REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
August 1995

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE

Monitoring Cruise at the New London Disposal Site
June 1991

5. FUNDING NUMBERS

6. AUTHOR(S)

Science Applications International Corporation

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Science Applications International Corporation
221 Third Street
Newport, RI 02840

8. PERFORMING ORGANIZATION REPORT NUMBER

SAIC-92/7622&C101

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

DAMOS Contribution No. 96

11. SUPPLEMENTARY NOTES

Available from DAMOS Program Manager, Regulatory Division
USACOE-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)

The objectives of the monitoring cruise at the New London Disposal Site (NLON) were to 1) delineate the footprint and characterize the topography of the dredged sediment deposited in the vicinity of the NL-TR mound during 1990-1991; 2) assess the benthic recolonization rate at the active disposal site and monitor the successional status at the inactive NL-88 mound; 3) measure near-bottom and surface dissolved oxygen (DO) concentrations at the active disposal site and reference areas and; 4) collect sediment samples at the three reference areas to provide information on percent total organic carbon (TOC), grain size, and levels of polynuclear aromatic hydrocarbons (PAHs), cadmium, lead, and zinc. During the 1990-1991 disposal season, 31,475 m^3 of dredged material was disposed in the vicinity of the NL-TR mound at the 1990-1991 buoy location, 41°16.428' N and 72°04.333' W.

A comparison of the June 1991 and July 1990 bathymetric surveys showed an increase in height of 2.4 m at NL-TR. Also apparent was a smaller mound that developed around the buoy and was adjacent to the NL-TR mound. This mound was 0.6 m in height and approximately 100 m in diameter. The combined radii of these two mounds was about 150 m

Information obtained from the REMOTS® survey indicated the presence of recently deposited dredged material within 200 m north, 400 m west, and 300 m south of the disposal site center. The majority of disposal site and reference area stations were dominated by Stage II, Stage II on III, or Stage III assemblages. Stage II represents a transitional sere between Stages I and III and is associated with recovery of a disturbed benthic habitat. Organism-Sediment Indices for both the disposal site and reference area stations were variable and indicative of a patchy benthic environment.

Results of the metal and PAH analyses indicate relatively low concentrations for the reference areas and no immediate need for further testing beyond the collection of baseline information. Near-bottom dissolved oxygen concentrations were very similar at the reference areas and disposal site, and results indicated a well-oxygenated water column throughout the surveyed area.

14. SUBJECT TERMS

dredged material
monitoring
capping
ocean disposal
contaminated sediment
sediment chemistry

15. NUMBER OF PAGES
56

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

MONITORING CRUISE AT THE NEW LONDON DISPOSAL SITE JUNE 1991

CONTRIBUTION #96

August 1995

Report No.
SAIC- 92/7622&C101
Contract No. DACW33-90-D0001

Submitted to:

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

Submitted by:

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

Page

LIST OF TABLES iv
LIST OF FIGURES v
EXECUTIVE SUMMARY vii

1.0 INTRODUCTION 1

2.0 METHODS 5
2.1 Bathymetry and Navigation 5
2.2 REMOTS® Sediment-Profile Photography 5
2.3 Sediment Sampling and Analysis 6
2.3.1 Grain Size Analysis 8
2.3.2 Total Organic Carbon 8
2.3.3 Metal and PAH Analyses 8
2.3.4 QA/QC 8
2.4 CTD and Dissolved Oxygen Sampling 10

3.0 RESULTS 11
3.1 Bathymetry 11
3.2 REMOTS® Sediment-Profile Photography 17
3.2.1 Grain Size Distribution 17
3.2.2 Boundary Roughness 17
3.2.3 Dredged Material Footprint 17
3.2.4 Apparent RPD Depth 23
3.2.5 Successional Stages 30
3.2.6 Organism-Sediment Index (OSI) 30
3.3 Sediment Analysis 33
3.3.1 Grain Size and Total Organic Carbon 33
3.3.2 Metals 33
3.3.3 PAHs 33
3.4 CTD and Dissolved Oxygen Sampling 39

4.0 DISCUSSION 41
4.1 Disposal Mound Topography 41
4.2 Recolonization Status at the New London Disposal Site 46
4.3 New London Disposal Site Sediment Chemistry 46
4.4 Bottom Water Dissolved Oxygen 52

5.0 CONCLUSIONS 53

TABLE OF CONTENTS (cont.)

Page

6.0 REFERENCES 54

INDEX

LIST OF TABLES

Page

Table 2-1. Summary of Laboratory Analytical Work, Summer 1991 9

Table 3-1. Results of Sediment Grain Size Analyses and Percent Total Organic Carbon for Reference Areas at the New London Disposal Site, June 1991 36

Table 3-2. Metal Results (ppm Dry Weight) for Sediments Collected at the New London Reference Areas, June 1991 37

Table 3-3. Results of PAHs (ppb Dry Weight) for Sediments Collected at the NLON Reference Areas, 1991 38

Table 3-4. Dissolved Oxygen Concentrations ($mg \cdot l^{-1}$) by Modified Winkler Titration at the New London Reference Stations and Active Disposal Site, June 1991 40

Table 4-1. Metal Concentrations (ppm Dry Weight) in Sediments Collected at NLON, CLIS, and WLIS in 1986 and 1987 47

Table 4-2. Metal Concentrations (ppm Dry Weight) in Sediments Collected at the NOAA NS&T Program Stations ELI and LICR, 1984-1987 49

Table 4-3. Concentrations of PAHs from New England Estuarine Sediments and the Mud Dump Site in the New York Bight 50

Table 4-4. Dissolved Oxygen Concentrations ($mg \cdot l^{-1}$) at the New London Reference Stations, July 1990 52

LIST OF FIGURES

Page

Figure 1-1. General location map with disposal site boundaries and reference areas 2

Figure 1-2. Map of New London Disposal Site precision bathymetric survey lanes and REMOTS® survey grid occupied in 1991 3

Figure 2-1. Map of New London Disposal Site REMOTS® station locations and names 7

Figure 3-1. Bathymetric contour plot at the New London Disposal Site, June 1991, showing current and relic disposal mounds 12

Figure 3-2. Bathymetric contour plot at the New London Disposal Site, July 1990, showing current and relic disposal mounds 13

Figure 3-3. Enlarged bathymetric contour plot of the NL-TR region, June 1991 14

Figure 3-4. Contour plot of volumetric differences between July 1990 survey and June 1991 survey, in the vicinity of the NL-TR mound, New London Disposal Site 15

Figure 3-5. Depth profile plots of bathymetric survey lanes 15 and 16 which transect the NL-TR mound 16

Figure 3-6. Distribution map of grain size major mode at the New London Disposal Site and reference areas 18

Figure 3-7. REMOTS® photographs of disposal site stations 100SE and 200E 19

Figure 3-8. REMOTS® photographs of reference area stations WREF (200E) and NLON (200E) 20

Figure 3-9. Frequency distribution of mean boundary roughness values at the pooled disposal site and reference stations 21

Figure 3-10. Spatial distribution of mean boundary roughness values at the pooled disposal site and reference stations 22

Page

Figure 3-11. Distribution map of dredged material, sand cap depth, and unique station characteristics at the New London Disposal Site and reference stations 24

Figure 3-12. REMOTS® photographs of fresh dredged material at the disposal site center and 400W 25

Figure 3-13. REMOTS® photographs of fresh dredged material at 200S and 300S . . . 26

Figure 3-14. REMOTS® photographs of the sand cap at NL-TR at Stations 200NE and 300E 27

Figure 3-15. Frequency distribution of mean apparent RPD depths at the combined disposal site and reference stations 28

Figure 3-16. Spatial distribution of mean apparent RPD depths at the New London Disposal Site and reference stations 29

Figure 3-17. Spatial distribution of successional stages at the New London Disposal Site and reference stations 31

Figure 3-18. REMOTS® photographs from disposal site stations 300N and 200SW 32

Figure 3-19. Spatial distribution map of median Organism-Sediment Index (OSI) values at the New London Disposal Site and reference stations 34

Figure 3-20. Frequency distribution of median Organism-Sediment Index (OSI) values at the New London Disposal Site and reference stations 35

Figure 4-1. Contour plot of volumetric differences beteween October 1988 (prior to capping) and June 1991, showing locations of the LORAN-C disposal points 42

Figure 4-2. Distribution of recently deposited dredged material as determined by REMOTS® photographs compared with the isopach map delineating depth difference for 1991 44

Figure 4-3. Plot of reported barge log disposal positions (LORAN-C) between September 1990 and June 1991 45

EXECUTIVE SUMMARY

The objectives of the monitoring cruise at the New London Disposal Site (NLON) were to 1) delineate the footprint and characterize the topography of the dredged sediment deposited in the vicinity of the NL-TR mound during 1990–1991; 2) assess the benthic recolonization rate at the active disposal site and monitor the successional status at the inactive NL-88 mound; 3) measure near-bottom and surface dissolved oxygen (DO) concentrations at the active disposal site and reference areas and; 4) collect sediment samples at the three reference areas to provide information on percent total organic carbon (TOC), grain size, and levels of polynuclear aromatic hydrocarbons (PAHs), cadmium, lead, and zinc.

The New London Disposal Site covers a one square nautical mile (nmi) area and is centered at 41°16.100′ N latitude and 72°04.600′ W longitude. It is located approximately 3 nmi south of Eastern Point in Groton, CT. During the 1990–1991 disposal season, 31,475 m^3 of dredged material was disposed in the vicinity of the NL-TR mound at the 1990–1991 buoy location, 41°16.428′ N and 72°04.333′ W. From 24 to 27 June 1991, Science Applications International Corporation (SAIC) conducted routine bathymetric and Remote Ecological Monitoring of the Seafloor (REMOTS®) sediment-profile surveys, sediment sampling, and measurements of near-bottom DO.

A comparison of the June 1991 and July 1990 bathymetric surveys showed an increase in height of 2.4 m at NL-TR. Also apparent was a smaller mound that developed around the buoy and was adjacent to the NL-TR mound. This mound was 0.6 m in height and approximately 100 m in diameter. The combined radii of these two mounds was about 150 m. Based on the 31,475 m^3 project volume, the DAMOS Capping Model predicted a mound 2.0 m in height with a 150 m radius.

The objective of the REMOTS® survey was to map that portion of the recently deposited dredged material not detectable with bathymetry. Information obtained from the REMOTS® survey indicated the presence of recently deposited dredged material within 200 m north, 400 m west, and 300 m south of the disposal site center. The REMOTS® sediment-profile survey also provided information on the rate of benthic recolonization. The majority of disposal site and reference area stations were dominated by Stage II, Stage II on III, or Stage III assemblages. Stage II represents a transitional sere between Stages I and III and is associated with recovery of a disturbed benthic habitat. Organism-Sediment Indices for both the disposal site and reference area stations were variable and indicative of a patchy benthic environment.

Results of the metal and PAH analyses indicate relatively low concentrations for the reference areas and no immediate need for further testing beyond the collection of baseline information. Near-bottom dissolved oxygen concentrations were very similar at the reference areas and disposal site, and results indicated a well-oxygenated water column throughout the surveyed area.

1.0 INTRODUCTION

The New London Disposal Site (NLON) covers a one square nautical mile (nmi) area and is centered at 41°16.100′ N latitude and 72°04.600′ W longitude. It is located approximately 3 nmi south of Eastern Point, Groton, CT (Figure 1-1). The Disposal Area Monitoring System (DAMOS) Program has monitored this disposal site since 1977. Initially, monitoring was conducted in response to concerns about possible environmental impacts resulting from the disposal of dredged material removed from the Thames River to accommodate deep draft submarines. Subsequent surveys (with the most recent occurring during June–July 1990) were initiated to monitor mound formation and stability as well as benthic recolonization. Several disposal mounds currently exist at NLON as a result of past and recent dredging operations from the Thames River and at other locations in the eastern Long Island Sound region.

During the 1990–1991 disposal season, 31,475 m^3 of dredged material was deposited in the vicinity of the NL-TR mound at the 1990–1991 buoy location, 41°16.428′ N and 72°04.333′ W (Figure 1-2). The NL-TR disposal mound is located in the northeast quadrant of the New London disposal site at 41°16.425′ N and 72°04.320′ W. NL-TR was created in 1988 for disposal of contaminated sediment generated by dredging activities at the Thames Shipyard and Repair Company. This original mound was capped with material released at six different locations from 1 October 1988 to 23 January 1989. The volume of this material was estimated at 59,500 m^3 based on disposal logs (SAIC 1993). The release of additional cap material was recommended following a bathymetric survey of the area in February 1989 (SAIC 1990a). Disposal at NL-TR was resumed in March 1990, and continued through June 1990 (SAIC 1993).

From 24 to 27 June 1991, SAIC conducted field operations near the NL-TR mound (Figure 1-2) to provide information on the effects of the 1990–1991 disposal operations. Field operations included a precision bathymetric survey, Remote Ecological Monitoring of the Seafloor (REMOTS®) sediment-profile photography, sediment sampling for chemical and physical analyses, and measurements of near-bottom dissolved oxygen (DO). The objectives of the 1991 survey were to

- delineate the footprint and characterize the topography of the dredged sediment deposited in the vicinity of the NL-TR mound during 1990–1991 using precision bathymetric and REMOTS® sediment-profile surveys.

- assess the benthic recolonization rate at the active disposal site and monitor the successional status at the inactive NL-88 mound.

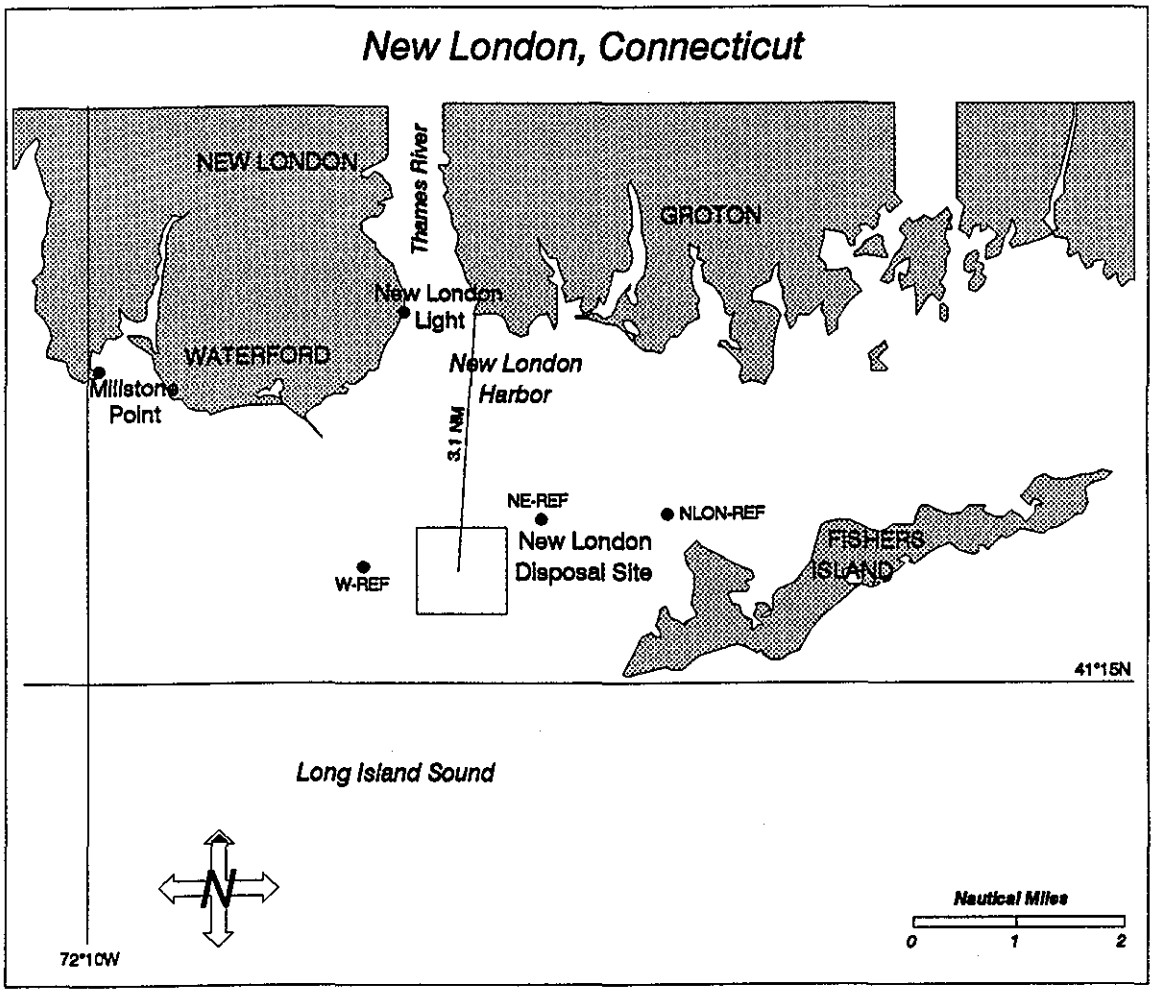

Figure 1-1. General location map with disposal site boundaries and reference areas

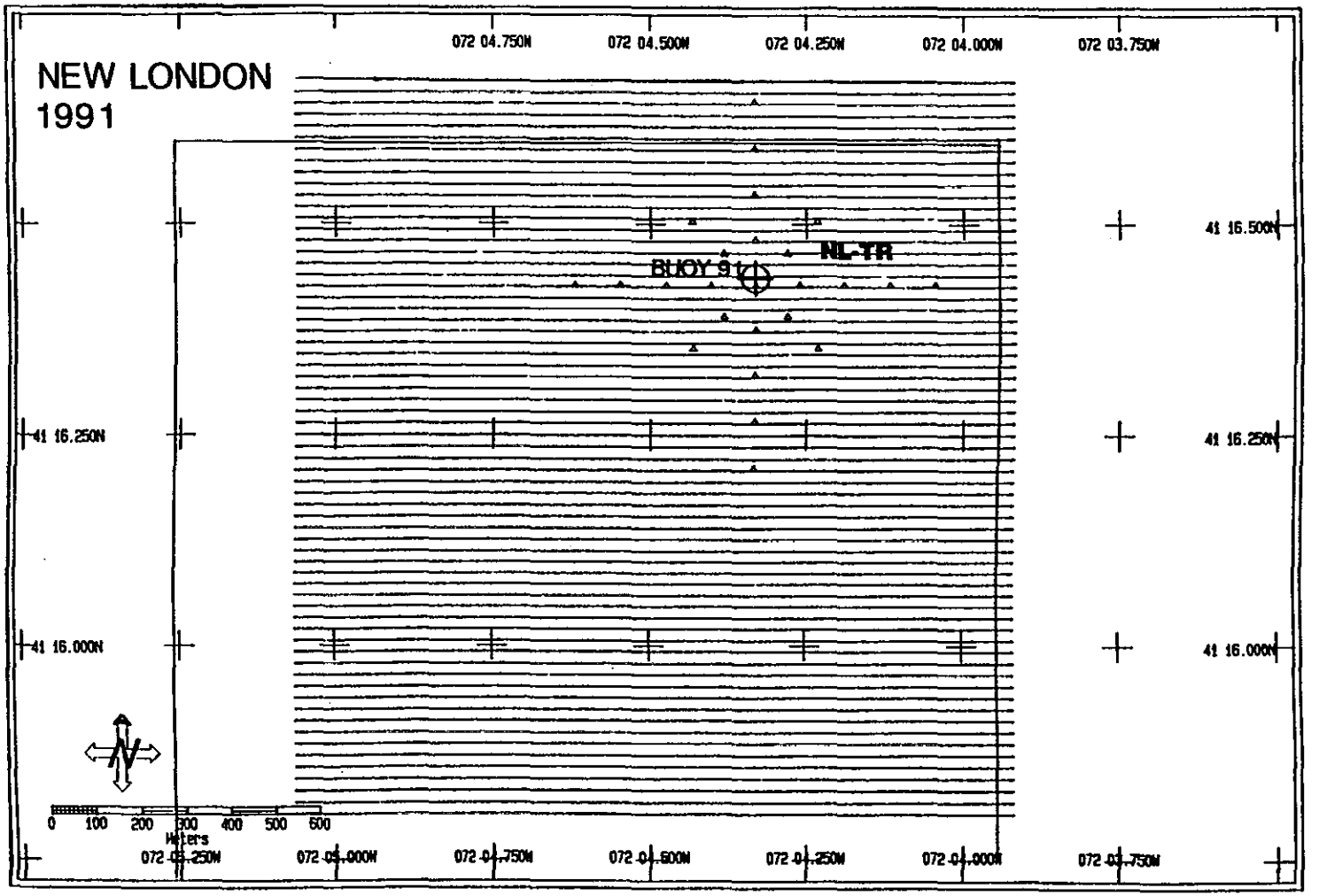

Figure 1-2. Map of New London Disposal Site precision bathymetric survey lanes and REMOTS® survey grid occupied in 1991. The grid sampling stations are centered on an area that received 31,425 m^3 of dredged material between March 1990 through June 1991. This site received dredged material since 1988.

- measure near-bottom and surface DO concentrations at the active disposal site and reference areas. These data were used to assess the potential role of DO as a biologically important variable for benthic recolonization.

- collect sediment samples at the three reference areas to provide information on percent total organic carbon (TOC), grain size, and potential effects of the following contaminants: polynuclear aromatic hydrocarbons (PAHs), cadmium (Cd), lead (Pb), and zinc (Zn).

The 1991 monitoring plan was designed to test the following predictions that are part of the DAMOS tiered monitoring protocol:

- Based on a disposal simulation model, the volume of sediments disposed near the NL-TR mound from September 1990 to May 1991 should result in formation of a mound with a radius of approximately 150 m and height of 2 m. Further disposal is expected to contribute additional material to the cap at this location.

- On the active area of the disposal site, recolonization will be dominantly Stage I, while recolonization on the flanks of the mound will be primarily in Stage II and/or Stage III. Stage I consists of small pioneering polychaetes, whereas Stage II is characterized by tubicolous amphipods, and Stage III by larger burrowing (head-down) deposit feeders. Stage III taxa represent high-order successional stages typically found in low disturbance habitats.

- Near-bottom DO concentrations should be similar at stations within the disposal site compared to reference areas.

2.0 METHODS

2.1 Bathymetry and Navigation

The SAIC Integrated Navigation and Data Acquisition System (INDAS) provided the precision navigation required for all field operations. A complete description of this system can be found in DAMOS Contribution No. 48 (SAIC 1985). Quality assurance and quality control procedures utilized throughout this survey are described in the QA/QC plan for the DAMOS Program (SAIC 1990b). The INDAS system uses a Hewlett-Packard 9920 series computer to collect position, depth, and time data for real-time navigation and for subsequent data analysis. A Del Norte Trisponder® System determined positions to an accuracy of ±3 meters. Shore stations for the present survey were established in Connecticut at known benchmarks at the Millstone Point nuclear power plant and the New London Lighthouse (Figure 1-1). The continued use of these shore station locations allows accurate comparisons of past and present surveys.

An Odom DF3200 Echotrac® Survey Recorder with a narrow-beam 208 kHz transducer recorded depth to a resolution of 3.0 cm (0.1 feet). However, the acoustic records could reliably detect changes in depth on the order of only 20 cm or more 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 used in depth calculations was determined from water temperature and salinity data measured by a Seabird SEACAT SBE 19-01 CTD (Conductivity, Temperature, and Depth) probe (see Section 2.4 below). During analysis, raw bathymetric data were corrected for speed of sound in seawater and standardized to Mean Low Water by compensating for transducer depth and changes in tidal height during the survey. A detailed discussion of the bathymetric analysis technique is given in DAMOS Contribution No. 60 (SAIC 1989).

The bathymetric survey conducted at NLON on 25 and 27 June 1991 encompassed a 1600 × 1600 m grid with 25 m lane spacing, centered at coordinates 41°16.235′ N and 72°04.492′ W (Figure 1-2). This was the same grid used for the bathymetric survey in June–July 1990, permitting depth differences to be calculated relative to the 1990 survey.

2.2 REMOTS® Sediment-Profile Photography

REMOTS® sediment-profile photographic surveys of the New London Disposal Site have been carried out since June 1984. REMOTS® photography has been used to detect and map the distribution of thin (1-20 cm) dredged material layers. This capability complements the precision bathymetric surveys which can measure bottom elevation changes greater than 20 cm. In addition, REMOTS® is used to map benthic disturbance gradients, and monitor

the process of infaunal recolonization on, and adjacent to, disposal mounds. Specific measurement/observational techniques for determining REMOTS® parameters include a visual estimate of the sediment grain size major mode and range, prism penetration depth, surface boundary roughness, presence/absence and size of mud clasts, apparent redox potential discontinuity (RPD) depth, apparent presence/absence of sedimentary methane, estimate of infaunal successional stage, and calculation of the REMOTS® Organism-Sediment Index (OSI). A detailed description of REMOTS® photograph acquisition, analysis, and interpretative rationale is stated in DAMOS Contribution No. 60 (SAIC 1989). Quality assurance and quality control procedures are explained in the QA/QC plan for the DAMOS Program (SAIC 1990b).

REMOTS® stations occupied during the present survey were radially distributed around the disposal site center (41°16.428′ N, 72°04.333′ W; Figure 2-1). Triplicate photographs were obtained on 24, 26, and 27 June 1991 for each of the 25 stations. Stations were spaced 100 m apart and extended 400 m to the north, south, east, and west and 200 m to the northwest, northeast, southwest, and southeast of the central station.

In addition, thirteen REMOTS® stations, arranged in a cross-shaped pattern and spaced 100 m apart, were established at each of the reference areas to allow comparisons between the disposal site mound and the ambient bottom. Photographs were obtained at all reference area stations with the exception of WREF 200N. A fourth 13-station cross-shaped grid was centered on the inactive NL-88 mound (41°16.100′ N, 72°04.350′ W), 700 m south of the NL-TR region. Results of REMOTS® photographs from the NL-88 mound were used to provide a rapid field evaluation of the colonization status of this inactive mound. Disposal at NL-88 occurred 25 January to 10 March 1989, and October 1989 to February 1990 (SAIC 1993). Reference area station locations were the same as those occupied in June–July 1990; WREF (41°16.200′ N, 72°06.000′ W), NE-REF (41°16.680′ N, 72°03.400′ W), and NLON-REF (41°16.660′ N, 72°02.000′ W).

2.3 Sediment Sampling and Analysis

Sediment samples were collected from the center of the reference areas using a 0.1 m^2 teflon-lined Van Veen grab sampler. Three samples were collected for analysis at each reference area with each sample originating from a separate grab. Subsamples from each grab were obtained using a 10 cm polycarbonate plastic core liner (6.5 cm ID). Cores (0-10 cm) were composited to provide sufficient sediment to fill precleaned I-Chem® 250 ml glass jars for chemistry analyses (metals and PAHs). Sediments for grain size and TOC were placed in plastic bags. Samples were kept cold (approximately 4° C) and delivered to the NED lab. The triplicate samples for each reference area were analyzed for TOC, PAHs, Cd, Pb, and Zn. Grain size analyses were not run in triplicate but were combined for each reference area at the NED laboratory.

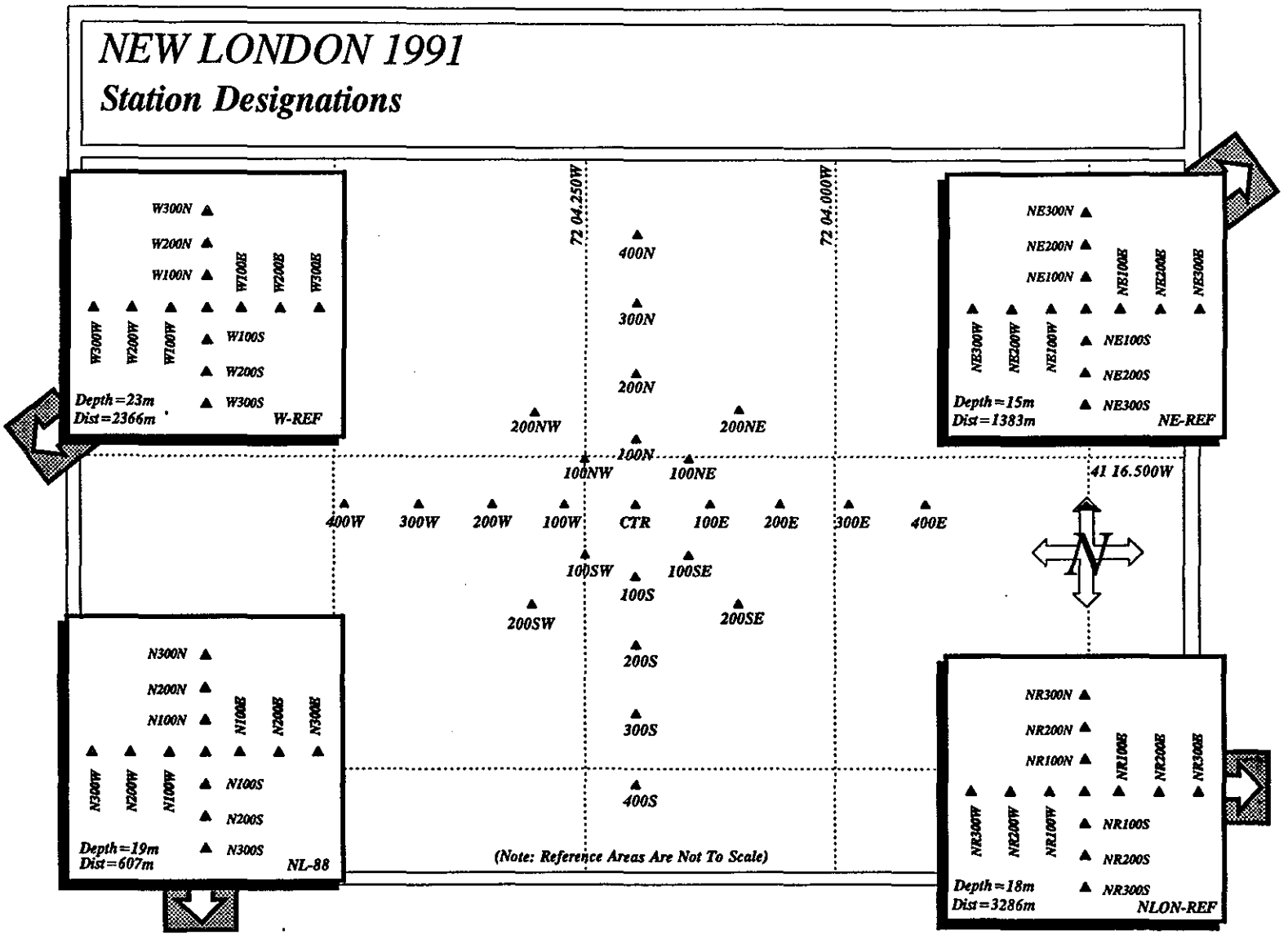

Figure 2-1. Map of New London Disposal Site REMOTS® station locations and names. Distances are measured from the disposal area center to the respective reference area center.

2.3.1 Grain Size Analysis

ASTM Method D422 (Table 2-1) was used for the analysis of sediment grain size. Grain sizes were classified using the Wentworth classification (phi scale) which assigns gravel phi values between -2 and -1, sand between -1 and +4 inclusive, silts between 4 and 8 inclusive, and clays greater than or equal to 9. Prior to initiating the grain size analysis, a subsample (approximately 5-20 g) was taken for determination of percent total solids (% dry weight) to allow for correction of percent moisture. A sieve analysis was then performed in which the sample was separated into size fractions greater than 62.5 μm ($<$4 phi), sand and gravel, and less than or equal to 62.5 μm ($\geq$4 phi) silt and clay. The gravel/sand fraction was subdivided further by mechanically dry sieving it through a graded series of screens. The wet-sieved and dry-sieved fractions less than 62.5 μm were combined for each sample. The silt/clay fraction was then subdivided using a pipet technique dependent upon the differential settling rates of particles in a water column.

2.3.2 Total Organic Carbon

Total organic carbon was measured using a carbon analyzer (EPA Method 9060). Organic carbon in the samples was converted by the analyzer to carbon dioxide (CO_2) and the carbon dioxide measured by an infrared detector. The amount of CO_2 is directly proportional to the concentration of carbonaceous material in the sample. Inorganic forms of carbon (carbonate and bicarbonate) are separated from the reported total organic carbon value. Total organic carbon is a measurement of organic matter (both labile and refractory) in sediments.

2.3.3 Metal and PAH Analyses

Samples were analyzed using standard EPA procedures (Table 2-1). Cadmium and Pb were analyzed by graphite furnace atomic absorption techniques and Zn by inductively coupled argon plasma emission spectrophotometry (ICP). Atomic absorption techniques by graphite furnace allow for low detection limits. Digestates can be heated in several stages allowing removal of unwanted matrix components. Atomic absorption spectrophotometry determinations are completed as single element analyses whereas analysis by ICP allows simultaneous or rapid sequential determination of many different metals. The detection limits associated with ICP analysis are frequently higher than those with atomic absorption spectrophotometry. Polynuclear aromatic hydrocarbons were analyzed by EPA Method No. 8270 which utilizes gas chromatography/mass spectrophotometry (GC/MS).

2.3.4 QA/QC

Results submitted by the NED lab were found to be acceptable and supported by appropriate documentation. Quality control checks from the NED laboratory consisted of

Table 2-1

Summary of Laboratory Analytical Work, Summer 1991

TYPE OF TEST	TEST METHOD		INSTRUMENTATION
Metals	EPA Test Method No.		
	Sample Prep	Analytical	
Cadmium (Cd)	3050	7131	GFAA
Lead (Pb)	3050	7421	GFAA
Zinc (Zn)	3050	6010	ICP
Polynuclear Aromatic Hydrocarbons (PAHs)	3540	8270	GCMS
Total Organic Carbon		9060	
Grain Size	ASTM D422-63		

method blanks, matrix spikes, duplicate samples, and laboratory control samples. Method blanks are laboratory QC samples processed with the samples but containing only reagents. Method blanks test for contamination which may have been contributed by the laboratory during sample preparation. No contaminants were measured in these method blanks. Analysis of matrix spike samples provided a measure of the efficiency and effectiveness of sample preparation and analysis procedures. The matrix spike samples also indicate how tightly a compound is bound to its matrix and the presence of interfering compounds.

Matrix spikes were also used to assess the accuracy of analytical measurements. Duplicate samples indicate variability in laboratory procedures and degrees of difference between individual samples. Duplicate blank spike and duplicate matrix spike samples were used to measure precision in laboratory procedures.

Laboratory control samples in this case were standard reference materials analyzed using identical procedures for samples. Accuracy for the reference materials was within the control limits for the metals as well as the PAHs with the exception of fluoranthene. The laboratory result for the reference material was above the acceptable range; however, this high result was felt to be specific for the reference material rather than an analytical problem reflected in sample results (Knowles 1992).

2.4 CTD and Dissolved Oxygen Sampling

Speed of sound measurements were obtained prior to and following the bathymetric survey using a Seabird SEACAT SBE 19-01 CTD probe. The CTD was lowered over the side and allowed to equilibrate in ambient seawater for 1-2 minutes prior to initiating the cast. Near-bottom DO concentrations at the center of the active disposal site and at all of the reference areas were measured on 27 June 1991 by modified Winkler titrations. (Malfunctioning of the CTD at this point required DO to be measured by titration). A Niskin bottle was used to obtain water samples from approximately 1 m below the surface and 1 m above the bottom. A 300 ml subsample was drawn from the bottle, preserved, and titrated (duplicate aliquots of 50 ml) within 12 hours using a modification of the standard Winkler titration method (Strickland and Parsons 1972, Parsons et al. 1984).

3.0 RESULTS

3.1 Bathymetry

The results of the June 1991 bathymetric survey (Figure 3-1) depict bottom topographic features present at the New London Disposal Site. In general, the ambient bottom slopes from a depth of approximately 16 m in the northern portion of the disposal site to a depth of 23 m to the south. In an east/west direction the disposal site has topographic relief of about 2.5 m. In the extreme southwest corner, there is a steep slope of approximately 5 m. The six relic disposal mounds at NLON are clearly visible from deflections in the bottom contours: NL-RELIC, NL-I, NL-II, NL-III, NL-85, and NL-88 (Figure 3-1; SAIC 1993). The NL-88 mound was first identified in the 1988 NLON master survey, approximately 150 m west of NL-85. Minimum depths of the inactive mounds have remained unchanged since the 1990 bathymetric survey. NL-TR was also present in the 1990 survey and is located roughly 150 m northwest of NL-II. The June 1991 survey showed a distinct mound at NL-TR in comparison to 1990 (Figures 3-2 and 3-3). This mound has a diameter of approximately 150 m and minimum water depth of 14.5 m (Figure 3-3).

The depth differences between the 1990 and 1991 surveys (Figure 3-4) showed a maximum change in height of 2.4 m at the NL-TR region with small peaks of 0.8 m and 1 m located approximately 230 m west of the disposal point. The NL-TR mound, as shown by the depth difference plot was 140-160 m in diameter with a height of 2.4 m. The depth profile of lanes 15 and 16 (the bathymetric survey lanes transecting the maximum height of NL-TR; Figure 3-5) showed changes in mound height of 2.4 m (lane 15) and 3 m (lane 16). A small mound that developed adjacent to the NL-TR mound and immediately to the west had a maximum height of 0.6 m and a diameter of 110 m. The combined radius of this mound plus the NL-TR mound was approximately 150 meters. Depth differences on the order of 20 cm (i.e., approaching the limits of detection in this comparison of the 1990 and 1991 surveys) were present 400 m west, 200 m south, and 150 m to the north of the 1990–1991 disposal site center.

Volume calculations based on the depth difference between the 1990–1991 surveys indicated that 10,500 $m^3 \pm 320$ m^3 (95% C.I.) of sediment have accumulated in the vicinity of the NL-TR disposal mound between the June–July 1990 survey and the present. During this period, disposal logs showed an estimated deposition volume of 31,475 m^3. Sources of discrepancy between the measured and estimated deposition volumes are presented in the discussion.

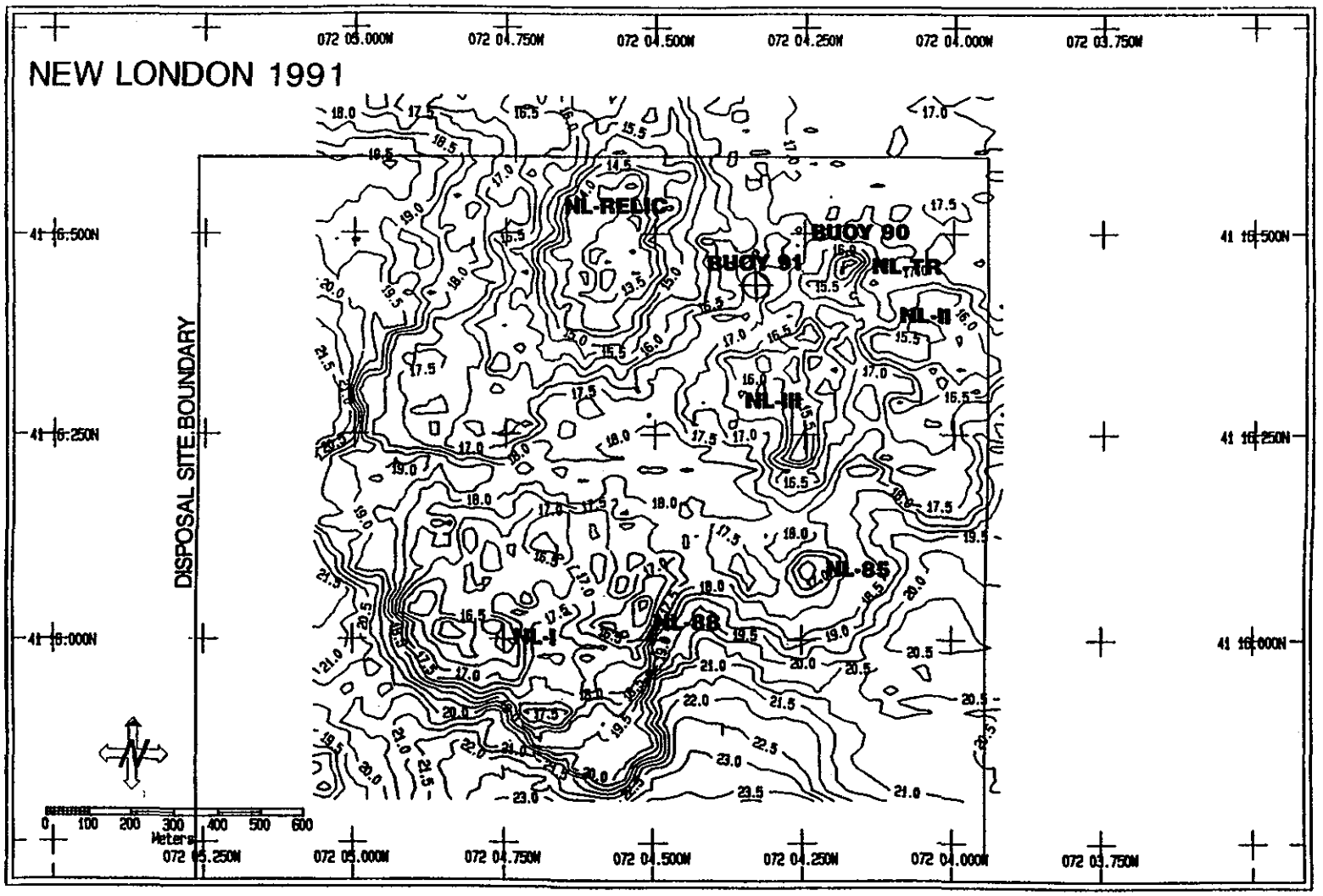

Figure 3-1. Bathymetric contour plot (depth in meters) at the New London Disposal Site, June 1991, showing current and relic disposal mounds

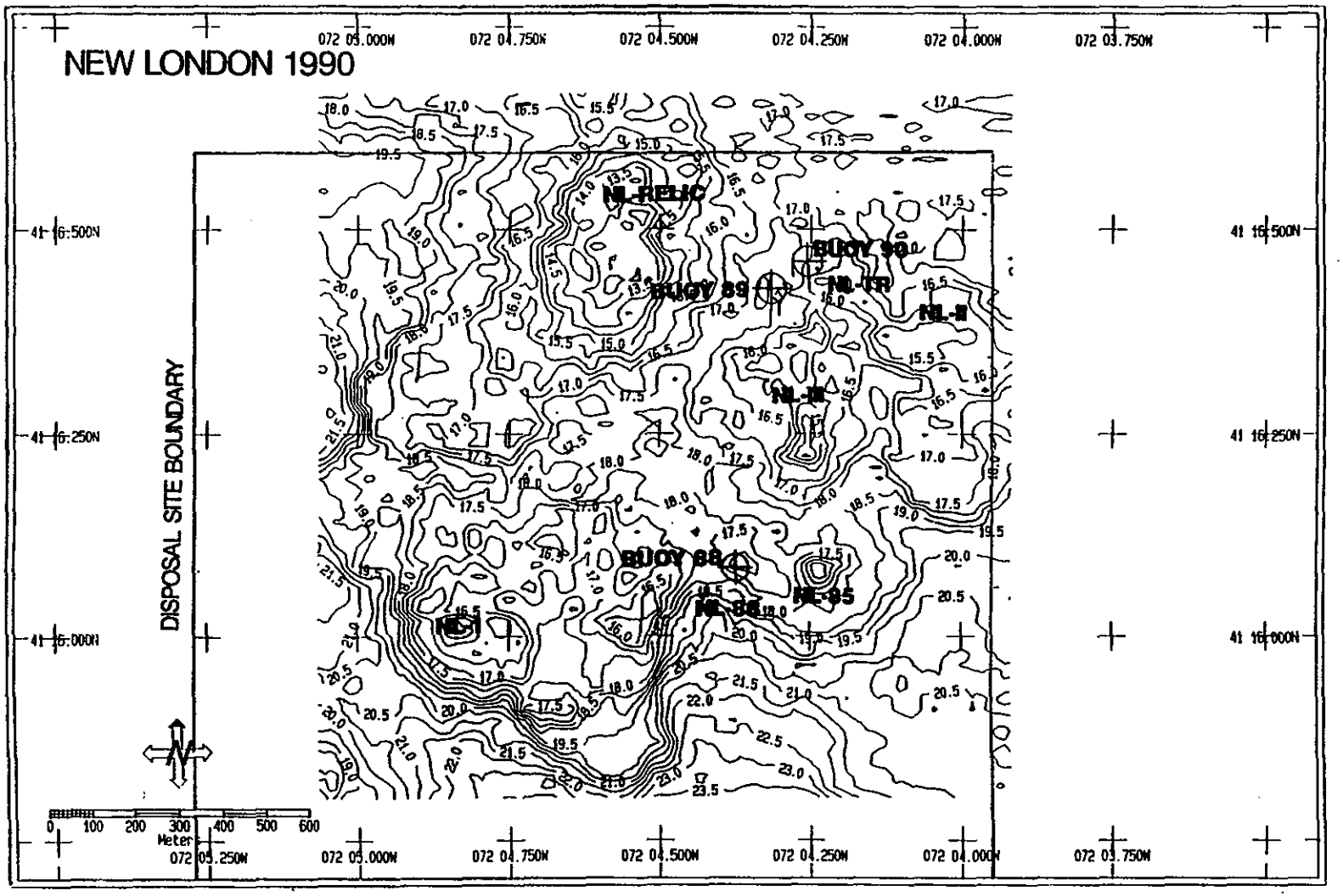

Figure 3-2. Bathymetric contour plot (depth in meters) at the New London Disposal Site, July 1990, showing current and relic disposal mounds

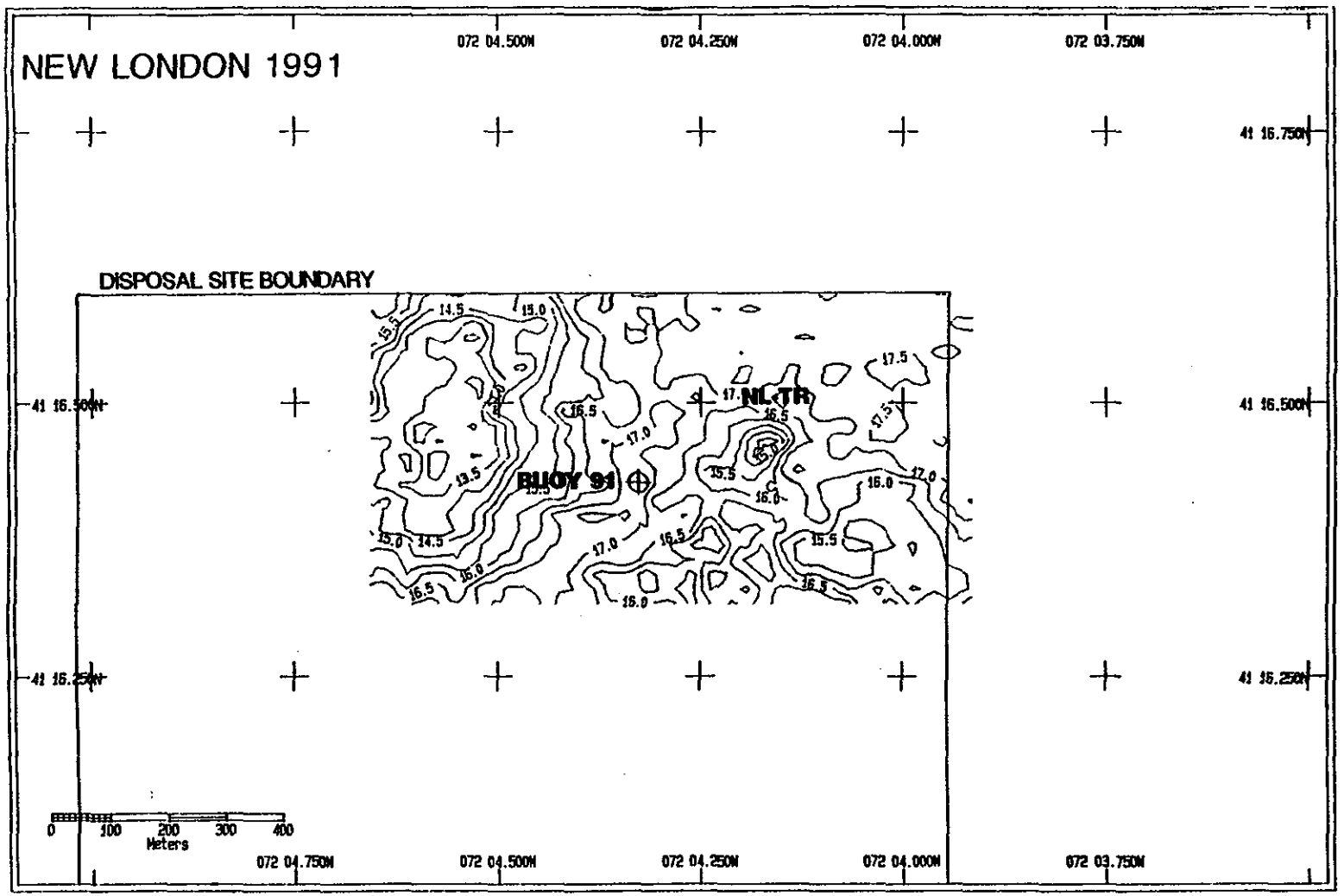

Figure 3-3. Enlarged bathymetric contour plot (depth in meters) of the NL-TR region, June 1991

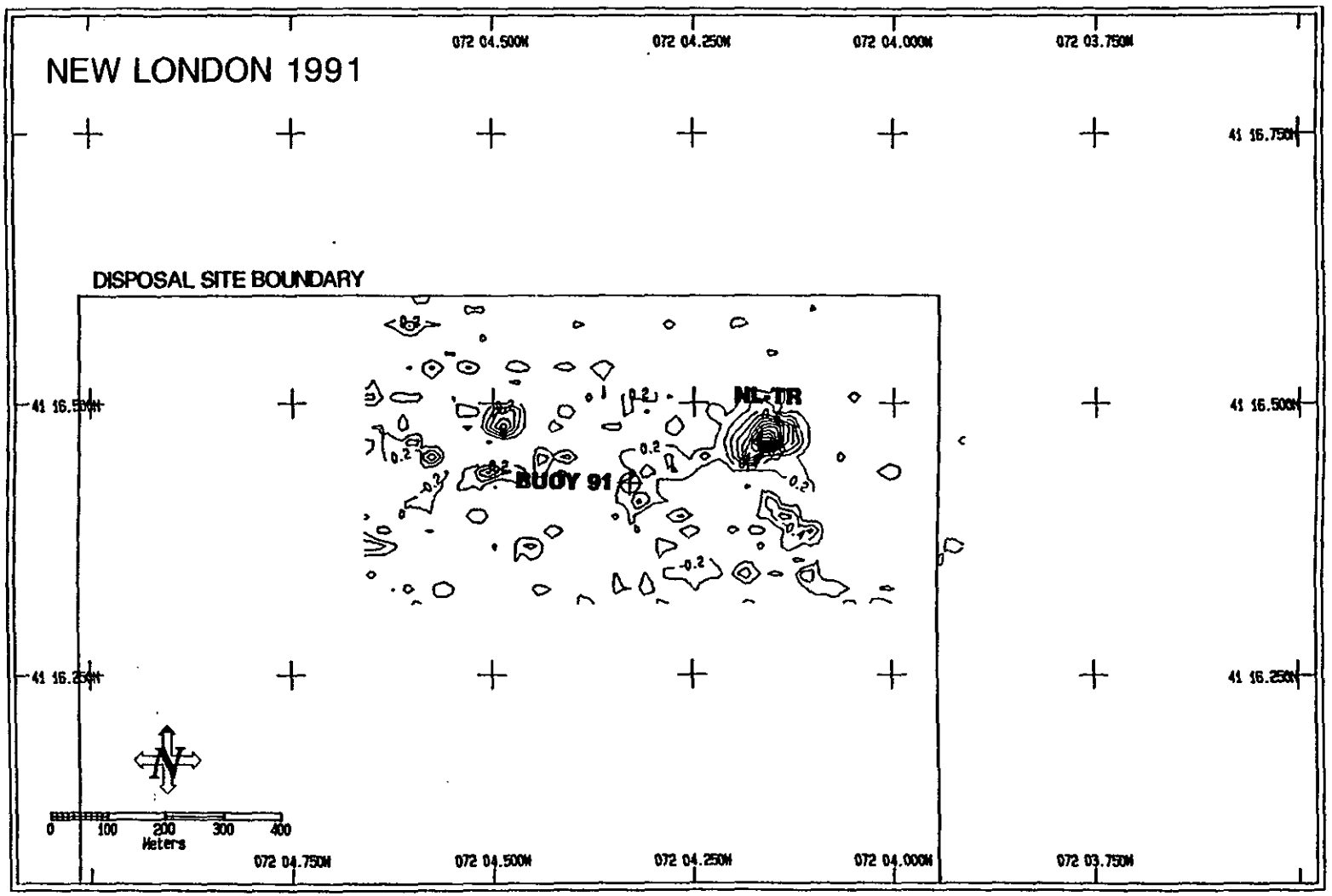

Figure 3-4. Contour plot of volumetric differences (contour interval = 0.2 meters) between July 1990 survey and June 1991 survey, in the vicinity of the NL-TR mound, New London Disposal Site

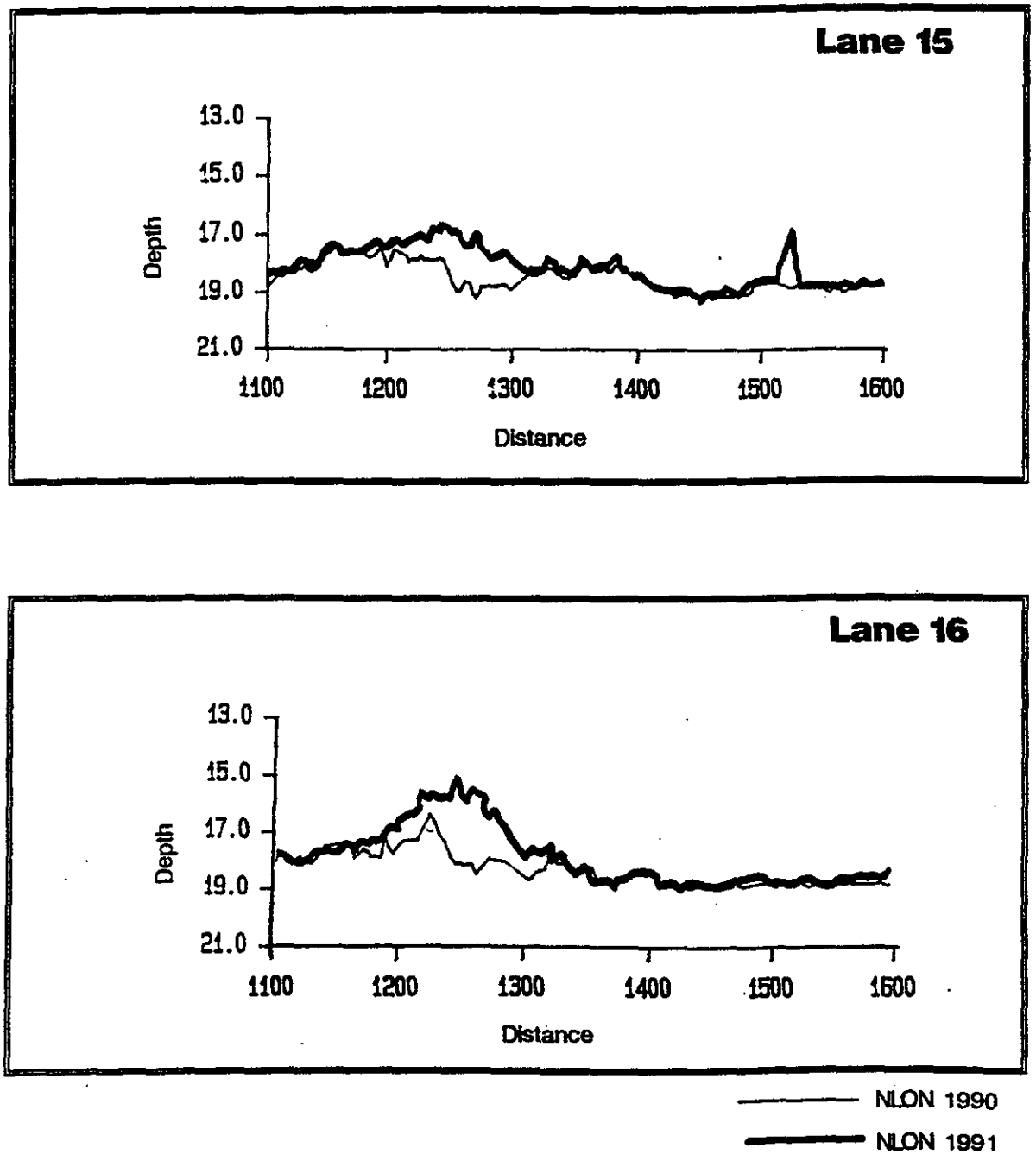

Figure 3-5. Depth profile plots of bathymetric survey lanes 15 and 16 which transect the NL-TR mound. The depth profile plot of lane 16 indicates a maximum change in height at the mound of 3 m.

3.2 REMOTS® Sediment-Profile Photography

3.2.1 Grain Size Distribution

The major modal grain size in the NL-TR survey area ranged from gravel (-1-0 phi) to silt/clay (>4 phi; Figure 3-6). The coarsest sediments, consisting of cobble, gravel, and coarse sands, were located at stations 100SE, 100E, 200E, 300W, 400S, and 100N. This coarse material may represent recent (100SE, 300W, and 100N) as well as relic (400S) dredged material. Coarse sands were also present at some of the stations with active bedforms (100SE, 100E, and 200E; Figure 3-7). The finest sediments (≥4) were located at NL-TR stations 400W and 400E and consisted of fine (3-2 phi) and medium (2-1 phi) sands overlying mud (≥4). Very fine sands (4-3 phi) were present to 400 m north, 300 m south, and 200 m west, southwest, and northwest of the NL-TR survey center (Figure 3-6). In general, these stations consisted of fine and medium sands (3-1 phi) overlying very fine sands (4-3 phi) mixed with mud (≥4 phi). Evidence of sand ripples were present at stations 100E to 300E, 100NE and 200NE, 100SE, and 200W.

Sediment grain size distributions at reference areas NE-REF and NLON-REF were very similar with a major mode of 4-3 phi (very fine sands; Figures 3-6 and 3-8). Surface characteristics at some of the NLON-REF stations included erosional shell lag deposits and sand ripples. Mud clasts, possibly formed by bottom scour, were present at both reference areas. The WREF reference area was characterized by fine sands (3-2 phi), scoured shell lag deposits, and mussel beds (Figure 3-8).

3.2.2 Boundary Roughness

The frequency distribution of mean boundary roughness values for the NL-TR survey area showed an equal distribution among classes 3-5 (Figure 3-9). Values over the area ranged from 0.6 to 3.5 cm. Roughness values (calculated by measuring the vertical distance between the highest and lowest points of the sediment-water interface) were highest at stations located 100 m to 300 m from the NL-TR survey center and reflected surface physical disturbance related to disposal operations and presence of sand ripples (Figure 3-10). The majority of mean boundary roughness values for the reference area stations ranged from 0.6 to 1.4 cm (Figure 3-9). The mean boundary roughness of all stations on the disposal site was significantly different from the mean for the pooled reference areas ($p = 0.05$, Mann-Whitney U-test).

3.2.3 Dredged Material Footprint

Recently deposited (or "fresh") dredged material was indicated by the presence of chaotic sedimentary fabrics, anomalous grain size distributions, and optical reflectance. The distribution of fresh dredged material, as deduced from REMOTS® photographs, extended at

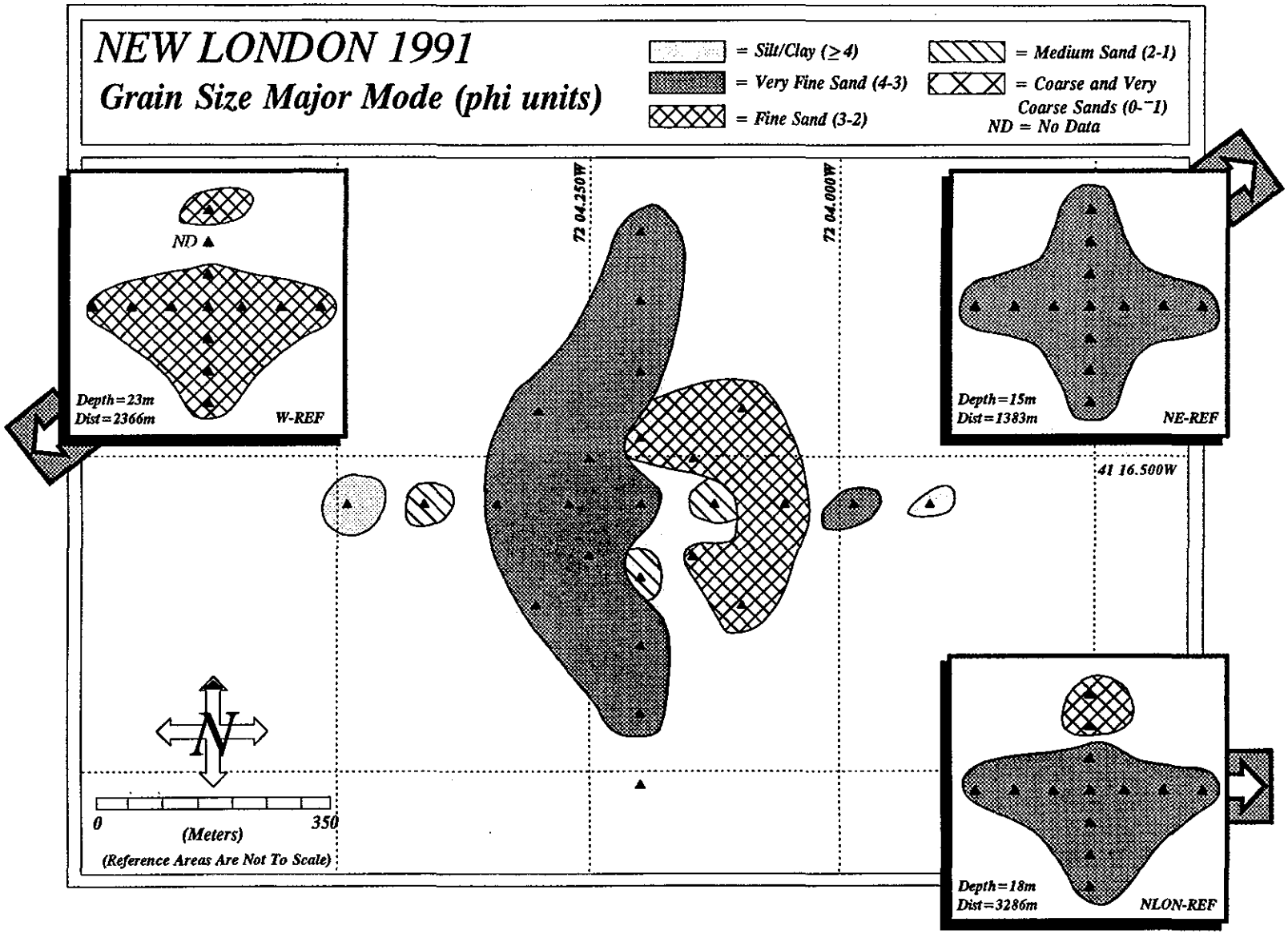

Figure 3-6. Distribution map of grain size major mode at the New London Disposal Site and reference areas. Distances are measured from the disposal site center to the respective reference area center.

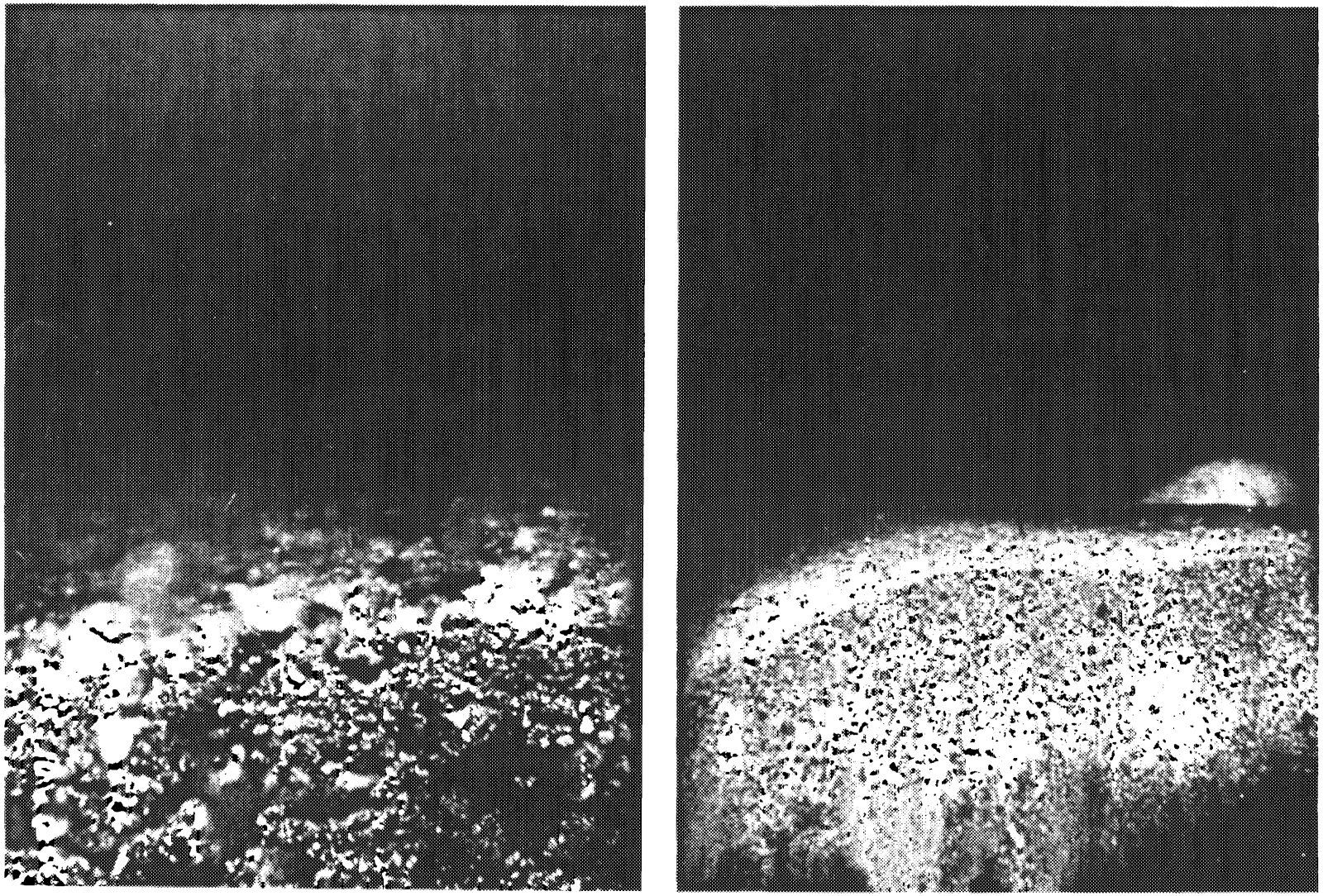

Figure 3-7. REMOTS® photographs of disposal site Stations 100SE (left) and 200E (right). Station 100SE sediments consisted of cobble, gravel, and coarse sands. Coarse sands were also present at stations with active bedforms such as 200E.

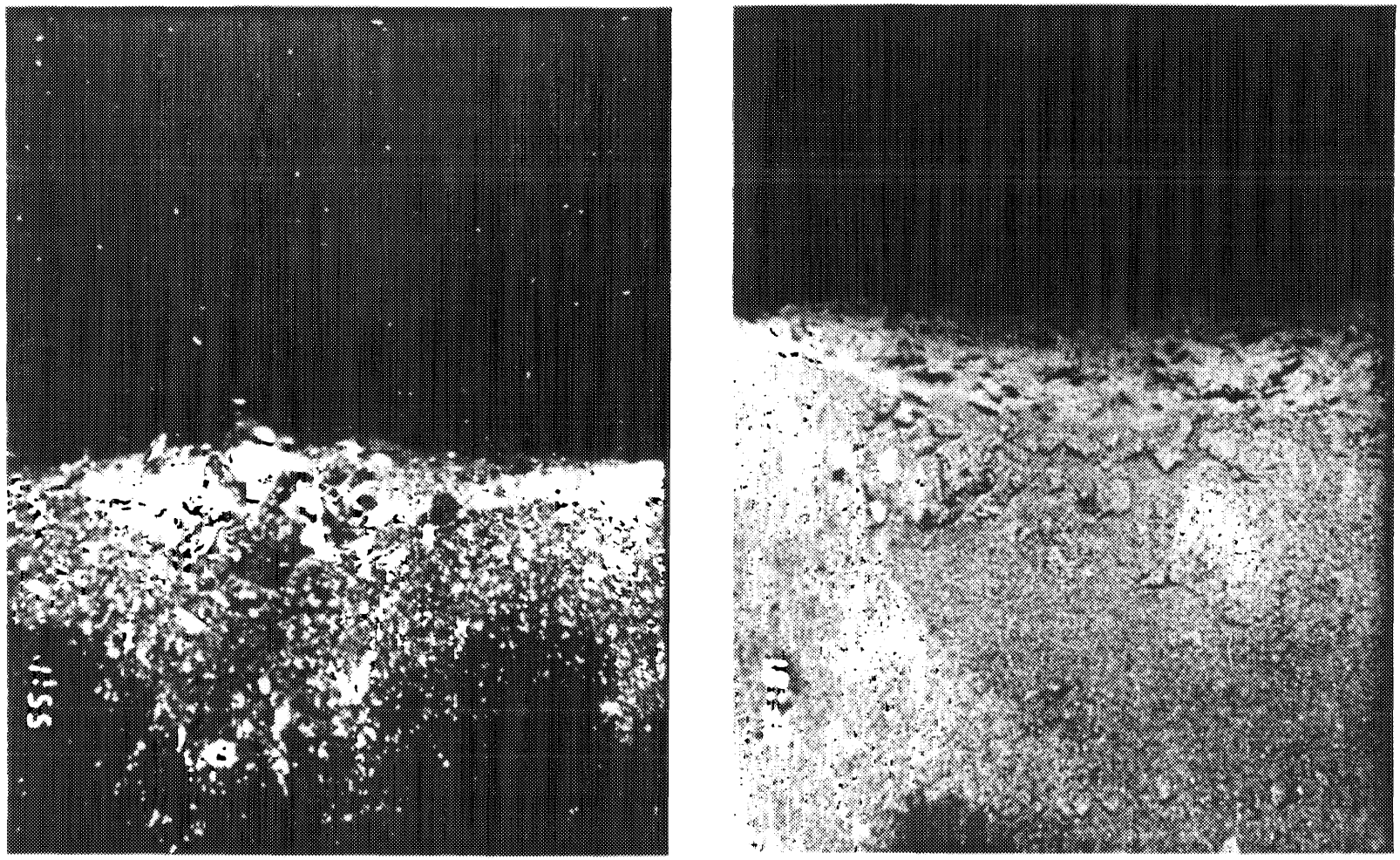

Figure 3-8. REMOTS® photographs of reference area stations WREF (200E) and NLON (200E). The WREF site was characterized by scoured shell lag deposits and fine sands. The successional stage at this reference area station was indeterminate. Sediment grain size major mode at NLON-REF consisted of very fine sands (4-3) phi. An intact tube mat formed by tubicolous amphipods or Stage II organisms characterized the sediment surface of NLON-REF station 200E.

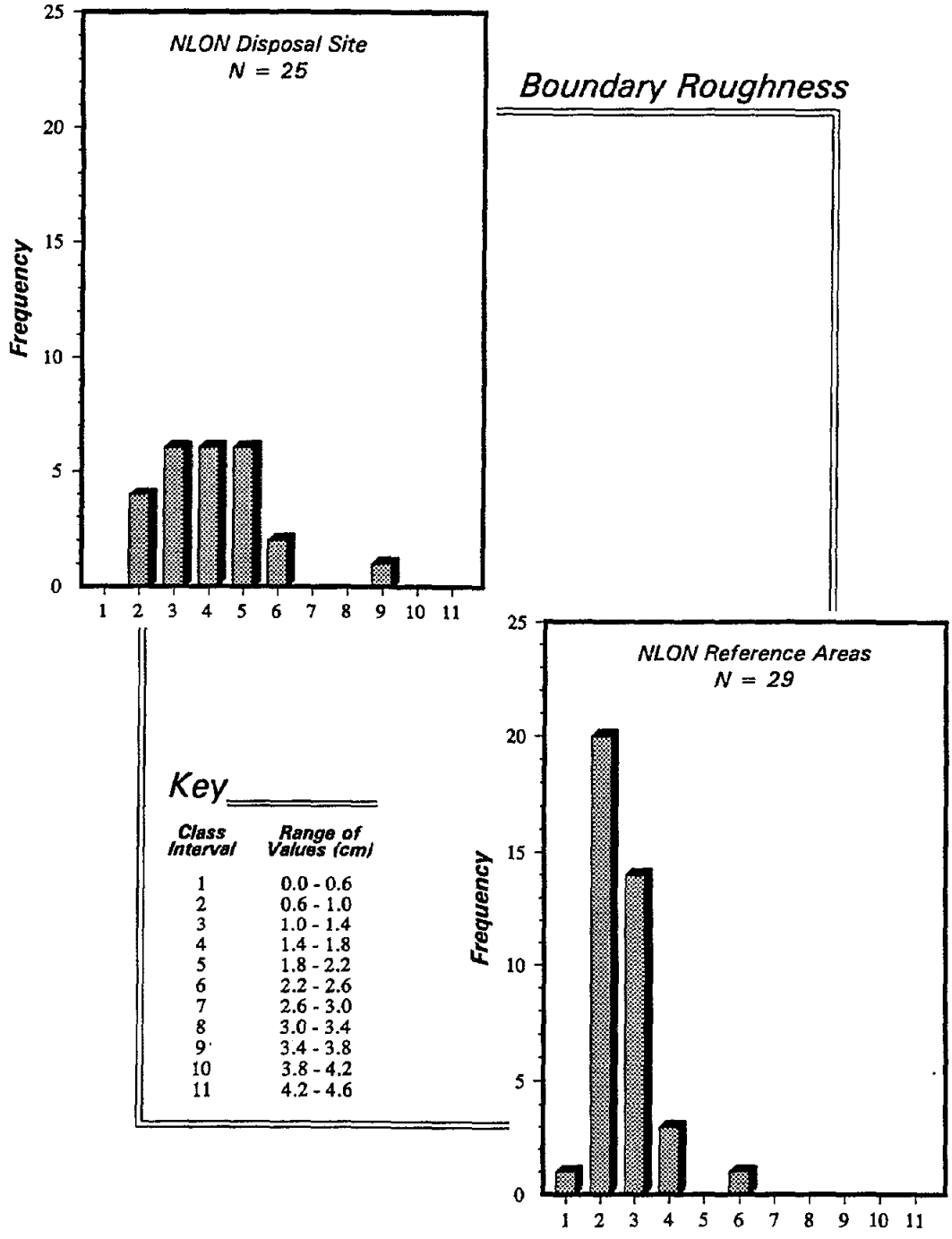

Figure 3-9. Frequency distribution of mean boundary roughness values at the pooled disposal site and reference stations

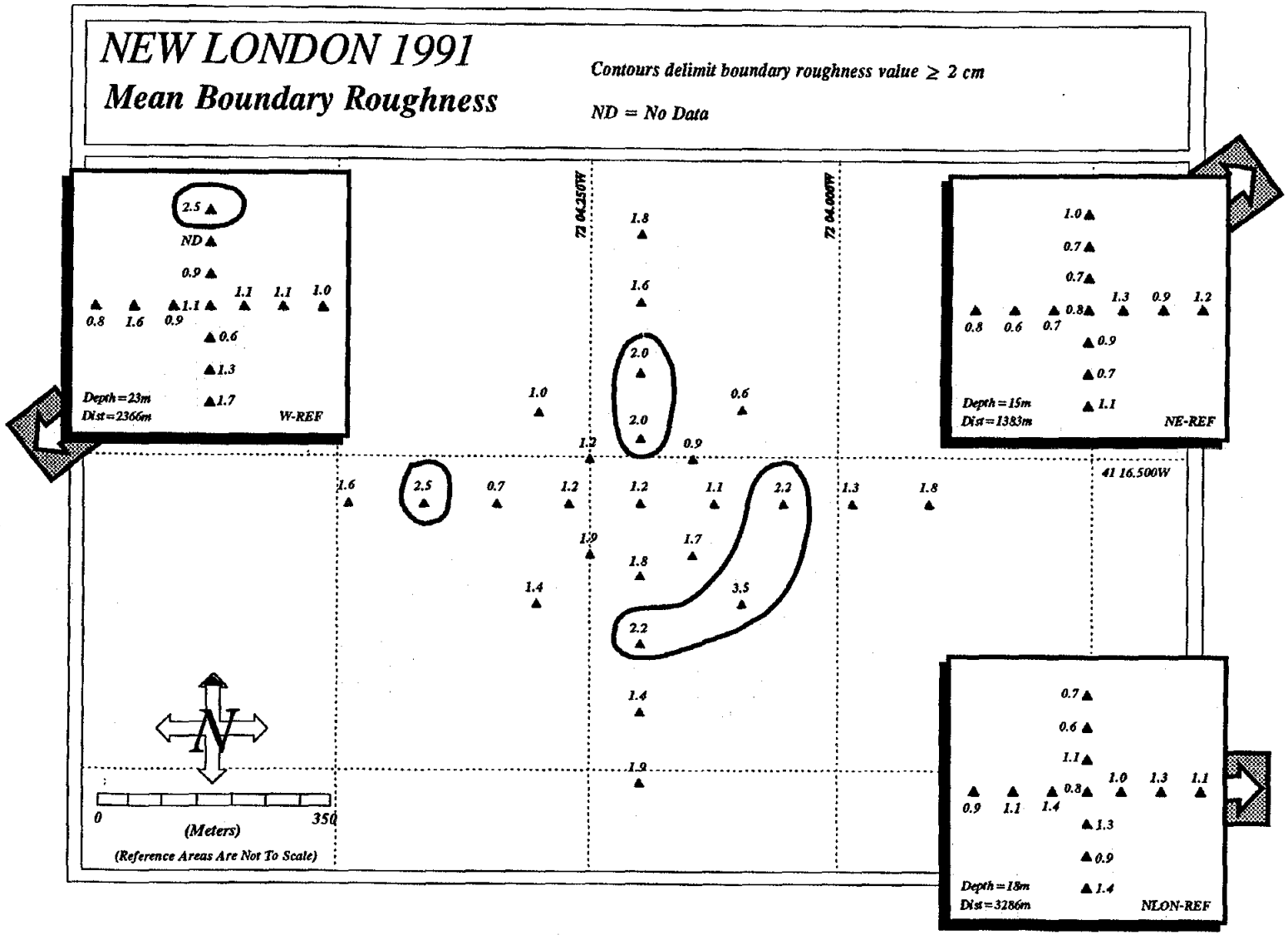

Figure 3-10. Spatial distribution of mean boundary roughness values at the pooled disposal site and reference stations. Distances are measured from the disposal site center to the respective reference area center.

least 200 m north, 400 m west, and 300 m south of the disposal site center (Figure 3-11). Recently deposited dredged material was also present at Station 400E. Fresh dredged material at the center of the disposal site and 400W consisted of coarse-grained sands and gravel overlying fine-grained mud (Figure 3-12). The surface of Station 200S consisted of shellhash and mud clasts formed from the deposition of fresh dredged material. Station 300S showed a large difference in optical reflectance between the sands (high reflectance) and underlying mud (low reflectance; Figure 3-13). This area also showed the presence of sand ripples and washing of fine sediments from the sediment surface layer of the mound by bottom currents. At Station 100SE, dredged material, consisting of gravel and cobble, limited penetration of the bottom by the REMOTS® camera (Figure 3-7). Prism penetration depth was lowest at those stations having active bedforms and a thick surface layer of coarser grained sands (Figure 3-11). At the majority of the disposal site stations, the thickness of the dredged material layer exceeded the penetration depth of the camera. Dredged material was not apparent at the reference stations.

A thin layer of sand deposited in the spring of 1990, as a component of the clean material cap, was readily visible in REMOTS® photographs taken at stations 200 m northeast, 200 m southeast, and 300 m east of the NL-TR survey center (Figure 3-14). The depth of the sand overlaying fine-grained cap material varied from 1.9 cm to 5.3 cm at stations 100SE and 200SE (Figure 3-11). Patches of densely aggregated mussels were present on the NL-TR survey area at 400W and at the WREF area, Station 300N. Scoured shell lag deposits, characteristic of the WREF area, were also present at the western and southwestern portions of the NL-TR survey area, and at stations west and north of the NLON reference center. Hydroids were also abundant throughout the western section of the survey area and within 300 m north and south of the NL-TR survey center.

3.2.4 Apparent RPD Depth

The frequency distribution for the mean apparent Redox Potential Discontinuity (RPD) depth (i.e., the boundary between the oxygenated sediment and hypoxic or anoxic sediment underlying it) indicated that the majority of disposal site stations ranged from 1.5 to 2.0 cm (Figure 3-15). The mean RPD depths of the combined reference stations ranged from 1.0 to 2.0 cm. The mean apparent RPD depths for the reference areas and disposal site were not different (null hypothesis accepted, $p=0.05$, Mann-Whitney U-test). The coarse sediments and shell deposits over much of the WREF area restricted the penetration depth of the camera, permitting RPD measurements at only 7 of the 13 stations (Figure 3-16). The RPD depths measured in the WREF area were much shallower in comparison to the NE-REF and NLON-REF areas, lowering the combined RPD values for the reference areas. Compared to the overall NL-TR region surveyed in June–July 1990, the RPD values measured in this survey were lower at both the disposal site and reference areas.

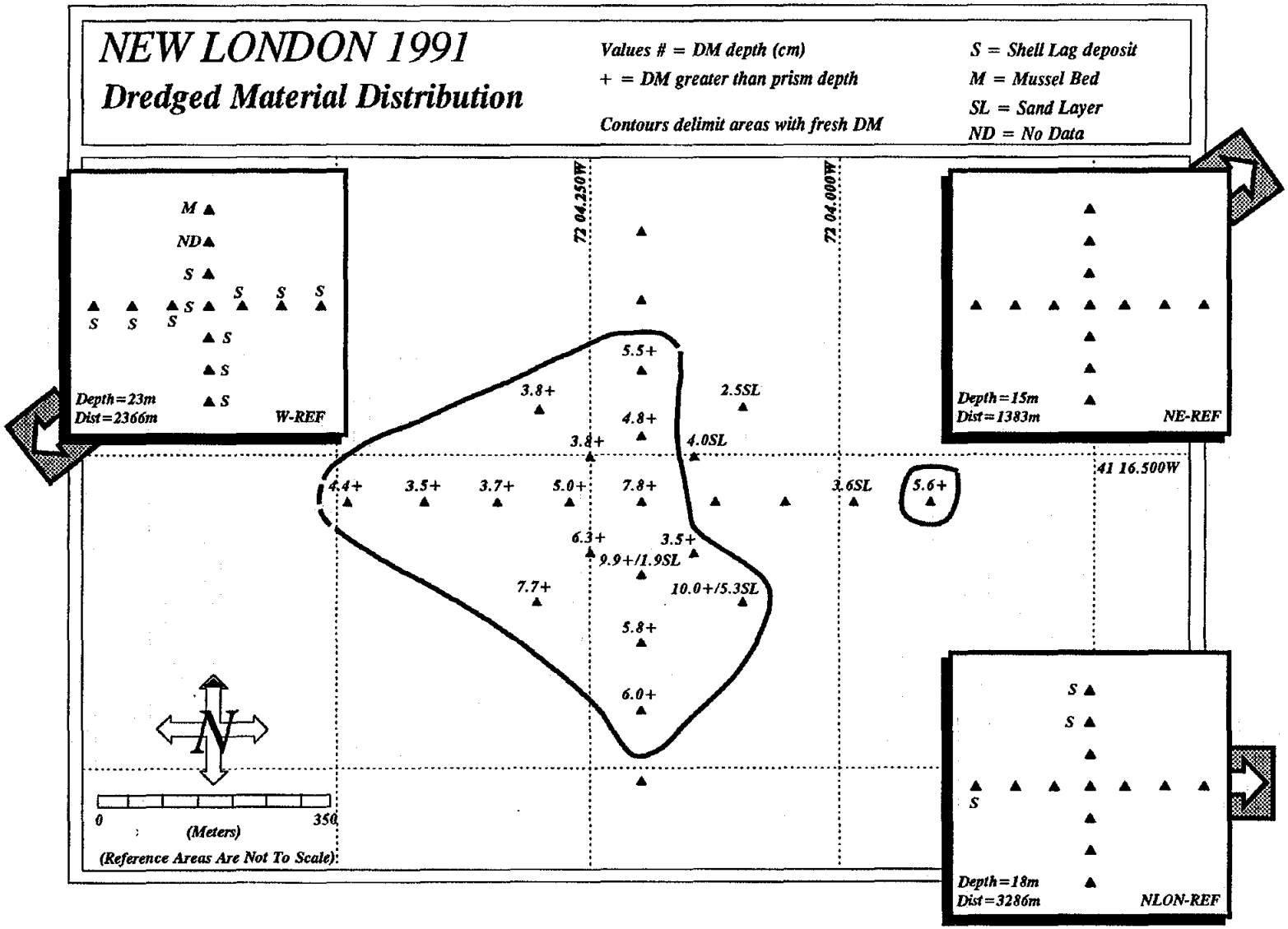

Figure 3-11. Distribution map of dredged material, sand layer, and unique station characteristics at the New London Disposal Site and reference stations. Distances are measured from the disposal site center to the respective reference area center.

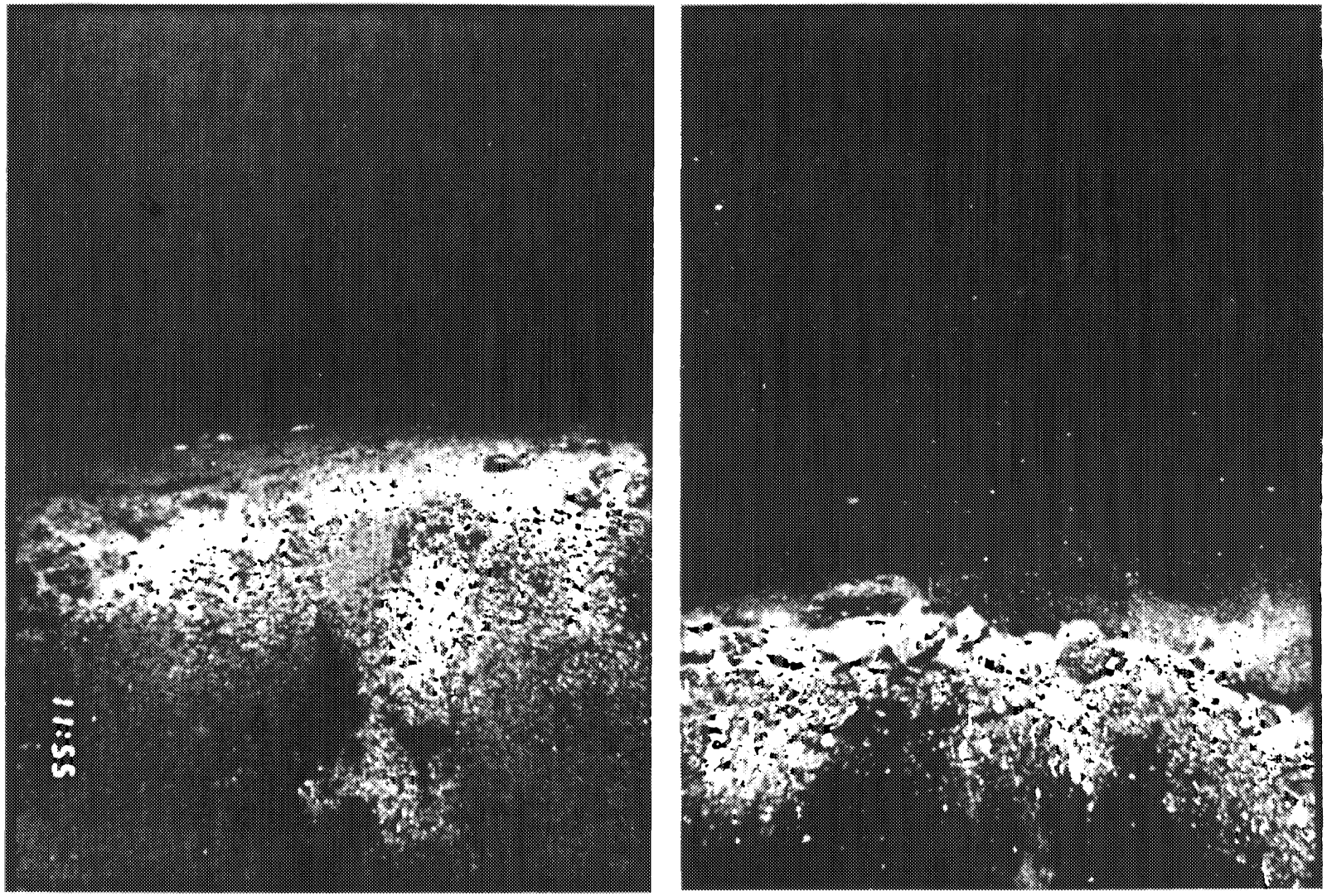

Figure 3-12. REMOTS® photographs of fresh dredged material at the disposal site center (left) and 400W (right). At both of these stations, the recently deposited material consisted of coarse-grained sands and gravel overlying fine-grained mud.

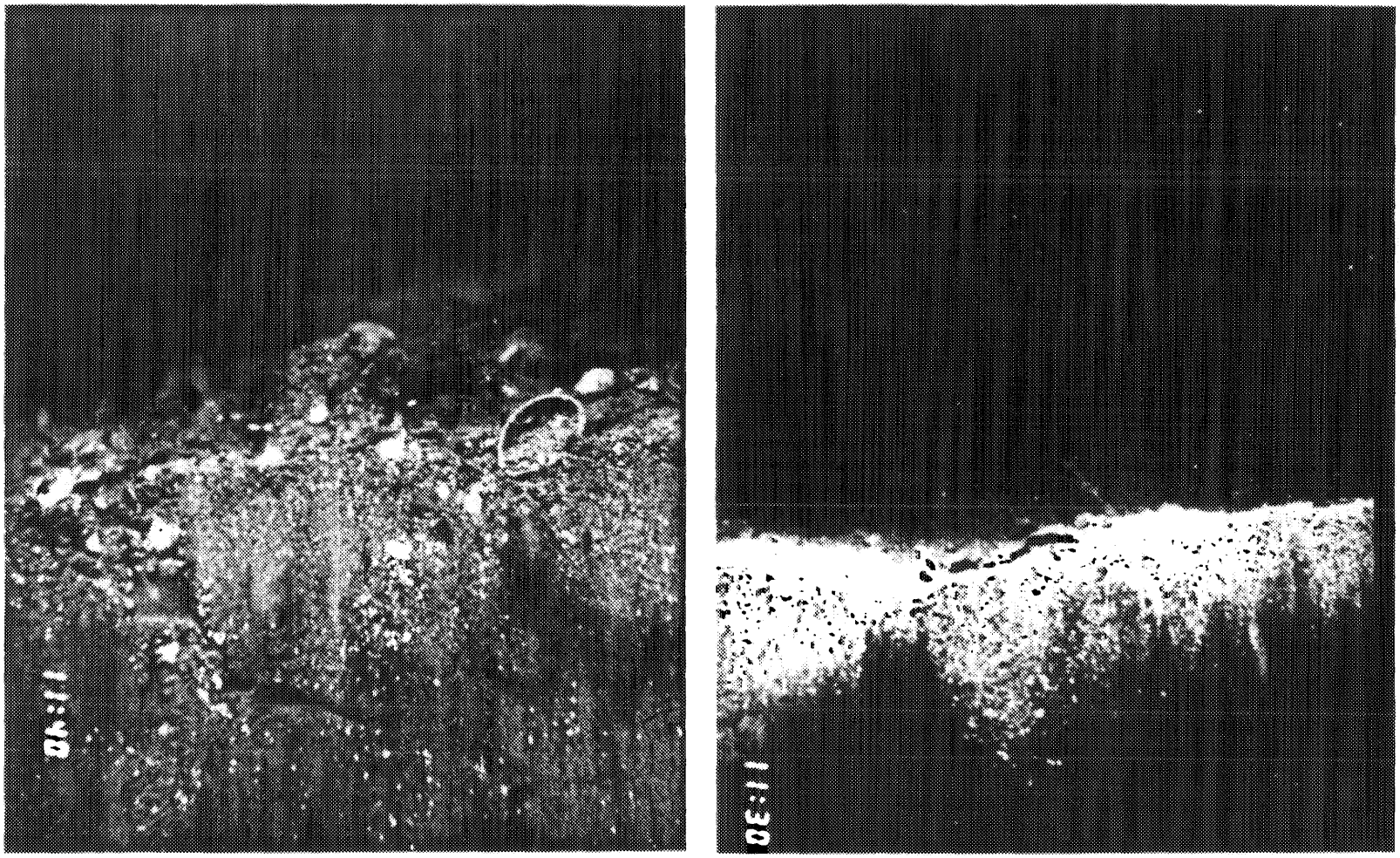

Figure 3-13. REMOTS® photographs of fresh dredged material at 200S (left) and 300S (right). The surface of Station 200S consisted of shellhash and mud clasts while 300S showed a large difference of optical reflectance between the sands (high reflectance) and underlying mud (low reflectance). This station also showed the presence of bedforms and washing of fine sediments by bottom currents from the sediment surface layer.

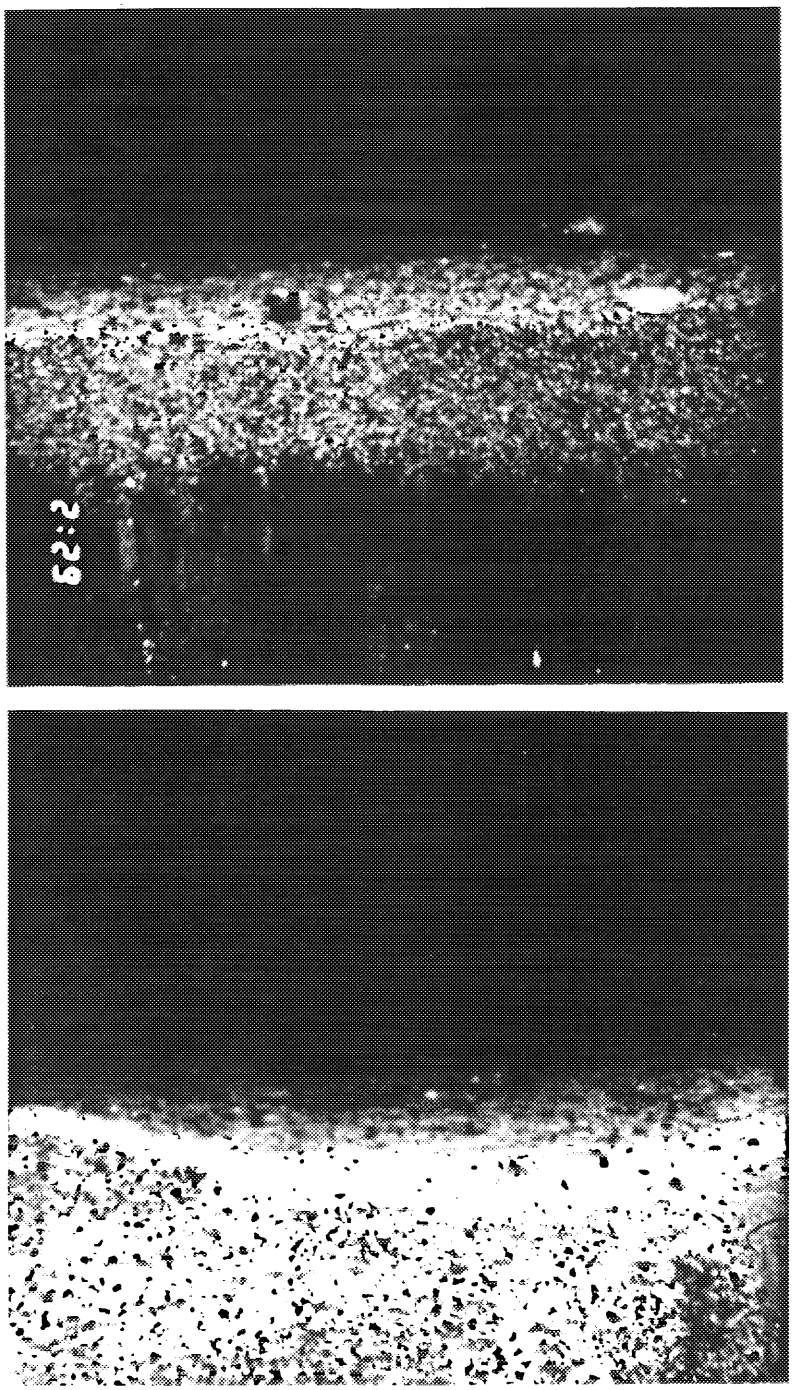

Figure 3-14. REMOTS® photographs of the sand cap at NL-TR at Stations 200NE (top) and 300E (bottom). Active bedforms were apparent at Station 300E.

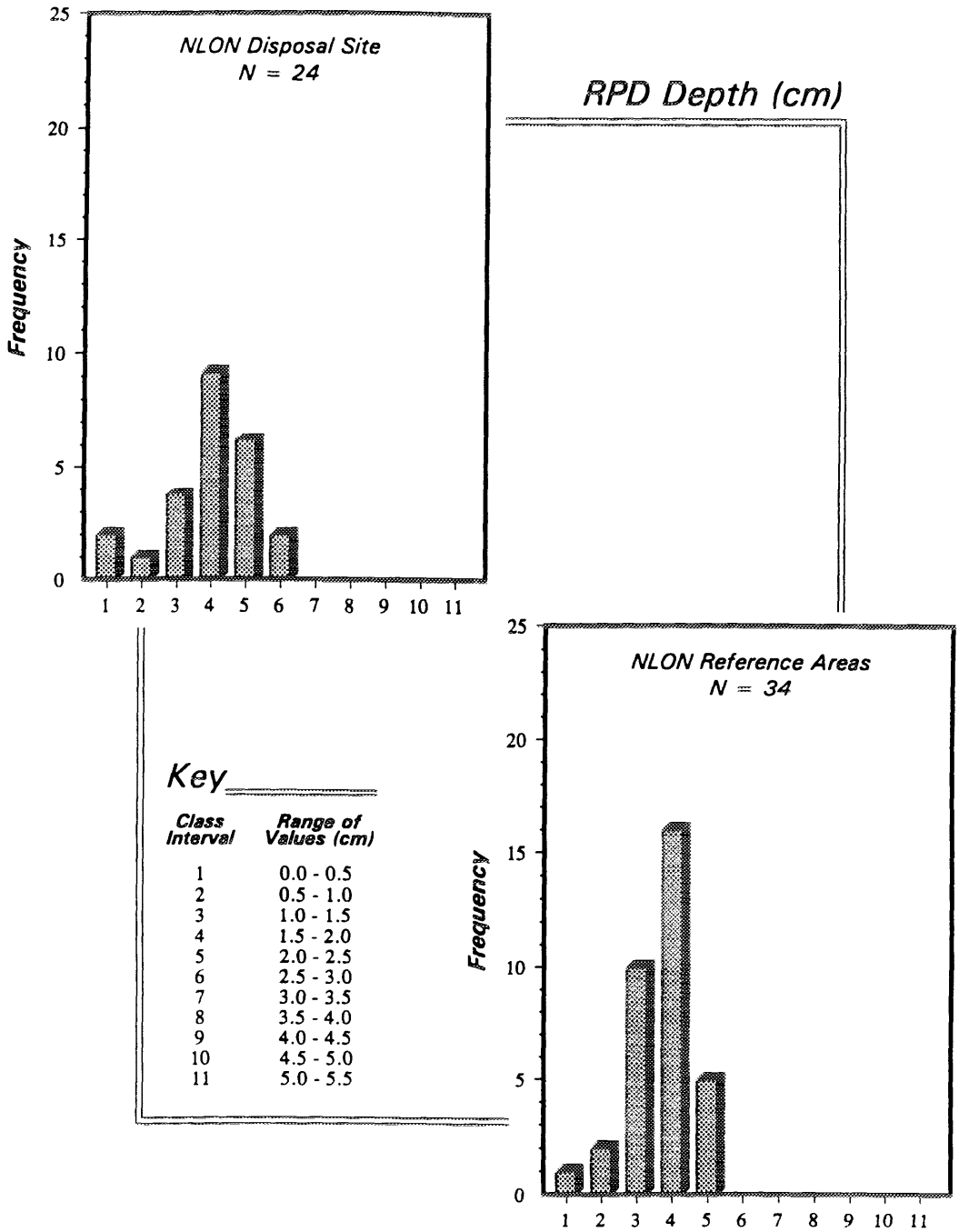

Figure 3-15. Frequency distribution of mean apparent RPD depths at the combined disposal site and reference stations

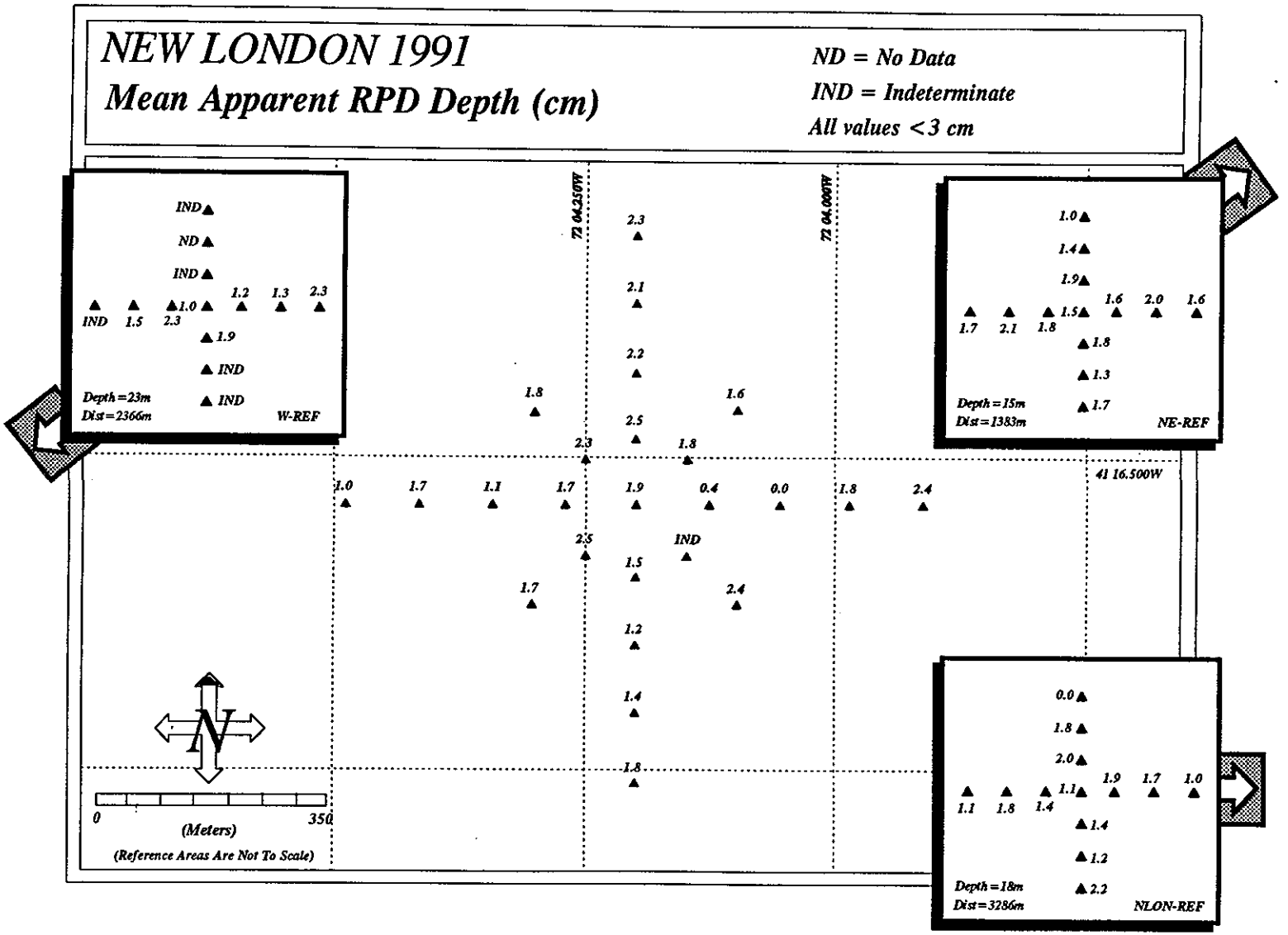

Figure 3-16. Spatial distribution of mean apparent RPD depths at the New London Disposal Site and reference area stations

3.2.5 Successional Stages

Stage II, Stage II on III, and Stage III taxa dominated the successional seres present in the NL-TR survey area (Figure 3-17). Stage II, a transitional stage to Stage III, was characterized by tubicolous amphipods which formed extensive tube mats on the sediment surface. When these organisms were present with the deep-dwelling, head-down feeders in Stage III, the successional stage was classified as Stage II on III. A typical Stage II on Stage III assemblage was present at 300N while feeding voids originating with Stage III taxa were readily apparent at 200SW (Figure 3-18). Stage III taxa were present in at least one of the replicate photographs at 60% of the disposal site stations while a combination of the above stages accounted for 76% of the disposal site stations. Stage III polychaetes are known to be able to move upward through decimeters of sediment as observed at the Field Verification Program (FVP) site in Long Island Sound (Germano and Rhoads 1984). It is likely that colonization of fresh dredged material by adult Stage III organisms occurred as the adults burrowed upward through the dredged material. The majority of stations with Stage I only (small pioneering polychaetes) or Indeterminate (IND) designations occurred primarily on the eastern half of the NL-TR survey area where active bedforms and/or fresh dredged material were present.

Reference areas NE-REF and NLON-REF were similar in successional status to the NL-TR survey area; however, more of the reference area stations were at Stage II (Figure 3-17). Stage II taxa were also present with Stage III organisms in replicate photographs at many of the Stage III stations at NLON-REF. Much of the NLON-REF area was dominated by torn tube mats of Stage II organisms. Ripped tube mats were also present at NE-REF although less extensively; the majority of these tube mats were intact. Successional stages at the WREF were largely indeterminate due to the scoured shell lag surface and shallow camera prism penetration depth (Figure 3-8). At the few WREF stations with sufficient penetration, Stage I only, Stage II only, and Stage III taxa were evident.

3.2.6 Organism-Sediment Index (OSI)

The multiparameter Organism-Sediment Index (OSI), used to characterize gradients in habitat disturbance, could only be calculated at those stations where RPD and infaunal successional stage were also determined. The OSI is determined on the basis of RPD depth, infaunal successional stage, the presence or absence of methane, and presence of no/low dissolved oxygen near the sediment surface as deduced from optical reflectance of the sediment. The range of potential indices is -10 to +11. Based on results of past REMOTS® surveys OSI values of +6 or less are considered indicative of chronically stressed benthic habitats and/or those which have experienced recent disturbance (e.g., erosion, sediment transport, dredged material disposal, hypoxia, intense demersal predator foraging, etc.; Rhoads and Germano 1986).

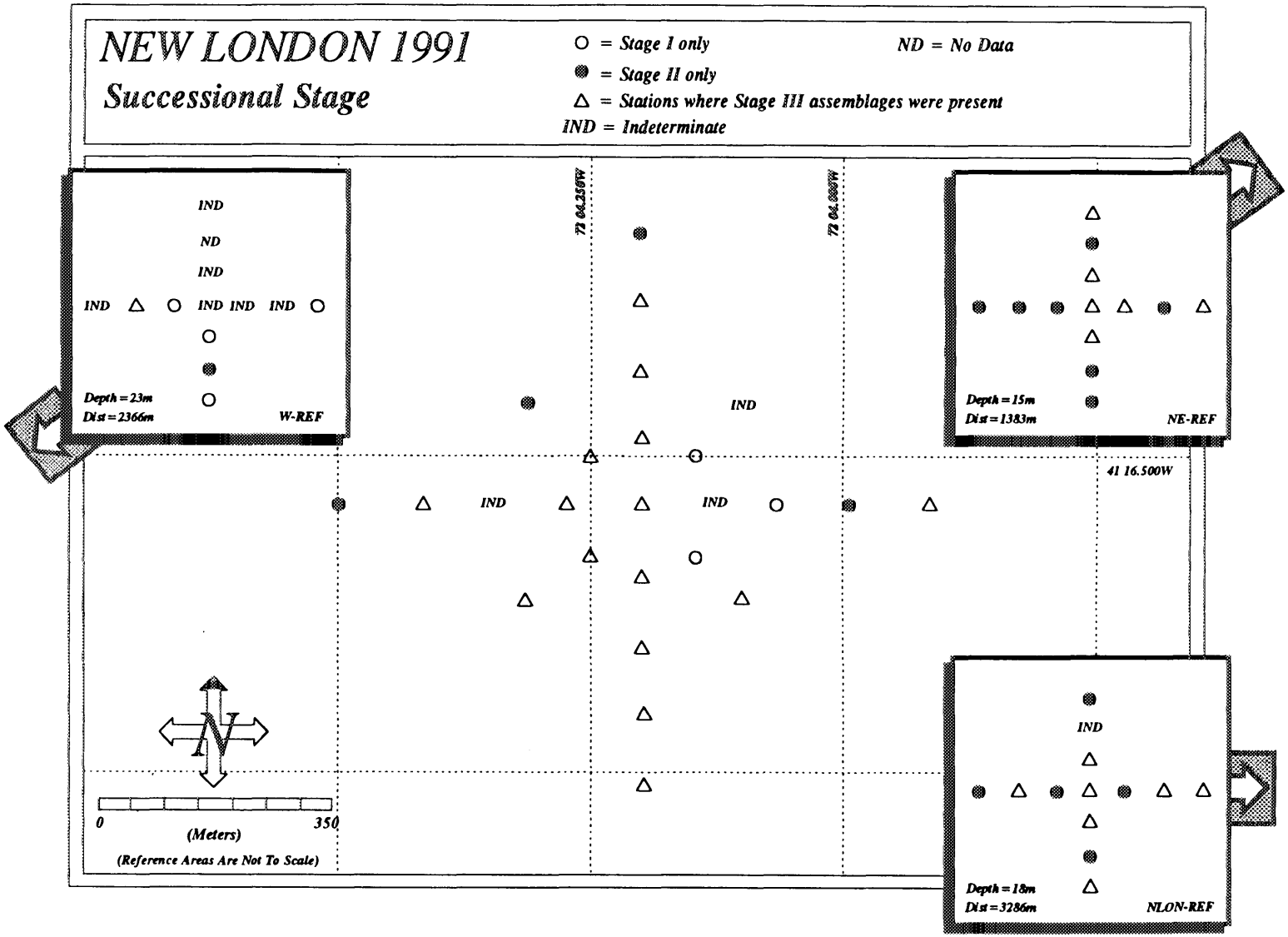

Figure 3-17. Spatial distribution of successional stages at the New London Disposal Site and reference stations. Distances are measured from the disposal site center to the respective reference area center.

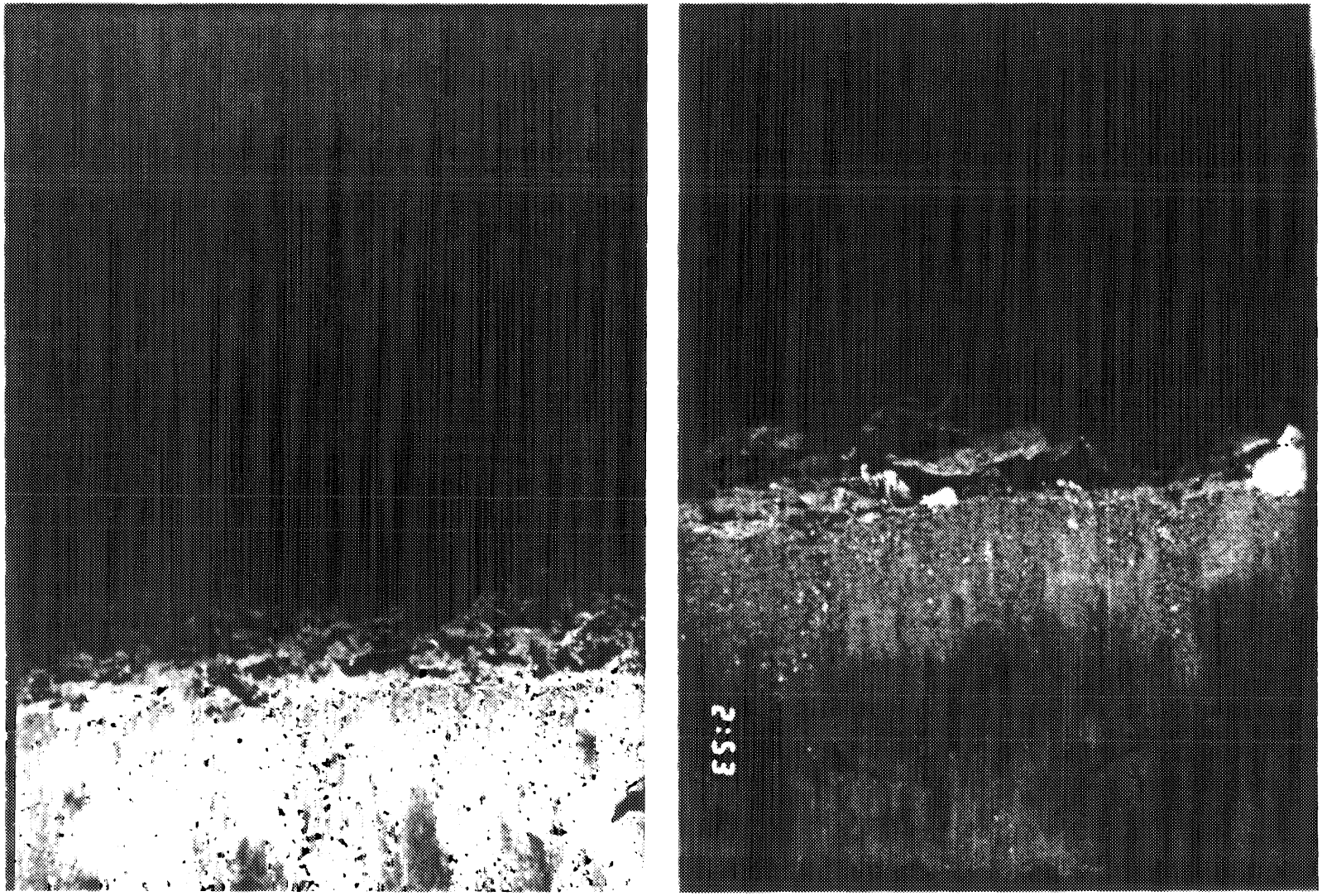

Figure 3-18. REMOTS® photographs from disposal site stations 300N (left) and 200SW (right). The successional stages present at these stations, Stage II on Stage III (300N; left) and Stage III (200SW; right) typified the majority of stations on the site.

The indices over the NL-TR survey area ranged widely in value (1.0-9.0; Figure 3-19) indicative of a patchy benthic environment. The frequency distribution of the median OSI values at the disposal site indicated that the majority of stations had OSI values of 8.0 and 6.0 (Figure 3-20). OSI values were highest near the NL-TR survey center. This result may be related to the reworking of the sediment by reburrowing Stage III adult organisms with the fresh source of dredged material. Reference area OSI values had a narrower uniform range (4 to 7.5) than at the NL-TR stations. Overall, the mean OSI value of the NL-TR survey area were greater than the mean value of the reference areas, therefore, the null hypothesis was rejected ($p=0.05$, Mann-Whitney U-test; Figure 3-20). The number of indeterminate successional stages at the WREF (in addition to indeterminate RPD values) decreased the number of OSI values calculated for this reference area.

3.3 Sediment Analysis

3.3.1 Grain Size and Total Organic Carbon

The results of the sediment grain size (Table 3-1) analysis corresponded well with the mapped distribution of sediment grain size as determined from REMOTS® photographs (Figure 3-6). The sediments were typically dark gray sands with shell fragments present in sediments from NE-REF and NLON-REF. Fine sands (4-2 phi) were dominant with a mix of silt and clay ($\geq$4 phi) at all three areas. Silt made up a larger proportion of the $\geq$4 phi fraction at NE-REF and NLON-REF while silt and clay were equally distributed at the WREF. Total organic carbon was 0.48% at WREF, 0.50% at NE-REF, and 0.39% at NLON-REF.

3.3.2 Metals

Cadmium, Pb, and Zn were detected at all reference areas (Table 3-2). Cadmium values ranged from <0.05 to 0.22 ppm; lead from 13 to 30 ppm; and zinc from 28 to 64 ppm. Replicate values for each reference area were within approximately one standard deviation of the mean (Table 3-2). The average values for Cd, Pb, and Zn were similar for the three reference areas.

3.3.3 PAHs

Replicate values for each reference area were more variable for the organic compounds than the metals; values fell within two standard deviations of the mean (Table 3-3). Also, there were several estimated values (J values) that indicated a compound was present in a concentration above the method detection limit and below the practical quantitation limit. The method detection limit is based on results obtained from the method blank processed with the samples. The practical quantitation limit is the lowest level of

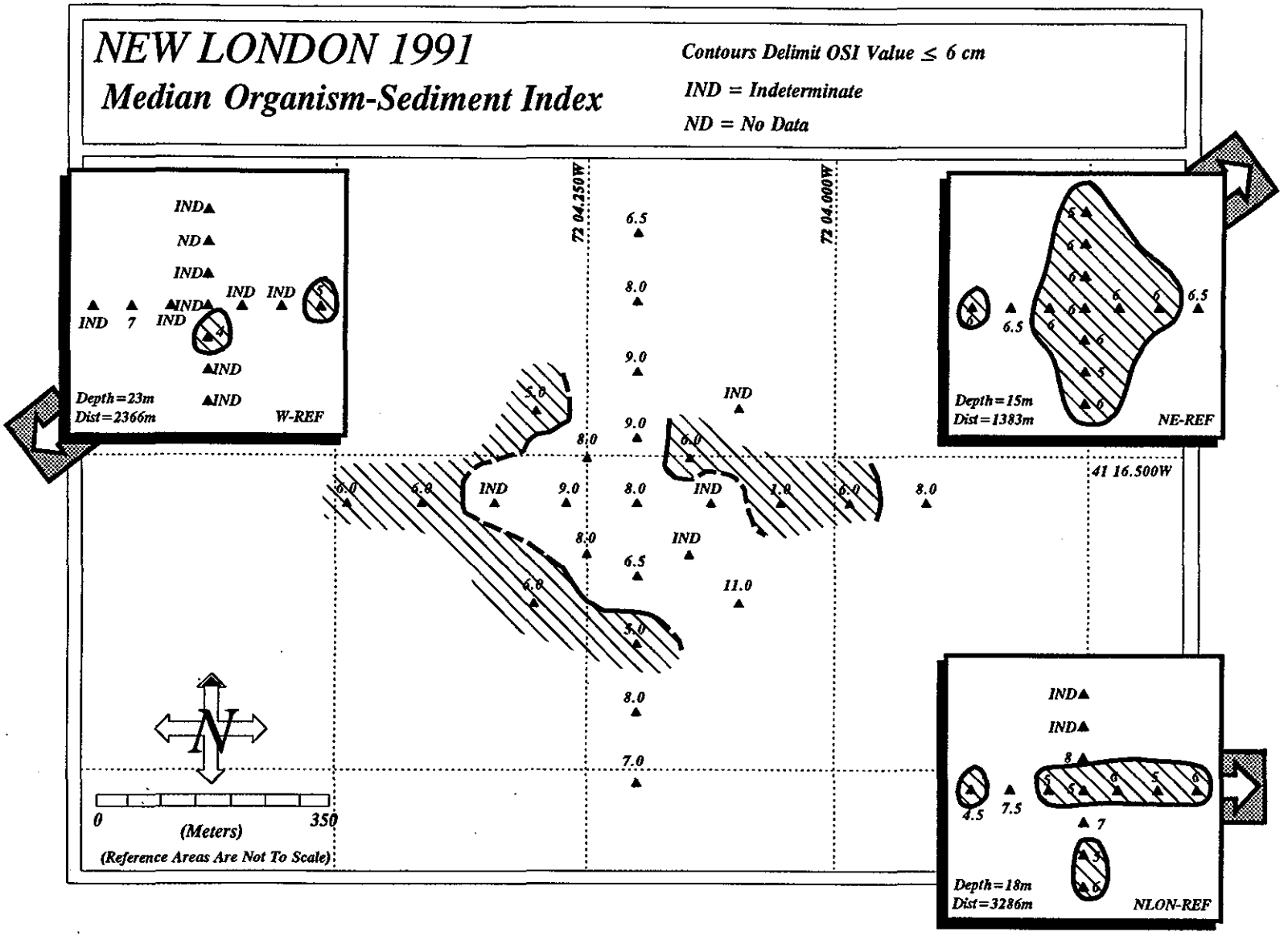

Figure 3-19. Spatial distribution map of median Organism-Sediment Index (OSI) values at the New London Disposal Site and reference stations. Distances are measured from the disposal site center to the respective reference area center.

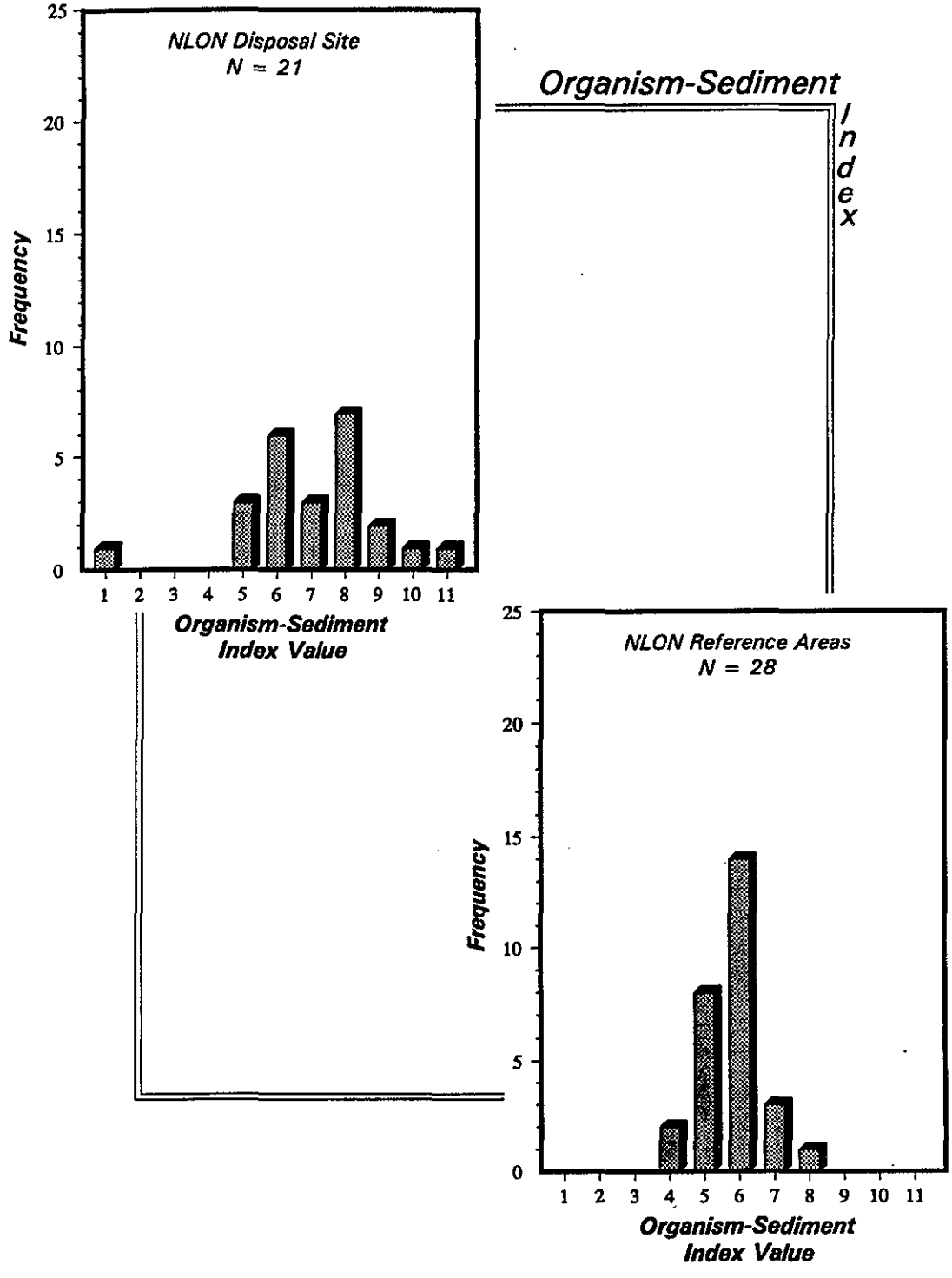

Figure 3-20. Frequency distribution of median Organism-Sediment Index (OSI) values at the New London Disposal Site and reference stations

Table 3-1

Results of Sediment Grain Size Analyses and Percent Total Organic Carbon for Reference Areas at the New London Disposal Site, June 1991

	WREF	NE-REF	NLON-REF
DESCRIPTION	**Dark grey sand**	**Dark grey sand with shell fragments**	**Dark grey sand with shell fragments**
% TOTAL ORGANIC CARBON			
Rep 1	0.48	0.54	0.38
Rep 2	0.29	0.51	0.38
Rep 3	0.68	0.45	0.40
Average	0.48	0.50	0.39
GRAIN SIZE ANALYSIS			
% Coarse Sand (1-'1 phi)	2	1	2
% Medium Sand (2-1 phi)	10	50	4
% Fine Sand (4-2 phi)	61	58	67
% Silt (≥4 phi)	13.7	22.7	16.7
% Clay (≥4 phi)	13	13	10

Table 3-2

Metal Results (ppm Dry Weight) for Sediments Collected at the New London Reference Areas, June 1991

Metals (ppm dry weight)	Cd	Pb	Zn
WREF			
Rep1	0.10	22	48
Rep2	0.05	18	28
Rep3	0.22	30	64
Average	0.12	23	47
1 SD	0.07	5	15
NLON			
Rep1	<0.05	16	37
Rep2	0.13	15	38
Rep3	0.07	17	44
Average	0.08	16	40
1 SD	0.03	1	3
NE REF			
Rep1	0.09	23	48
Rep2	0.07	13	34
Rep3	0.09	22	52
Average	0.08	19	45
1 SD	0.01	4	8
Method Detection Limit	0.05	0.30	0.50

1 SD = 1 Standard Deviation from the mean; detection limit used in calculations below detection limit (<).

Table 3-3

Results of PAHs (ppb Dry Weight) for Sediments Collected at the NLON Reference Areas, 1991

REFERENCE AREAS:	WREF					NLON REF					NE REF					
PAHs (ppb) Dry weight	Rep1	Rep2	Rep3	Mean	1 SD	Rep1	Rep2	Rep3	Mean	1 SD	Rep1	Rep2	Rep3	Mean	1 SD	MDL
Low Molecular Weight																
naphthalene	J14	<8	J26	16	8	<8	J8	J8	8	0	J19	J18	J8	15	5	<6.7
2-methyl naphthalene	J14	<8	J17	13	4	<8	<8	J8	8	0	J10	J12	<8	10	2	<6.7
acenphthylene	<7	<8	J9	8	1	<8	<8	<8	8	0	<10	<6	<8	8	1	<6.7
acenaphthene	<7	<8	<9	8	1	<8	<8	<8	8	0	<10	<6	<8	8	1	<6.7
fluorene	J7	<8	<9	8	1	<8	<8	<8	8	0	<10	<6	J8	8	1	<6.7
phenanthrene	J50	J23	J69	47	19	J31	J50	J49	43	9	J68	61	87	72	11	<9.8
anthracene	J14	<8	J34	19	11	<8	J8	J8	8	0	J19	J18	J24	20	3	<6.7
TOTAL				119					91					141		
High Molecular Weight																
fluoranthene	86	J31	94	70	28	J54	<8	J73	45	27	J87	98	120	102	14	<6.7
pyrene	140	J55	280	158	93	100	120	130	117	12	184	170	210	188	17	<6.7
benzo(a)anthracene	J43	J23	86	51	26	J38	J41	J49	43	5	J78	68	J72	73	4	<6.7
chrysene	J43	J23	86	51	26	J46	J41	J49	45	3	J78	74	J72	75	2	<6.7
benzo(b)fluoranthene	J36	J16	J77	43	25	J31	J33	J41	35	4	J58	J49	J56	54	4	<6.7
benzo(k)fluoranthene	J36	J16	J69	40	22	J31	J33	J33	32	1	J58	J55	J56	56	1	<6.7
benzo(a)pyrene	J43	<8	J77	43	28	J46	J41	<8	32	17	J48	<6	J56	37	22	<6.7
dibenzo(a,h)anthracene	<7	<8	<9	8	1	<8	<8	<8	8	0	<10	<6	<8	8	1	<6.7
benzo(g,h,i)perylene	J36	<8	77	40	28	<8	J25	J33	22	11	J58	J43	J48	50	6	<6.7
indeno(1,2,3-cd)pyrene	<7	<8	<9	8	1	<8	<8	<8	8	0	<10	<6	<8	8	1	<6.7
TOTAL				512					387					651		

1 SD: 1 Standard Deviation from the mean; detection limit used in calculations below detection (<).
J= Estimate value; greater than detection limit, but less than practical quantitation limit.

measurement that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions for a sample of a particular matrix.

Results of the PAH analyses for the New London reference areas showed generally low levels of the organic compounds (Table 3-3). Levels of low molecular weight (LMW) PAHs were higher at the WREF and NE-REF areas in comparison to NLON-REF. Of the LMW PAHs, phenanthrene was the most abundant. Concentrations of phenanthrene ranged from 23 ppb to 87 ppb with average concentrations at the reference areas of 47 ppb (WREF), 43 ppb (NLON REF), and 72 ppb (NE-REF). Fluorene, acenaphthene, and acenaphthylene were generally below the method detection limit at all three reference areas.

In general, concentrations of high molecular weight (HMW) PAHs were greatest at NE-REF followed by WREF and NLON-REF. The HMW PAHs dibenzo(a,h)anthracene and indeno(1,2,3-cd) pyrene were below detection limit at all of the reference areas (Table 3-3). Pyrene was the most abundant HMW PAH at all reference areas with average values of 117 ppb (NLON REF), 158 ppb (WREF), and 188 ppb (NE-REF). Fluoranthene was also higher at the WREF and NE-REF areas in comparison with NLON-REF with average values of 70, 102, and 45 ppb, respectively. Of the remaining HMW PAHs, benzo(a)anthracene and chrysene were detected at slightly higher concentrations than the fluoranthenes, benzo(a)pyrene, and benzo(g,h,i)perylene.

3.4 CTD and Dissolved Oxygen Sampling

On 27 June 1991, near-bottom (approximately 1 m above the bottom) oxygen concentrations ranged from 7.1 to 7.7 $mg \cdot l^{-1}$ over the disposal site mound as well as the three reference areas (Table 3-4). Surface oxygen concentrations (approximately 1 m below the surface) at the disposal site and reference areas ranged from 7.1 to 7.6 $mg \cdot l^{-1}$. The dissolved oxygen concentrations were uniformly distributed throughout the water column and similar at the disposal site and reference areas. These dissolved oxygen concentrations would have been limiting to benthic organism colonization or growth (Tyson and Pearson 1991).

Table 3-4

Dissolved Oxygen Concentrations ($mg \cdot l^{-1}$) by Modified Winkler Titration at the New London Reference Stations and Active Disposal Site, June 1991

Station	Depth	Surface	Bottom
NLON-REF	18 m	7.5	7.1
NE-REF	15 m	7.5	7.4
WREF	23 m	7.6	7.7
NL-Buoy 91	17 m	7.1	7.3

4.0 DISCUSSION

The New London Disposal Site region is in close proximity to the "dispersive" Cornfield Shoals Disposal Site. A study of bottom currents in the area suggests that the region near NLON has high bottom currents, averaging about 30 $cm \cdot s^{-1}$ (DAMOS 1979). Evidence of significant bottom currents initiating sediment transport at NLON was also present in REMOTS® photographs. REMOTS® photographs from the reference area WREF indicated that coarse/medium grained rippled sands (0-2 phi) were prevalent on the surface at almost all stations (Figure 3-8). This was probably the result of active bedload transport by bottom currents. The coarseness of clastic and biogenic particles in this region resulted in shallow REMOTS® camera penetrations. Active bedforms (ripples) were readily apparent in the eastern section of the disposal site and in a few replicate photographs obtained at NLON-REF.

4.1 Disposal Mound Topography

An objective of the 1991 survey was to delineate the topographic relief and footprint of dredged material deposited at the New London Disposal Site during 1990–1991. The bathymetric survey showed a mound approximately 160 m in diameter and a minimum water depth of 14.5 m (Figure 3-3). The depth difference calculation showed an increase in height of 2.4 m at NL-TR over the past year (Figure 3-4). Also apparent was a smaller mound that developed around the buoy and was adjacent to the NL-TR mound. This mound was 0.6 m in height and approximately 110 m in diameter. The predicted height (2 m) and radius of the mound (150 m) was based on a disposal simulation model for one mound. The combined radius of these two mounds was approximately 150 m. However, the observed heights of the two mounds from the depth difference plot were 0.6 m and 2.4 m, significantly more than the predicted height of 2 m for one mound.

Following the original deposit of material dredged from the Thames Shipyard and Repair Company (TSR) in October 1988, cap material was placed from October 1988 through June 1990 (98,983 m^3), and from September 1990 through June 1991 (31,475 m^3), prior to this survey. Cap material was placed at six separate LORAN-C locations (A-F); in order to gauge the total accumulation of two years of capping, a depth difference was calculated between the 1991 and the 1988 bathymetric survey conducted after disposal of TSR material (Figure 4-1). This figure shows that there is at least 50 cm of cap at all disposal points except for point C. Point C was selected originally as a precaution because possible TSR material was detected at this location during the post-disposal survey, although relatively far from the disposal buoy (150 m; Kullberg and Fredette, 1993). The calculated contours of cap material are minimum thicknesses because of consolidation; actual cap thicknesses are potentially 15 to 25 cm thicker because of consolidation of TSR material (Brandes et al., 1991).

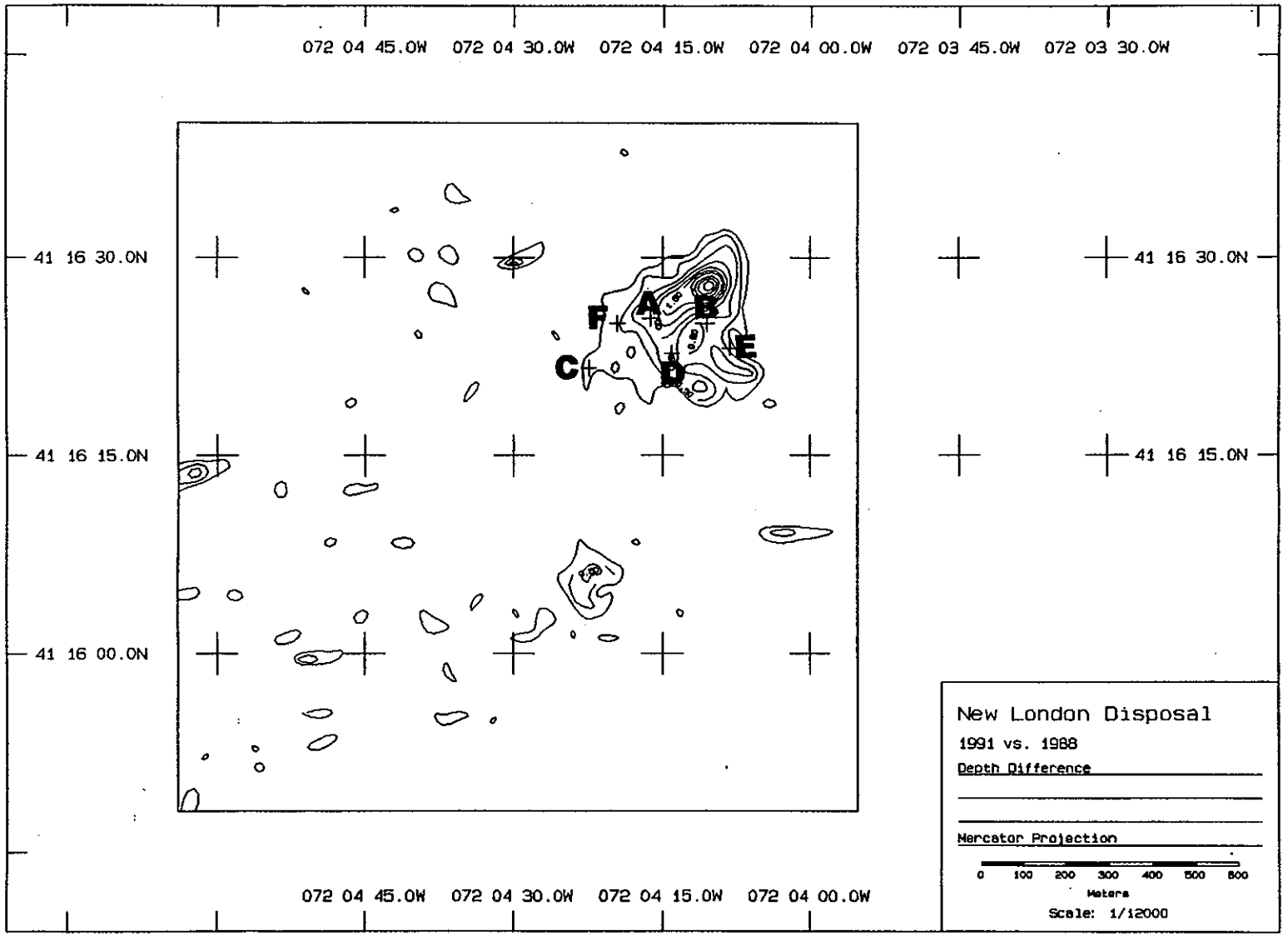

Figure 4-1. Contour plot of volumetric differences between October 1988 (prior to capping) and June 1991, showing locations of the LORAN-C disposal points

The depth profile plot of lane 16 indicated a maximum change in height of 3.0 m at the NL-TR mound compared to the maximum change in height of 2.4 m as calculated by the depth difference (Figure 3-5). These results may originate from the limitations of bathymetric analyses on steep slopes and the resulting variability of recorded depths in consecutive bathymetric surveys. Smooth topographies minimize the effect of the ship's position within a survey lane on the recorded depth. Examination of the bathymetric contour plot (Figure 3-3) revealed a 1.0 to 1.25 m change in depth within a 25 m distance (equivalent to the width of one bathymetric survey lane) along some regions of the NL-TR mound. Examination of the raw navigation data records at the peak of the NL-TR mound revealed an 11 m separation between the positioning of the fathometer's transducers during the 1990 and 1991 surveys, representing a possible 0.50 m variation in recorded depth. Depth profile plots represent raw bathymetric data while depth difference results present data that has been filled, smoothed, and corrected to the previous year's surveys.

Disposal logs showed an estimated disposed volume of 31,475 m^3 for 1990–1991. Volume calculations based on the depth difference between the 1990–1991 surveys indicated that 10,500 $m^3 \pm 320$ m^3 (95% C.I.) of sediment accumulated in the vicinity of NL-TR. Tavolaro (1984) showed that volume estimates, based on disposal logs, overestimate the amount of dredged material because of the significant amount of interstitial pore water and sediment "fluffing" associated with material placed into the barges. In addition, discrepancies occur due to compaction of dredged material on the bottom and the significant volume of material deposited on the flanks of the mound in layers too thin to be detected acoustically. Tavolaro calculated that the depth difference volume estimates based on successive bathymetric surveys will be as much as 41% less than the disposal log volume estimates. Applying the 41% factor to the disposal log estimate of 31,475 m^3 for dredged material released in the vicinity of NL-TR resulted in a corrected volume of 18,541 m^3 of dredged material. The bathymetric survey was able to detect 57% of this adjusted volume.

The dimensions of recently deposited dredged material in the vicinity of NL-TR as detected by REMOTS® photographs (Figure 4-2) extended 200 m north, 400 m west, and 300 m south of the disposal site center. Recently deposited dredged material was also present at Station 400E. The depth difference plot based on bathymetry also showed small deposits of material distributed to the north, south, and west of the disposal buoy. The REMOTS® survey grid did not encompass the center of the NL-TR mound, but photographs did show evidence of the sand, the last component of cap material, east of the disposal center (Figure 3-11). The presence of dredged material in a large number of REMOTS® stations away from the disposal buoy indicates that thin dredged material layers, less than 20 cm thick, were present. This volume of material would likely contribute significantly to the remaining 43% of the corrected disposal log volume. A plot of the barge release points over the 1990–1991 disposal season indicated that the majority of barges were releasing near the designated Buoy 91 location (Figure 4-3).

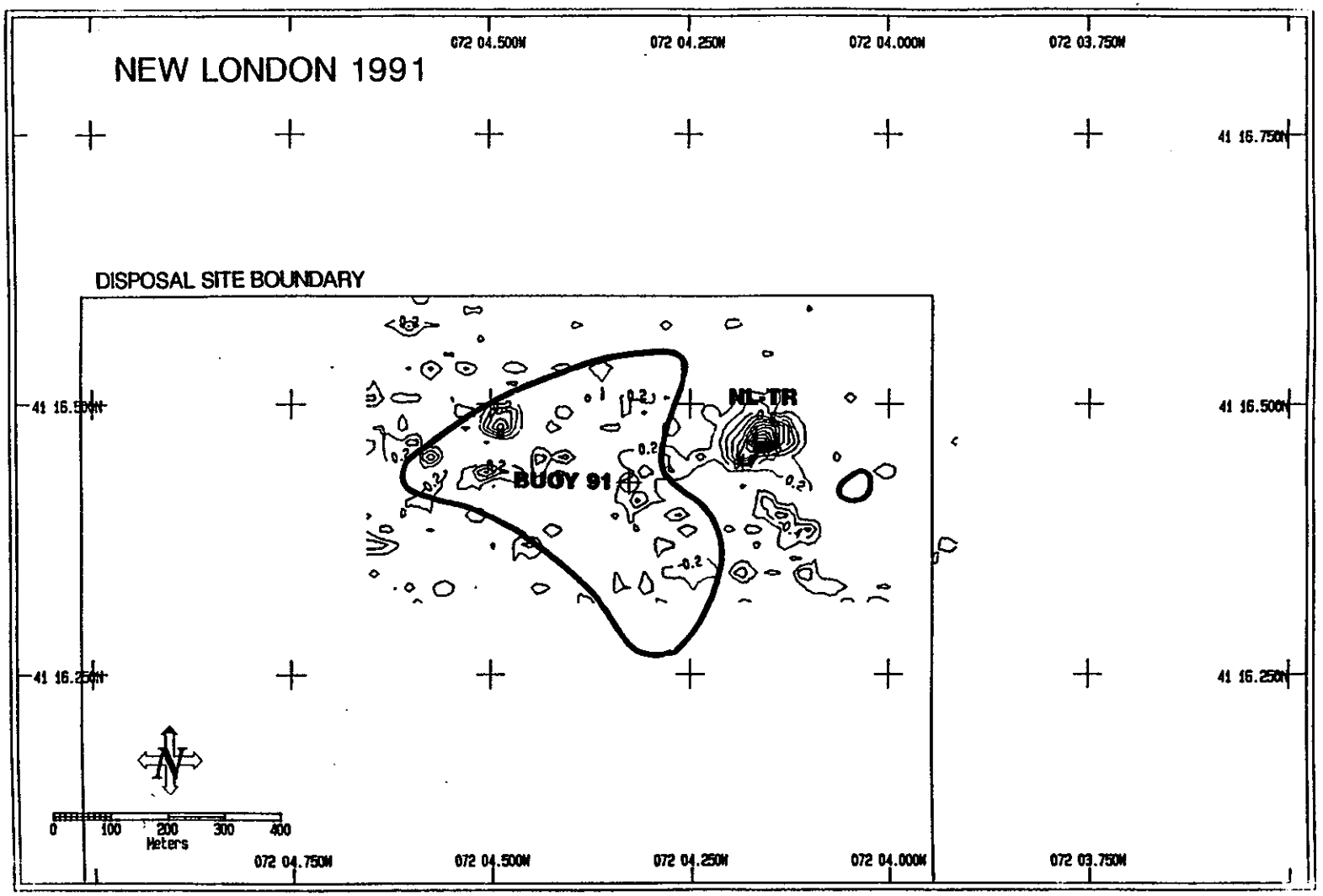

Figure 4-2. Distribution of recently deposited dredged material as determined by REMOTS® photographs compared with the isopach map delineating depth difference for 1991 (depth in meters)

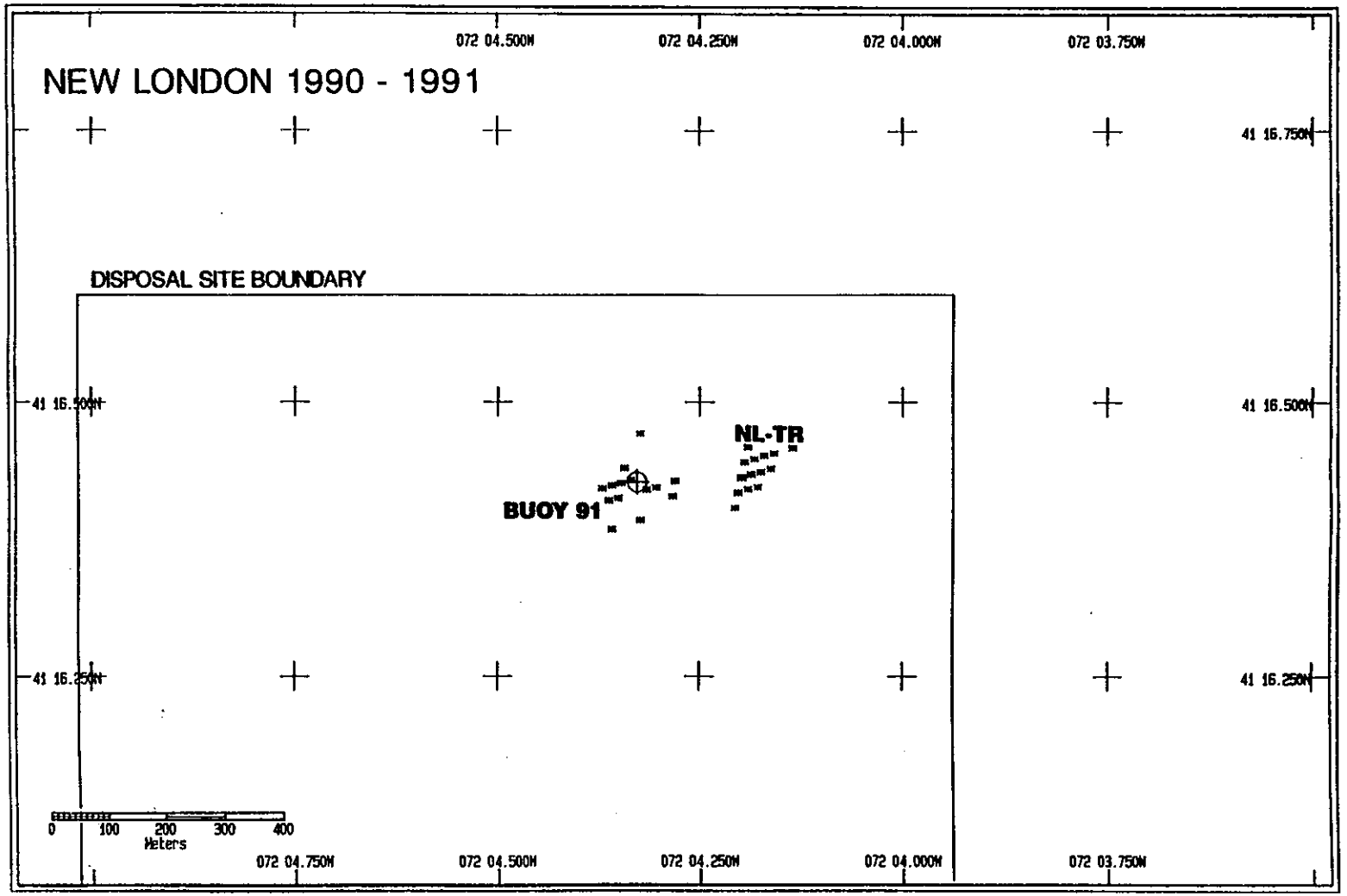

Figure 4-3. Plot of reported barge log disposal positions (LORAN-C) between September 1990 and June 1991

4.2 Recolonization Status at the New London Disposal Site

Benthic recolonization at the active disposal area was predicted to be mostly in Stage I in the central portion of the mound, while the margins were expected to be at or progressing to Stage III. The majority of the disposal site stations and NE-REF were dominated by Stage II, Stage II on III, or Stage III assemblages. Much of NLON-REF was dominated by torn tube mats of Stage II organisms resulting from decomposition, erosion (if the mats were formed during the 1990 summer-fall period), or possibly a trawling disturbance. Stage I only assemblages were present at just three disposal site stations which were in areas of active bedforms and/or deposits of fresh dredged material. Stage II represents a transitional sere between Stages I and III and is associated with recovery of a disturbed benthic habitat (Rhoads and Germano 1986). Organism-Sediment Indices were variable and indicative of a patchy benthic environment (Figure 3-19).

In comparison to the June–July 1990 survey of the New London Disposal Site, the RPD values measured in the present survey were lower at both the NL-TR survey area and surrounding reference areas. The difference in RPD values for the 1990 and 1991 surveys is largely due to the fact that the 1991 survey was done earlier in the season than the 1990 survey. Between June and July, bioturbation rates in Long Island Sound may increase 1.2 times the initial low rate in June due to rapid changes in bottom water temperatures (Rhoads 1992). Bioturbation by benthic biota directly affects development of the RPD layer; a significant increase in bioturbation between June and July will be accompanied by an increase in depth of the oxygenated sediment layer. In addition, lack of penetration and apparent RPD data collection at the WREF reference area lowered the combined RPD values for the reference areas.

4.3 New London Disposal Site Sediment Chemistry

Analysis of sediment grain size correlated well with the mapped distribution of grain size as determined from REMOTS® photographs. Sediment grain size is commonly correlated with both metallic and organic contaminants in sediments. Studies of both natural and polluted sediments have demonstrated that higher concentrations of contaminants are invariably associated with the silt/clay fraction (Forstner and Wittman 1983, Pequegnat et al. 1990, Kennish 1992). Particulate and colloidal organic matter, because of its fine grain size, surface charges, high surface area to volume ratio, and microbial coatings, serves to adsorb or chelate organic and metallic contaminants. The percent silt/clay and TOC were greatest at NE-REF. Silt/clay fractions were similar for WREF and NLON-REF with percent TOC greater at the WREF (Table 3-1).

Heavy metal contamination is of concern because of the tendency for metals to bioaccumulate in the foodchain. Of the three metals analyzed, Cd and Pb have no known biological functions while Zn is a trace element necessary for life processes. At elevated

Table 4-1

Metal Concentrations (ppm Dry Weight) in Sediments
Collected at NLON, CLIS, and WLIS in 1986 and 1987

Metals (ppm dry weight)	Cd	Zn
NLON-REF		
1986	<3	45±27
1987	ND	NA
CLIS-REF		
1986	ND	110±4
1987	ND	121±9
2500W		
1987	ND	153±7
4500E		
1987	ND	148±10
WLIS-REF		
1986	<3	141±52
1987	ND	135±9
2000S		
1987	ND	99±18
2000W		
1987	ND	215±2

Reference areas in Long Island Sound
NLON: New London Disposal Site: SAIC 1989; SAIC 1990c
CLIS: Central Long Island Sound Disposal Site: SAIC 1990d; SAIC 1990e
WLIS: Western Long Island Sound Disposal Site: SAIC 1987; SAIC 1990f
All samples were 0-2 cm in depth.
NA=Not Analyzed ND=Not Detected

levels (which are species specific), these heavy metals act as enzyme inhibitors in organisms (Kennish 1992). NLON-REF was analyzed for Cd and Zn by the NED laboratory in 1986 and 1987 (Table 4-1). The values for Cd in 1986 and 1987 were below detection limit and/or less than 3 ppm. Average Cd values for the reference areas in 1991 were equal to or below 0.12 ppm (Table 3-2). Average values for Zn were fairly similar for 1986 and 1991 at NLON-REF (Tables 3-2 and 4-1).

Data collected as part of NOAA's National Status and Trends (NS&T) Program were compared to the NLON data to provide a frame of reference for the NLON reference area data (Table 4-2). The NS&T Program has collected and analyzed coastal and estuarine sediment data from 300 sites since 1984. Two sites in Long Island Sound that were sampled over a period from 1984 to 1987 were compared to the NLON reference area data (NOAA 1991).

The two NOAA NS&T stations most representative of the NLON reference areas are Station LICR located outside the mouth of the Connecticut River (41°15.833′ N and 72°20.500′ W) and Station ELI in Eastern Long Island Sound (41°14.000′ N and 72°15.000′ W). Station ELI has been characterized as a sand bottom with ≥80% of the particles collected ≥63 *um* (4 phi) in diameter. The data set generated for Station ELI consists of non-normalized values only, due to the lack of fine-grained sediments. Station LICR is described as a bottom made up of 50% fine-grained sediment (<63 *um* or 4 phi) and 50% sand (≥63 *um* or 4 phi). Two data sets exist for Station LICR: normalized values for the fine-grained sediment and non-normalized values for the sand component.

In comparison to the normalized and non-normalized data generated at NOAA stations ELI and LICR, the values for NLON reference stations WREF, NLON-REF, and NE REF are equal to or below the NS&T values for Cd and Zn (Table 4-2). There is only a slight elevation in Pb concentrations at WREF when compared to the sandy sediment at ELI. Reference stations NLON-REF and NE REF both have Pb concentrations equal to or below the non-normalized values at ELI. All reference station heavy metal concentrations are well below the normalized values for the fine-grained sediment at LICR.

PAHs are organic trace contaminants in estuarine and marine environments and consist of carbon and hydrogen arranged in the form of two or more fused benzene rings in linear, angular, or cluster arrangements. They include a wide range of chemicals and enter aquatic environments through industrial and municipal wastewater effluents, oil spills, combustion of fossil fuels, commercial and recreational boating activities, riverborne influx, nonpoint source runoff of materials from terrestrial habitats, and *in situ* diagenesis of organic matter in sediments. Petroleum spillage and atmospheric deposition are regarded as the major sources of PAHs in the aquatic environment (Kennish 1992).

Low molecular weight PAHs (including naphthalenes, anthracenes, fluorenes, and phenanthrenes) tend to be more soluble, more volatile, and acutely toxic to some organisms, but are noncarcinogenic. LMW PAH compounds originate principally from relatively fresh, unburned petroleum. HMW PAH compounds are generally derived from fossil fuel combustion (Kennish 1992).

Table 4-2

Metal Concentrations (ppm Dry Weight) in Sediments
Collected at the NOAA NS&T Program Stations ELI and LICR, 1984-1987

Metals (ppm dry weight)	**Cd**	**Pb**	**Zn**
Non-normalized Sand Component			
Station ELI	0.1	19	59
Station LICR	0.29	26	78
Normalized Fine-grained Component			
Station LICR	0.94	62	200

Of the NLON reference areas, concentrations of PAH compounds were greatest at the NE-REF area followed by WREF and NLON-REF. Comparisons can be made with detailed PAH data collected from sediments in the New England area and the New York Mud Dump Site in New York (Table 4-3). New Bedford Harbor, Massachusetts, is an estuarine area noted for having high levels of contaminants. Fall River, Massachusetts is a moderately industrialized, estuarine area located in northeastern reaches of Narragansett Bay. Fox Point is located at the head of Narragansett Bay in Providence, Rhode Island, and receives both sewer and industrial output from the Providence metropolitan area. North Jamestown, Rhode Island is located in a nonindustrial region of central Narragansett Bay. The two locations at the New York Mud Dump, stations DM11 and DM28, are located along the southern boundary of the Mud Dump site and consist of at least 50% (by weight) silt/clay.

Table 4-3

Concentrations of PAHs from New England Estuarine Sediments and the Mud Dump Site in the New York Bight

PAHs (ppb dry weight)	New Bedford Harbor, MA 1986	Fall River, MA 1984	Fox Point, RI 1984	North Jamestown, RI 1984	Mud Dump Site, New York 1990 DM11	Mud Dump Site, New York 1990 DM28
Depth Sampled	0-5cm	0-2.5 cm	0-5cm	0-2.5cm	0-10cm	0-10cm
TOC/Grain Size	5.7 % TOC			2.9-3.6 % TOC	5% sand 78% silt 17% clay	47% sand 50% silt 2% clay
Low Molecular Weight						
naphthalene		19	134	16	<DL	<DL
2-methyl naphthalene		97	167	6		
acenaphthylene					<DL	<DL
acenaphthene					<DL	<DL
fluorene	160	41	347	6	<DL	<DL
phenanthrene	870	393	2085	36	<DL	3730
anthracene	250				<DL	1440
TOTAL	1280	550	2733	64	<DL	5170

DL = Detection Limit = 330 ppb
<DL = Below Detection Limit
Source for New Bedford Harbor, MA: Pruell et al. 1990.
Source for New York Mud Dump, 1990: Charles and Muramoto 1991.
Source for the remaining locations: Pruell 1984.

Table 4-3 (cont.)

PAHs (ppb dry weight)	New Bedford Harbor, MA 1986	Fall River, MA 1984	Fox Point, RI 1984	North Jamestown, RI 1984	Mud Dump Site, New York 1990 DM11	Mud Dump Site, New York 1990 DM2
High Molecular Weight						
fluoranthene	3500	376	5225	51	1020	5090
pyrene	3500	305	5332	44	980	4750
benzo(a)anthracene	1500	58	2175	5	860	2030
chrysene	2000				<DL	1420
benzo(b)fluoranthene					750	2370
benzo(k)fluoranthene					<DL	1000
benzo(a)pyrene	1800				<DL	1630
dibenzo(a,h)anthracene	400				<DL	<DL
benzo(g,h,i)perylene	1200				<DL	<DL
indeno (1,2,3-cd)pyrene	1200				<DL	580
TOTAL	15100	739	12732	100	3610	18870

DL = Detection Limit = 330 ppb
<DL = Below Detection Limit
Source for New Bedford Harbor, MA: Pruell et al. 1990.
Source for New York Mud Dump, 1990: Charles and Muramoto 1991.
Source for the remaining locations: Pruell 1984.

Fox Point, RI, New Bedford Harbor, MA, and DM28 of the New York Mud Dump Site offer a high end comparison with elevated levels of LMW and HMW PAHs, especially the LMW PAHs phenanthrene and anthracene, and the HMW PAHs fluoranthene, pyrene, and benzo(a)anthracene. DM11 of the New York Mud Dump Site represents the mid-range with concentrations of many PAHs below the 300 ppb detection limit, except for elevations in the HMW PAHs fluoranthene, pyrene, benzo(a)anthracene, and benzo(b)fluoranthene. Values for LMW PAH compounds at the NLON reference areas were similar to those detected in the relatively unpolluted section of Narragansett Bay at North Jamestown with the exception of higher levels of phenanthrene at NLON. HMW PAH levels were between those values measured in North Jamestown, Rhode Island and Fall River, Massachusetts.

4.4 Bottom Water Dissolved Oxygen

The objective of the DO sampling was to assess near-bottom DO concentrations at the reference areas and active disposal site in relation to benthic habitat conditions at the site. Bottom waters will generally remain well oxygenated in the absence of a strong pycnocline. Oxygen concentrations measured at approximately 1 m above the bottom at the disposal site and reference stations ranged from 7.1 to 7.7 $mg \cdot l^{-1}$. The lack of low-oxygen bottom water was consistent with the presence of oxidized surface layers of sediment (as determined by the RPD) at the disposal site and reference stations. Surface oxygen concentrations ranged from 7.1 to 7.6 $mg \cdot l^{-1}$. These results indicated uniformly high oxygen concentrations across the region and confirmed the prediction that oxygen levels would be similar both on and off the disposal site. The similarity in near-surface and near-bottom oxygen values indicates a well-mixed water column and no problem with hypoxia. The measured DO values were consistent with near-surface oxygen values (at the time of the June survey) of 7.6 to 8.6 $mg \cdot l^{-1}$ (recorded with YSI oxygen meter) in the vicinity of NL-TR during July 1990 (Table 4-4). Near-bottom oxygen values for the 1990 survey as measured by modified Winkler titration were 8.3 mg·l.

Table 4-4

Dissolved Oxygen Concentrations ($mg \cdot l^{-1}$) at the New London Reference Stations, July 1990

Station	Depth	Surface[1]	Bottom[2]
NLON-REF	18 m	7.6	8.3
NE-REF	15 m	8.6	8.3
WREF	23 m	8.4	8.3

[1] = Measured with YSI oxygen meter
[2] = Measured by Winkler titration

5.0 CONCLUSIONS

The information obtained from the bathymetric survey showed an increase in mound development at the NL-TR region. The original disposal simulation model was generated based on the formation of one mound. However, the results of the depth difference calculations indicated the presence of a second, smaller mound that developed around the disposal buoy, adjacent to the NL-TR mound. The combined heights of these two mounds were more than the predicted value of the disposal simulation model. The predicted mound radius was approximately equal to the combined radii of the two mounds. The footprint of recently deposited dredged material as determined from REMOTS® photographs coincided with small deposits detected acoustically. However, the REMOTS® survey also showed evidence of dredged material deposition beyond that detected from the bathymetric survey.

The increase in mound height between the 1990 and 1991 surveys detected at the NL-TR region was primarily over locations "B" and "D". An additional 20 cm of new sediment was added to disposal locations "A", "C", and "F". The cumulative cap thickness (comparing the 1988 with the 1991 survey) indicates that there is at least 50 cm of cap over the NL-TR mound except at capping point "C". The effect of consolidation, however, indicates that the actual cap is thicker than observed, and may be approaching 50 cm at point "C". As a conservative precaution, this area should receive additional cap sediment when it is available.

Analysis of REMOTS® parameters indicated that significant differences existed between reference areas and on-site stations for boundary roughness and the OSI. Benthic recolonization at the active disposal area had progressed, for the majority of stations, beyond the Stage I pioneering assemblages. Stage II and Stage III organisms were dominant throughout the area. This finding, together with data from DO and RPD depths, indicates a recovery well within expected recolonization rates.

Results of the sediment grain size analyses were in agreement with the visual estimate of grain size range and major mode as determined from REMOTS®. Results of the metal and PAH analyses indicate relatively low levels for the reference areas, and therefore, no immediate need for further testing beyond the collection of baseline information.

Near-bottom DO concentrations were similar at the reference areas and disposal site, and results indicated a well-oxygenated water column throughout the surveyed area. The DO concentrations were similar to those measured in previous surveys. The presence of Stage III taxa and fairly well-developed apparent RPD depths for this early a survey, in conjunction with the measured DO levels, suggest that low oxygen stress had not affected benthic recolonization on the disposal site, at least within several weeks prior to the survey.

6.0 REFERENCES

Benson, B. B.; Krause, D. Jr. 1984. The concentration and isotopic fractionation of oxygen dissolved in freshwater and seawater in equilibrium with the atmosphere. Limnol. Oceanogr. 29(3):620-632.

Charles, J. B.; Muramoto, J. 1991. Assessment of contaminants in sediment and biota at the mud dump site, New York Bight, October 1990. SAIC Report No. SAIC-91/7608&256. EPA Contract No. 68-C8-0061.

DAMOS. 1979. Disposal Area Monitoring System annual data report - 1978. Supplement G. Site report - Cornfield Shoals.

Forstner, U.; Wittman, C. T. W. 1983. Metal pollution in the aquatic environment. 2nd ed. New York: Springer-Verlag. 486 pp.

Germano J. D.; Rhoads, D. C.; Lunz, J. D. 1994. An integrated, tiered approach to monitoring and management of dredged material disposal sites in the New England region. DAMOS Contribution No. 87 (SAIC Report No. SAIC-90/7575&234). US Army Corps of Engineers, New England Division, Waltham, MA.

Germano, J.; Rhoads, D. 1984. REMOTS® sediment profiling at the Field Verification Program (FVP) Disposal Site. In: Montgomery, R. L.; Leach, J. W., eds. Dredging and dredged material disposal. Volume 1. New York: American Society of Civil Engineers. p. 536-544.

Kennish, M. J. 1992. Ecology of estuaries: anthropogenic effects. Boca Raton, FL: CRC Press, Inc. 494 pp.

Knowles, F. 1992. Waltham, MA. Personal communication by telephone with the New England Corps of Engineers Laboratory Supervisor, 24 January 1992.

NOAA. 1991. Secondary summary of data on chemical contaminants in sediments from the National Status and Trends Program. NOAA Tech. Memo. NOS OMA 59, Rockville, MD.

Parsons, T. R.; Maita, Y.; Lalli, C. M. 1984. A manual of chemical and biological methods for seawater analysis. New York: Pergamon Press. 173 pp.

Pequegnat, W. E.; Galloway, B. J.; Wright, T. D. 1990. Revised procedural guide for designation surveys of ocean dredged material disposal sites. Final report. Technical

Report D-90-8. Prepared for the Department of the Army, US Army Corps of Engineers, Washington, D.C.

Pruell, R. J. 1984. The geochemistry of organic contaminants in Narragansett Bay sediments and the availability of these compounds to the blue mussel, Mytilus edulis. PhD dissertation, Graduate School of Oceanography, University of Rhode Island.

Pruell, R. J.; Norwood, C. B.; Bowen, R. D.; Boothman, W. S.; Rogerson, P. F.; Hackett, M.; Butterworth, B. C. 1990. Geochemical study of sediment contamination in New Bedford Harbor, Massachusetts. Marine Environmental Research. 29:77-101.

Rhoads, D. C. 1992. SAIC, Woods Hole, MA. Personal communication by letter to Mary Wiley (SAIC, Newport, RI), 7 January 1992.

Rhoads, D. C. 1994. Analysis of the contribution of dredged material to sediment and contaminant fluxes in Long Island Sound. DAMOS Contribution No. 88 (SAIC Report No. SAIC-89/7571 & C82). US Army Corps of Engineers, New England Division, Waltham, MA.

Rhoads, D. C.; Germano, J. D. 1986. Interpreting long-term changes in benthic community structure: a new protocol. Hydrobiol.142:291-308.

SAIC. 1985. Standard operating procedures 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. 1987. Seasonal monitoring cruise at the Western Long Island Sound Disposal Site, August 1986. DAMOS Contribution No. 61 (SAIC Report No. SAIC-87/7500&C61). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1989. 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. 1990a. Capping survey at the New London Disposal Site, February 3, 1989. DAMOS Contribution No. 71 (SAIC Report No. SAIC-89/7554-C76). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1990b. QA/QC plan for the DAMOS program. SAIC Report No. SAIC-90/7573&232. US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1990c. Monitoring cruise at the New London Disposal Site, July 1987. DAMOS Contribution No. 66 (SAIC Report No. SAIC-88/7511&C66). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1990d. Monitoring cruise at the Central Long Island Sound Disposal Site, July 1986. DAMOS Contribution No. 63 (SAIC Report No. SAIC-87/7514&C63). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1990e. Monitoring cruise at the Central Long Island Sound Disposal Site, August & September 1987. DAMOS Contribution No. 68 (SAIC Report No. SAIC-88/7523&C68). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1990f. Monitoring cruise at the Western Long Island Sound Disposal Site, November 1987. DAMOS Contribution No. 74 (SAIC Report No. SAIC-88/7527&C72). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1993. Monitoring cruise at the New London Disposal Site, June–July 1990. (SAIC Report No. SAIC-90/7599&C93). Draft report submitted to US Army Corps of Engineers, New England Division, Waltham, MA.

Strickland, J. D. H.; Parsons, T. R. 1972. A practical handbook of seawater analysis. Fish. Res. Board Can. Bull. 167 pp.

Tavolaro, J. F. 1984. Sediment budget study for clamshell dredging and ocean disposal activities in the New York Bight. Environ. Geol. Water Sci. 6(3):133-140.

Tyson, R. V.; Pearson, T. H. 1991. Modern and ancient continental shelf anoxia: an overview. In: Tyson, R. V.; Pearson, T. H., eds. Modern and ancient continental shelf anoxia. p. 1-24. London: Geol. Soc. London, Sp. Pub. 58. 470 pp.

INDEX

anoxia 23, 56
atomic absorption
spectrophotometry 8
barge vi, 43, 45
barges 43
benthos vii, 1, 4-6, 30, 33, 39, 46, 52, 53, 55
amphipod 4, 20, 30
deposit feeder 4
mussels 17, 23, 55
polychaete 4, 30
bioaccumulation 46
bioturbation 46
feeding void 30
foraging 30
body burden
bioaccumulation 46
boundary roughness v, 6, 17, 21, 22, 53
buoy vii, 1, 40, 41, 43, 53
disposal 41, 43, 53
capping vii, 41, 42, 55
Central Long Island Sound (CLIS) iv, 47, 56
FVP 30, 54
colonization 6, 30, 39
conductivity 5
consolidation 41, 53
contaminant 4, 9, 46, 48, 49, 54, 55
CTD meter 5, 10, 39
currents 23, 26, 41
decomposition 46
deposition 11, 23, 48, 53
dispersion 41
dispersive site
Cornfield Shoals 41, 54
disposal site
Central Long Island Sound (CLIS) iv, 47, 56
Cornfield Shoals 41, 54
New London 0, iv, v, vi, vii, 1, 3, 5-7, 11-13, 15, 17, 18, 20, 23, 24, 29, 30, 31, 33, 34, 35-41, 46, 47-49, 52, 55, 56
Western Long Island Sound (WLIS) iv, 47, 55, 56
dissolved oxygen iv, vii, 1, 10, 30, 39, 40, 52
dredging
clamshell 56
erosion 30, 46
feeding void 30
Field Verification Program (FVP) 30, 54
fish 56
grain size iv, v, vii, 4, 6, 8, 9, 17, 18, 20, 33, 36, 46, 53
habitat vii, 4, 30, 46, 48, 52
hydroids 23
hypoxia 30, 52
interstitial water 43
methane 6, 30
mud clast 6, 17, 23, 26
organics
polyaromatic hydrocarbon (PAH) iv, vii, 4, 6, 8, 9, 10, 33, 38, 39, 48, 49, 50, 52, 53
total organic carbon vii, 4, 8, 9, 33, 36
recolonization vii, 1, 4, 6, 46, 53
reference area v, vii, 6, 7, 17, 18, 20, 22, 24, 29-31, 33, 34, 41, 46, 48
reference station iv, v, vi, 21-24, 28, 31, 34, 35, 40, 48, 52
CLIS-REF 47

REMOTS®
boundary roughness v, 6, 17, 21, 22, 53
Organism-Sediment Index (OSI) vi, 6, 30, 33, 34, 35, 53
redox potential discontinuity (RPD) 6, 23
REMOTS® v, vi, vii, 1, 3, 5-7, 17, 19, 20, 23, 25, 26, 27, 30, 32, 33, 41, 43, 44, 46, 53, 54
camera 23, 41
RPD
REMOTS®;redox potential discontinuity (RPD) vi, 6, 23, 28-30, 33, 46, 52, 53
salinity 5
sandy 48
sediment
chemistry 46
clay 8, 17, 33, 36, 46, 49
cobble 17, 19, 23
gravel 8, 17, 19, 23, 25
sand vi, 8, 17, 19, 20, 23, 24, 25-27, 33, 36, 41, 43, 48, 49
silt 8, 17, 33, 36, 46, 49
transport 30, 41
sediment sampling vii, 1, 6
cores 6
grabs 6
shore station 5
species
dominance 33, 53
spectrophotometry
atomic absorption 8
statistical testing
Mann-Whitney U-test 17, 23, 33
succession
pioneer stage 4, 30, 53
seres vii, 30, 46
successional stage vi, 4, 6, 20, 30, 31, 32, 33
survey
baseline vii, 53
bathymetry v, vii, 1, 3, 5, 10, 11-14, 16, 41, 43, 53
REMOTS® v, vii, 3, 30, 43, 53
temperature 5
tide 5
topography vii, 1, 11, 41
toxicity 49
trace metals iv, vii, 6, 8-10, 33, 37, 46-49, 53, 54
cadmium (Cd) vii, 4, 6, 8, 9, 33, 37, 39, 46-49
magnesium (Mg) iv, 39, 40, 52
zinc (Zn) vii, 4, 6, 8, 9, 33, 37, 46-49
trawling 46
volume
estimate 43