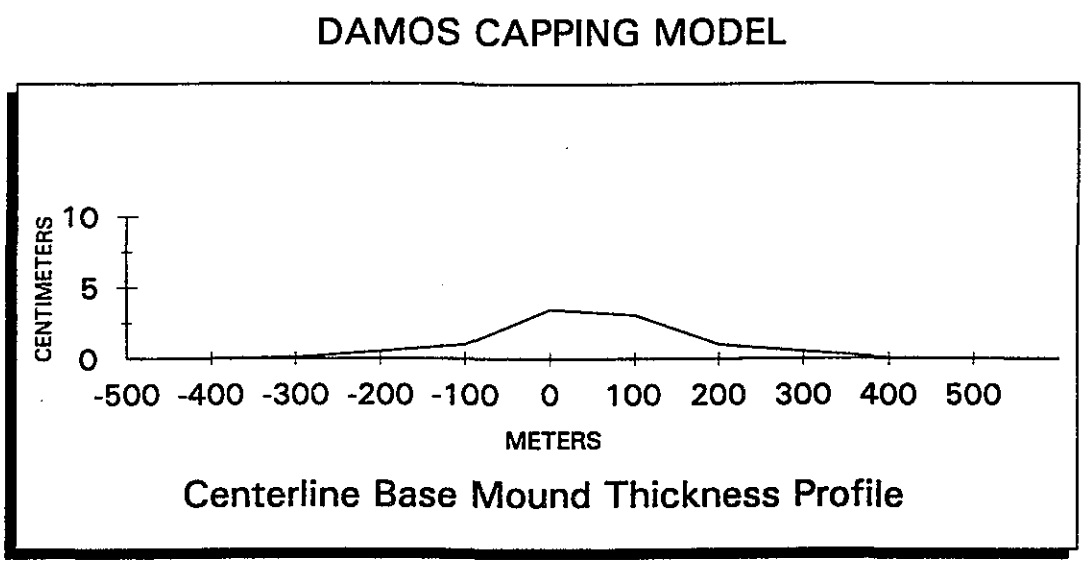


Figure 4-2. Distribution of dredged material from a single disposal event at MBDS as calculated by the DAMOS capping model (2,000 m^3 of material with a water depth of 90 m). The mound thickness profile indicates that material less than 1 cm in thickness may be deposited within 300 m of the disposal location.

5.0 CONCLUSIONS

Dredged material deposited since the November 1988 bathymetric and January 1989 REMOTS® surveys formed a distinct mound, centered slightly east of the buoy with gradually sloping sides, and a maximum thickness of 0.8 m at the apex. Based on changes in bathymetry, the diameter of the mound was estimated to be approximately 420 m, while results from REMOTS® photographs extended the detected dredged material to 500 m north and south, 400 m east, and 800 m west of the disposal site center. Depth difference between the 1988 and 1990 surveys indicated a maximum change in depth of 1 m and an average diameter of 450 m. The mound is well within the disposal site boundaries. These results indicate that when there has been tight operational control during disposal operations, a distinct dredged material mound can be formed at MBDS which is detectable by bathymetry and REMOTS® sediment-profile photography. The formation of a well-defined mound supports the use of capping at MBDS as an effective management option for proposed projects in the Boston Harbor area.

The benthic communities surrounding the "MDA" buoy were similar to those in January 1989. Despite ongoing disposal activity, the percentage of disposal site stations containing Stage III organisms increased since the 1989 survey. The higher OSI values also indicated a steady recovery of the benthic infauna.

The bathymetric volume calculation accounted for 50.9% of the corrected (41%) barge log estimates. Comparison of the depth difference volume estimates and barge log volume estimates resulted in a discrepancy. This discrepancy is probably due to the consolidation of basement sediments and the need for improved techniques for measuring barge log volume. Combined bathymetric and REMOTS® analyses (average camera penetration depth of 10 cm) accounted for a conservative estimate of 65.5% of the corrected barge log volume (Table 4-1). A more reasonable assumption is that the dredged material layers were at least as thick as the maximum camera penetration depth (20 cm). With this thickness, the bathymetry and REMOTS® measurements accounted for 95.5% of the corrected barge log volume. These results support past oceanographic studies (SAIC 1987a, SAIC 1988) which indicated that deposited dredged material was contained within the disposal site boundaries and also indicated that capping of dredged material would be successful at this site. Continued monitoring at MBDS by the DAMOS Program is recommended to ensure protection of nearby resources such as Stellwagen Bank.

6.0 REFERENCES

Bajek, J.; Morton, R. W.; Germano, J. D.; Fredette, T. J. 1987. Dredged material behavior at a deep water open ocean disposal site. In: Proceedings of the twentieth dredging seminar. Western Dredging Association Annual Meeting, Toronto, Canada, pp. 95-107.

Butman, B. 1977. On the dynamics of shallow water currents in Massachusetts Bay and on the New England continental shelf. Unpublished manuscript. Rpt. No. WHOI-77-15. Woods Hole Oceanographic Institution, Woods Hole, MA. 174 pp.

EPA. 1989. Evaluation of the continued use of the Massachusetts Bay dredged material disposal site. Draft Environmental Impact Statement September 1989.

Gilbert, T. R. 1975. Studies of the Massachusetts Bay Foul Area. Prepared for Commonwealth of Massachusetts, Division of Water Pollution Control. New England Aquarium, Boston, MA. 197 pp.

SAIC. 1984. Dredged material disposal operations at the Boston Foul Ground, June 1982-February 1983. DAMOS Contribution No. 41 (SAIC Report No. DACW-33-82-D-0001). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1985. Standard operating procedure manual for DAMOS monitoring activities, volume I. DAMOS Contribution No. 48 (SAIC Report No. SAIC-85/7516&C48). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1987a. Environmental information in support of site designation documents for the Foul Area Disposal Site: physical oceanography. (SAIC Report No. SAIC-85/7528&93). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1987b. Distribution of dredged material at the Rockland Disposal Site, May 1985. DAMOS Contribution No. 50 (SAIC Report No. SAIC-85/7533&C50). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1988. A summary of DAMOS physical monitoring of dredged material disposal activities. (SAIC Report No. SAIC-88/7527&C71). Submitted to US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1989a. Monitoring surveys at the New London disposal site, August 1985-July 1986. DAMOS Contribution No. 60 (SAIC Report No. SAIC-86/7540&C60). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1989b. Monitoring cruise at the Massachusetts Bay Disposal Site, November 1988-January 1989. DAMOS Contribution No. 73 (SAIC Report No. SAIC-89/7558&C79). US Army Corps of Engineers, New England Division, Waltham, MA.

Tavolaro, J. F. 1980. Sediment budget study for clamshell dredging and disposal activities. US Army Corps of Engineers, New York District, New York, New York. pp. 1-27.

Wiley, M. 1991. Deep water capping. (SAIC Report No. SAIC-90/7609&C96). Submitted to US Army Corps of Engineers, New England Division, Waltham, MA.