Monitoring Cruise at the
Western Long Island Sound Disposal Site
July 1991

Disposal Area Monitoring System DAMOS

Contribution 99
October 1995

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
October 1995

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Monitoring Cruise at the Western Long Island Sound Disposal Site, June 1991

5. FUNDING NUMBERS

6. AUTHOR(S)
R. W. Williams

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

8. PERFORMING ORGANIZATION REPORT NUMBER
SAIC-92/7623&C102

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 Number 99

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)*

In June 1991, SAIC conducted field operations at the the Western Long Island Sound Disposal Site (WLIS) as a part of the DAMOS (Disposal Area Monitoring System) Program for the U.S. Army Corps of Engineers, New England Division (NED). The objectives of this study were (1) to provide information on the fate and effects of dredged materials disposed since the previous July 1990 survey; (2) to assess the stability of the inactive disposal mounds; (3) to determine the extent of infaunal recolonization; (4) to measure near-bottom dissolved oxygen concentrations; and (5) to collect additional PAH and metals data at the three reference areas. Field operations included a 1200 x 800 m bathymetric survey, REMOTS sediment profile photography, near-bottom dissolved oxygen measurements, and sediment sampling for chemical and physical analyses.

Based on recorded disposal volumes, 86,462 m^3 of material was disposed during the 1990-1991 season. The resulting WLIS "E" mound was 3.0 m high with an elliptical footprint of 400 x 175 m. The WLIS "A", "B", and "C" mound heights remained unchanged since the previous July 1990 bathymetric survey and were considered to be stable. The height of the WLIS "D" mound decreased approximately 0.5 m, primarily due to the consolidation of the mound sediments.

Infaunal recolonization of the recently deposited material occurred rapidly as 90% of the on-site stations provided evidence on Stage III activity. Several stations west of the WLIS "D" mound continued to exhibit low reflectance subsurface sediments although the recolonization status was normal. Low reflectance, inferred to represent sediments from the previous year's survey with high oxygen demand, indicated potential deleterious effects of disposal operations and therefore, warranted further investigation.

Dissolved oxygen and sediment chemistry were analyzed at three WLIS reference areas (2000W, 2000S, and WLIS-REF). Concentrations of dissolved oxygen in near-bottom waters at the disposal site and reference areas were spatially homogeneous and within aerobic levels. REMOTS parameters indicated that reference areas 2000S and WLIS-REF had received disposed material in the past, whereas reference area 2000W had benthic habitat conditions characteristic of ambient sediments. Sediment chemistry analyses reflected this disparity among the three reference areas, with the highest concentrations of PAH's and metals occurring at 2000S and the lowest concentrations occurring at 2000W. Consideration should be made to replace reference areas 2000S and WLIS-REF (as comparison areas for the disposal site) with areas deemed not affected by historical disposal operations.

14. SUBJECT TERMS
WLIS SAIC DAMOS disposal mounds dissolved oxygen REMOTS PAH's

15. NUMBER OF PAGES
45

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 WESTERN LONG ISLAND SOUND
DISPOSAL SITE
JUNE 1991

CONTRIBUTION #99

October 1995

Report No.
SAIC- 92/7623&C102

Submitted to:

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

Prepared by:
R.W. Williams

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

TABLE OF CONTENTS (cont.)

LIST OF TABLES

LIST OF FIGURES

In June 1991, SAIC conducted field operations at the Western Long Island Sound Disposal Site (WLIS) as part of the DAMOS (Disposal Area Monitoring System) Program for the U.S. Army Corps of Engineers, New England Division (NED). The objectives of this study were (1) to provide information on the fate and effects of dredged materials disposed since the previous July 1990 survey; (2) to assess the stability of the inactive disposal mounds; (3) to determine the extent of infaunal recolonization; (4) to measure near-bottom dissolved oxygen concentrations; and (5) to collect additional PAH and metals data at the three reference areas. Field operations included a 1200 × 800 m bathymetric survey, REMOTS® sediment-profile photography, near-bottom dissolved oxygen measurements, and sediment sampling for chemical and physical analyses.

Based on recorded disposal volumes, 86,462 m^3 of material was disposed during the 1990–1991 season. The resulting WLIS "E" mound was 3.0 m high with an elliptical footprint of 400 × 175 m. The WLIS "A", "B", and "C" mound heights remained unchanged since the previous July 1990 bathymetric survey and were considered to be stable. The height of the WLIS "D" mound decreased approximately 0.5 m, primarily due to the consolidation of the mound sediments.

Infaunal recolonization of the recently deposited material occurred rapidly as 90% of the on-site stations provided evidence of Stage III activity. Several stations west of the WLIS "D" mound continued to exhibit low reflectance subsurface sediments although the recolonization status was normal. Low reflectance, inferred to represent sediments from the previous year's survey with high oxygen demand, indicated potential deleterious effects of disposal operations and, therefore, warranted further investigation.

Dissolved oxygen and sediment chemistry were analyzed at three WLIS reference areas (2000W, 2000S, and WLIS-REF). Concentrations of dissolved oxygen in near-bottom waters at the disposal site and reference areas were spatially homogeneous and within aerobic levels. REMOTS® parameters indicated that reference areas 2000S and WLIS-REF had received disposed material in the past, whereas reference area 2000W had benthic habitat conditions characteristic of ambient sediments. Sediment chemistry analyses reflected this disparity among the three reference areas, with the highest concentrations of PAHs and metals occurring at 2000S and the lowest concentrations occurring at 2000W. Consideration should be made to replace reference areas 2000S and WLIS-REF (as comparison areas for the disposal site) with areas deemed not affected by historical disposal operations.

1.0 INTRODUCTION

The Western Long Island Sound Disposal Site (WLIS) is located 2.7 nm north of Lloyd Point, New York and 2.5 nm south of Long Neck Point, Connecticut, between the Stamford and Eaton's Neck historic disposal grounds (Figure 1-1). Dredged material has been deposited annually since disposal first began at the site in March 1982, resulting in the formation of five dredged material disposal mounds (Figure 1-2).

The disposal buoy was located approximately 250 m southeast of the "C" mound at coordinates 40°59.333′ N and 73°28.888′ W during the 1990–1991 disposal period. Reported volume estimates indicated that 86,462 m^3 of dredged material was disposed near the buoy between November 7, 1990 and May 31, 1991. The resulting dredged material mound is referred to as WLIS "E".

Field operations at WLIS were initiated on 15 June 1991 (two weeks after disposal operations ceased) to provide information on the fate of recently disposed dredged material at WLIS "E" and to assess the environmental effects of past and recent disposal operations. Field operations included a bathymetric survey, REMOTS® sediment-profile photography, near-bottom dissolved oxygen (DO) analyses, sediment metal and PAH chemistry, and grain size sampling. The objectives for the 1991 monitoring cruise at WLIS were

- *to delineate the areal extent and topography of dredged material deposited* since the July 1990 survey and to determine the stability of disposal mounds formed prior to the July 1990 survey;
- to assess the extent of recolonization at the WLIS disposal mounds and monitor the ambient benthic infaunal successional stages present within the three reference areas;
- to assess near-bottom dissolved oxygen concentrations and compare these to the REMOTS® benthic analyses at and near the disposal site and at the three reference areas; and
- to provide additional sediment metal and PAH baseline information and grain size distributions at each of three reference areas.

The 1991 monitoring plan was designed to test the following predictions that are part of the DAMOS tiered monitoring protocol (Germano et al. 1994):

- Based on a disposal simulation model, the volume of sediments disposed at WLIS from November 1990 to May 1991 was predicted to form a mound with a radius of approximately 200 m and height of 2.7 m.

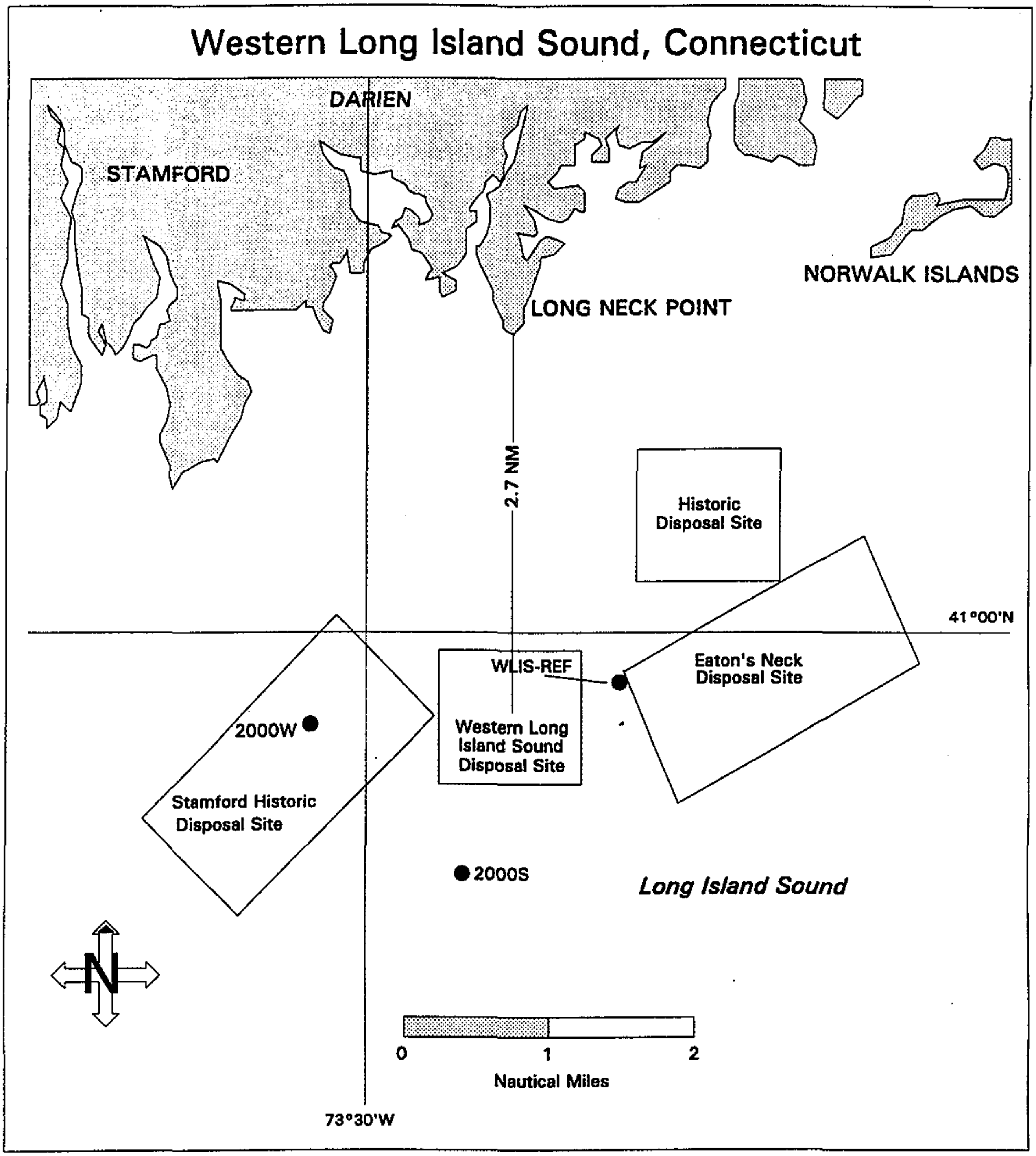


Figure 1-1. The Western Long Island Sound Disposal Site (WLIS) and associated reference areas 2000W, 2000S, and WLIS-REF

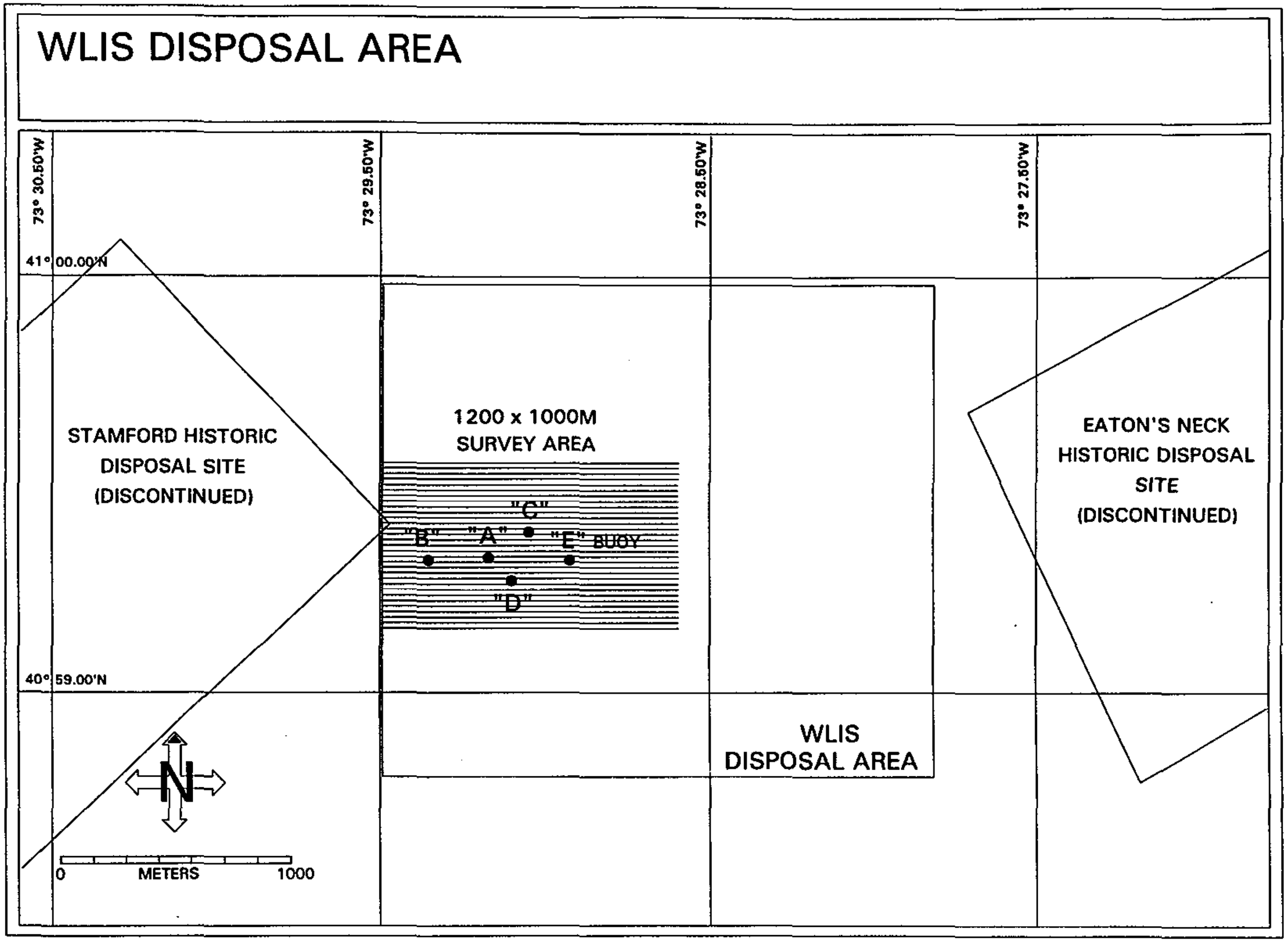


Figure 1-2. The WLIS 1991 bathymetric survey grid. The discontinued Stamford and Eaton's Neck Disposal Sites border WLIS to the west and east. The buoy location ("E") for disposal operations during the 1990-1991 disposal season is also shown.

- At the designated disposal point, benthic recolonization should be predominantly in Stage I, while recolonization on the flanks of the mound should be primarily Stage II and/or Stage III. Stage I consists of small pioneering polychaetes while 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 dissolved oxygen concentrations should be similar at stations within the disposal site and at the 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. This system uses a Hewlett-Packard 9920 series computer to collect position, depth, and time data for subsequent analysis and to provide real-time navigation. A Del Norte Trisponder® system provided positioning to an accuracy of ±3 meters. Shore stations were established in Connecticut at known benchmarks at Greenwich Point and the Norwalk electric-generating facility. A detailed description of the navigation system and its operation can be found in the DAMOS QA/QC Plan (SAIC 1990a).

An Odom DF3200 Echotrac® Survey Fathometer with a narrow-beam 208 kHz transducer measured depths to a resolution of 3.0 cm (0.1 feet). Prior to the bathymetric survey, the speed of sound was determined with a bar check apparatus. In addition, a Seacat Model SBE 19-01 profiler obtained a sound velocity profile to verify the bar check measurement. Depth values transmitted to the computer were adjusted for speed of sound and transducer depth. During data analysis, correction for changes in tidal height standardized the raw bathymetric data to Mean Low Water. A complete description of the bathymetric analysis technique is also given in the DAMOS QA/QC Plan (SAIC 1990a).

The previous three bathymetric surveys of the WLIS Disposal Site (November 1987, July 1988, and July 1990; SAIC 1990b, 1990c, and Germano et al. 1993, respectively) utilized an 800 × 800 m grid which included the WLIS "A", "B", "C", and "D" disposal mounds. The June 16, 1991 bathymetric survey was extended 400 m eastward (1200 × 800 m) to include the recently formed WLIS "E" mound (Figure 1-2). As with the previous surveys, the 1991 grid consisted of thirty-three lanes running east and west at a 25 meter lane spacing.

2.2 REMOTS® Sediment-Profile Photography

REMOTS® photography was used to detect the distribution of thin (≤ 20 cm) dredged material layers, map benthic disturbance gradients, and monitor the progress of infaunal recolonization on, and adjacent to, the WLIS "E" mound. A detailed description of REMOTS® image acquisition, analysis, and interpretative rationale is given in the DAMOS QA/QC Plan (SAIC 1990a).

REMOTS® monitoring at WLIS utilized a 25-station star grid, with 100 m spacing, centered at the buoy coordinates for the 1990–1991 disposal season (40°59.333′ N, 73°28.888′ W, "E" mound) and a 13-station cross-shaped grid centered at the "D" mound (Figure 2-1). Triplicate photographs were taken at each station. In addition, sampling at

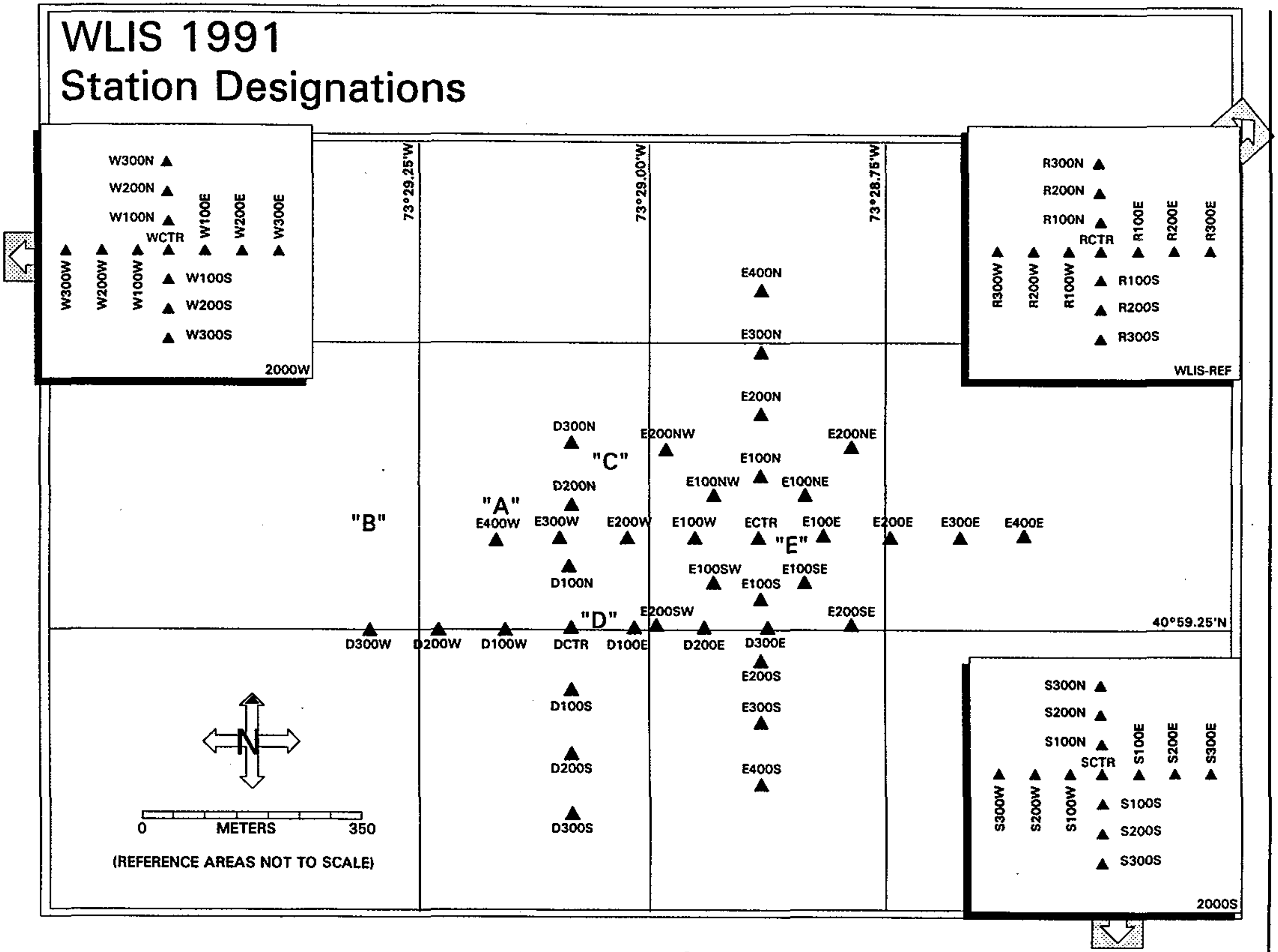


Figure 2-1. Locations and designations of the REMOTS® stations at WLIS and reference areas, June 1991. Thirteen-station cross-shaped girds with 100 m spacing were used at the three outlying reference areas (200W, 2000S, and WLIS-REF).

three reference areas allowed comparison of ambient versus on-site conditions. Within each reference area, triplicate REMOTS® photographs were taken at each of thirteen stations arranged in a cross-shaped pattern and spaced 100 m apart. These reference areas, also occupied during the July 1990 survey, were approximately 2000 m west (2000W), 2000 m south (2000S), and 2200 m northeast (WLIS-REF) of the "B" mound (see Figure 1-1).

2.3 CTD and Dissolved Oxygen Sampling

A Sea-Bird Instruments, Inc. Seacat Model SBE 19-01 Conductivity, Temperature, and Depth (CTD) profiler obtained vertical profiles of temperature, salinity, and dissolved oxygen (DO) at the center of each reference area and the WLIS "E" REMOTS® sampling grid. A Compaq Portable II microcomputer sent commands to and read data from the instrument via an RS-232 serial interface. During deployment, the SBE 19-01 recorded data at two-second intervals. The microcomputer received and stored data on a floppy disk for later analysis.

To verify the CTD dissolved oxygen measurement, near-surface and near-bottom (within 1 meter) water samples were collected with a Niskin bottle. A 300 ml subsample was drawn from the bottle, preserved, and titrated within 12 hours using a modification of the standard Winkler titration method (Strickland and Parsons 1972, Parsons et al. 1984).

2.4 Sediment Chemistry and Grain Size

Sediment samples were collected at 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 in length) were composited to provide sufficient sediment to fill precleaned 250 ml glass jars, certified to meet U.S. Environmental Protection Agency (EPA) container standards for both trace metal and PAH analyses. Sediments for grain size and total organic carbon (TOC) were placed in plastic bags. Samples were kept cold (approximately 4° C) and delivered to the NED laboratory. The triplicate samples for each reference area were analyzed for TOC, PAHs, cadmium (Cd), lead (Pb), and zinc (Zn). Grain size analyses were not run in triplicate but were composited for each reference area at the NED laboratory.

2.4.1 Grain Size Analysis

Grain size analyses were performed using ASTM Method D422 (Table 2-1). Classification of grain size was by the Wentworth classification (phi scale) which assigns gravel phi values between -2 and -1, sand between -1 and +4 inclusive, silts between 4 and

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		

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 total solids analysis (% dry weight) to allow for determination 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.

2.4.2 Total Organic Carbon

Total organic carbon was measured using EPA Method 9060. Organic carbon in the samples was converted by the analyzer to carbon dioxide (CO_2), which was subsequently 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 not included as part of the reported total organic carbon value. Total organic carbon is a measurement of organic matter (both labile and refractory) in sediments.

2.4.3 Metal and PAH Analysis

Samples were analyzed using standard EPA procedures (Table 2-1). Cadmium and lead were analyzed by graphite furnace atomic absorption techniques which allow for low detection limit thresholds, whereas zinc was analyzed by inductively coupled argon plasma emission spectrophotometry (ICP). 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 threshold associated with ICP analysis is frequently higher than that of atomic absorption spectrophotometry.

Polynuclear aromatic hydrocarbons (PAHs) were analyzed by EPA Method 8270 which utilizes gas chromatography/mass spectrophotometry (GC/MS). The method detection limit for PAHs is based on results obtained from the method blank processed with the samples. The practical quantitation limit is the lowest level of 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.

2.4.4 QA/QC

Results submitted by the NED laboratory were found to be acceptable and supported by appropriate documentation. Quality control checks from the NED laboratory consisted of 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. Matrix spike sample analyses provide a measure of the efficiency and effectiveness of sample preparation and analysis procedures, in addition to an indication of how tightly a compound is bound to its matrix. Matrix spikes are 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 as samples. Accuracy for the laboratory analytical reference materials was within the control limits for the metals as well as the PAHs with the exception of fluoranthene, which was above the acceptable range. However, since no other QC samples indicated problems with the analysis of this compound, no qualifiers were necessary.

3.0 RESULTS

3.1 Bathymetry

The July 1990 bathymetric results indicated that minimum water depths at the "A", "B", "C", and "D" mounds were 29.75, 30.75, 28.25, and 28.00 m, respectively (Figure 3-1). In comparison to the June 1991 survey (1200 × 800 m), the heights of the "A", "B", and "C" mounds remained relatively unchanged (minimum water depths of 29.75, 31.00, and 28.00 m, respectively) while the height of the "D" mound decreased approximately 0.5 m (minimum water depth of 28.50 m;Figure 3-2).

The 1990-1991 disposal operations resulted in the formation of the WLIS "E" mound. Based on acoustically detected changes in depth, WLIS "E" had a diameter of approximately 175 m. The minimum water depth at the WLIS "E" mound was 29.75 m, with a surrounding ambient bottom depth of approximately 32.75 m. This represented a mound height of approximately 3.0 m. WLIS "E" is located beyond the eastern boundary of the area surveyed prior to the 1991 field effort; therefore, the height and volume of material comprising this mound could not be calculated by depth difference analysis (comparing the 1990 and 1991 depth data).

3.2 REMOTS® Sediment-Profile Photography

3.2.1 Dredged Material Footprint

Due to the magnitude of historic disposal operations at the WLIS Disposal Site and the proximity of the five disposal mounds, virtually all stations in the WLIS "E" and "D" REMOTS® grids, except 400N (Figure 3-3), provided evidence of dredged material. The most recent disposal took place near the center of the WLIS "E" grid where approximately 86,462 m^3 was disposed between November 7, 1990 and May 31, 1991 (Figure 3-4). The footprint of this material is a NW-SE trending ellipsoid centered on the WLIS "E" grid with a maximum diameter of approximately 400 m and a minimum width of 275 m. This footprint is adjacent to, and overlaps some sections of, the dredged material footprint developed during the 1989-1990 disposal season (Figure 3-5).

Within the area covered by dredged material, recently deposited dredged material exceeded the penetration of the camera prism at several stations adjacent to the disposal point. Criteria used to differentiate fresh (1991) from old (pre-1991) dredged material included the presence of a thin (1 cm deep or less) or patchy Redox Potential Discontinuity (RPD), a chaotic fabric or physical layering (i.e., relic/buried RPD or sand/mud layering) near the sediment surface, high physical boundary roughness, and/or unconsolidated, high water content sediments (Figure 3-6).

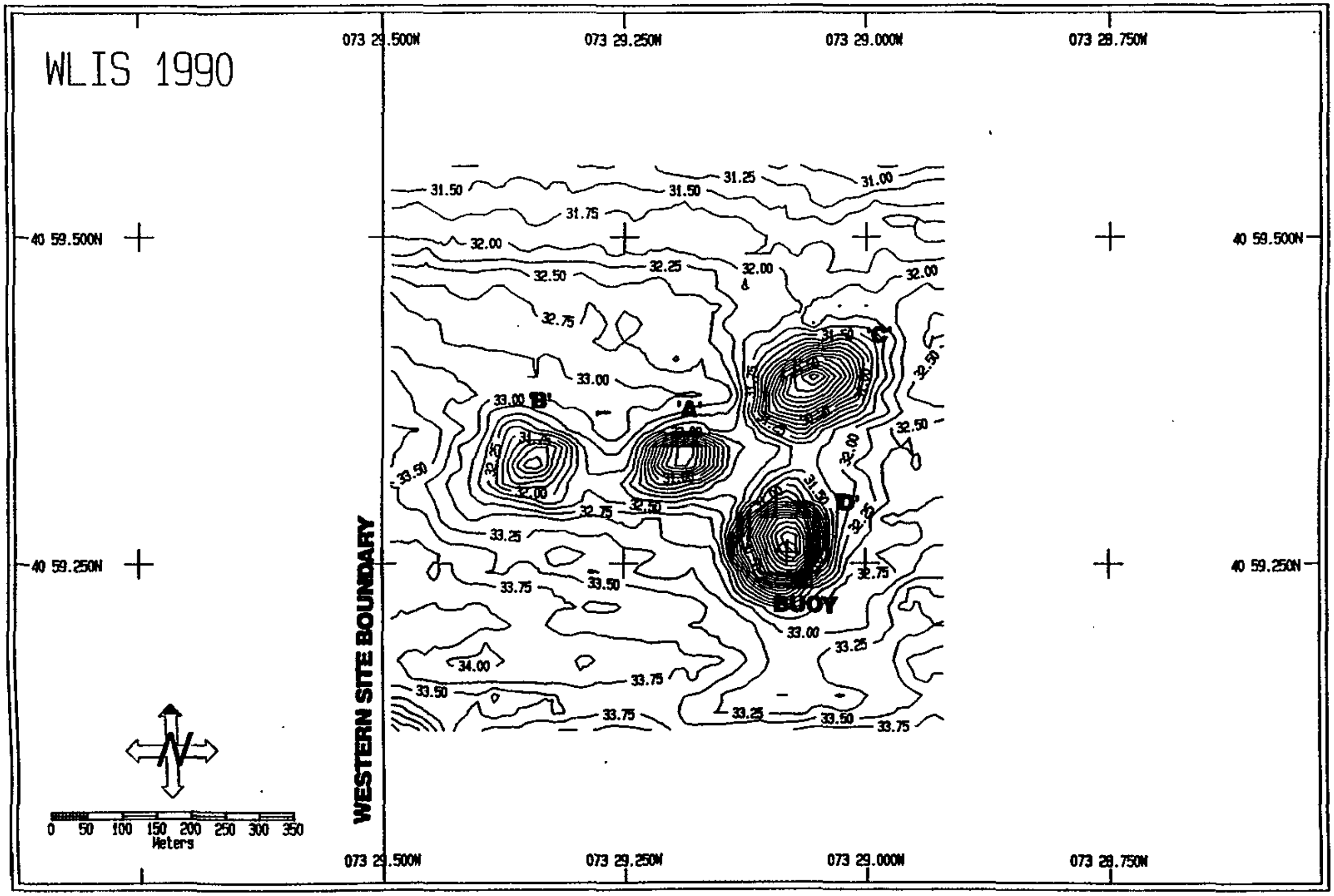


Figure 3-1. The July 1990 bathymetric contour plot of WLIS. Contours at 0.25 m intervals.

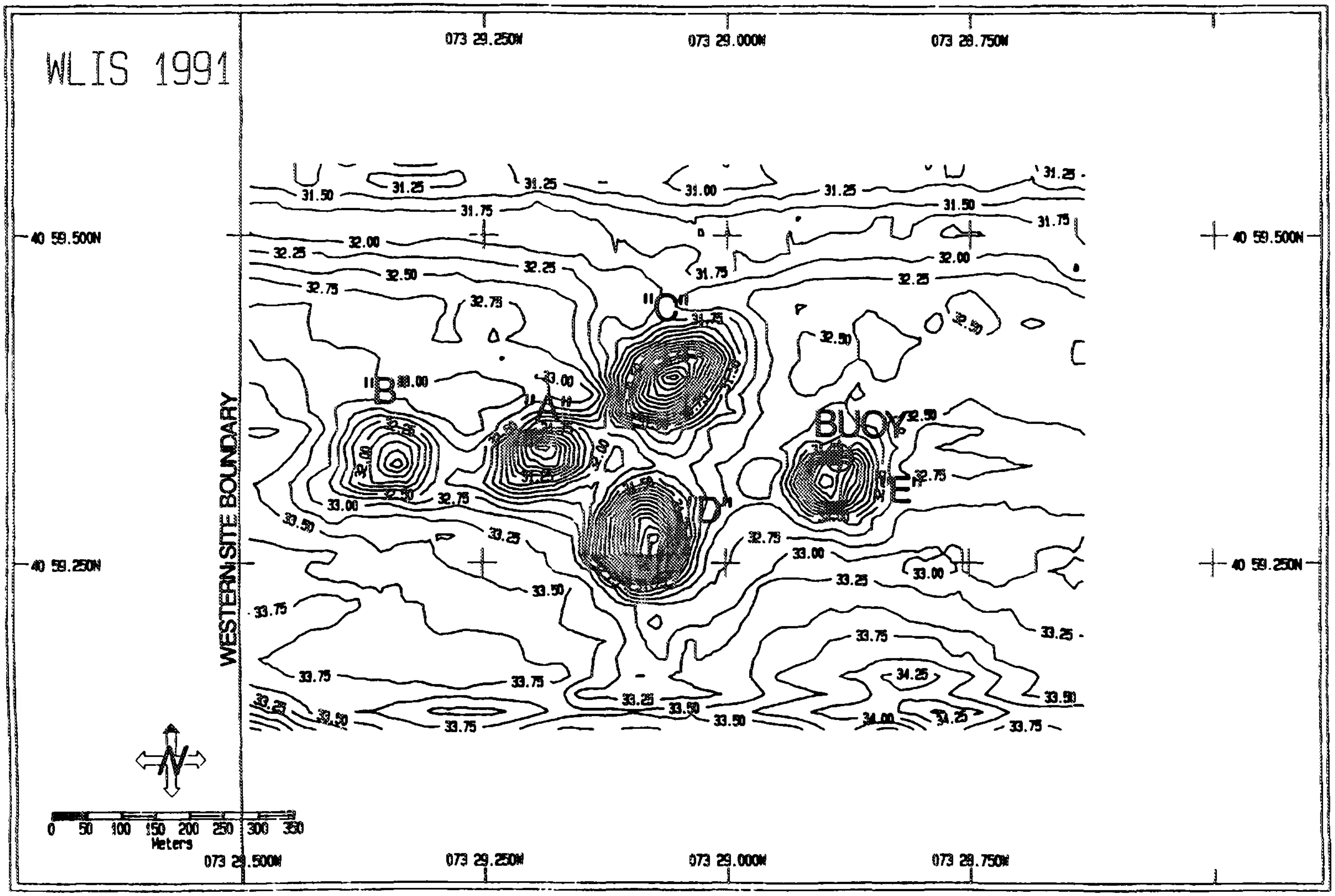


Figure 3-2. The June 1991 bathymetric contour plot of WLIS. Contours at 0.25 m intervals.

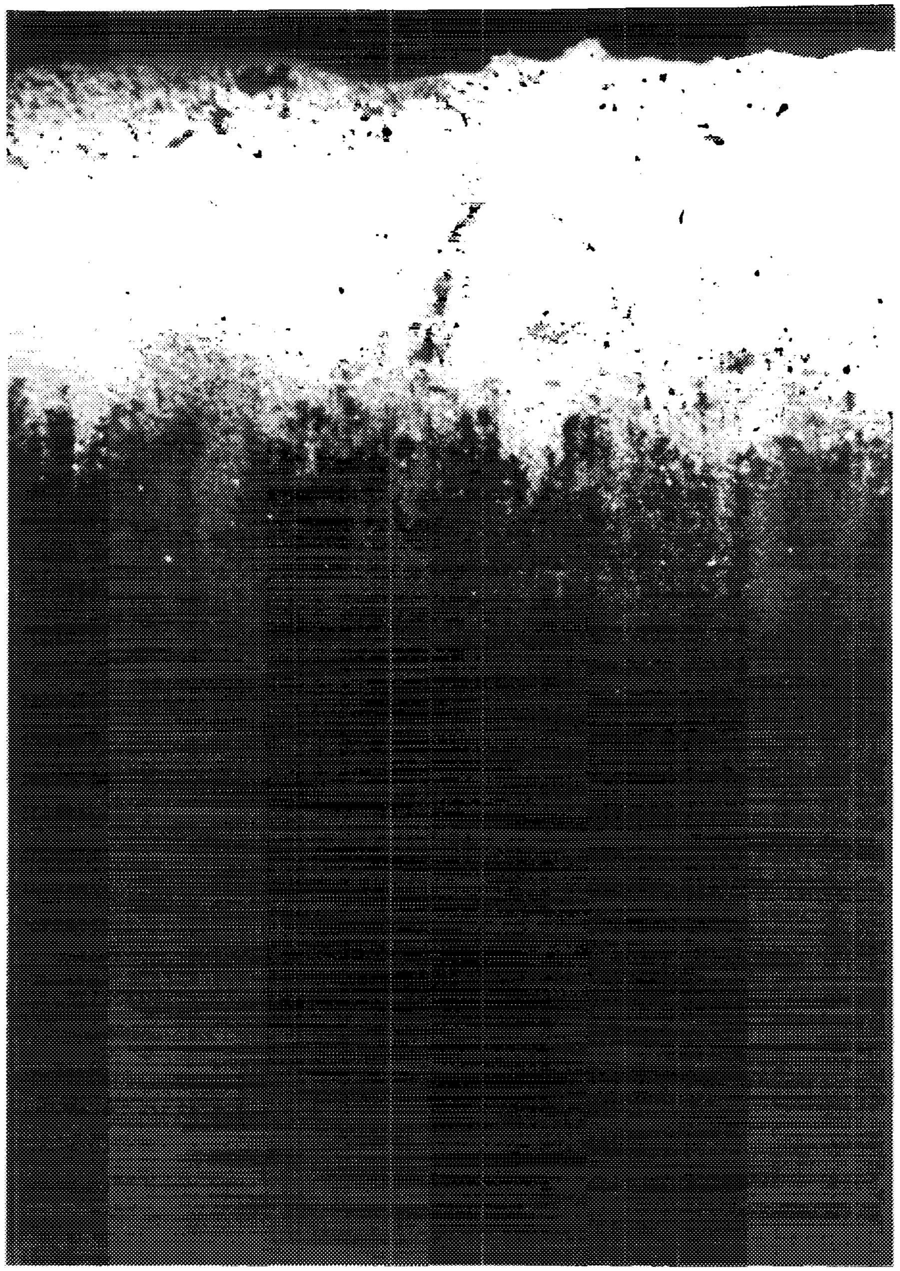


Figure 3-3. REMOTS® photograph from station E400N showing a uniform sediment-profile characteristic of ambient sediments. This is the only station sampled within WLIS showing ambient bottom conditions. Note the well-developed, relatively deep (approximately 4.0 cm) RPD boundary layer. Scale = 1x.

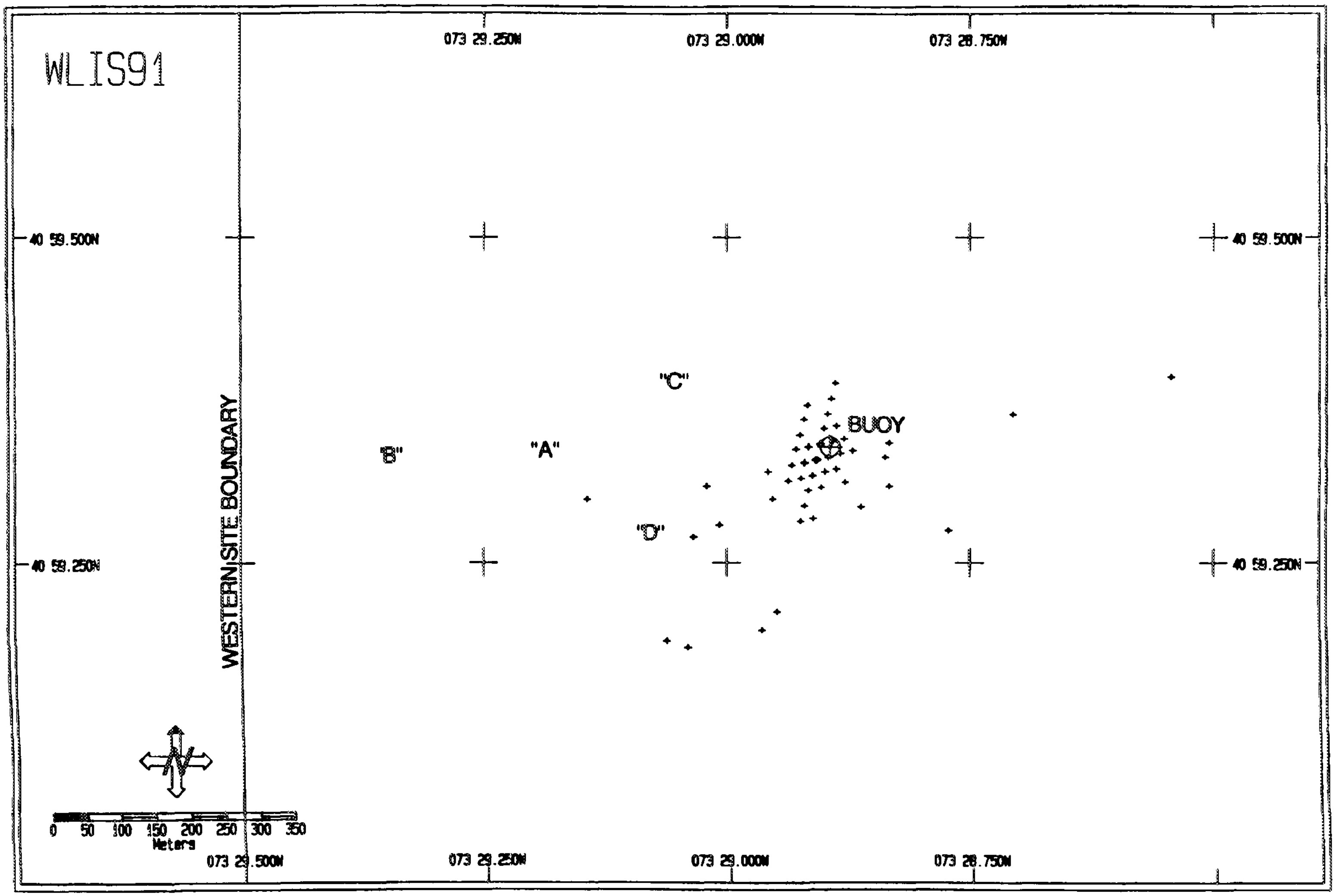


Figure 3-4. A plot of disposal barge positions recorded during 1990–1991 disposal operations

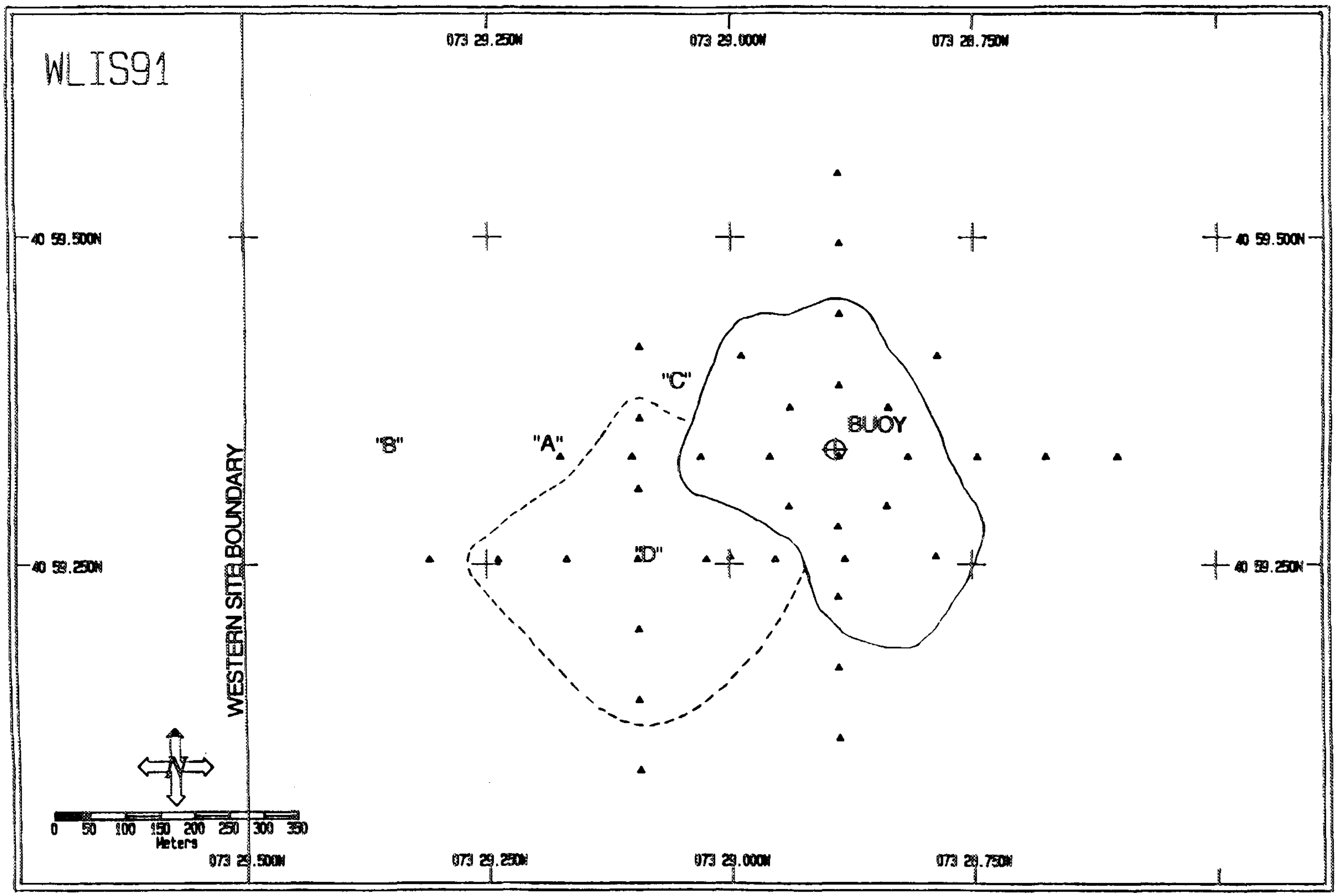
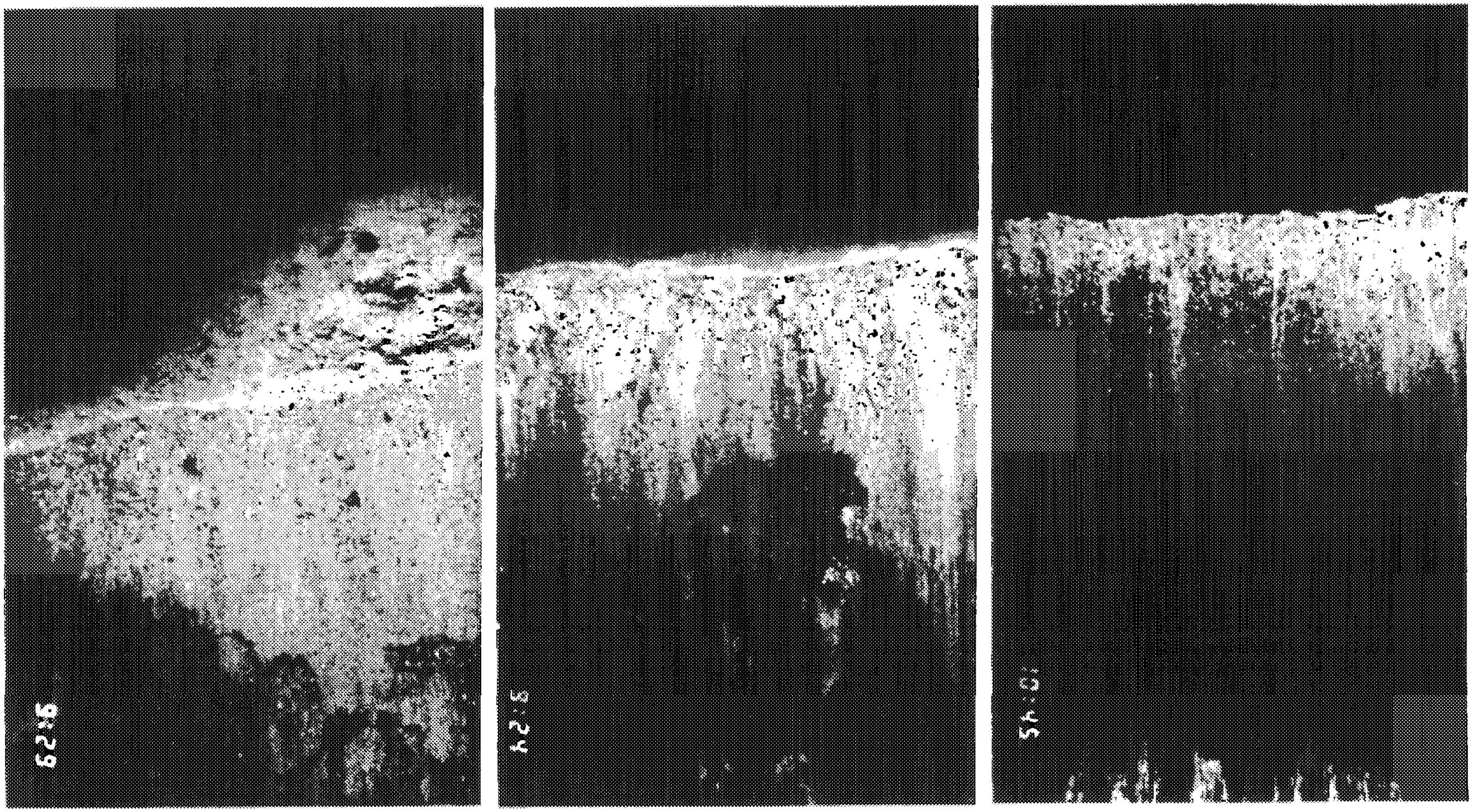


Figure 3-5. The mapped distribution of dredged material deposited during the 1990–1991 disposal season (solid line) based on REMOTS® sediment-profile photography and acoustically observed changes in depth. This material is adjacent to and overlaps some sections of the dredged material footprint developed during the 1989–1990 disposal season (dashed line).



A B C

Figure 3-6. REMOTS® photographs from WLIS "E" grid stations E100S (A), ECTR (B), and E100W (C) exhibiting consolidated mud clumps, highly variable or otherwise patchy apparent RPD layers, and relic RPD layers characteristic of recently deposited dredged material. Scale = 0.5×.

3.2.2 Grain Size Distribution

The majority of disposal site stations (WLIS "E" and "D" REMOTS® grids) exhibited a grain size major mode of 4-3 phi, with no obvious grain size anomalies differentiating recently deposited dredged material from ambient sediments (Figure 3-7). At several stations on the mound, surface sediments appeared to be coarser than underlying sediments. This can result when the fine-grained component of surface sediments is washed away and transported to nearby lower-lying stations. Some of this redistributed material may account for the predominately silt/clay ($\geq$4 phi) sediments north and south of the disposal point. Surface sand and shell lag deposits characterized several stations on the WLIS "D" mound which was formed during the 1989–1990 disposal season (Figure 3-8).

Sediments at the 2000W and WLIS-REF reference areas consisted of mixtures of silt/clay and very fine sand. As noted during the 1990 survey, several stations within the 2000S reference area continued to exhibit poorly sorted sediments with layering of sand and mud in addition to surface shell lags (Figure 3-9).

3.2.3 Boundary Roughness

The frequency distribution of mean boundary roughness values for the disposal site stations had major modes in the 2 and 3 class intervals (ranging from 0.6 to 1.4 cm; Figure 3-10). Observed boundary roughness was attributed primarily to physical (as opposed to biological) processes resulting from disposal operations and/or sediment surface ripples. The mean boundary roughness of the pooled reference sites had similar major modes of 2 and 3 (Mann-Whitney U-Test, $p = 0.884$). As noted with the disposal site stations, boundary roughness at the reference areas was attributed primarily to physical processes.

3.2.4 Apparent RPD Depth

The frequency distribution of apparent RPD depths for the WLIS "E" survey grid had a major mode in the 2.0 - 2.5 cm depth range (Figure 3-11) and a mean of 2.16 cm. The areal distribution of RPD depths showed no clear relationship between RPD depths and the proximity of a station to the designated disposal point (Figure 3-12). Most stations within 100 m of the WLIS "E" mound center exhibited moderately developed RPD layers ($\geq$ 2.0 cm). Many of the western stations including the station nearest the "A" mound (E400W) exhibited relatively shallow RPD depths ($\leq$ 2.0 cm). Dark subsurface sediments, indicative of a high sulphide content and a high apparent sediment oxygen demand (SOD), characterized many of the sediment profiles from these shallow RPD stations (Figure 3-13).

RPD depths for the pooled 1991 reference areas had a major mode in the 1.0 - 1.5 cm depth range (mean of 2.03 cm) and were not significantly different from the WLIS "E" REMOTS® stations (Mann-Whitney U-Test, $p = 0.836$). As noted during the 1990

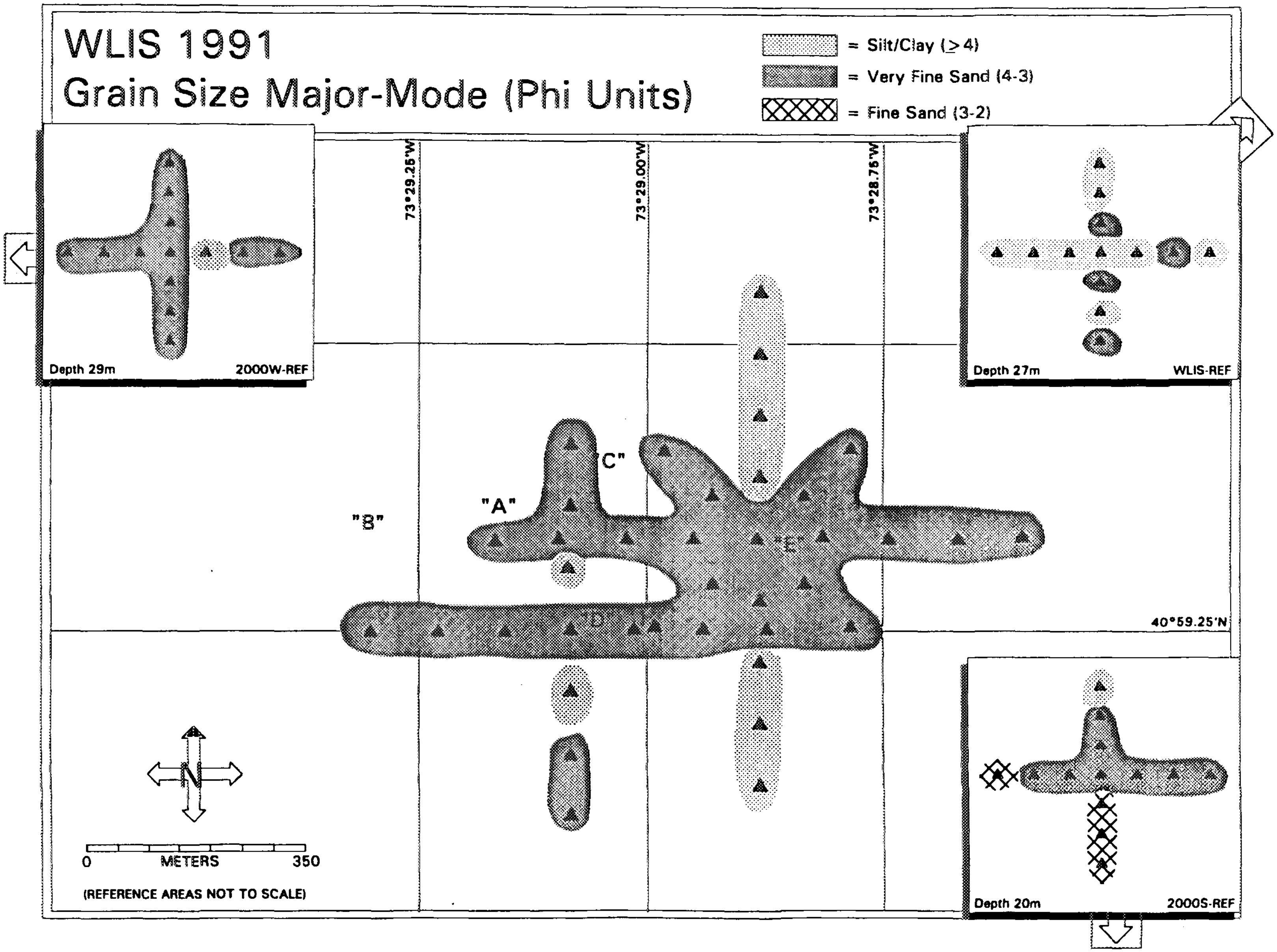


Figure 3-7. Distribution of sediment grain size major mode (phi units) at WLIS and reference areas, June 1991

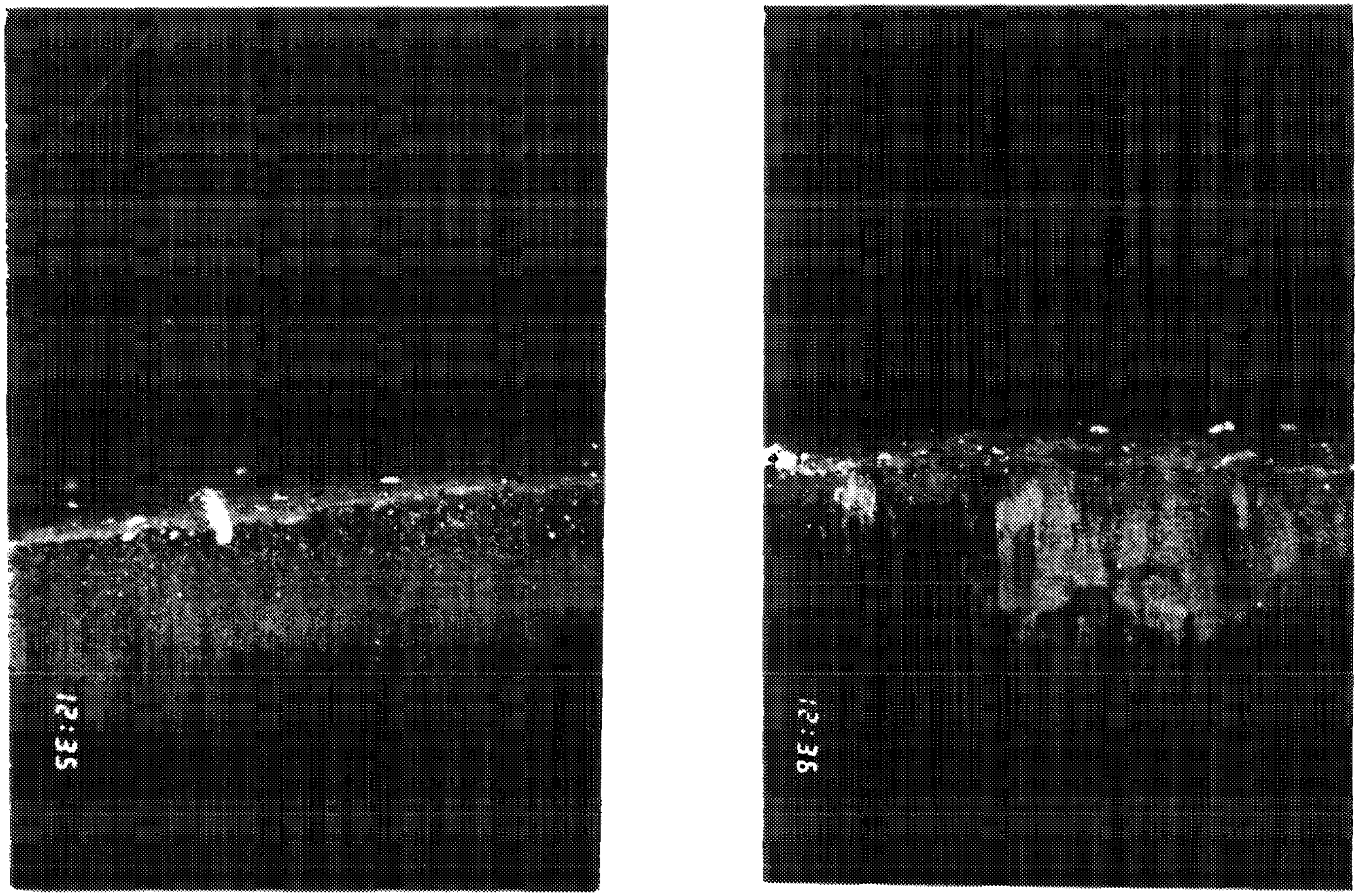
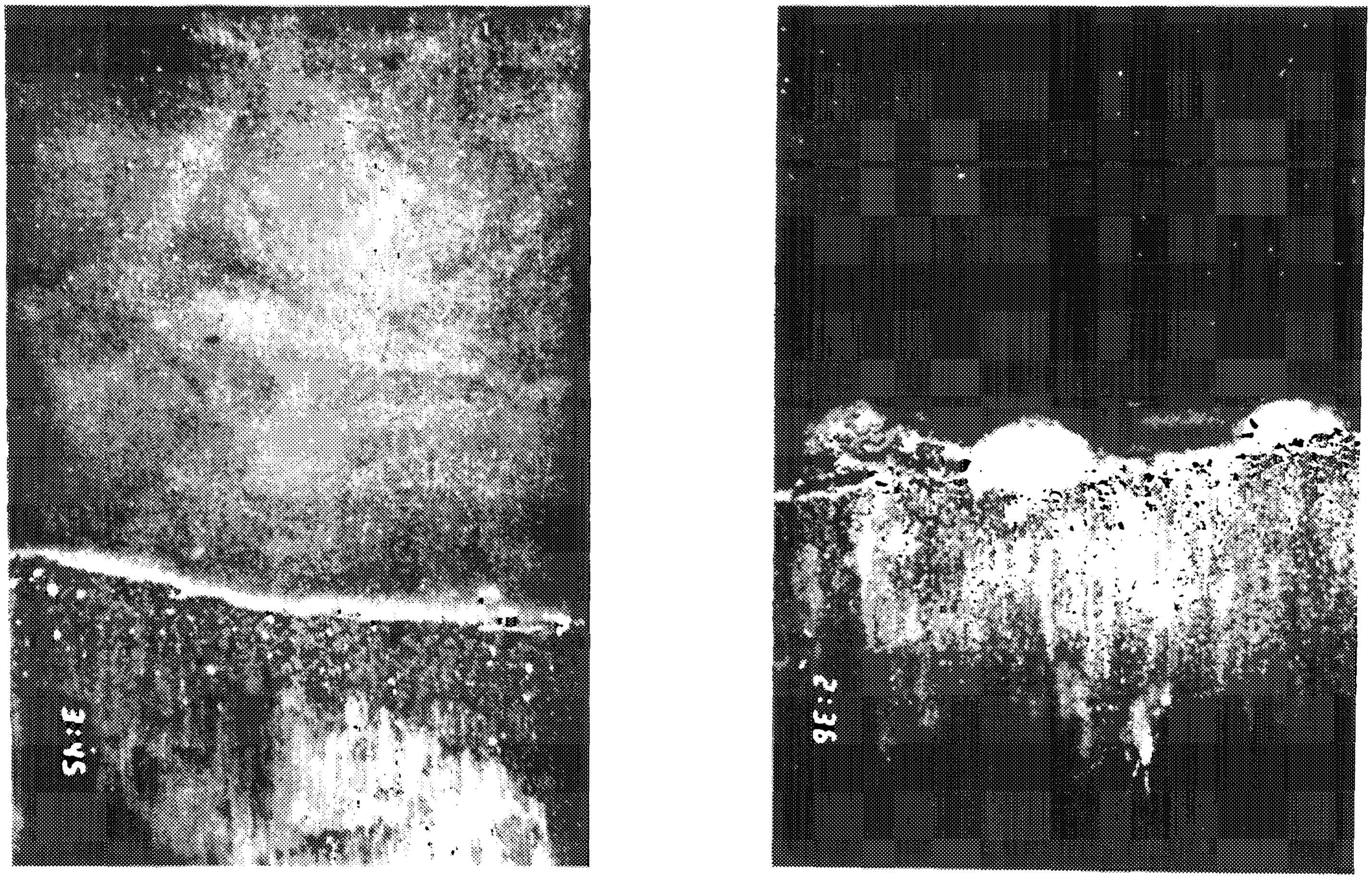
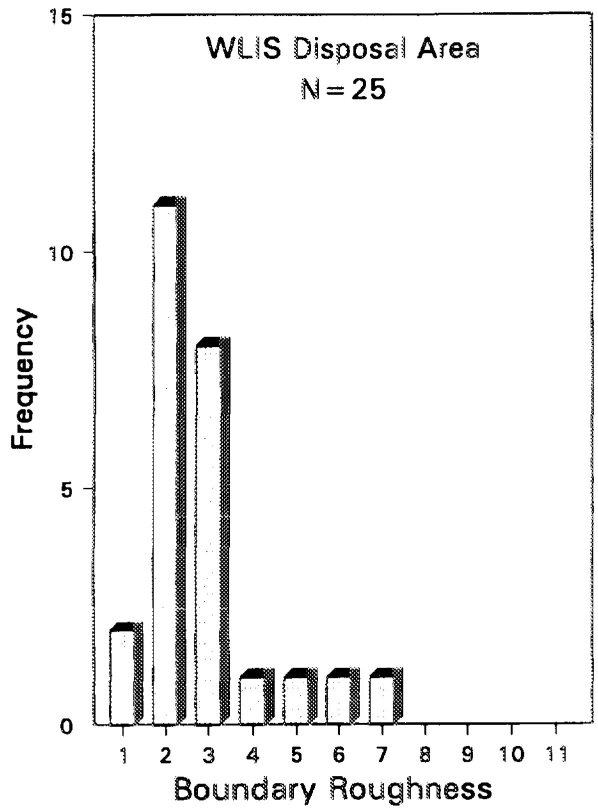


Figure 3-8. Replicate REMOTS® photographs from station DCTR on the apex of the WLIS "D" mound showing surface shell lag indicative of the possible washing away of fine-grained sediments. Scale = 0.5×.



A B

Figure 3-9. REMOTS® photographs from stations S300W (A) and S100W (B) in the 2000S reference area showing mud/sand stratigraphy and relic RPD layering. This area presumably experiences periodic disturbance (e.g., sediment transport). Scale = 0.5×.



Key

Class Interval	Range of Values (cm)
1	0.0 - 0.6
2	0.6 - 1.0
3	1.0 - 1.4
4	1.4 - 1.8
5	1.8 - 2.2
6	2.2 - 2.6
7	2.6 - 3.0
8	3.0 - 3.4
9	3.4 - 3.8
10	3.8 - 4.2
11	4.2 - 4.6

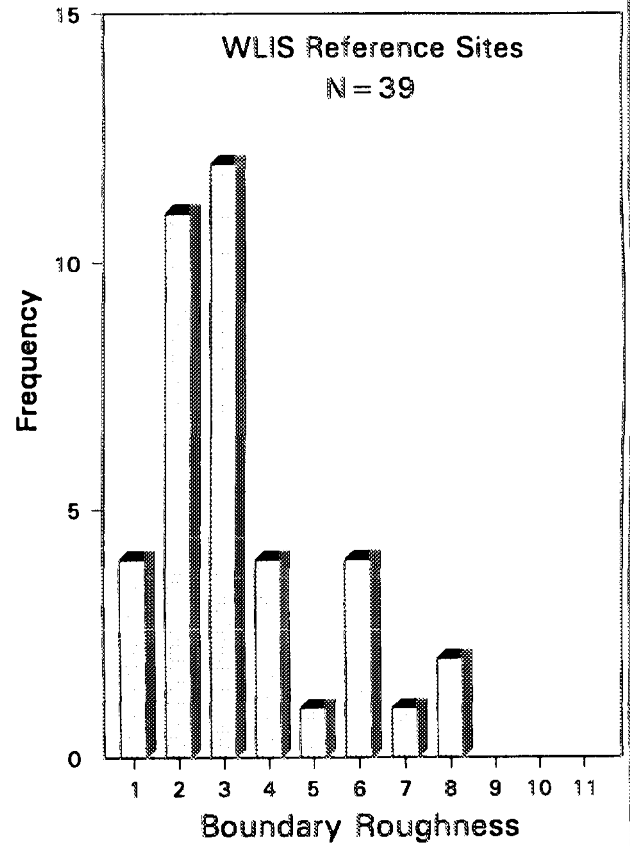
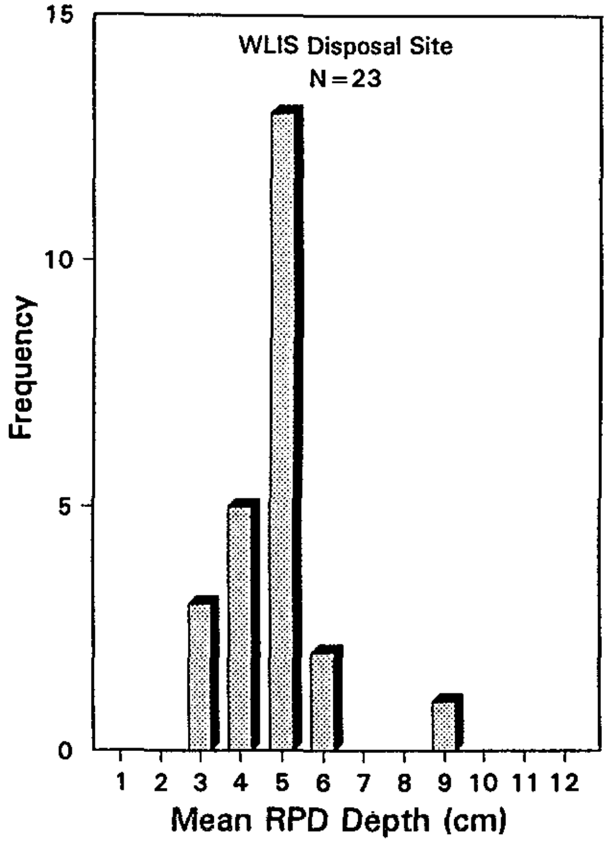


Figure 3-10. Frequency distribution of WLIS "E" and pooled reference area boundary roughness values. Based on analysis of the REMOTS® photographs, observed boundary roughness was attributable primarily to physical processes (e.g., bedform formation, consolidated clumps of material, etc.).



Key

Class Interval	Range of Values (cm)
1	0.0 - 0.5
2	0.5 - 1.0
3	1.0 - 1.5
4	1.5 - 2.0
5	2.0 - 2.5
6	2.5 - 3.0
7	3.0 - 3.5
8	3.5 - 4.0
9	4.0 - 4.5
10	4.5 - 5.0
11	5.0 - 5.5
12	5.5 - 6.0
13	6.0 - 6.5

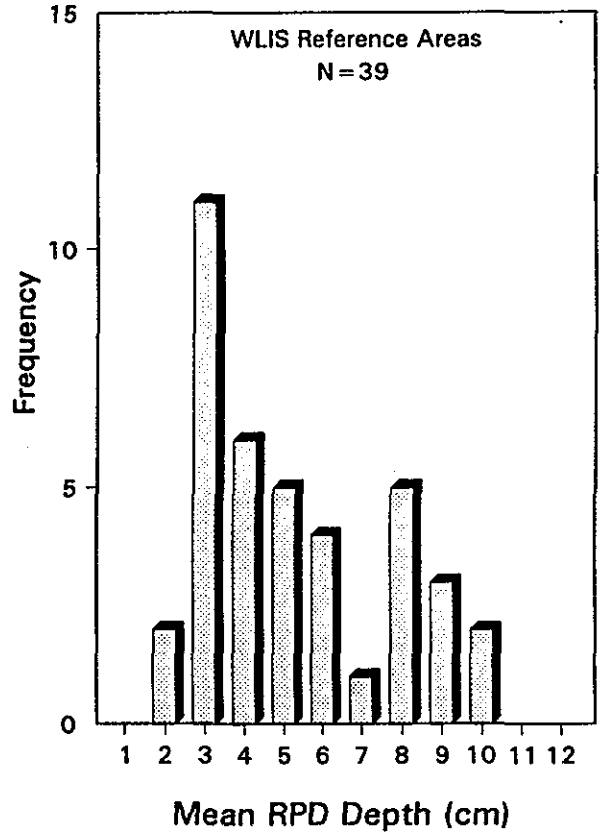


Figure 3-11. Frequency distribution of RPD depths for the WLIS "E" and pooled reference areas

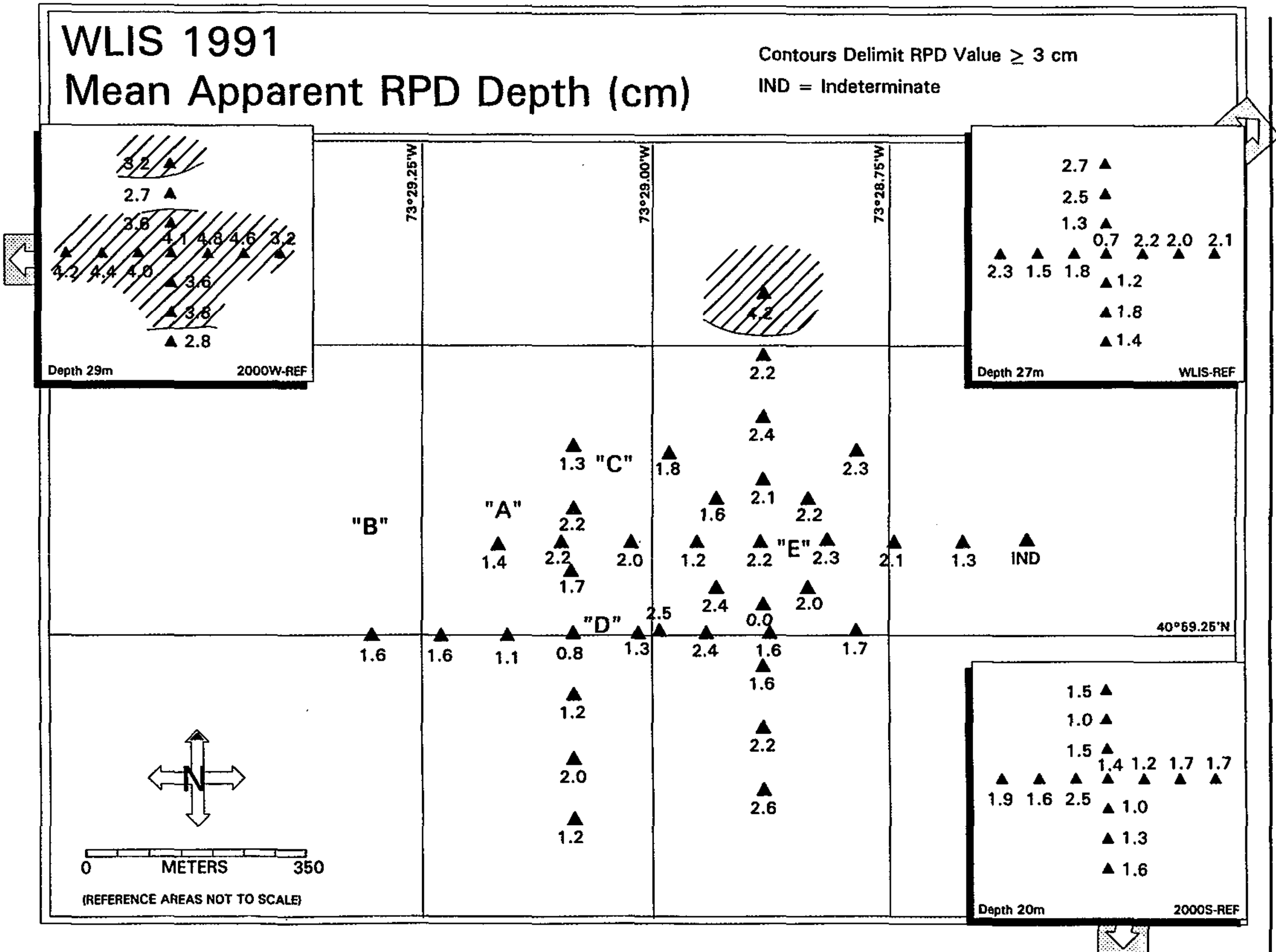


Figure 3-12. Mapped distribution of mean apparent RPD depths at WLIS and reference areas, June 1991, with overlay of the 1990 on-site data

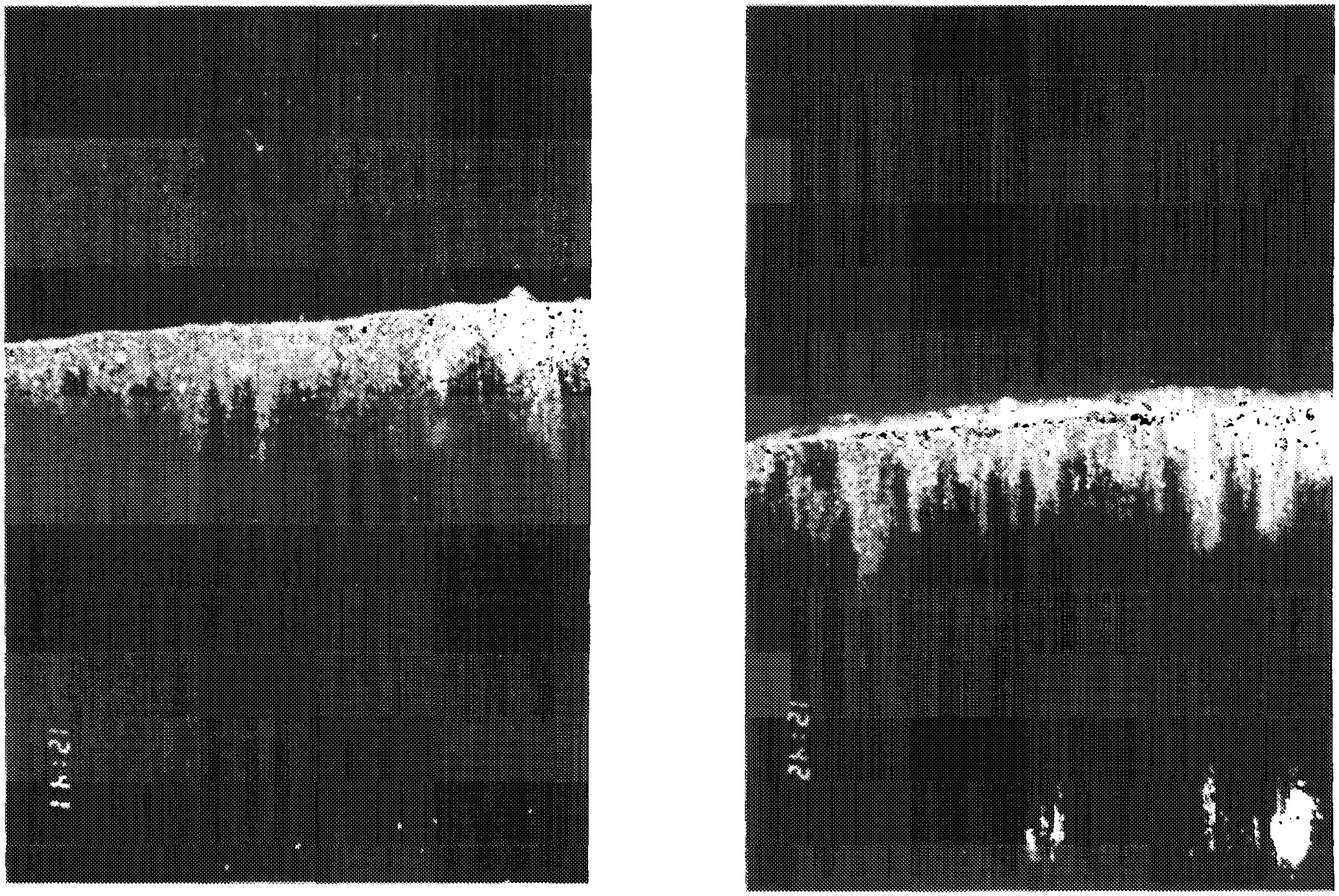


Figure 3-13. REMOTS® photographs from station D100W showing low reflectance subsurface sediments with a high apparent sulphide content. Stations with this dark sediment warrant further investigation according to the DAMOS tiered monitoring protocol. Scale = 0.5×.

survey, sediment profiles from several stations within the WLIS-REF and 2000S reference areas continued to exhibit relic or buried RPD layers indicative of past disposal operations (Figure 3-14). REMOTS® photographs from stations within the 2000W reference area exhibited uniform sediment profiles with well-developed RPD layers (mean apparent RPD depth of 3.8 cm), with the exception of station W300S where variability among replicate photographs (Figure 3-15) provided some evidence of past disturbance (e.g., disposal operations or trawling).

3.2.5 Successional Stage

REMOTS® photographs from approximately 90% of all disposal site stations (WLIS "D" and WLIS "E" grids, N = 38) provided evidence of Stage III infaunal activity (Figure 3-16). The majority of stations had combinations of Stage I on Stage III and Stage III seres. Several stations on, and adjacent to, the WLIS "E" mound have apparently experienced rapid recolonization of the recently deposited dredged material by Stage III infauna as shown by the presence of large feeding voids at depth (Figure 3-6B). Photographs from disposal site stations (N = 4) exhibiting exclusively Stage I activity revealed extensive reworking of the upper few centimeters of sediment by these pioneering infauna (Figure 3-17) indicating that the initial phases of recolonization were in progress. Within the three reference areas, five of thirty-nine stations exhibited exclusively Stage I infauna. Four of these five stations (80%) occurred within the 2000S area. During the 1990 survey, six of thirty-nine stations (three stations in the 2000S reference area) exhibited exclusively Stage I taxa. All other reference area stations had combinations of Stage I, Stage III, and/or Stage I on Stage III seres.

3.2.6 Organism-Sediment Index (OSI)

The Organism-Sediment Index (OSI), a multiparameter REMOTS® index incorporating apparent RPD depth and infaunal successional stage, is useful in mapping regions which have experienced disturbance (i.e., dredged material disposal, trawling, etc.). The frequency distribution of median OSI values for the WLIS "E" stations (Figure 3-18) had a major mode of +8 (median of +7). Approximately 38% of the on-site stations had an OSI of ≤ +6, compared to 53% as noted during the 1990 survey. Based on the results of past REMOTS® surveys, OSI values of ≤ +6 are considered indicative of stressed benthic habitats which have experienced recent disturbance (i.e., erosion, dredged material disposal, hypoxia, etc.; Rhoads and Germano 1986). Low OSI values in 1991 occurred primarily as a small cluster of stations west of the active disposal point (Figure 3-19). Additionally, several stations in the vicinity of the "A" mound (E400W) and WLIS "D" (D200W, D200N, D100S, and D300S) continued to exhibit low OSI values during the 1991 survey. All but D300S exhibited low OSI values in 1990.

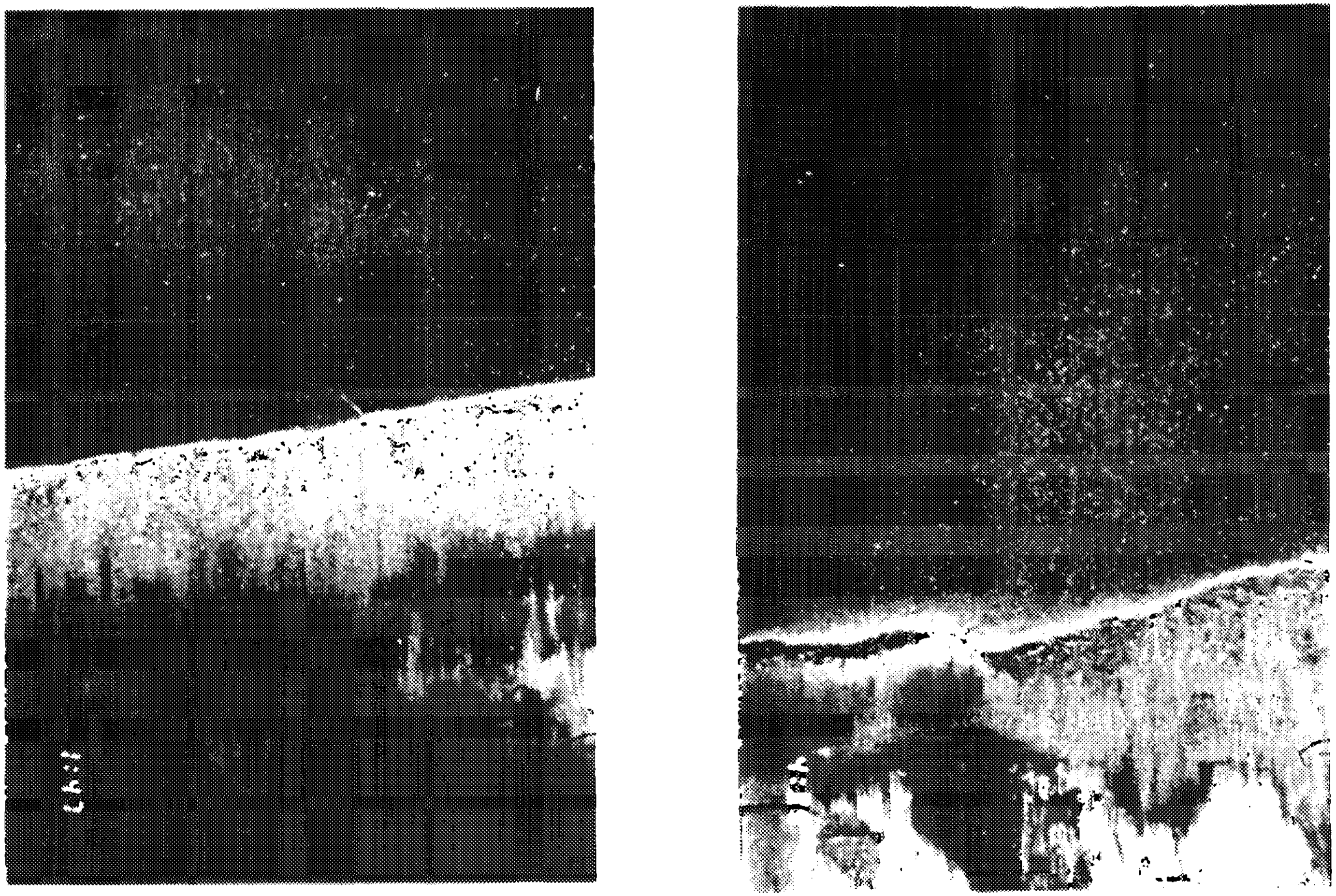


Figure 3-14. REMOTS® photographs showing relic RPD and sand/mud layering at stations R300W and RCTR. These features presumably persist from historical disposal operations directed to the discontinued Eaton's Neck disposal area. Scale = 0.5×.

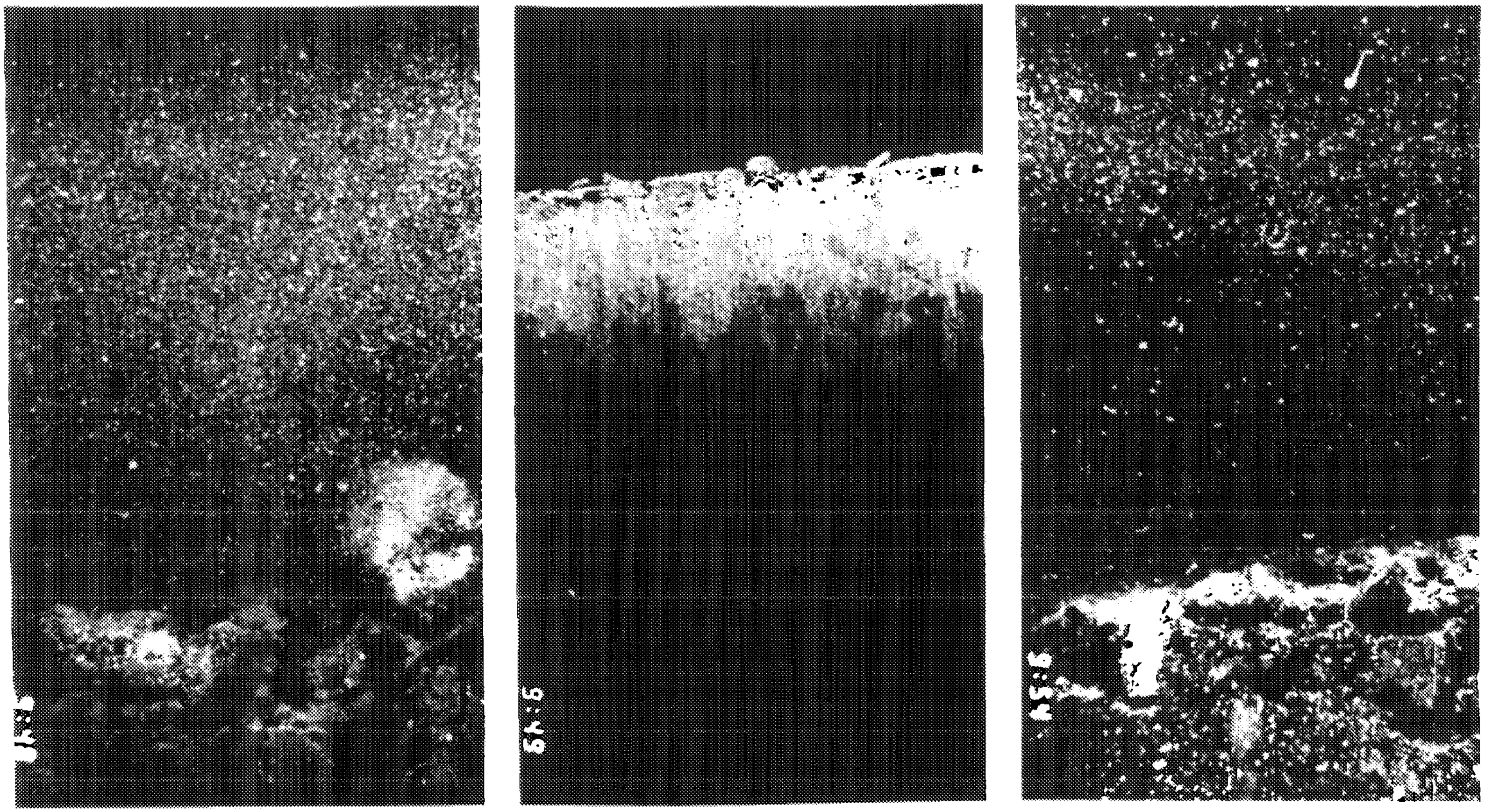


Figure 3-15. Replicate REMOTS® photographs from station W300S within the 2000W reference area showing variability. REMOTS® photographs from all other stations within this area depict uniform, homogeneous sediment profiles characteristic of ambient sediments. Scale = 0.5×.

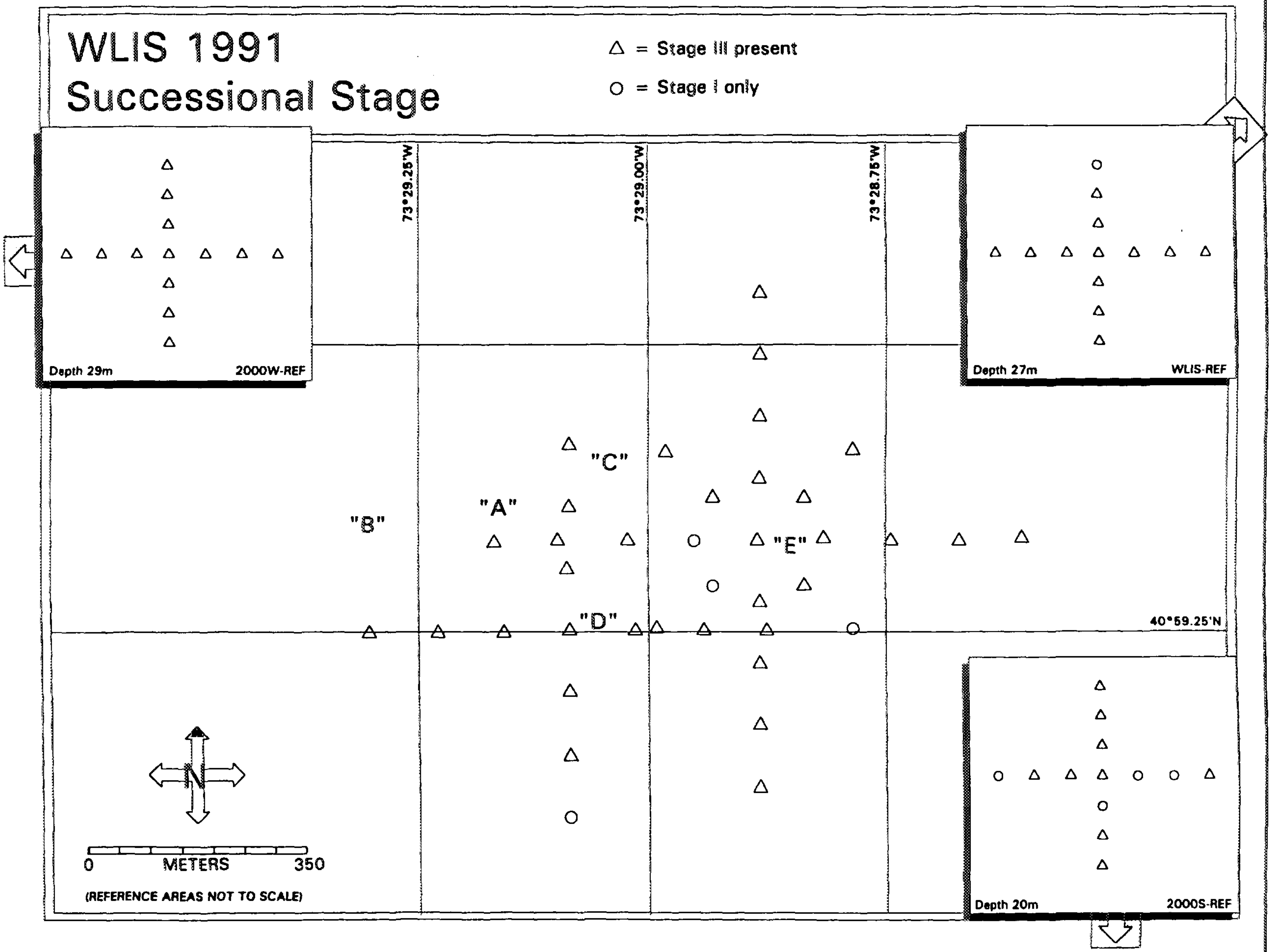
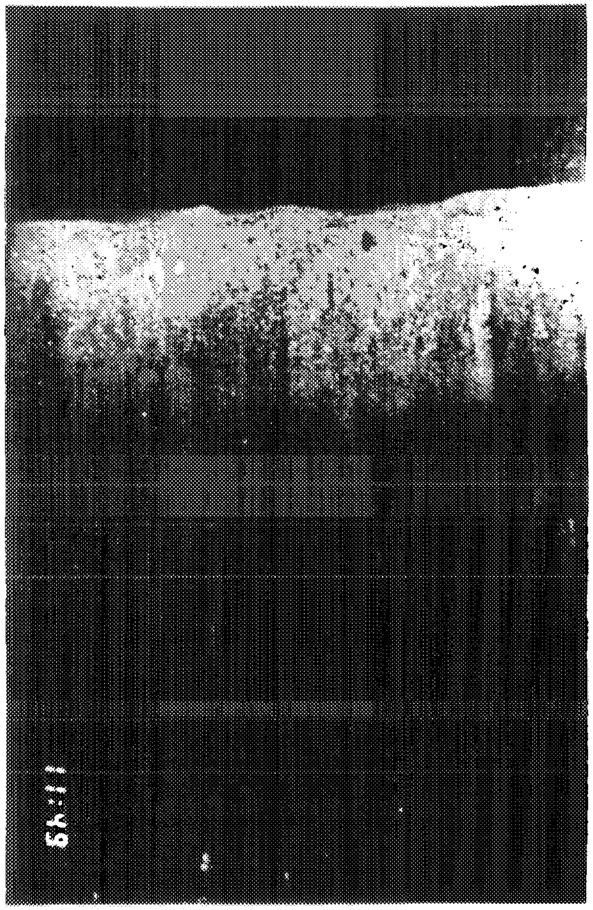


Figure 3-16. Mapped distribution of infaunal successional stages at WLIS and reference areas, June 1991



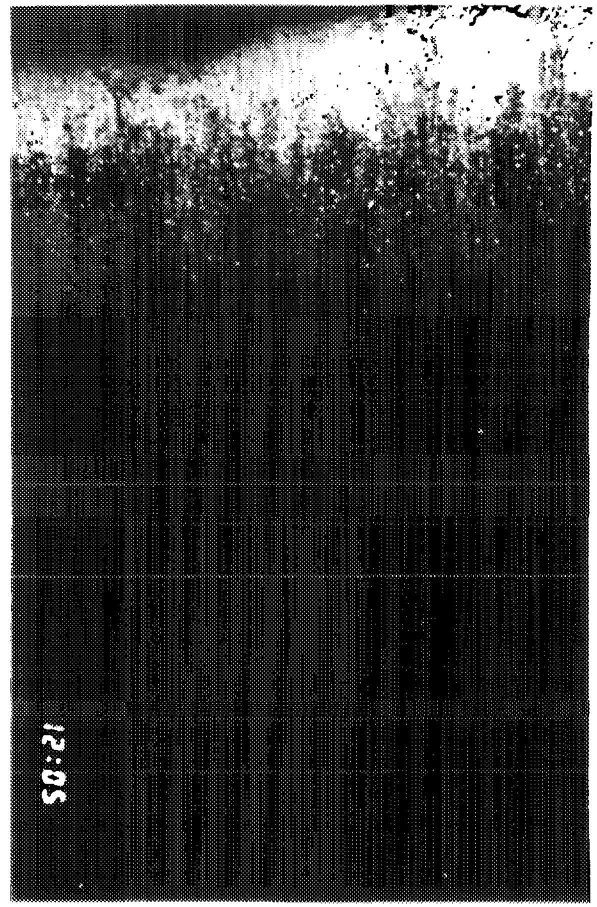


Figure 3-17. REMOTS® photographs from WLIS "E" stations E100SW (A) and E200SE (B) exhibiting exclusively Stage I infauna. Scale = 0.5×.

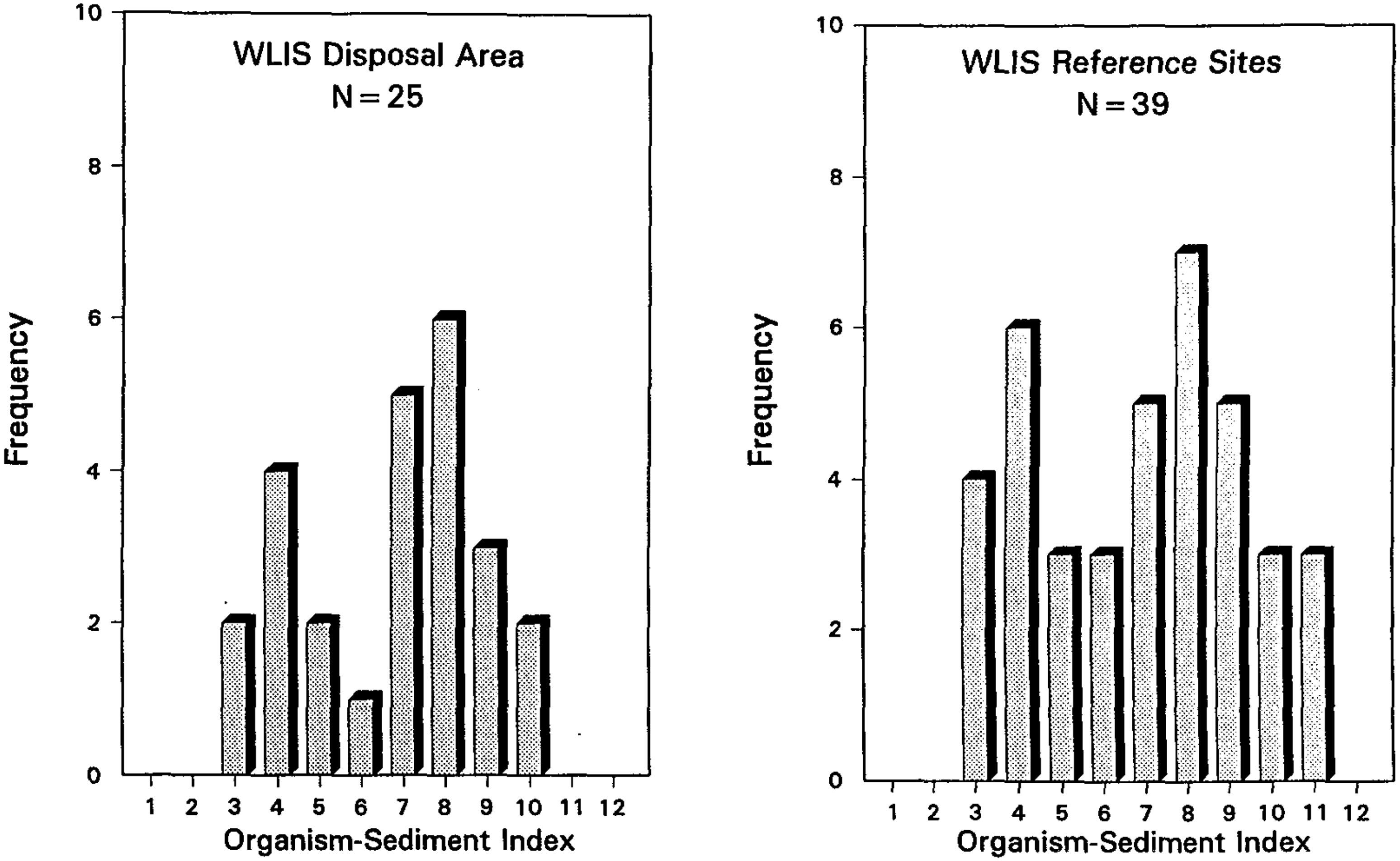


Figure 3-18. Frequency distribution of median OSI values for the WLIS "E" stations and pooled reference areas, June 1991

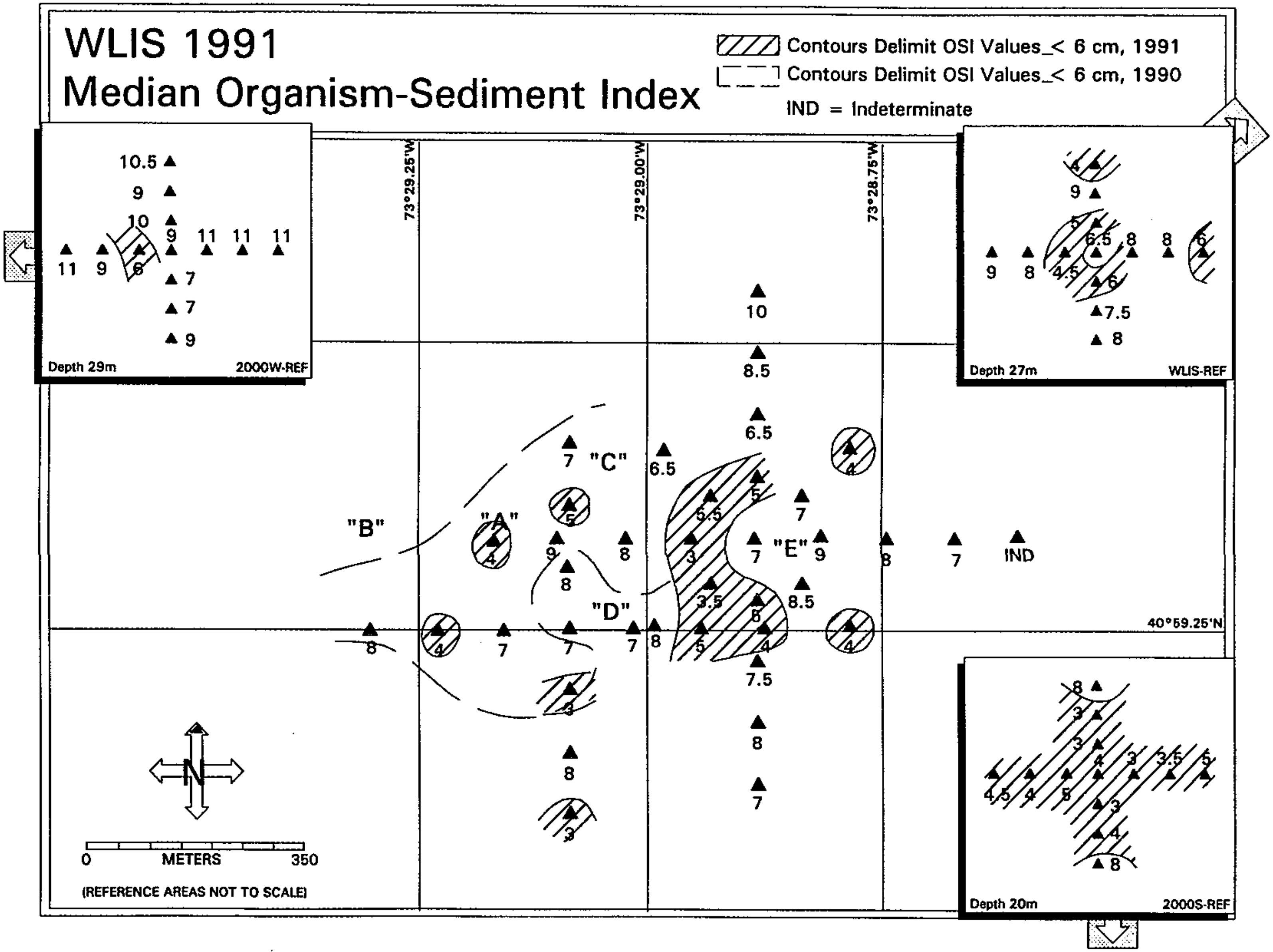


Figure 3-19. Mapped distribution of median OSI values at WLIS reference areas, June 1991. Contours delineate regions where calculated OSI values were $\leq +6$. Delineation of the 1990 REMOTS® stations where OSI $\leq +6$ is also shown (dotted line).

Several stations within 100 m of WLIS "E", including the mound apex, had OSI values of ≥ +7. Median OSI values were +9, +7, and +4 for reference areas 2000W, WLIS-REF, and 2000S, respectively. Median OSI values for the pooled reference areas had major modes of +4 and +8 (median of +7) and were not statistically different from disposal site OSI values (Mann-Whitney U-Test, $p = 0.884$).

3.3 CTD and Dissolved Oxygen Sampling

Depth gradients of temperature, salinity, and DO at the three reference areas and the active disposal point are given in the Appendix. Surface salinity at each of the four sampling locations was approximately 26 ppt, increasing slightly (0.5 ppt) with depth. A well-defined thermocline at 5 - 10 meters water depth was present at each site. Surface temperatures of 18.5° C decreased to approximately 14° C within one meter of the bottom.

Dissolved oxygen concentrations near the surface ranged from 9.5 to 11.0 $mg \cdot l^{-1}$ (2000S and WLIS "E", respectively) (Table 3-1). DO levels decreased significantly in the upper 5 - 10 m of the water column resulting in near-bottom concentrations which ranged from 5.6 to 5.9 $mg \cdot l^{-1}$ (WLIS-REF and WLIS "E", respectively). Dissolved oxygen concentrations, as determined by Winkler titration, were approximately 1.0 $mg \cdot l^{-1}$ less than DO concentrations measured by the CTD (Table 3-1). Near-surface DO levels (via Winkler titration) ranged from 8.9 $mg \cdot l^{-1}$ to 10.4 $mg \cdot l^{-1}$ (2000S, WLIS-REF, and WLIS "E", respectively), while near-bottom concentrations ranged from 5.0 to 5.2 $mg \cdot l^{-1}$ (WLIS-REF and WLIS "E", respectively).

3.4 Sediment Analysis

Grain Size. The results of the sediment grain size analysis (Table 3-2) corresponded well with the mapped distribution of sediment grain size as determined from REMOTS® photos (Figure 3-7). The sediments at 2000W and WLIS-REF were dark grey clay/silts (≥4 phi) with shell fragments present in sediment collected from 2000W. Sediments at 2000S were predominantly dark gray fine and very fine sands (4-2 phi). The average TOC was 0.56 at 2000S, 0.96 at WLIS-REF, and 1.4 at 2000W.

Metals. Cadmium (Cd), lead (Pb), and zinc (Zn) were detected at all three reference areas (Table 3-3). Values for cadmium ranged from 0.18 to 1.20 ppm; lead 31 to 130 ppm; and zinc 83 to 230 ppm. Replicate concentration values were within approximately one standard deviation from the mean; however, the largest standard deviation in the concentration of each of these metals was observed at the 2000S reference area (Table 3-3). The average values for Pb and Zn were slightly higher at reference areas 2000W and 2000S in comparison with WLIS-REF. Concentrations of Cd were fairly similar for the three reference areas with average values ranging from 0.31 ppm to 0.53 ppm.

Table 3-1

Dissolved Oxygen Concentrations of Near-bottom and Near-Surface Waters at the WLIS Reference Areas and Active Disposal Point as Determined by CTD Profiling and Modified Winkler Titration, WLIS Disposal Site, June 1991

	CTD Profile DO ($mg \cdot l^{-1}$)	
Station	Near-Surface	Near-Bottom
Disposal Site	11.0	5.9
2000W	10.0	5.7
2000S	9.5	5.8
WLIS-REF	10.5	5.6

	Modified Winkler Titration ($mg \cdot l^{-1}$)	
Station	Near-Surface	Near-Bottom
Disposal Site	10.4	5.2
2000W	9.3	5.1
2000S	8.9	5.2
WLIS-REF	8.9	5.0

Table 3-2

Results of Sediment Grain Size Analyses and Percent Total Organic Carbon (%TOC) for Reference Areas at WLIS, June 1991

	2000W	**2000S**	**WLIS-REF**
DESCRIPTION	**Dark grey clay-silt with shell fragments**	**Dark grey sand**	**Dark grey clay-silt**
% TOTAL ORGANIC CARBON			
Rep 1	1.48	0.42	0.79
Rep 2	1.28	0.73	1.15
Rep 3	1.43	0.53	0.94
Average	1.40	0.56	0.96
GRAIN SIZE ANALYSIS			
% Coarse Sand (1 to -1 phi)	3	3	2
% Medium Sand (2 to 1 phi)	4	10	6
% Fine Sand (4 to 2 phi)	6	45	7
% Silt (≥4 phi)	49	19	47
% Clay (≥4 phi)	38	23	38

Table 3-3

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

Metals (ppm dry weight)	Cd	Pb	Zn
2000W			
Rep1	0.35	67	170
Rep2	0.29	59	140
Rep3	0.28	61	140
Average	0.31	62	150
1 SD	0.03	3	14
2000S			
Rep1	1.20	130	230
Rep2	0.20	50	100
Rep3	0.18	31	83
Average	0.53	70	138
1 SD	0.48	43	66
WLIS-REF			
Rep1	0.20	41	110
Rep2	0.38	64	140
Rep3	0.49	56	120
Average	0.36	54	123
1 SD	0.12	10	12
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 (<).

PAHs. Replicate values for organic compounds at each reference area were more variable than results for the metal analyses; values fell within one or two standard deviations of the mean (Table 3-4). Also, several estimated values (J values) indicated that a compound was present in a concentration above the method detection limit and below the practical quantitation limit.

Of the low molecular weight (LMW) PAHs, phenanthrene was the most abundant at all three reference areas; average values were 160 ppb at 2000W, 283 ppb at WLIS-REF, and 403 ppb at 2000S. Values of anthracene, naphthalene, and 2-methyl naphthalene were present in concentrations higher than acenaphthylene, acenaphthene, and fluorene. LMW PAH values were highest at the 2000S reference area followed by WLIS-REF and 2000W.

Reference area 2000S also had the highest concentration of high molecular weight (HMW) PAH compounds followed by WLIS-REF and 2000W. Concentrations were greatest for pyrene, followed by fluoranthene. Dibenzo(a,h)anthracene and indeno(1,2,3-cd)pyrene were either below detection limits or present at low concentrations at the reference areas. The remaining HMW PAH compounds (except low values of benzo(g,h,i)perylene) were present in similar concentrations at the reference areas. As noted in the sediment metals analyses, reference area 2000S exhibited the largest standard deviation in HMW and LMW PAH concentration values.

Table 3-4
Results of PAHs (ppb Dry Weight) for Sediments Collected at the WLIS Reference Areas, June 1991

REFERENCE AREAS	2000W					2000S					WLIS-REF					
PAHs (ppb) Dry weight	Rep1	Rep2	Rep3	Mean	1 SD	Rep1	Rep2	Rep3	Mean	1 SD	Rep1	Rep2	Rep3	Mean	1 SD	Method Detection Limit
Low Molecular Weight:																
naphthalene	J 89	J 35	J 54	59	0	400	J 41	J 52	164	189	J 53	J 110	J 93	85	0	< 6.7
2-methyl naphthalene	J 74	J 35	J 41	50	0	350	J 20	J 21	130	165	J 40	J 75	J 67	61	0	< 6.7
acenaphthylene	J 15	J 12	J 14	14	0	J 120	J 20	J 10	50	0	< 13	J 25	J 53	30	17	< 6.7
acenaphthene	J 15	J 12	< 14	14	1	J 66	J 20	< 10	32	24	< 13	J 37	J 27	26	10	< 6.7
fluorene	J 30	J 24	J 14	23	0	160	J 41	< 10	70	65	J 13	J 62	J 53	43	0	< 6.7
phenanthrene	180	160	140	160	16	770	300	140	403	267	J 110	390	350	283	175	< 9.8
anthracene	J 60	J 47	J 41	49	0	360	110	J 31	167	151	J 53	170	150	124	76	< 6.7
TOTAL				369					1016					652		
High Molecular Weight:																
fluoranthene	270	210	160	213	45	860	480	210	517	267	190	440	650	427	188	< 6.7
pyrene	460	520	450	477	31	2200	470	280	983	864	300	1050	890	747	323	< 6.7
benzo(a)anthracene	150	150	140	147	5	580	230	120	310	196	J 120	370	430	307	190	< 6.7
chrysene	190	200	190	193	5	770	220	130	373	283	130	420	480	343	153	< 6.7
benzo(b)fluoranthene	160	180	J 110	150	81	820	130	140	363	323	J 79	290	370	246	159	< 6.7
benzo(k)fluoranthene	160	180	J 110	150	81	810	130	140	360	318	J 79	290	360	243	156	< 6.7
benzo(a)pyrene	150	150	150	150	0	1000	170	130	433	401	130	340	470	313	140	< 6.7
dibenzo(a,h)anthracene	< 15	< 12	< 14	14	1	J 93	< 10	< 10	38	39	< 13	< 12	< 13	13	1	< 6.7
benzo(g,h,i)perylene	J 120	150	140	137	68	530	120	J 60	237	227	J 40	220	290	183	124	< 6.7
indeno(1,2,3-cd)pyrene	< 15	< 12	< 14	14	1	360	< 10	< 10	127	165	< 13	< 12	< 13	13	1	< 6.7
TOTAL				1645					3741					2835		

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

4.0 DISCUSSION

The following discussion addresses the four major objectives of the 1991 DAMOS WLIS survey: to define the topography and footprint of the active disposal mound and the status of the inactive mounds at WLIS, to assess the extent of infaunal recolonization at the active disposal point and compare it with reference area benthic habitats, to collect sediment chemistry information at the three reference areas, and to determine the potential role of bottom water dissolved oxygen as an ecological variable.

4.1 Disposal Mound Topography

One objective of the REMOTS® sediment-profile survey and 1200 × 800 m bathymetric survey was to delineate the extent and topography of the dredged material deposited during the 1990–1991 disposal season. Based on the recorded disposal volumes, approximately 86,462 m^3 of dredged material was deposited at WLIS during that period. The bathymetric analysis showed well-defined accumulation of dredged material at the designated disposal point. The previous 1990 bathymetric survey of WLIS (800 × 800 m) did not include the 1990–1991 designated disposal point; therefore, a depth difference analysis (comparing the 1990 and 1991 surveys) could not be used to determine the height of WLIS "E". Instead, the height of WLIS "E" was estimated to be 3.0 m based on comparison to the surrounding ambient bottom depth of 32.75 m. This mound was an elliptical deposit with a maximum diameter of approximately 200 m and a minimum diameter of 150 m. Although the diameter of WLIS E fell within the predicted diameter (200 m), the mound was higher than predicted (3 m versus 2.7 m). This is within the combined error of the disposal simulation model and the bathymetry.

Due to the proximity of the five WLIS disposal mounds, the volume of dredged material deposited since 1982, and the proximity of the discontinued Stamford and Eaton's Neck disposal grounds, virtually all stations within WLIS (except E400N) provided evidence of past disposal operations. Relic/buried RPD boundary layers and physical layering of fine sands and mud (4-3 phi) associated with dredged material can be distinguished from the homogeneous, deeply bioturbated sediment profiles of ambient silt/clay materials ($\geq$4 phi) typically found in this part of the Sound (i.e., E400N, Figure 3-3). Such dredged material signatures can persist for years in the low energy, nondispersive regime which characterizes WLIS.

Individual REMOTS® parameters (i.e., RPD depth, successional stage, and boundary roughness) did not allow unique identification of 1990–1991 dredged material relative to older dredged material deposits. Several stations adjacent to the WLIS "E" mound apex had RPD depths greater than, or equal to, the on-site mean of 2.2 cm, and the distribution of infaunal successional stages showed evidence of Stage III activity at six of eight stations within 100 m of the mound center. In addition, grain sizes of dredged material deposited at

WLIS typically consist of mixtures of fine sand and silt/clay and provide no unique anomalies to distinguish one dredging project from another. As a result, SAIC employed both bathymetric and spatial gradients of several REMOTS® parameters to delimit the perimeter of fresh dredged material.

A second objective of the June 1991 monitoring cruise was to assess the stability of the inactive "A", "B", "C", and "D" disposal mounds (formed prior to the 1990–1991 disposal season). The 1991 bathymetric data showed that the heights of the "A", "B", and "C" mounds remained relatively unchanged since the previous July 1990 bathymetric survey; therefore, these mounds are stable. At the time of the July 1990 survey, a 1.0 m decrease in the WLIS "B" mound height was observed when compared to the prior 1988 bathymetric survey. Poindexter-Rollins (1990) showed that mound consolidation can continue several months after disposal, resulting in significant decreases (approximately 1.5 m) in mound height (Figure 4-1). Disposal on the "B" mound (the active disposal point during the 1987–1988 disposal season) occurred within two months prior to the 1988 survey; therefore, mound consolidation was likely still in progress. Given that no dredged material has been disposed at these mounds ("A", "B", and "C") during the past three years, one might expect that these sediments are consolidated and that these mounds are relatively well-armored and stable. The depth profile plot of lane 18 (the bathymetric survey lane transecting the apex of the WLIS "B" mound) shows the changes in mound height observed during the 1988, 1990, and 1991 surveys (Figure 4-2).

The 1991 bathymetric data revealed an apparent 0.5 m decrease in the height of the WLIS "D" mound (the active disposal point for the 1989–1990 disposal season). WLIS "D" received dredged materials within two months before the July 1990 survey; therefore, we infer that mound consolidation continued during this period. Previous studies have not provided evidence of significant mound erosion at WLIS (SAIC 1990b, 1990c), nor did the REMOTS® photographs from WLIS during this survey. The WLIS mounds are deeper than the dynamic equilibrium between depositional and erosion forces previously shown to exist at water depths of 20 m in Long Island Sound (McCall 1978). However, surface scour can occur at the top of dredged material mounds as the flow field accelerates over and around these topographic features. As a result, some fine-grained materials could be washed away from the mound apex and transported to deeper regions. The surface shell lag deposit observed in REMOTS® photographs from the apex of the WLIS "D" mound provided further evidence of the possible washing away of fine-grained ($\geq$4 phi) sediments. It is likely that a combination of mound consolidation and scouring accounts for the observed changes in the WLIS disposal mounds. We infer that, because dredged material was deposited on the WLIS "E" mound two weeks prior to the 1991 survey, consolidation of this material and scouring processes will result in an apparent decrease in mound height in a subsequent bathymetric survey of the WLIS Disposal Site.

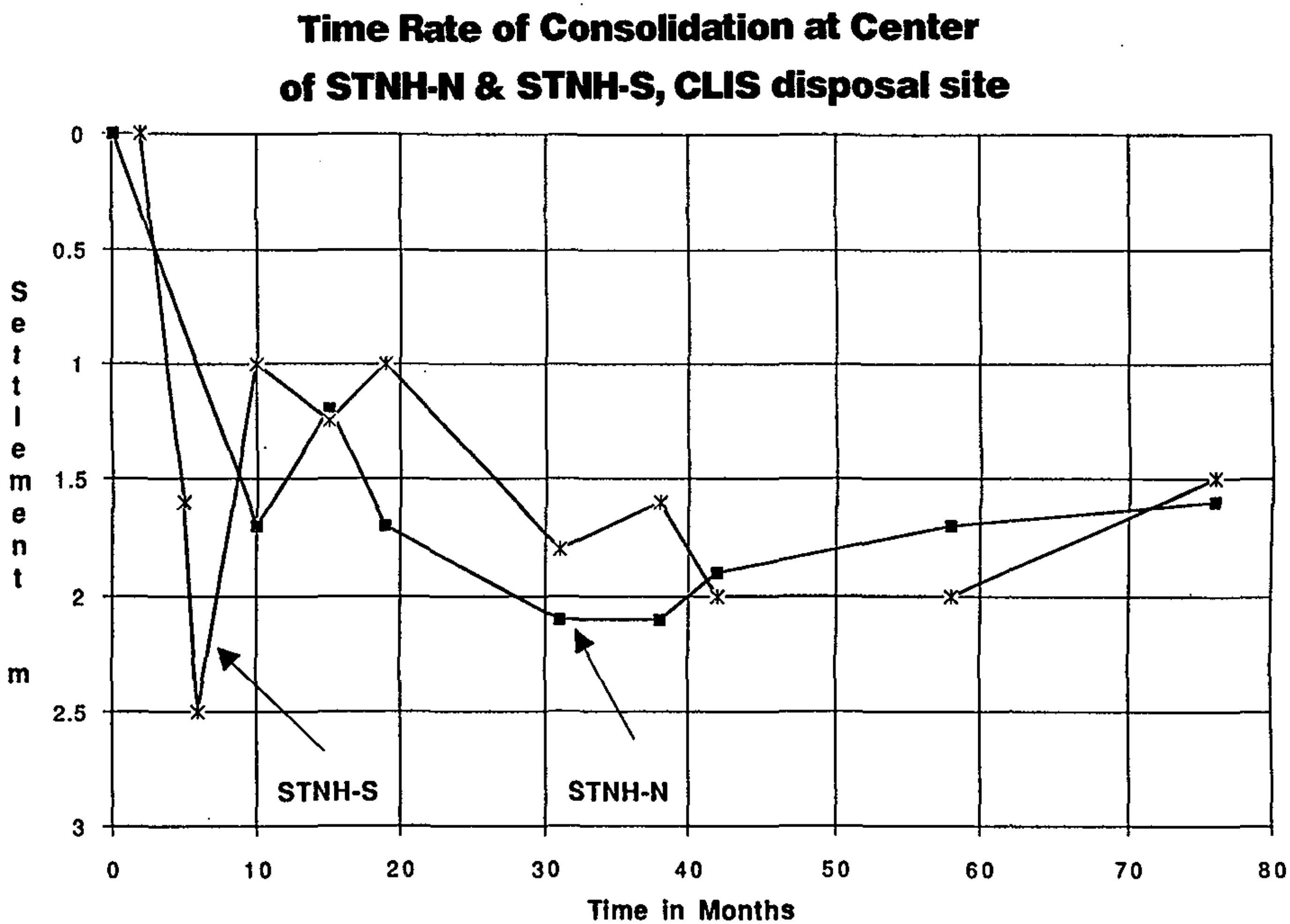


Figure 4-1. Rate of consolidation at the center of disposal mounds located at the Central Long Island Sound Disposal Site (CLIS). Note that substantial consolidation of sediments continued in the 4 - 5 months following termination of disposal and long-term increase of mound height (possibly due to ambient sedimentation; Poindexter-Rollins 1990).

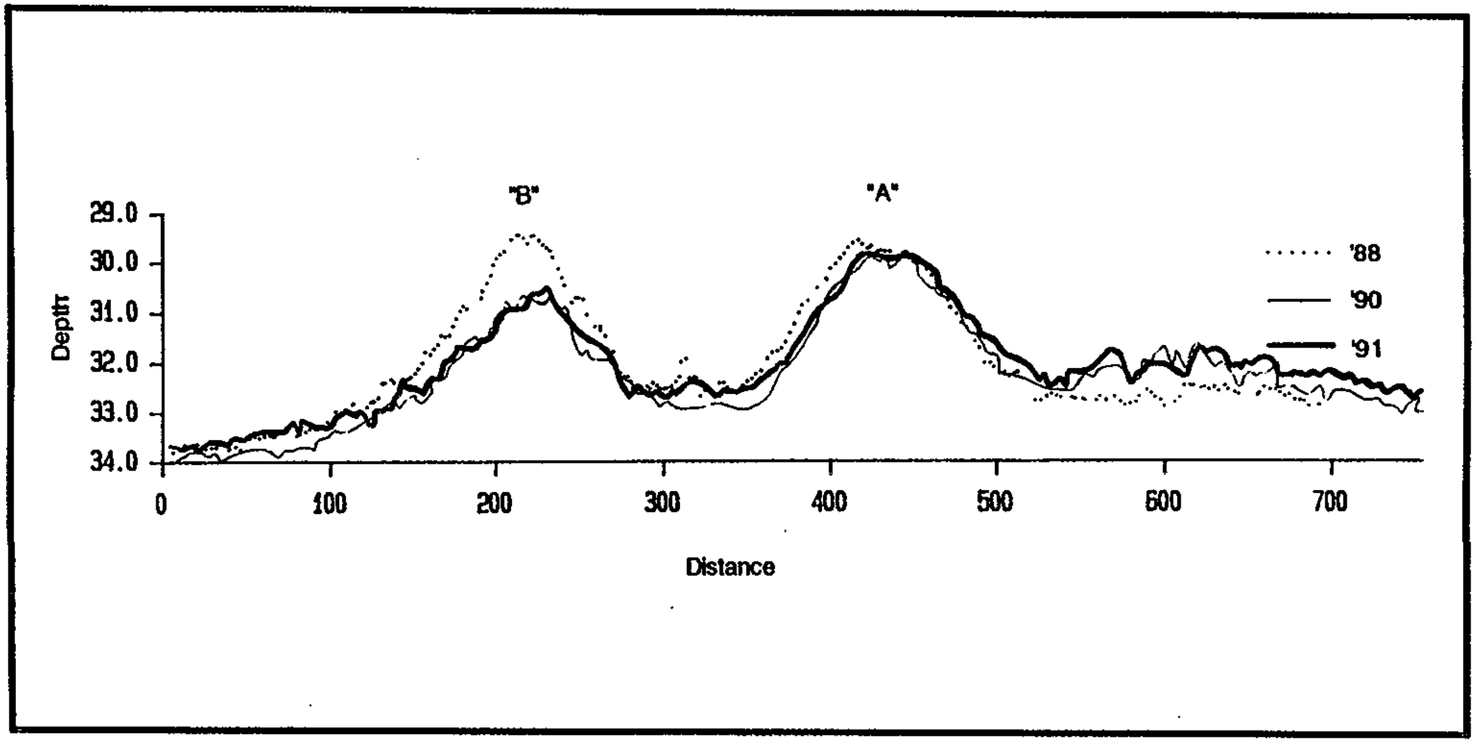


Figure 4-2. Overlays of the 1988, 1990, and 1991 depth profile plots from lane 18 of the bathymetric survey grid. The 1.0 m decrease in the WLIS "B" mound height observed during the 1990 bathymetric survey was attributed largely to mound consolidation.

4.2 Recolonization Status at WLIS

In addition to determining the areal distribution of dredged materials, the REMOTS® sediment-profile survey was conducted to assess the extent of infaunal recolonization at the active disposal point. Approximately 90% of the WLIS on-site stations showed the presence of Stage III infauna. This result exceeds our prediction that most of the WLIS "E" mound would be in a Stage I condition. Such rapid colonization probably reflects the survival of Stage III taxa buried by a blanket of disposed material spread over WLIS "E". Rapid catastrophic burial of burrowing infauna does not always result in death (Goldring 1964, Kranz 1974, Maurer et al. 1978). Each taxon has a "critical overburden" thickness. If the layer of dredged material is less than this overburden thickness, the infauna will initiate an escape burrowing response and move upward through the sediment to reestablish a connection with the new sediment-water interface. Another mechanism of rapid adult colonization of newly deposited dredged materials can take place by immigration, for example, by swimming stages of the polychaete *Nephtys incisa* (Rhoads et al. 1977). Because disposal took place during a period of low water temperatures (November to May, 1991), recolonization of WLIS "E" likely involved a nonlarval mode of recolonization. The Stage III status of the WLIS "E" and WLIS "D" grids indicates that disturbances relating to dredged material disposal were primarily physical and relatively short-lived.

As noted during the 1990 survey, the 1991 OSI values of $\leq +6$ were clustered primarily at stations west of the active disposal point. Most likely, this clustering of low OSI stations reflects those areas where the most recent dredged material disposal had occurred. Given the rapid recolonization and predominance of Stage III infauna observed throughout much of the WLIS Disposal Site, we expect the continued development (deepening) of the RPD layer and subsequent increase in the OSI value at these stations.

Several stations near WLIS "A" (E400W) and WLIS "D" (D200W, D200N, D100S, and D300S) that had low ($< +6$) OSI values in the 1991 survey continued to exhibit low OSI values in the 1991 survey. Closer examination of the REMOTS® photographs from these stations revealed extremely dark subsurface sediments characteristic of high concentrations of labile organic material and sulphides. From this observation, we infer high sediment oxygen demand (SOD) at these stations. Stage III infaunal activity was evident at five of these six stations; however, the DAMOS tiered monitoring strategy (Germano et al. 1994) views persistence of low reflectance sediment near the surface as a potentially adverse habitat condition resulting from anthropogenic activity. According to the tiered approach, "...even if (investigators) have not defined the precise line at which a non-adverse condition becomes an adverse condition, the inherent assumption (of the tiered approach) was that we could monitor for changes in the necessary precursors that eventually would lead to an adverse impact" (Germano et al. 1994). In this instance, future monitoring efforts should include sediment grab sampling and bulk sediment contaminant level analyses and/or bioassay testing. Given the results of these analyses, "a manageable and interpretable monitoring plan can be structured" which might incorporate periodic sampling or remedial action (e.g., capping; Germano et al. 1994).

REMOTS® sampling at the reference areas was conducted to provide a comparison of on-site versus ambient benthic habitats. The uniform sediment profiles from the 2000W reference area indicated that these sediments represent ambient conditions. This is supported by evidence of Stage III infaunal activity at all stations and a relatively deep mean RPD comparable to the results of the 1990 survey (means of 3.8 cm and 3.9 cm, 1991 and 1990, respectively). Interestingly, the mapped distributions of RPD depths at WLIS-REF/2000S reference areas and at the disposal site were significantly shallower than those observed in 1990. The 1990 survey was conducted in July when water temperatures were higher than during the 1991 survey. Water temperatures rise rapidly between June and July in Long Island Sound and have an important effect on organism activity, rates of bioturbation, and the depth of the apparent RPD. Had the 1991 survey been conducted in July, we would expect to observe deeper RPDs in these areas. Nevertheless, areas determined to consist of ambient sediments (Station E400N and the 2000W reference area) did not exhibit RPD depths significantly shallower than those measured in 1990.

Based on results from REMOTS® surveys in 1990 and 1991, the WLIS-REF area appears to contain some relic dredged material. While these results show no evidence of ecological degradation, clearly they are not consistent with the accepted definition of "reference". The presence of dredged material in this area is likely the result of disposal operations directed to the Eaton's Neck disposal area. Disposal within Eaton's Neck was discontinued after 1972; therefore, the relic oxidized layers and sand/mud stratigraphy observed in these REMOTS® photographs reflect the persistence of such features. This persistence can serve to complicate the delineation of recently deposited dredged material within the active disposal site. The level of infaunal recolonization at WLIS-REF, with twelve of thirteen stations providing evidence of Stage III organisms, indicated that the benthic habitat is relatively stable.

Individual REMOTS® parameters observed at the 2000S reference area indicated that this area has colonization attributes similar to the disposal site. With four of thirteen stations exhibiting exclusively Stage I organisms and a median OSI of +4, this area is presumably subject to disturbance gradients not experienced at the other reference areas. Wind-driven current velocities in western Long Island Sound can increase rapidly as a result of storm events and spring tides (SAIC 1988). With a relatively shallow water depth of 20 m, 2000S is subject to erosional and depositional forces not experienced either within the WLIS disposal site or at the other reference stations, 2000W and WLIS-REF. In addition to relic RPD layers and sand/mud stratigraphy, the 2000S reference area exhibited a greater percentage of coarser grain sizes than found at the WLIS-REF/2000W reference areas or the disposal site. The sediment grain size analyses showed that sediments at 2000S consisted of 45% fine sand (4-2 phi) and 42% silt/clay ($\geq$4 phi) whereas reference areas 2000W and

WLIS-REF consisted of 87% and 85% silt/clay, respectively. While the 1990 REMOTS® results did not reveal such disparity among the reference areas (in terms of OSI values, RPD depths, etc.), the 1991 data show that the implications of retaining the 2000S and WLIS-REF reference areas (representing "ambient" sediment conditions) as comparison sites for the WLIS Disposal Site could, in some instances, have a marked affect on the overall evaluation of the disposal site.

4.3 WLIS Reference Area Chemistry

PAH concentrations at two of the reference stations, 2000W and WLIS-REF, appear to be within ranges measured in Western Long Island Sound by the NS&T Program. However, the relatively higher concentrations of PAHs at 2000S of both LMW and HMW PAHs make this station less suitable for use as a reference station.

WLIS reference areas were 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 the detection limit and/or less than 3 ppm. Average values for 1991 were equal to or below 0.5 ppm (Table 3-3). Average values for Zn were fairly similar for 1986, 1987, and 1991 at WLIS-REF (Tables 3-3 and 4-1). Values of Zn were somewhat higher at 2000S in 1991 (138 ppm versus 99 ppm in 1987) and lower at 2000W in 1991 (150 ppm versus 215 ppm in 1987).

Sediment grain size and TOC are 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 usually associated with the fine-grained fraction (silt/clay) of sediments (Forstner and Wittman 1983, Kennish 1992, Pequegnat et al. 1990). Particulate and colloidal organic matter, because of its fine grain size, surface charges, high surface area to volume ratio, and microbial coatings, serve to adsorb or chelate organic and metallic contaminants. Because of the regional variation of grain size and organic content, all data are normalized (divided by a common constituent like grain size or TOC) when comparing WLIS reference areas to regional Long Island Sound.

PAH baseline information at the three WLIS reference areas was determined in conjunction with grain size and TOC. The highest concentrations of both LMW and HMW PAHs were found at 2000S; this station also contained the lowest concentration of TOC (0.56%) and the lowest fine-grained fraction (42%). The sum of averaged HMW PAH values at 2000S (3741 ppb) was over twice that at 2000W (1645 ppb), even though 2000W had twice as much TOC (1.4%) and a higher clay and silt content (87%). The measured PAH concentrations at WLIS-REF were intermediate between the other two stations (HMW PAHs: 2835 ppb with a TOC content of 0.96% and 85% fine grains). The variability (measured as one standard deviation; see Table 3-4) in PAH values between sample replicates of the 2000S and WLIS-REF reference areas was greater than at 2000W. Such between-sample variability is expected in dredged materials as they typically represent a

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

All samples were 0-2 cm in depth.
NA=Not analyzed ND=Not detected

physical and chemical "mosaic". In ambient sediments, the contaminant-laden particles settle to the bottom from a relatively uniform suspension and are subsequently mixed into the sediment column. This contributes to a lower between-sample variance in chemical and physical properties.

Data collected as part of the National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends Program (NS&T) were compared with the WLIS data to provide a frame of reference (Table 4-2). The NS&T Program has collected and analyzed coastal and estuarine sediment data from 300 sites since 1984. Several sites in Long Island Sound were sampled over the period of 1984-1989 (NOAA 1991) and compared to the WLIS reference area data. Of the NS&T sites in Western Long Island Sound, all are nearshore except for the Western Long Island station (WLI); (Figure 4-3). In general, the Throgs Neck station (the farthest west station in Long Island Sound) and the Sheffield Island station, located northwest of WLIS, had the highest PAH concentrations (Table 4-2). Hempstead and Huntington Harbors on the north shore of Long Island, and the Mamaroneck station on the southern coast of Connecticut had the lowest PAH concentrations. Since the WLI station had intermediate PAH values and is located nearest to WLIS, it will be used as a primary reference to the WLIS data. PAH data were normalized both to the fine-grained fraction and to TOC for comparison purposes (Table 4-2).

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 encompass a wide range of chemicals, with the principal sources in estuaries including 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 (Kennish 1992). Higher molecular weight PAHs (containing 4 to 7 rings) are carcinogenic, mutagenic, or teratogenic to a wide variety of organisms, including fish and other aquatic life (Kennish 1992, Pequegnat et al. 1990). These compounds are less volatile and have longer residence times in the aquatic environment. They include fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(a)pyrene, and benzo(g,h,i)perylene. HMW PAH compounds are generally derived from fossil fuel combustion (Kennish 1992). It is currently thought that these pyrogenic PAHs are more tightly bound to the particles than petroleum source PAHs (McGroddy et al. 1992).

Table 4-2
Normalized PAH Concentrations from WLIS Reference Areas as Compared to Regional Long Island Sound

					Raw Data (ppb)		Normalized - FGF*		Normalized - TOC	
Sampling Year (s)	NS&T Code	Location	FGF* (%)	TOC (%)	LMW (Total)	HMW (Total)	LMW (Total)	HMW (Total)	LMW (Total)	HMW (Total)
84-89	LISI	Sheffield Island	54	1.37	1626	4391	30	82	1187	3205
84-89	LIHU	Huntington Harbor	46	1.60	129	980	3	21	80	612
84-89	LIMR	Mamaroneck	74	2.17	478	2936	6	40	220	1353
84-89	LIHH	Hempstead Harbor	91	3.20	788	3138	9	35	246	981
84-89	LITN	Throgs Neck	57	1.78	1368	5847	24	102	768	3285
84-89	WLI	Western LIS	73	3.32	1053	3059	14	42	317	921
Date	WLIS	Reference Area								
June 91		WLIS-REF	85	0.96	652	2835	8	33	679	2953
June 91		2000W	87	1.4	369	1645	4	19	264	1175
June 91		2000S	42	0.56	1016	3741	24	89	1814	6680

*Fine grained fraction (percent total silt and clay).

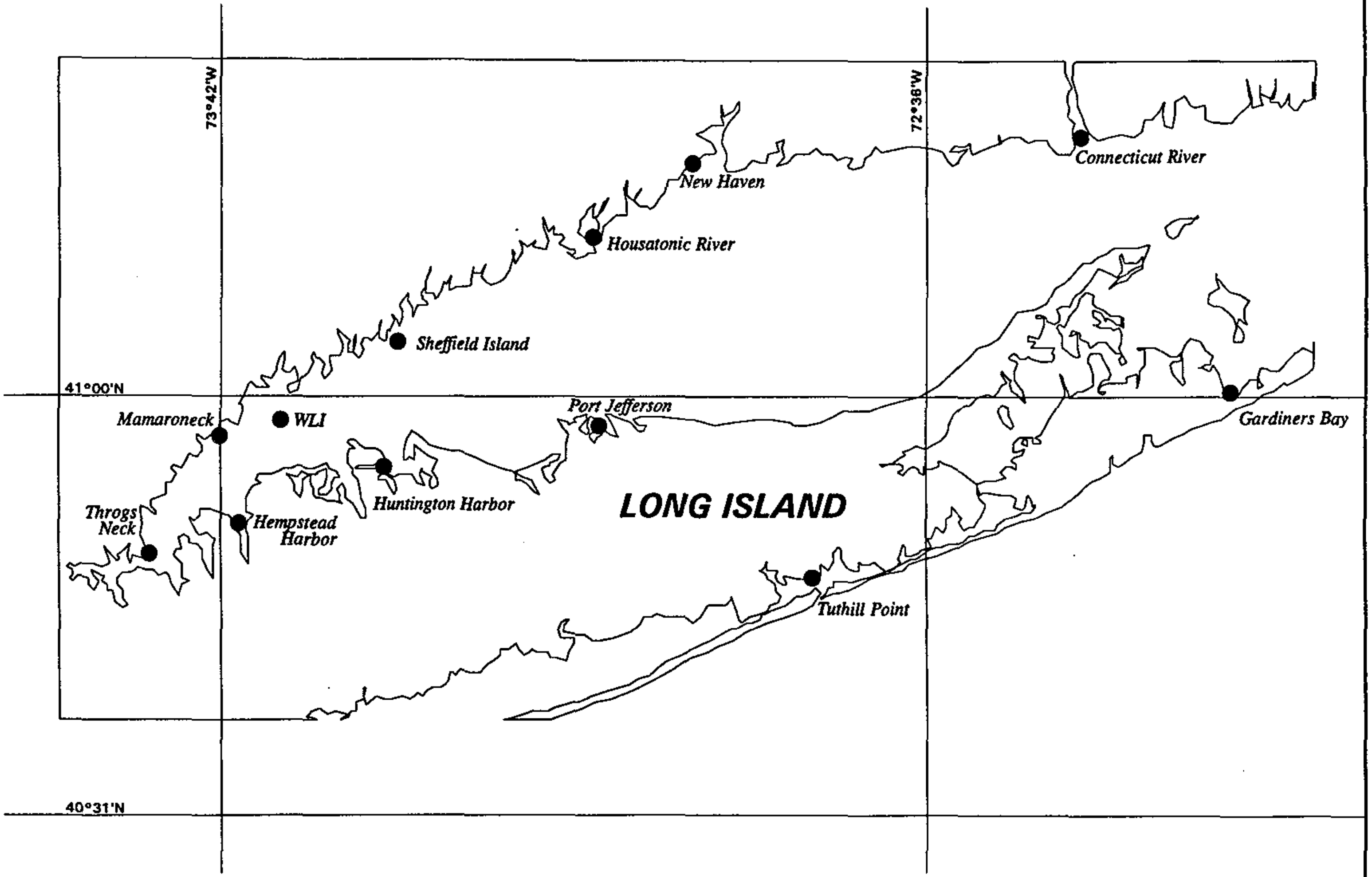


Figure 4-3. NS&T sites in Western Long Island Sound

As PAHs enter seawater from various sources, they quickly become adsorbed onto organic and inorganic particulate matter, and the majority are then deposited in bottom sediments. Once in bottom sediments, PAHs may undergo biotransformation and biodegradation by benthic organisms. The principal degradative processes for PAHs in the marine environment are photoxidation, chemical oxidation, and biological transformation by microbes and aquatic animals (Kennish 1992).

Normalized and non-normalized PAH concentrations were highest at 2000S. The sums of LMW and HMW non-normalized PAH concentrations at 2000S were approximately the same as at WLI, and concentrations at the other two reference stations were lower than at WLI. After normalizing to fine-grained percentages, 2000S data were higher than at WLI and were close to concentrations measured at the two higher NS&T stations (Sheffield Island and Throgs Neck). Fine-grained normalized data at 2000W and WLIS-REF were still lower than at WLI.

Normalizing data to TOC serves to increase the relative PAH concentrations at the WLIS reference stations. The sum of TOC-normalized PAH concentrations at 2000S was higher than at all of the other stations for both LMW and HMW PAHs. Summed concentrations of PAHs at 2000W and WLIS-REF were also higher when normalized, and were higher than at WLI except for total LMW PAHs at 2000W. The apparent increases in TOC-normalized data are due to the fact that TOC values at the WLIS reference stations are lower overall than the NS&T data.

4.4 Bottom Water Dissolved Oxygen

The objective of the dissolved oxygen (DO) sampling was to assess near-bottom DO concentrations relative to benthic habitat conditions within the reference areas and at the active disposal point. Bottom waters DO concentrations, ranging from 5.6 to 5.9 $mg \cdot l^{-1}$, were within the aerobic range (Table 4-3) and were slightly greater than the 4.1 to 4.5 $mg \cdot l^{-1}$ range observed in 1990 (Germano et al. 1993). This increase in DO is expected due to the cooler water temperatures during the June 1991 survey compared to temperatures during the July 1990 survey. Near-surface DO concentrations, ranging from 9.0 to 11.0 $mg \cdot l^{-1}$, were significantly greater than near-bottom values; however, this difference is most likely attributable to thermal stratification which was apparent in the CTD profiles.

Low DO levels do not appear to affect the behavior of benthic organisms or structure of benthic assemblages until the concentration decreases to the dysaerobic threshold of ~ 3 ppm (Table 4-4 and Tyson and Pearson 1991). Given the similarity of bottom water DO concentrations at the disposal site and reference stations, this parameter has apparently not been affected by disposal operations. Dissolved oxygen concentrations are usually not dependent on localized phenomenon; DO levels in Long Island Sound have been linked to broader oceanographic events, including seasonal temperature shifts and nutrient inputs.

Table 4-3

Recommended Terminology for Low Oxygen Regimes and the Resulting Biofacies in Marine Environments; from Tyson and Pearson 1991

Dissolved Oxygen Range ($mg \cdot l^{-1}$)	Biofacies
11.2 - 2.8	Aerobic
2.8 - 0.28	Dysaerobic
0.28 - 0	Quasi-anaerobic
0.0 (H_2S)	Anaerobic

Table 4-4

Progressive Effects of Low Dissolved Oxygen Concentrations on Modern Shelf Faunas; from Tyson and Pearson 1991

Dissolved Oxygen Range ($mg \cdot l^{-1}$)	Effect on Fauna
2.8 - 1.4	Avoidance and migration by nekton and some mobile epifauna.
2.0 - 1.4	Behavioral responses to stress by stenoxic benthic fauna.
1.4 - 1.0	Emergence of euryoxic infauna.
1.4 - 0.7	Physical inactivity. Duration or severity of conditions exceeds homeostatic capabilities and mortalities.

5.0 CONCLUSIONS

SAIC conducted the June 1991 monitoring cruise at the Western Long Island Sound Disposal Site to delineate the areal extent of dredged material disposed during the 1990-1991 season and to assess the recolonization response of the benthic infauna to the newly deposited material. Model predictions for the WLIS "E" mound were based on the reported volume of 86,462 m^3 of dredged material deposited during the 1990-1991 disposal season and would result in the formation of a mound up to 2.7 m in height with a radius of 200 meters. Based on acoustically detected changes in depth at the buoy location, disposal operations resulted in the formation of a mound with a diameter of 200 × 150 m and height of 3.0 meters. The REMOTS® sediment-profile survey detected thin layers of "fresh" dredged material beyond this 200 × 150 m area. The footprint of fresh material was estimated to be 400 × 175 m.

The status of infaunal recolonization was predicted to be primarily Stage I at the active disposal point and combinations of Stage II/Stage III on the flanks of the mound; however, Stage III infauna rapidly recolonized much of the newly deposited dredged material at the "E" mound. Stations exhibiting exclusively Stage I seres were located primarily west of the active disposal point. This conspicuous clustering of Stage I stations reflects those regions where the most recent dredged material disposal occurred. Several stations near the WLIS "D" mound (developed during the 1989-1990 disposal season) had low reflectance, high SOD sediments at depth. The presence of Stage III organisms at these stations and at stations on and near the active disposal point indicated that disturbances resulting from disposal operations are primarily physical and short-term; however, under the management strategy outlined in the SAIC tiered monitoring protocol, the persistence of dark subsurface sediments near the WLIS "D" mound represents the early stages of a potentially adverse condition resulting from disposal operations. This potential for a detrimental environmental impact warrants continued monitoring which may include REMOTS® sampling, sediment chemistry analyses, and sediment toxicity testing. In subsequent surveys the first step will be to evaluate the status of Stage III fauna prior to determining if any additional monitoring is required.

Results of the laboratory sediment grain size analyses were found to be consistent with the visual estimate of grain size major mode determined visually from REMOTS® photographs. Metal concentrations of Cd and Zn have not increased notably since the 1986 and 1987 surveys.

Both REMOTS® and PAH data strongly suggest that the WLIS-REF and 2000S reference areas have been affected by past disposal operations. Evidence of relic dredged material at WLIS-REF and the presence of fine sand, relic RPD layers, and persistent Stage I organisms at 2000S were inconsistent with their continued use as reference areas. The variation in PAH concentrations within these two reference areas revealed a heterogeneity in what was assumed to be areas of ambient sediment. In addition, reference area 2000S exhibited a patchy distribution of pyrogenic PAHs in replicate samples which would typically be expected in dredged material. Only sediments from the 2000W reference areas appeared to represent natural ambient sediment conditions. Alternative reference areas (replacing 2000S and WLIS-REF) more representative of ambient sediment conditions should be selected for the subsequent evaluation of the on-site stations.

6.0 REFERENCES

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

Germano, J. D.; Parker, J.; Williams, R. W. 1993. Monitoring cruise at the Western Long Island Sound Disposal Site, July 1990. DAMOS Contribution No. 85 (SAIC Report No. SAIC-90/7598&C92). US Army Corps of Engineers, New England Division, Waltham, MA.

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.

Goldring, R. 1964. Trace fossils and the sedimentary surface in shallow water marine sediments. In: van Straaten, L.M.J.U., ed. Deltaic and shallow marine deposits: developments in sedimentology, vol. 1, 136 - 143.

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

Kranz, P. 1974. The anastrophic burial of bivalves and its paleontological significance: Jour. Geol. 82: 237 - 265.

Maurer, D. L.; Keck, R. T.; Tinsman, J. C.; Leathern, W. A.; Wethe, C. A.; Hunkzinger, M.; Lonl, C.; Church, T. M. 1978. Vertical migration of benthos in simulate dredged material overburdens: V.I. Marine Benthos, Tech. Report. D-78-35, Waterways Experiment Station, Vicksburg, MS.

McCall, P. L. 1978. Spatial and temporal distributions of Long Island Sound infauna: the role of bottom disturbances in a near-shore marine habitat. In: Wiley, M., ed. Estuarine interactions. New York: Academic Press.

McGroddy, S. E.; Farrington, J. W.; Phinney, C. S.; Johnson, C. G. 1992. Partitioning of polycyclic aromatic hydrocarbons between sediments and porewaters from Boston Harbor, MA. Seventh Annual Boston Harbor/Mass. Bay Symposium Proceeding, Mass. Bay Marine Studies Consortium, P.O. Box 660, Boston, MA 02125-0005 (Abstract).

NOAA. 1991. Second summary of data on chemical contaminants in sediments from the National Status and Trends Program. NOAA Tech. Mem. NOS OMA 59. National Oceanographic & Atmospheric Administration, 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.

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.

Poindexter-Rollins, M. E. 1990. Methodology for analysis of subaqueous sediment mounds. Technical Report D-90-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Rhoads, D. C.; Aller, R. C.; Goldhaber, M. B. 1977. The influence of colonizing benthos on physical properties and chemical diagenesis of the estuarine seafloor. In: B. C. Coull, ed. The ecology of marine benthos. Bell Baruch Library in Marine Science, vol. 6: 113 - 138.

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

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

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

SAIC. 1990b. Monitoring cruise at the Western Long Island Sound Disposal Site, November 1987. DAMOS Contribution No. 74 (SAIC Report No. SAIC-88/7532&C72). US Army Corps of Engineers, New England Division, Waltham, MA.

SAIC. 1990c. Monitoring cruise at the Western Long Island Sound Disposal Site, July 1988. DAMOS Contribution No. 76 (SAIC Report No. SAIC-88/7547&C74). 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. Bd. Can. Bull., 167pp.

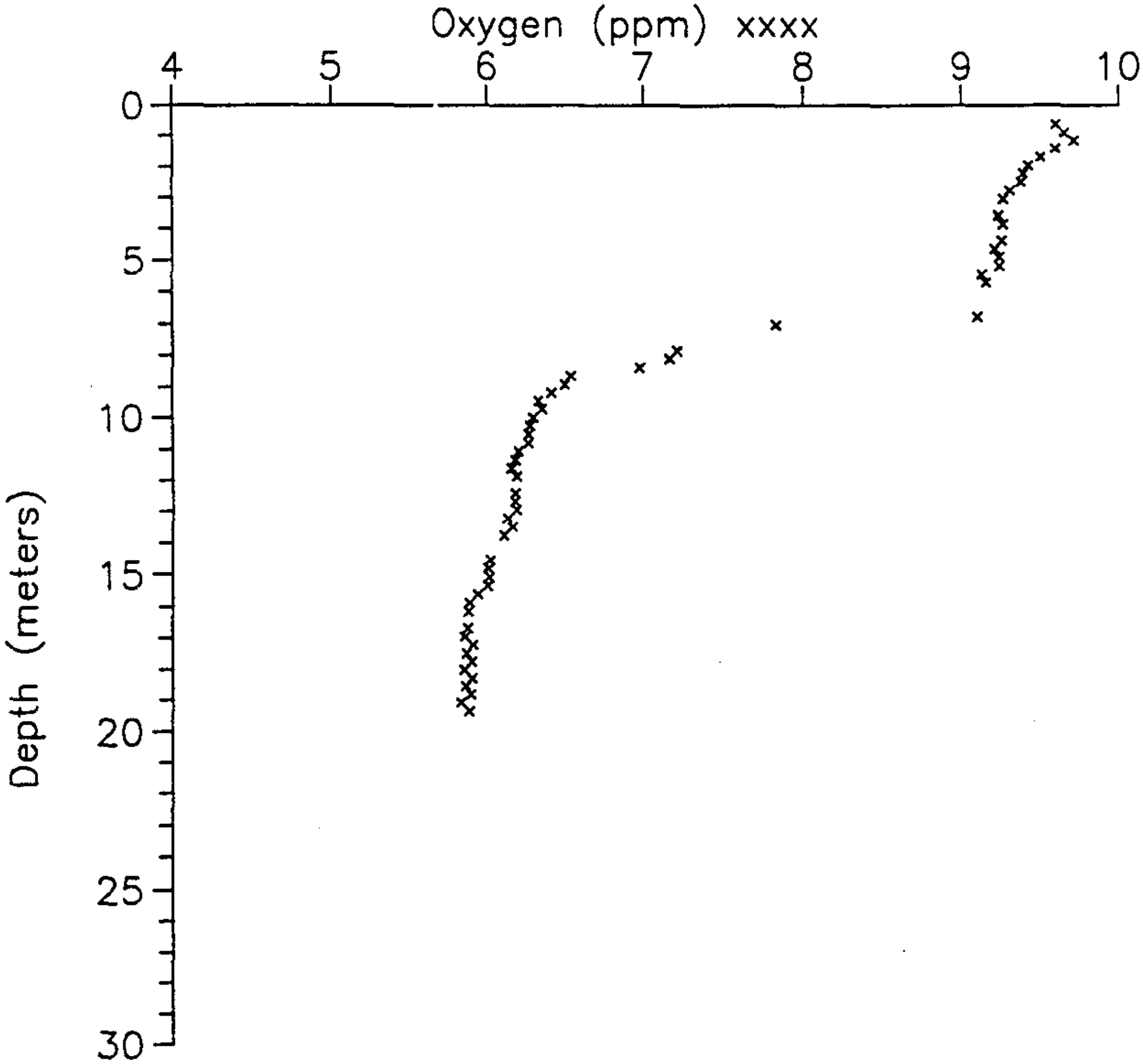
Tyson, R. V.; Pearson, T. H. 1991. Modern and ancient continental shelf anoxia: an overview. In: Tyson, R. V.; Pearson, T. H. eds. Modern and ancient continental shelf anoxia. Geol. Soc. of Lond., Spec. Pub., 58, pp. 1-24.

INDEX

Appendix

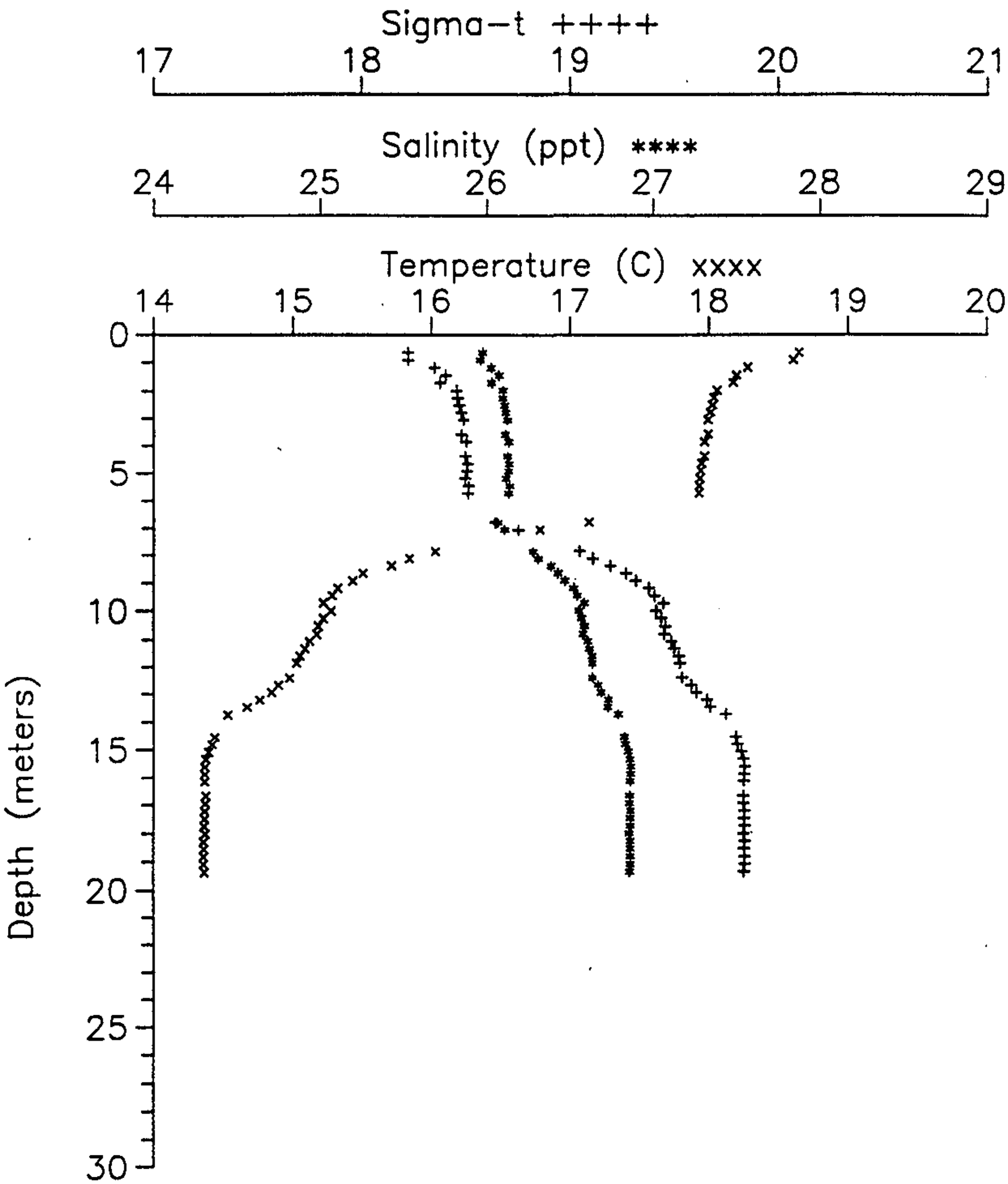
WLIS-91

2000S Reference Area



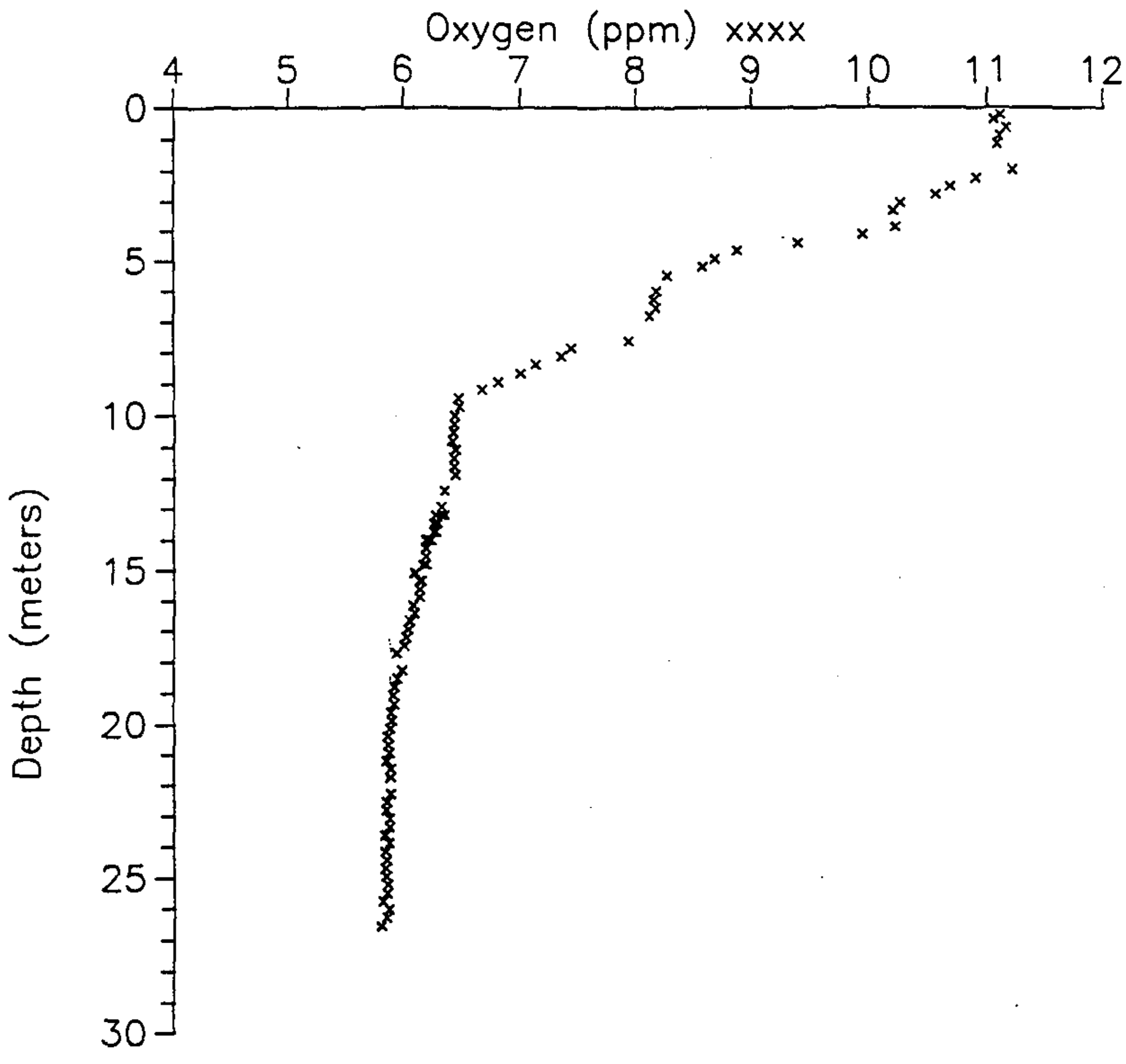
WLIS-91

2000S Reference Area



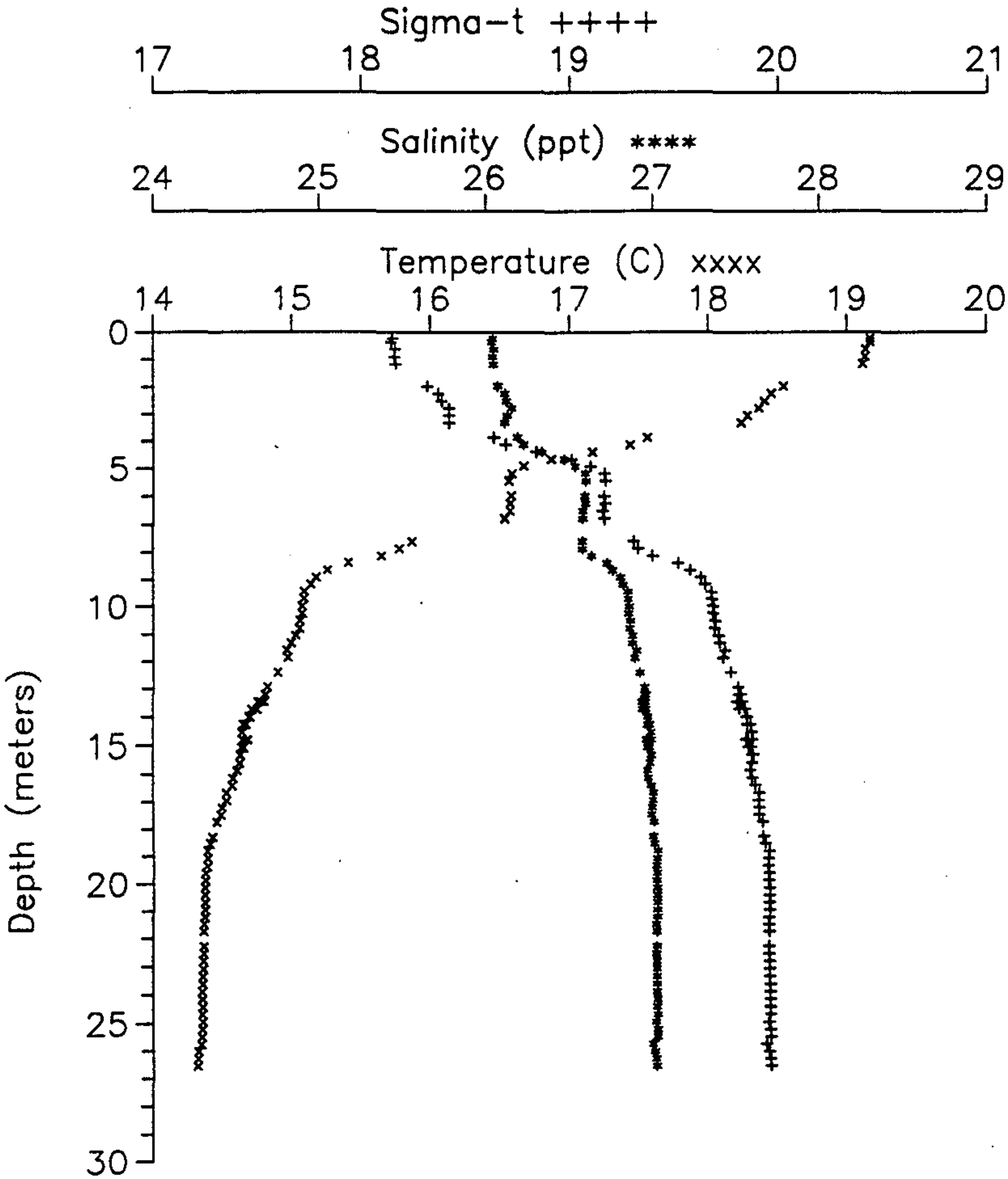
WLIS-91

Disposal Site Station "ECTR"



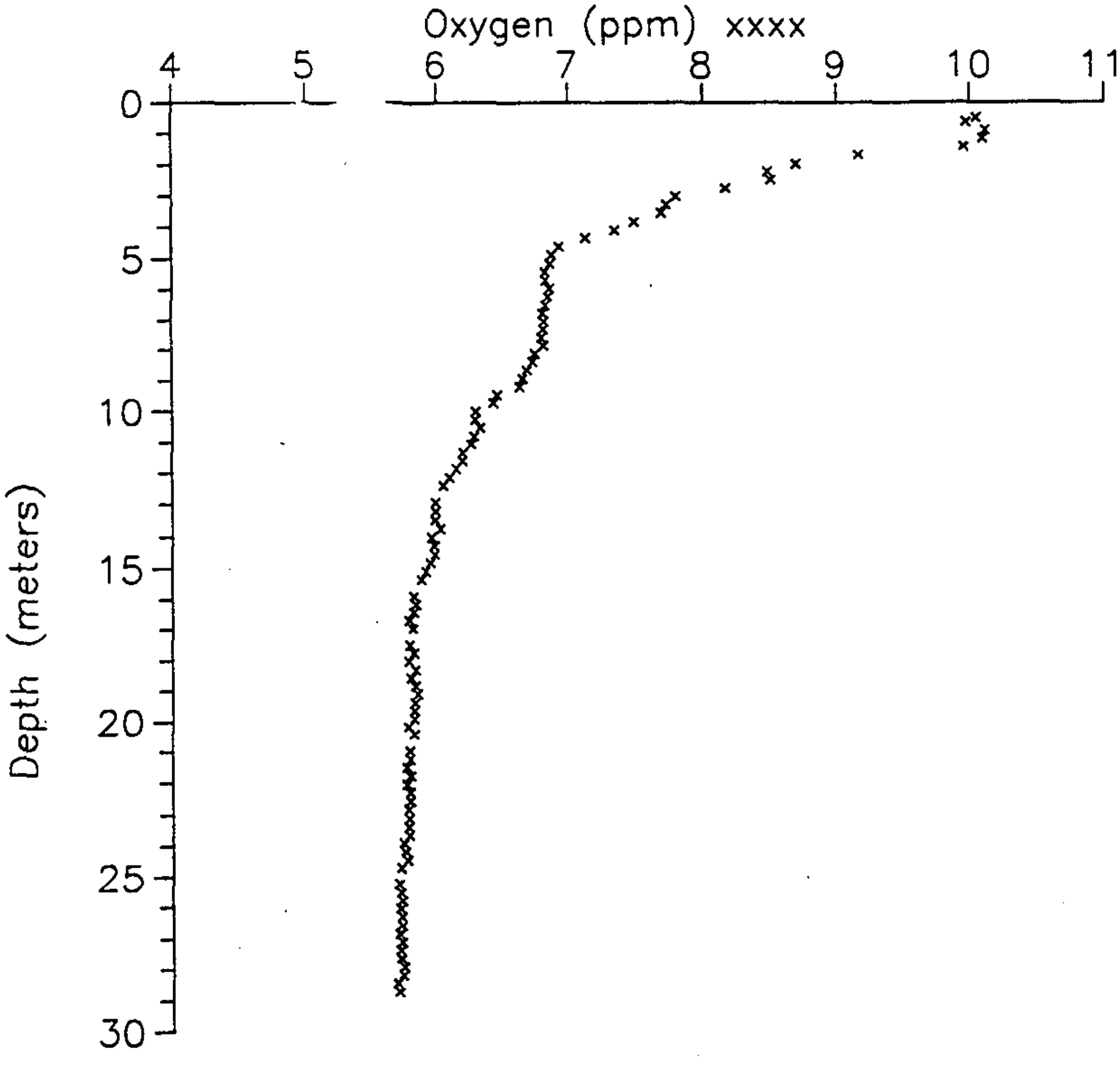
WLIS-91

Disposal Site Station "ECTR"



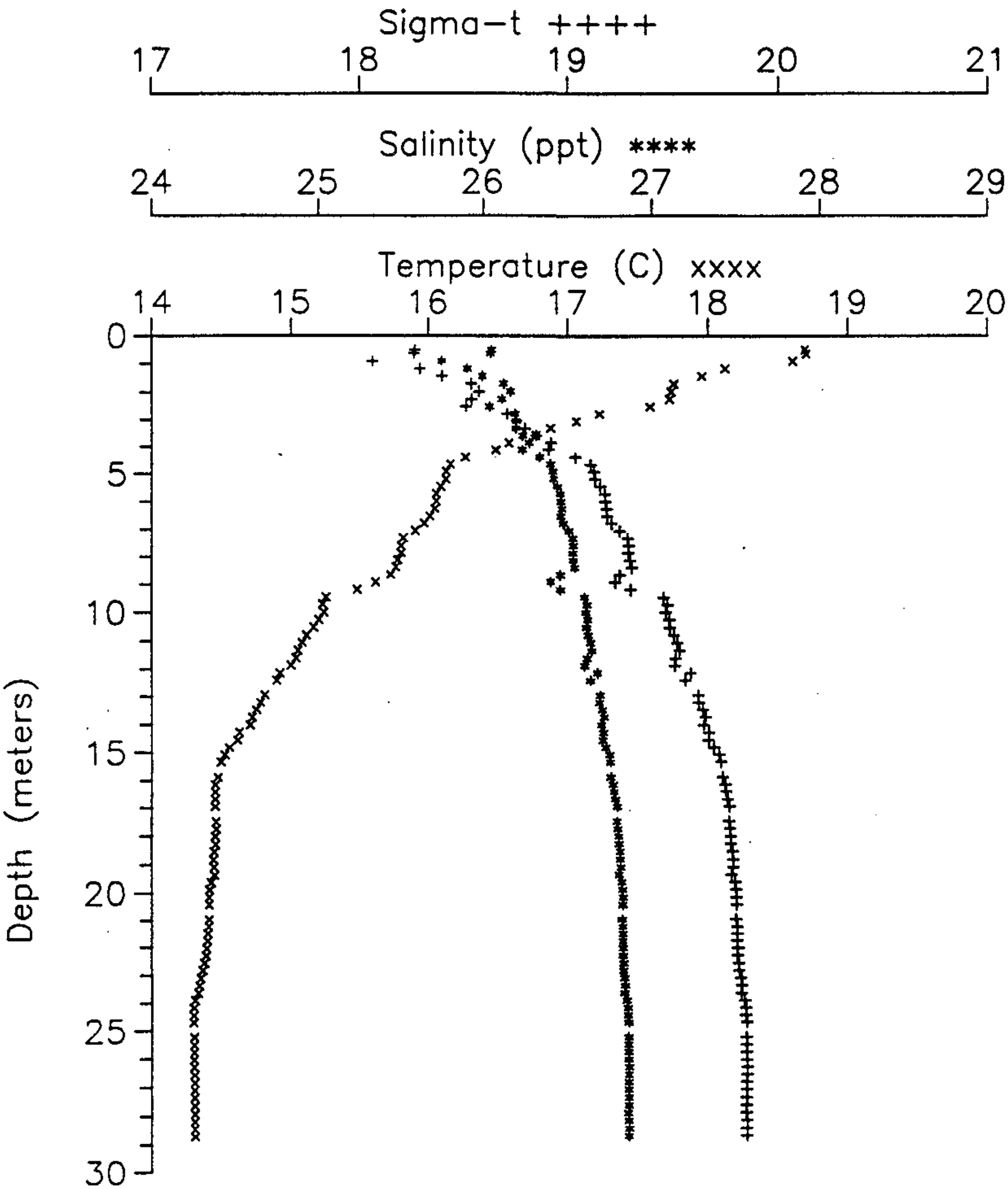
WLIS-91

2000W Reference Area



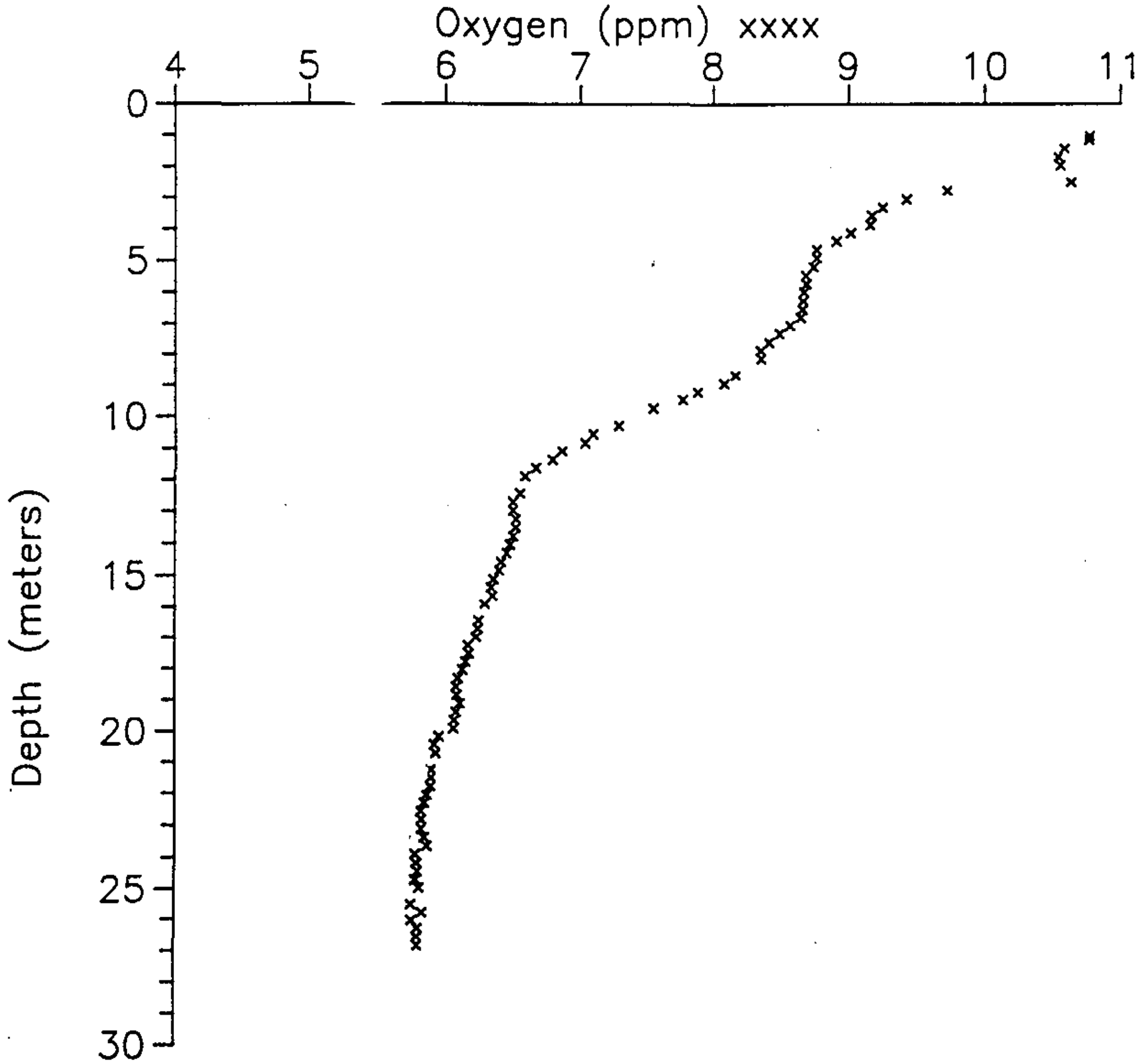
WLIS-91

2000W Reference Area



WLIS-91

WLIS-REF Reference Area



WLIS-91

WLIS-REF Reference Area