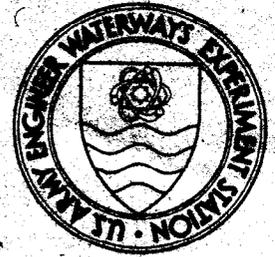


DREDGED MATERIAL RESEARCH PROGRAM



TECHNICAL REPORT D-77-42

AQUATIC DISPOSAL FIELD INVESTIGATIONS ASHTABULA RIVER DISPOSAL SITE, OHIO

APPENDIX C: INVESTIGATION OF WATER-QUALITY AND SEDIMENT PARAMETERS

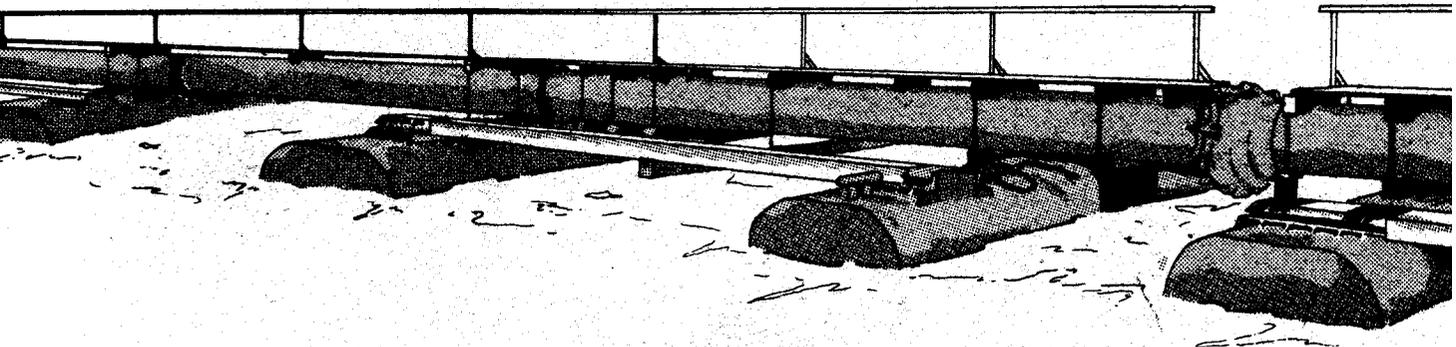
by

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July 1978

Final Report

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Monitored by Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

**AQUATIC DISPOSAL FIELD INVESTIGATIONS,
ASHTABULA RIVER DISPOSAL SITE,
OHIO**

- Appendix A: Planktonic Communities, Benthic Assemblages, and Fishery**
- Appendix B: Investigation of the Hydraulic Regime and Physical Nature of Bottom Sedimentation**
- Appendix C: Investigation of Water-Quality and Sediment Parameters**

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Errata Sheet

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July 1978

Page 131, LITERATURE CITED. Authorship of the tenth item should be changed to read:

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31 July 1978

SUBJECT: Transmittal of Technical Report D-77-42 (Appendix C)

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of several research efforts (Work Units) undertaken as part of Task 1A, Aquatic Disposal Field Investigations, of the Corps of Engineers' Dredged Material Research Program. Task 1A was a part of the Environmental Impacts and Criteria Development Project (EICDP), which had as a general objective determination of the magnitude and extent of effects of disposal sites on organisms and the quality of surrounding water, and the rate, diversity, and extent such sites are recolonized by benthic flora and fauna. The study reported herein was an integral part of a series of research contracts jointly developed to achieve the EICDP general objective at the Ashtabula, Ohio, site in Lake Erie, one of five sites located in several geographical regions of the United States. Consequently, this report presents results and interpretations of but one of several closely interrelated efforts and should be used only in conjunction with and consideration of other related reports for this site.
2. This report, Appendix C: Investigation of Water-Quality and Sediment Parameters, is one of three contractor-prepared appendices published relative to Waterways Experiment Station Technical Report D-77-42 entitled Aquatic Disposal Field Investigations, Ashtabula River Disposal Site, Ohio. The titles of all contractor-prepared appendices of this series are listed on the inside front cover of this report. The main report will provide additional results, interpretations, and conclusions not found in the individual appendices and will provide a comprehensive summary and synthesis overview of the entire project.
3. The objectives of this study, conducted as Work Unit 1A08C, were to examine natural temporal and spatial chemical variations within the lacustrine environment, to measure the initial impact of the disposal of dredged material on water quality, and to determine the long-term effects of the disposal event on water quality and character of the bottom sediments in the study area. In addition, studies were conducted to evaluate the physicochemical response of benthic macroinvertebrates and fish as a result of disposal of dredged material.

SUBJECT: Transmittal of Technical Report D-77-42 (Appendix C)

4. A conclusion of this report, based on the data presented, was that the disposal of dredged material in the open-lake environment produced immediate effects on many of the measured chemical parameters. Generally, however, these effects were very short term, with a return to ambient predisposal conditions within 90 minutes of disposal. Interstitial water and sediment chemistry data displayed similar trends, with return to ambient predisposal levels occurring within periods ranging from 30 days to 1 year. Benthic macroinvertebrates and fish showed no large accumulation of heavy metals when contrasted to reference areas.

5. The evaluations at all of the EICDP field sites were developed to determine the base or ambient physical, chemical, and biological conditions at the respective sites from which to determine impacts due to the subsequent disposal operations. Where the disposal sites had historical usage, the long-term impacts of disposal at these sites could also be ascertained. The results of this study are important in determining placement of dredged material for open-water disposal. Referenced studies, as well as the ones summarized in this report, will aid in determining the optimum disposal conditions and site selection for either the dispersion of the material from the disposal site or for its retention within the confines of the site, whichever is preferred for maximum environmental protection.



JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An investigation to evaluate impacts of the release of dredged material on chemical aspects of the aquatic and benthic environments was conducted in Lake Erie off Ashtabula, Ohio, from June 1975 through September 1976. Samples and measurements were taken prior to, during, and after the release of materials from a hopper dredge during August 1975 and May 1976.		

(Continued)

20. ABSTRACT (Continued).

The impact on the water column was short-lived with a return to ambient pre-disposal conditions for most parameters within 90 minutes after release of dredged material. Impacts on interstitial water generally dissipated in less than 90 days after disposal. The benthic environment was the most affected in terms of chemical changes. A return to predisposal conditions did occur within a year primarily due to erosion.

There was no evidence of heavy metals accumulations by either benthos or fish as a consequence of disposal of dredged material. A Standard Elutriate Test preparation time dependency study also was done. This investigation resulted in some suggested changes for improving reliability.

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PREFACE

This report presents the results of an investigation in Lake Erie of the effects of open-lake disposal on water and sediment quality and the bioaccumulation of metals by benthos and fish. The study was performed under Contract No. DACW39-75-C-0110 between the U. S. Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL), Vicksburg, Mississippi, and the Great Lakes Laboratory (GLL) of State University College at Buffalo. The report forms part of the Dredged Material Research Program (DMRP).

The portion of the Ashtabula study reported herein was conducted during the period December 1974 to January 1977 by GLL under the supervision and coordination of Dr. Robert A. Sweeney. Water quality and sediment studies were conducted by Mr. Robert K. Wyeth. Studies of metal content in benthic organisms were conducted by Messrs. Larry Rosengrant and Robert K. Wyeth and are contained in Appendix A'. Studies on the metal content of fish from selected areas were conducted by Mr. Arthur H. Pethybridge and are contained in Appendix B'. Time dependency of standard elutriate test preparation studies were conducted by Messrs. Paul Letki and R. Wyeth and are reported in Appendix C'.

The authors wish to acknowledge the assistance of Dr. Andrew White and his staff of the Cleveland Environmental Research Group, who collected the fish while under contract to GLL. The cooperation of Dr. James Seelye, who was the former Ashtabula Site Manager, and the staff of the U. S. Fish and Wildlife Service Laboratory at Ann Arbor, Michigan, also was appreciated. Other GLL staff members who assisted in the study were Messrs. Roger Haas, Vincent Tabone, and Mark Ocuto.

The study was conducted under the direction of Dr. John Harrison, Chief, EL, and Dr. R. M. Engler, Project Manager, Environmental Impacts and Criteria Development Project.

The Directors of WES during the study and preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

The U. S. customary units of measurement used in this report can be converted to metric units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	meters
horsepower (550 footpounds per second)	745.6999	watts
inches	25.4	millimeters
miles (U. S. statute)	1.609344	kilometers
ounces (U. S. fluid)	29.57353	cubic centimeters
pounds (force) per square inch	6894.757	pascals
square miles	2.589988	square kilometers

AQUATIC DISPOSAL FIELD INVESTIGATIONS
ASHTABULA RIVER DISPOSAL SITE, OHIO
APPENDIX C: INVESTIGATION OF WATER-QUALITY
AND SEDIMENT PARAMETERS

PART I: INTRODUCTION

1. For centuries man has found it necessary to seek more and better ways to modify the aquatic environment and exercise control over natural processes to accommodate his needs. Seldom have man's habits coincided adequately with naturally occurring waterways, thus requiring modification of existing waterways or creation of new ones. There are numerous major commercial water routes throughout the United States that require periodic maintenance if they are to be kept operational. These include harbors and rivers which to be maintained for commercial use must be dredged periodically.

2. Dredging is a process by which sediments are removed from the bottom of streams, lakes, and coastal waters, transported via ship, barge, or pipeline, and discharged (as spoil) to the land or water (U. S. Army Corps of Engineers 1976). Dredged material can consist of a wide range of substances, including those contaminated by industrial, urban, and agricultural discharges and runoff.

3. In the past there has been much nationwide concern over the environmental effects of dredged material disposal. Even without possible water-quality deterioration and toxic effects on organisms caused by contaminated material, there can be disruption of biological communities and processes and destruction of valuable resources by the improper disposal of uncontaminated material.

4. Much of the concern over water-column effects has been shown to be unwarranted because of dispersal characteristics of currents and seiches. Effects of dredged materials disposal on the lake bottom, though, are completely different. It is well known that, depending on individual circumstances, bottom sediments are continuously being resuspended by natural processes. In contrast to the natural phenomenon of sediment resuspension, however, open-water disposal often results

in the resuspension of large volumes of sediments over a relatively short period of time in a very small area.

5. In addition, possible direct effects of open-water disposal of dredged materials include sediment buildup, changes in spawning grounds, reduced habitat diversity, and changes in sediment-water chemical interactions. Furthermore, since much of the sediments in the nation's waters have become contaminated with chemical pollutants, there are possibilities that the artificial resuspension (deposition) of such sediments may increase the availability of these pollutants, particularly to the bottom biological communities. The end results of these potential effects are directly felt by man because, in most cases, the trophic web of an aquatic community is severely impacted by the changes described above.

6. By the River and Harbor Act of 1970 (Public Law 91-611, Section 123 (i)), the U. S. Army Corps of Engineers Waterways Experiment Station (WES) was delegated the responsibility of evaluating the impact that open-water dredged material disposal represents to the aquatic environment. As part of this responsibility, WES contracted the Great Lakes Laboratory (GLL) to conduct a research program in the offshore waters of Ashtabula, Ohio, to assess the effects of dredged material deposition. The overall objective of the research program developed by the Corps and the GLL was to provide, through surveys and experimentation, definitive information on the environmental impact of dredged material disposal operations that can be evaluated to develop technically satisfactory, environmentally compatible, and economically feasible procedures.

7. Ecological impacts of the discharge of dredged material can be divided into two main categories: physical effects and chemical-biological interactive effects. Physical effects are often straightforward and evaluation may often be made by examination of the type of material to be disposed of and relating this to the sediments of the prospective disposal site. The chemical-biological interactive effects resulting from deposition, however, are very complicated and involved and are difficult to predict without well-planned research

and experimentation. This appendix of the overall report by the GLL on the effect of open-water dredged material disposal will deal specifically with the chemical results obtained from the program and discuss these results in general terms with respect to definition of the biological environment. Also discussed in this report, in appendix form, are the heavy metal content of benthic macroinvertebrates, the heavy metal content of fish, and the time dependency of standard elutriate test preparations.

8. The specific objectives of this phase of the study were to:
 - a. Report natural, temporal, and spatial variations within the aqueous and lacustrine environment in the immediate area of investigation.
 - b. Document the initial impact of the deposition of dredged material on water quality.
 - c. Determine long-term effects of the disposal event on water quality and character of the bottom sediments in the immediate area of investigation.
 - d. Document the physicochemical response of the benthic environment as a consequence of deposition.
 - e. Provide additional information relevant to the planning of deposition of dredged materials.

PART II: SITE DESCRIPTION

Background Information

9. The Great Lakes area chosen for study by WES under the Dredged Material Research Program (DMRP) was in Lake Erie off Ashtabula, Ohio. Ashtabula Harbor is located in Ashtabula County, which is part of the Allegheny Plateau section on the northwestern edge of the Appalachian Plateau. A steep escarpment consisting of Mississippian and Pennsylvanian sediments is located about 2 miles* south of Ashtabula and characterizes the topography of the area (Danek et al. in preparation).

10. The geological formations that comprise the Allegheny Plateau include Ohio shales formed during the Devonian period. Fragments of this fossil shale were found in most clay fractions of the sediments in the Ashtabula vicinity (Danek et al. in preparation). This suggests that the Ohio shale was the parent rock for the soils and that shale had eroded through glacial abrasion. Large shale fragments also characterized areas of the proposed disposal site, located approximately 2 miles north of the harbor mouth. Superficial sediment materials in the general area consisted of alternating and mixed layers of mud, silt, sand, and hard sand with pebbles.

11. Located in the northeastern corner of Ohio, Ashtabula Harbor is a major coal transfer port on the Great Lakes and handles a large volume of heavy commercial traffic. As a result of both naturally-occurring and man-induced circumstances, the Ashtabula River and Harbor require almost annual dredging operations in order to keep the main channels of the Harbor and River open to this commercial traffic.

12. The earliest documented records of dredging activity in the harbor by the U. S. Army Corps of Engineers and other contractors date back to 1909 (Sweeney et al. 1975). With the exception of 1972, the harbor had been dredged yearly since 1945. Prior to the GLL's investigations beginning in 1975, almost 4,000,000 m³ (3,305,974 m³ soil

* A table of factors for converting U. S. customary units of measurement to metric (SI) can be found on page xx.

material and 638,094 m³ rock) had been removed from the harbor and river areas since annual dredging operations began. All dredged materials had been open-lake disposed in either the earth or rock dump areas as seen in Figure 1. The 1975 and 1976 dredging activities produced an additional 248,083 m³ and 87,639 m³ of earth, respectively.

Initial Survey Results

13. The study area consisted of stations within a 1 square mile region that incorporated the official Corps soil dump area. In order to characterize this area as well as a Reference Area of equal size with similar lake characteristics (depth, distance from shore, etc.) (Figure 2), an Initial Survey was conducted on 11 and 12 June 1975. This survey consisted of the collection of duplicate Ponar grab samples from 9 stations in the Reference Area and 16 stations in the Disposal Area (Figure 3). This figure also indicates by the shaded area, the presence of the Ohio shale previously mentioned. These sediments were analyzed for particle size, total organic carbon (TOC), and percent water. The results of these analyses are presented in Tables 1 and 2. These data showed an increasing trend in TOC and percent H₂O with distance from shore and a somewhat lower percent silt content in the disposal area compared to the Reference Area (possibly a result of the previous deposition). Based upon these results, specific locations within the disposal area were chosen for intensive study.

14. The first disposal site selected was at Station B13. This site was used for the deposition of dredged materials (considered unpolluted) to be taken from the Ashtabula Harbor area. The second site selected was at Station B24. This site was used for the deposition of dredged materials (considered polluted) to be taken from the river area. The reference sites chosen were Stations B1 and B7. At the time of selection of these reference sites, there was some question as to their suitability for this study. Sediment chemistry data showed some distinct differences between B1 and B13, and B7 and B24. However, similarity in physical characteristics of the sites and the fact that

core samples (with deeper penetration than the Ponar samples) would be used for all other sampling were significant considerations made in the selection of reference sites at B1 and B7.

15. The 1976 disposal site was selected near Station B10 and again the question of suitability with respect to the reference sites was raised. Again, however, physical conditions were considered to be of primary concern and not the analysis of the Ponar grab samples.

16. The Initial Survey also included the collection of middepth water-column samples from Stations SPW1 through SPW7 (Figure 4). These samples were collected in triplicate and analyzed for alkalinity, total Kjeldahl nitrogen (TKN), $\text{NH}_3\text{-N}$, suspended and total solids, and total and orthophosphorus. The results of these analyses are given in Table 3. The data presented are typical of nearshore chemical results for this period of the limnological season.

PART III: EXPERIMENTAL DESIGN AND SAMPLING REGIME

1975 Phase of Study

17. After the establishment of reference and experiment sites for intensive study, 4 reference and 12 experimental stations were defined for the 1975 phase of the project. Figure 5 shows the positions of these stations. Table 4 lists locations and depths. Stations D1 through D6 were to be used for the deposition of 1975 harbor dredgings and were, therefore, termed the harbor site and Stations D7 through D12 the deposition areas for river dredgings were designated the 1975 river site. Water-quality stations PW1 through PW11 were located in and around the disposal and reference sites in order to monitor general water-quality trends. Stations PW1, PW2, PW3, and PW5 were located at positions coinciding with C1, C3, D2, and D8, respectively (Figure 6).

18. In order to verify the assumptions regarding the degree of pollution of the harbor and river material scheduled to be dredged, sampling of 30 stations (15 each in the harbor and river areas) in duplicate (one each for biological and chemical quantifications) was completed on 24 June 1975. The location of 15 stations for each area were equally spaced within the areas to be dredged (Figure 7). Elutriate analyses on samples from the two areas, as well as bulk sediment and interstitial water determinations, were made in order to ascertain the basic differences between the indigenous lake concentrations and those of the materials to be dredged.

Predisposal sampling

19. Predisposal collections were made at the lake locations on 9-11 July 1975 and 30-31 July 1975. The first predisposal sampling consisted of four replicate box core samples from C1, C3, D2, and D8. The second predisposal collection was completed with 4 replicates from 16 stations (C1-C4 and D1-D12). All 11 water-quality stations (PW1-PW11) were sampled during both periods.

Disposal sampling

20. On 4 August 1975, dredging operations in the harbor and river were begun. These operations were carried out using the U. S. Army Corps of Engineers' hopper dredge Markham. In order to monitor the short-term, water-column effects of disposal, sampling for water chemistry was conducted from anchored and moving vessels (Figure 8) during disposal at both D2, the harbor dredging deposition area, and D8, the river dredging deposition area. The first day of disposal monitoring consisted of only transmissometer profiles every 10 min. from time zero (beginning of deposition). These data were used to determine the extent of the plume and the depths from which actual water bottle collections should be made during subsequent sampling. The transmissivity work suggested sampling depths of 1, 12, and approximately 16 meters (m) below the surface. The lowest sampling depth varied somewhat as a function of existing topography. The range of lower sampling depth generally indicated 1 m off the bottom. During actual sample acquisition, samples from all four anchored vessels were simultaneously collected at all depths at times of 0, 15, 30, 45, and 60 min. after the beginning of deposition. Due to time restrictions replicate samples during these collections were impractical and not attempted.

Postdisposal sampling

21. Postdisposal sampling was an attempt to ascertain acute effects of disposal. Collections to measure physicochemical changes and sediment transport were initiated on 14 August 1975 immediately upon completion of disposal. During this sampling only the water-quality stations (PW1-PW11) were sampled. The remaining postdisposal samplings were conducted on essentially a seasonal basis as long as the area was free of significant ice cover. Collections of both sediments and water for chemical analyses were made at all stations on 19-20 August, 14 September, and 16-17 November 1975.

1976 Phase of Study

22. In 1976 a reduced number of stations were revisited to assist

in definition of long-term effects. Water-quality stations which were resampled consisted of PW1, PW2, PW3, PW5, and the new disposal site (NDS). The NDS was located at the northwest corner of the disposal site (Figure 6). Sediment collections in 1976 were made at C1, C3, D2, D3, D8, and D9. These collections to measure long-term effects were completed on 21 April and 7-8 July 1976. All cores previously mentioned (collection between 9 July 1975 and 8 July 1976) were divided according to prevailing lithology into three sections/core. Interstitial water samples also were extracted from all core sections in order to estimate the effects of deposition on this element of the benthic environment.

Predisposal sampling

23. Variables considered in the chemical analyses for both water and sediment are found in Table 5. In addition to the reduced number of stations revisited in 1976, some variables also were discontinued as evidenced in the same table. In addition to revisiting some of the original stations in 1976, the monitoring of another disposal operation was planned. The major consideration in this planning was that the anchored and moving vessel technique of disposal surveillance was somewhat less than successful. With this information NDS was selected and a 16-point grid (400 x 400 m) was established around NDS as shown in Figure 9. The sixteen 100-m² areas with stations located at the centers of each and labeled SD1 through SD16 were sampled on 15-16 May 1976, as were the water-quality stations PW1, PW2, PW3, PW5, and NDS. In terms of data handling, both the previously mentioned 21 April 1976 sample collection and the 15-16 May 1976 sampling could be used as both 1975 postdisposal and 1976 predisposal information for water-quality variables. During 15-16 May 1976 sampling collections from five duplicate stations in the river area scheduled for dredging also were gathered in an attempt to ascertain background information on the materials to be deposited at NDS (SD1-SD16).

Disposal sampling

24. The 1976 disposal operation at NDS was set up using a single

vessel, the R/V C.A. Dambach. The vessel anchored at both bow and stern at the proposed disposal site. A continuous flow-through surveillance system was constructed and consisted of on-site determination of conductivity, turbidity, chloride or pH, and in situ dissolved oxygen (DO) measurements. Water was pumped from three depths to a specially constructed chamber where the above variables were monitored. This collection period consisted of monitoring four disposals each day for three days (24-26 May 1976). The sampling scheme consisted of collection of pumped samples at times of -10, 0, 5, 10, 15, 30, 45, 60, and 90 min. from the beginning of each disposal operation. Samples also were taken whenever the on-site monitoring system indicated high turbidity and/or conductivity. As was the case in the 1975 monitoring, no attempts were made at collection of replicate samples. On the 24th of May, collection depths were 1, 14, and 17 m below the surface. On the last two days (25-26 May) the middepth collection was changed to 16 m below the surface since no significant turbidity increases were noted at the 14 m depth. In addition to the on-site monitoring with the R/V C. A. Dambach, a vessel from John Carroll University was also used to monitor the third and fourth disposals on 25 May and the first and second disposals on 26 May 1976. The positions of these vessels are depicted in Figure 10.

Postdisposal sampling

25. The 1976 postdisposal collections were made on 10-11 June and 7-8 July 1976 from all 20 sediment stations (SD1-SD16 plus C1-C4) and at the 5 water-quality stations.

26. The only significant changes in the 1976 collections as contrasted with 1975 were the gathering of only two replicate sediment cores per station and two sections per core and two replicates per water-column depth. Another dimension of the total water sampling effort was added to the 1976 collections in the form of interface water samples (taken from the sediment-water interface). Analyses of these samples included the same variables listed in Table 5 for the other water samples.

27. Five other possible aspects of disposal operations were studied during 1976. Sediment oxygen demand (SOD) measurements were made in an attempt to evaluate whether or not the deposition of dredged materials that are reducing in nature will have an effect on the hypolimnetic oxygen deficits, which at times are critical in the Central Basin of Lake Erie. The second component involved an examination of the time dependency of elutriate preparation (Appendix C'). Thirdly, in order to better define the areal extent and depth of the disposal mound, cores from sites around NDS were collected, finely divided (2 cm sections), and analyzed for Cu and Fe concentrations. Also, benthic macroinvertebrates and fish from the Reference, Disposal, and River sites were analyzed for a variety of heavy metals (Appendices A' and B'). Lastly, sediment traps (Danek et al. in preparation) were used to further define the physico-chemical character of disposal operations

28. Table 6 summarizes collections made during both 1975 and 1976. In brief, the 1975 disposal has been used to evaluate long-term effects while the 1976 disposal has been used to evaluate short-term effects of deposition of dredged materials in the open-lake environment.

PART IV: METHODS

Aquatic Chemistry

29. All water samples acquired during the previously mentioned periods (except the 1976 disposal) were collected using 8.2-ℓ Van Dorn water bottles. During the 1976 disposal monitoring operations, a system was designed and built to continuously monitor disposal conditions. The system was designed to continuously monitor conductivity, turbidity, and chloride or pH at three different depths simultaneously. This was accomplished by continually pumping water from three depths to the deck of the R/V C. A. Dambach using three Jabsco Self-Priming Pumps, Model 12290-0001, and equal lengths of flexible 1 in. (2.5 cm) I.D. ribbed plastic tubing. The flexible tubing was attached to a weighted winch cable at three predetermined depths along the cable.

30. The continuous flow of water from the three depths was then directed to custom-designed flow-through cells which housed the monitoring sensors and electrodes. The flow-through cells were approximately 12 in. (30.5 cm) long and 5 in. (12.7 cm) in diameter. They were constructed of cast acrylic tubes and sheet plexiglass approximately three-eighths of an inch (1 cm) thick. Holes were cut and drilled out of the tubular bodies to allow sensors and electrodes to be placed into the cell. Pieces of sheet plexiglass were cut and affixed to the ends of the cylindrical bodies. The end pieces acted as a stand as well as sealing the body to form the cells. These ends also allowed enough bottom clearance to run subsampling lines from the bottoms of the chambers. The plexiglass pieces were permanently attached with methylene chloride (Figure 11).

31. The flow of the water through the cells was controlled with a series of PVC valves that controlled the flow input and output of the chamber. The water was delivered to and drained from the chamber through five-eighths of an inch (1.6 cm) Tygon tubing.

32. Conductivity was continuously monitored by Balsbaugh Laboratories Series 1210 Electrodeless Conductivity Monitors with

Model 1210 EV-L Sensors adapted to the flow-through cells. The electrodeless conductivity system is a new concept in conductivity monitoring that eliminates the fouling effects of solutions being monitored. The electrodeless sensors use two toroidally wound coils placed in close proximity within a cast epoxy body. When the sensor is placed into a solution, the solution couples the two coils. An AC signal is then applied to the primary toroid and a current is then generated in the solution loop that generates a current in the secondary toroid. The secondary toroid current, which is directly proportional to solution conductivity, is then fed to the monitor and displayed on a meter. A thermistor is also encapsulated within the epoxy body for temperature compensation capabilities.

33. Chloride or pH was continuously monitored with Orion 701 pH-specific Ion Meters. Orion 96-17 Combination Chloride Electrodes and/or Markson 1888 Combination pH Electrodes were used with the Orion Meters.

34. Turbidity was continuously monitored with Nephelometric turbidimeters manufactured by H. F. Instruments Limited (Model DRT-1000). A continuous sample flow was delivered to the turbidimeters' flow cells by drawing a constant subsample from the flowing water within the flow-through chambers. The water was drawn from the flow-through cells and through the turbidimeters by a small circulating pump.

35. All signals from each depth were outputted from the monitors and meters to Leeds and Northrup Speedomax M Mark III three pen recorders for readily comparative displays and recording of ongoing events. Signals from the Orion 701 pH Meters and the Balsbaugh Conductivity Monitors were interfaced and matched to the Speedomax Recorders with Rochester Instrument Systems, Inc., Model SC 306 Millivolt Transmitters (Figure 12).

36. Disposal events and elapsed times were monitored with Bronwill Timers.

37. Oxygen levels at each sampling depth were also monitored

via Yellow Springs Instrument (YSI) Model 5739 Oxygen Probe attached above the sample tube and connected to YSI Model 54 ARC Oxygen Meters.

38. All samples, whether pump or water-bottle collected, were placed in acid-washed 5-gal (18.9-ℓ) polyethylene cubitainers. The use of plastic cubitainers allowed the expulsion of overlying air prior to sealing in order to minimize contact with oxygen. At the time of sample collection at Stations PW1 through PW11, DO, temperature, and conductivity profiles were also taken. Temperature and conductivity profiles were completed using a YSI Model 33 S-C-T meter and oxygen profiles were made using a YSI Model 54 ARC Oxygen Meter equipped with a YSI Model 5739 Probe, YSI Model 5492A Battery Pack, and a YSI Model 5795A Submersible Stirrer.

39. Plastic cubitainers containing samples were returned to the on-site laboratory and logged according to station, date, and time of collection. The cubitainers were then arranged by station and depth in preparation for splitting. A schematic diagram for splitting and preservation of water samples is seen in Figure 13. Prelabeled sample bottles were set up prior to the processing of each cubitainer. A well-mixed sample was maintained throughout the splitting and preservation procedure.

40. The first step of the actual splitting operation was to measure out 100 ml of sample into a labeled beaker for pH, Eh, and alkalinity determinations. The pH measurements were made with either an Orion or Fisher Combination Electrode or Glass Universal and Calomel Reference Electrodes after two-point calibration (pH 7 and 9) on a Fisher Model 420 or 520 Accumet pH Meter. A Fisher Temperature Compensation Probe was also employed to correct for temperature variation of samples. Redox potential (Eh) measurements were made with either an Orion or Fisher Combination Platinum Electrode on a Model 701 Orion pH/Specific Ion Meter. Procedures used can be found in the Orion Platinum Redox Electrode Instruction Manual (Orion Research Inc. 1973). An additional reference used was Bulletin 99-D from Beckman Instruments Inc. (1967). The manual titrimetric method for determination of total alkalinity to pH points of 4.5 and 4.2 units

with 0.02 N H₂SO₄ were made on the previously mentioned pH meter assembly (APHA 1971).

41. For the eventual determination of soluble nutrients such as orthophosphorus, silica, sulfate, and dissolved metals, a 500-ml subsample was measured into a volumetric flask. The sample was then filtered through 0.45- μ , acid-washed membrane filters. Aliquots of the filtrate were then placed into two 120-ml polyethylene containers for nutrient and soluble metals determination and the filter was retained for eventual digestion and suspended metals determinations. Other splittings of 500-ml subsamples for solids, conductivity, turbidity, and chloride plus a subsample for total heavy metals were then completed. The last two subsamples (120 ml each) for particulate organic carbon (POC) and dissolved organic carbon (DOC) and TKN and total Phosphorus (P_T), respectively, were then made and the remaining sample in the cubitainer was discarded after verification that the necessary splitting and preserving of each subsample was complete.

42. All subsamples for various chemical variables that required preservation or special processing were handled using EPA-recommended techniques (U. S. EPA 1974). All subsamples were placed on ice in coolers prior to being returned to the Buffalo-based laboratories of the GLL. Upon receipt of samples at the GLL, they were received and logged and checked against the field collection records. Subsamples were then arranged according to variable to be measured and placed in 4° C incubators.

43. All elutriate preparations from harbor and river sediment in 1975 and river sediment again in 1976 were accomplished according to Keeley and Engler (1974).

44. All interface water collected during 1976 also was handled according to the above preservation techniques and subjected to the same following analytical methodologies as the lake and interstitial water samples. More details regarding the collection of both interface and interstitial water samples will be given in the Sediment Methods section.

45. The automated method for the determination of orthophosphorus,

PO₄-P, in water samples (lake, interface, interstitial, and elutriate) had a range of 0-1.00 mg P/l. Higher concentrations were determined after appropriate dilution. The method was based on the reaction of ammonium molybdate and antimony potassium tartrate with orthophosphate in an acid medium to form an antimony-phosphomolybdate complex that was reduced by ascorbic acid and yielded a blue color which was read at 880 nm. The automated analytical equipment used included: (a) a sampler, (b) a proportioning pump, (c) a Technicon Analytical Cartridge No. 116-D221-01 with a 37° C heating bath, (d) a colorimeter with a 50 mm x 1.5 mm I.D. flow cell and 800-nm filters, and (e) a recorder. The procedure used was Technicon Industrial Systems Industrial Method No. 155-71W (Technicon 1974).

46. The automated ammonia (NH₃-N) method (ionized plus un-ionized) was used to analyze all water samples (lake, interface, interstitial, and elutriate), within an overall range of 0-5.00 mg N/l. Higher concentrations were determined after appropriate dilution. The automated procedure for the determination of ammonia followed the Berthelot Reaction in which alkaline phenol and hypochlorite reacted with ammonia and formed indophenol blue, the intensity of the color being proportional to the ammonia concentration. Sodium nitroprusside was added to intensify the color that was read at 630 nm. A solution of potassium sodium tartrate and sodium citrate was added to eliminate the precipitation of calcium and magnesium hydroxides (Technicon 1974; APHA 1975). The automated analytical equipment included: (a) a sampler, (b) a proportioning pump, (c) a Technicon Analytical Cartridge No. 116-D223-01 with a 50° C variable temperature heating bath, (d) a colorimeter with a 50 mm x 1.5 mm I.D. flow cell and 630-nm filters, and (e) a recorder. The procedure used was Technicon Industrial Systems Industrial Method No. 154-71W (Technicon 1974).

47. The automated TKN method was used to analyze all lake and interstitial water samples within a range of 0-1.00 mg N/l. Higher concentrations were quantified after appropriate dilution. The same chemical method was employed for both TKN and ammonia nitrogen.

Equipment used was also the same for both methods. Samples prior to analyses, however, were digested simultaneously for TKN and P_T on a Technicon BD-40 Block Digestor according to directions from Industrial Method #376-75W (Technicon 1974). Twenty ml of sample and 5 ml of a solution containing 600 g of K_2SO_4 and 1 ml of a HgO slurry in 1 ℓ H_2SO_4 were used in the digestion procedure. Digested samples were neutralized by adding a NaOH dilution line to the automated manifold. For determination of P_T , NaCl also was added to complex the HgO to avoid precipitation.

48. After digestion, the automated P_T method was used to analyze all lake water samples within a range of 0-0.500 mg P/ ℓ . Higher concentrations were determined after appropriate dilution. The same chemical method was employed for both total phosphorus and orthophosphorus (PO_4-P) Equipment used for P_T determinations was the same as for the orthophosphorus method. All results of TKN and P_T derived from block-digested samples were calculated using a 3.75 multiplier as a consequence of the necessary dilution in the digestion procedure.

49. The automated nitrate and nitrite method was used to analyze all water samples within a range of 0-0.200 mg N/ ℓ . Higher concentrations were determined by dilution. In this method nitrate was reduced to nitrite by a Cu-Cd reduction column. The nitrite then reacted with sulfanilamide under acidic conditions to form a diazo compound. A reddish purple dye formed when the diazo compound coupled with N-1-naphthylethylenediamine dihydrochloride and was read at 550 nm. Samples were rerun without the Cu-Cd column for nitrite, and nitrate was determined by the difference (Technicon 1974). The automated analytical equipment included: (a) a sampler, (b) a proportioning pump, (c) a Technicon Analytical Cartridge No. 116-D233-01, (d) a colorimeter with a 50 mm x 1.5 mm I.D. flow cell and 550-nm filters, and (e) a recorder. The procedure used was Technicon Industrial Systems Industrial Method No. 158-71W (Technicon 1974).

50. The automated silica method was used to analyze all water samples (lake and interface) with an overall range of 0-2.00 mg SiO_2/ℓ . Higher concentrations were determined by dilution. The automated

procedure was based on the reduction of a silicomolybdate ion in acidic solution to molybdenum blue by ascorbic acid. Oxalic acid was introduced to eliminate the interference from phosphates. The automated analytical equipment used included: (a) a sampler, (b) a proportioning pump, (c) a Technicon Analytical Cartridge No. 116-D291-01, and (d) a colorimeter with a 50 mm x 1.5 mm I.D. flow cell, and (e) 660 nm-filters. The procedure used was Technicon Industrial Systems Industrial Method No. 105-71W (Technicon 1974).

51. Organic carbon analyses were performed according to Methods for Chemical Analysis of Water and Wastes (U. S. EPA 1974) and Model 915A Total Organic Carbon Analyzer Manual (Beckman Instruction Manual 1974). The Beckman Model 865 infrared analyzer was used in conjunction with the Beckman Model 915A total organic carbon analyzer. Two ranges of standards (100, 80, 60, 40, 20, 10, 5 ppm and 20, 16, 12, 8, 4, 2 ppm) were used according to the approximate concentration of TOC in the samples. Fresh deionized and distilled water was used in making up the standards. The equipment and standards used made the GLL's method applicable to measurement of organic carbon above 0.1 mg carbon/ ℓ . The acid-preserved samples ($\text{pH} \leq 2$) were purged with dried N_2 . The samples were gently mixed prior to injection to obtain a homogeneous subsample. Only samples with large particles ($> 170 \mu\text{m}$) were blended using a Waring blender. The samples were then injected into the total carbon channel to obtain a total organic carbon (TOC) measurement. The samples were then filtered through a pre-ashed (500°C for 1 hr) GF/C glass fiber filter. The injection of the filtrate into the total carbon channel yielded the DOC results. POC was found by difference ($\text{TOC} - \text{DOC} = \text{POC}$). A regression analysis was made of the standards calculated from percent absorbance readings vs. mg C/ ℓ . A typical regression equation was $\text{mg C}/\ell = 0.98 (\% \text{ T}) - 6.8$.

52. Chloride concentrations were determined using an Orion Combination Chloride Electrode (Model 96-D), which is suitable for measuring concentrations between 10-1000 mg Cl/ ℓ . The electrode measures millivolt change with respect to chloride concentration in the sample. Samples and standards were read at ambient temperature and

the resulting millivolt values were then plotted on semilog paper in order to establish the standard curve used to determine unknown chloride concentrations. The complete procedure is described in the Orion-Halide Electrode Instruction Manual (Orion Research 1976).

53. Specific conductance measurements were made according to Standard Methods (APHA 1975) using a YSI Model 31 conductivity bridge with a $K = 1.0$ conductivity cell. All data were temperature-compensated to 25° C.

54. Turbidity determinations were made according to the instruction manual for the H. F. Instruments Model DRT-1000 nephelometric turbidimeter (H. F. Instruments Limited 1975).

55. One of two methods was used to determine the concentration of suspended solids depending upon the character of the individual sample. The initial method used to determine suspended solids (nonfiltrable residue) was Method 208 in Standard Methods (APHA 1975). Suspended solids were determined by difference between total solids and dissolved solids. Samples that were analyzed using this method were also analyzed for the entire solids series (volatile, fixed, etc.). The only deviation from the accepted procedure was the use of 100 ml of sample rather than a larger volume. Although a larger sample volume would be advised, time permitted no larger sample volume due to the evaporation time on the steam bath.

56. The second method employed to determine suspended solids concentration was based upon turbidity results. Suspended solids data generated via Standard Methods was plotted against respective turbidity values and a regression equation was derived. A total of 101 data points were used to determine the regression equation. Suspended solids and turbidities ranged from 1 - 1810 mg/ℓ and 1.4 - 700 NTU, respectively. The regression equation, suspended solids = $(2.55 \times \text{Turbidity}) - 0.79$, was determined to be valid up to ~ 300 NTU's with a confidence level of > 95%. The corresponding correlation for the original data was $R = 0.96$. Although the regression appeared valid to 300 NTU's, any sample with a turbidity greater than 200 NTU's

was subjected to the initial method. It should be noted that originally 104 data points were considered in the regression. Three of these points were eliminated from the regression analysis because of obvious errors in either the suspended solids and/or the turbidity results.

57. Sulfate quantifications were made using the turbidimetric method found in Standard Methods (APHA 1975). A Bausch and Lomb spectrophotometer Model 88 was used for the determination.

58. Samples prepared for soluble metal analyses (0.45 μm filtered) were aspirated directly and measured with a Varian Model 1250 atomic absorption spectrophotometer. The concentration mode was used to obtain directly the concentration in $\mu\text{g}/\ell$ for cadmium, copper, manganese, and zinc, while twice the concentration was read for iron, lead, and nickel. Mercury was analyzed by the method of Hatch and Ott (1968) using a Coleman mercury analyzer MA S-50. The xl scale was used with standards of 0.1, 0.2, 0.3, 0.4, and 0.5 μg Hg. A volume of 5 ml of sample plus 45 ml of distilled water was used for the determinations.

59. For suspended metals determination, 500 ml of well-mixed sample was filtered through 0.45 μm membrane filter paper and the filter paper retained for analyses. When considerable suspended material was present, smaller volumes were filtered. The filter was then dissolved in 10 ml concentrated nitric acid and 10 ml concentrated hydrochloric acid in a 125-ml Erlenmeyer flask. After being placed on a hotplate, the flasks were heated until the total volume had decreased to about 2-5 ml (approximately 8 hr). The samples were then filtered and diluted to a volume of 25 ml. This solution was then analyzed as per dissolved metals. Suspended mercury was calculated by measuring the total mercury in 50 ml of unfiltered sample and subtracting the dissolved mercury as measured in the filtered sample.

60. All metals analyses, regardless of matrices, were analyzed using analytical wavelengths and slit widths as given by the manufacturer (Varian Techtron 1972). Other pertinent analytical instrument variables as well as typical detection limits and sensitivities also can be found in the above reference.

Sediment Chemistry

61. A General Oceanographic spade box corer with an area of 151 cm² and lengths of 30 cm in 1975 and 40 cm in 1976 was used to collect sediment samples. Four replicates were taken in 1975 and two replicates were gathered in 1976 at each station. A schematic diagram for onboard treatment of the samples is shown in Figure 14.

62. After collection, the sample was hoisted to the deck of the R/V C. A. Dambach. The sample container housing the sediment was then removed from the coring device and placed in a plastic pan with minimal disturbance of the sample. The depths of the sediment and of the interface water were measured and recorded. This was done to determine the total volumes of sediment and interface water. Disturbance of the water and sediment was kept to a minimum during these measurements. Interface water samples generally represented the water within approximately 5-10 cm above the sediment.

63. For the 1976 collections, approximately 250 ml of interface water was either siphoned or poured from the top of the box corer into a beaker. The water sample was then taken to the ship's lab where the temperature of the sample was determined with a Weston Dial Thermometer. The DO content was measured using a YSI Model 54 ARC Oxygen Meter. A pH measurement was taken using a Fisher 520 Accumet pH Meter with an Orion Double Junction Reference Electrode, a Fisher Glass Universal Electrode, and a Fisher Auto Temperature Compensation Electrode. The interface water sample was placed into four 50-ml glass centrifuge tubes and centrifuged at 2500 rpm for approximately 10 min using an International Model 433 Centrifuge. The four centrifuge tubes were decanted into filtering apparatus and filtered through 0.45- μ m, acid-washed and rinsed membrane filters. The filtrate was then combined and placed into two 20-ml vials and a 4.5-ml vial. One of the 20-ml subsamples was preserved with HNO₃ for metals analyses. The other 20-ml subsample was not chemically preserved. This latter subsample was analysed for NH₃-N, TKN, and PO₄-P. Both subsamples were incubated at 4° C. The 4.5-ml subsample was preserved with HCl and also kept at 4° C for DOC analysis.

Preservatives and storage methods used were from Manual of Methods For Chemical Analysis of Water and Wastes (U. S. EPA 1974). Quality control blanks were also run before, during, and after each sampling day by using distilled water carried throughout the procedure.

64. After the interface water from the top of the box core was sampled, a sediment core subsample was then removed from the box core. This was accomplished using a 4.8-cm-diameter plastic core tube liner approximately 40 or 50 cm long, depending on the length of the box core collected. This sediment sample was taken from the center of the box core excluding the interface water. The sediment sample was removed from the box core by tight placement of the palm of one hand over the top opening of the core tube and slow insertion of the lower end of the tube into the interface water, keeping the tube perpendicular to the surface of the sediment. This procedure kept the water from entering the tube until the core tube's lower opening reached the sediment surface. When the tube reached the top of the sediment, the hand covering the top opening of the tube was removed from the opening to prevent compaction of the sediment. Then the tube was slowly pushed into the sediment. When the tube was completely through the sediment, a cap was placed on the upper end of the tube and the box core liner was then raised over the plastic core tube until free. The core tube was kept in a vertical position at all times. The remaining sediment around the tube was then scraped away and the lower cap put in place. The tube was then rinsed and labeled. The height of the sediment and the water, if any, was marked on the tube along with any lithological observations, to detect any physical changes that might occur prior to extrusion and extraction.

65. To prevent oxidation, the upper cap was removed; the sample was purged with nitrogen gas; and the cap was replaced as quickly as possible. The caps and tubes were then sealed with tape. The core tube with sample was then placed into a plastic bag; the bag was purged with N₂ gas and sealed with tape. The samples were then stored in an upright position in a 4° C incubator while on the ship and were kept on ice during transport to the Buffalo laboratory of the GLL. Cores were

reincubated at 4° C upon arrival at the laboratory where they were extruded and interstitial water was extracted by a modification of techniques described by Brannon et al. (1976) and Engler et al. (1975).

66. After receipt and inventory of samples in the Lab, sediment core samples were placed one at a time in the outer chamber of a two-man glove box specifically designed and built for this project. The outer chamber was then purged with N₂ and evacuated simultaneously to match the inert environment of the larger inner chamber. The inner chamber was maintained at less than 2% oxygen as verified by a Polarographic Model IL 406 O₂ Analyzer. Keeping the samples in an upright position, they were brought into the glove box. The outer bag and both caps were carefully removed. If any water was observed on the top of the sediment in the core tube, it was added and mixed with the first or top section of sediment. The core was then extruded and sectioned (based on sample lithology) into plastic trays with a cork, glass rod, and rubber spatula of appropriate size. Each section was then split into halves for individual treatment. The 1975 cores were divided into three sections based on sample lithology. The 1976 cores were divided on the basis of lithology or into the top 10 cm and the remaining core. A schematic diagram for laboratory treatment of the cores is shown in Figure 15.

67. One-half of each section was weighted and sealed into an oxygen-free, tared, 500 ml plastic centrifuge bottle within the glove box. The sample was then centrifuged in a refrigerated centrifuge, a Beckman Model J-21B, at 9000 rpm for 5 min at 4° C, which was sufficient to obtain approximately 50% of the total interstitial water. The bottles were then returned to the oxygen-free glove box, and the interstitial water was vacuum-filtered through a filtering apparatus, using acid-washed and rinsed 0.45 µm membrane filters. The water was then placed into a beaker and analyzed for chloride ion concentration. These chloride analyses were only made for the 1976 samples. Chloride analysis was accomplished using an Orion Model 94-16 Chloride Electrode and a Fisher 420 Accumet pH Meter, as previously mentioned. A 20 ml subsample

was placed in a glass vial, preserved, and later analyzed for P_T , PO_4-P . A 4.5 ml subsample was placed into a glass vial and preserved with HCl and later analyzed for TOC. Approximately 100 ml was placed into a 120 ml plastic bottle and preserved with HCl and later analyzed for metals and nitrogen. All were placed in 4° C incubators.

68. The second half of the sediment sample was placed into a clean plastic jar and mixed thoroughly until it appeared to be homogeneous. The sediment sample was then measured for Eh and pH (and sulfide in 1975) using a Fisher 420 Accumet pH Meter, a Fisher Glass Combination Electrode, a Fisher Platinum Combination Redox Electrode, and an Orion Model 94-16A Sulfide Electrode (Orion Research 1970). Part of this sediment, after being removed from the box, was placed in clean, pre-dried, preweighted evaporating dishes and weighted. The sample was then dried at 70° C for 24 hrs, cooled, and dessicated. The sample was then reweighted for percent water and dry weight determinations. The dried sediment was then ground using a mortar and pestle and placed in dry 120 ml clean plastic bottles and was analyzed for particle size, carbon, ammonium and heavy metals. The remaining wet sediment was stored at 4° C and analyzed for Hg, cation exchange capacity (CEC), and oils and greases for all 1975 samples. Wet sediment samples collected during 1976 were analyzed for Hg content only. The sediment that remained in the centrifuge bottles was scraped out with nonmetallic utensils and placed in plastic jars. These samples were retained for historical purposes.

69. Sediment samples were analyzed for total phosphorus within a range of 0-20.0 mg P/ℓ. Higher concentrations were diluted prior to analysis. The determination of phosphorus is based on the colorimetric method in which a blue color was formed by the reaction of orthophosphate, molybdate ion, and antimony followed by reduction with ascorbic acid at an acidific pH. The blue phosphomolybdate ion complex was read at 660 nm. The automated equipment used included: (a) a sample, (b) a proportioning pump, (c) a Technicon Analytical Cartridge No. 116-0540-01, (d) a colorimeter with a 50 mm x 1.5 mm I.D. flow cell

and 660 nm filters, and (e) a recorder. Samples were digested using a Technicon BD-40 Block Digestor. The following modifications of Technicon Industrial Method No. 369-75A (Technicon 1974) for digesting were used. One gram of dried sediment was used. The acid digest solution consisted of 600 g K_2SO_4 in 1 ℓ of H_2SO_4 . Ten ml of solution were added to each sample. One ml of HgO solution was also added to each sample. Samples were digested for 1 hr at 225° C and 1 hr at 420° C. Samples were then diluted and analyzed as stated in the method. Technicon Industrial Systems Method No. 329-74W was then used to analyze the samples (Technicon 1974).

70. Samples were analyzed for TKN and ammonia to determine total organic nitrogen. Samples were analyzed for ammonia according to the procedure cited in Chemistry Laboratory Manual Bottom Sediments (FWQA 1969). Samples were digested for TKN using the digestion procedure stated for total phosphorus in sediment. Samples were analyzed according to the Technicon Industrial Systems Industrial Method No. 369-75A (Technicon 1974). Ammonia was calculated according to procedural directions. TKN was analyzed as mg N/ ℓ and converted to mg N/kg. Ammonia concentrations were then subtracted from TKN concentrations to yield total organic nitrogen (TON).

71. Organic carbon analysis was performed according to Coleman Model 33, Carbon-Hydrogen Analyzer, 33-900 Operating Directions (Coleman Instruments 1969). The use of the Coleman Model 33 Carbon-Hydrogen Analyzer allowed measurement of organic carbon in sediment to 0.01% carbon. Prior to analysis approximately 1 g of dried sediment sample was acidified with 1 N HCl, mixed, and taken to dryness at 70° C on a steam bath. This procedure removed the carbonates. The samples were then mixed with H_2O (deionized and distilled), permitted to settle, and the water was decanted off (removing the Cl^- ions). The samples were redried, crushed, and stored in a dessicator until analysis.

72. The method used for analysis of sediment samples for oils and greases content was from Standard Methods (APHA 1971). In these analyses reagent grade n-hexane was used.

73. Particle-size determinations applicable to dried sediments

with a practical range of quantification from < -1 (2.00 mm) to $> +9$ (0.0010 mm) Phi (ϕ) units were completed. Wet sieve analyses were not performed on the sediment samples. Dry sieve analyses were adapted for the particle-size determinations (Duncan and Rukavina 1970). At the request of WES personnel, dry and wet sieve techniques were evaluated on several sets of duplicate samples. These tests showed the dry sieve techniques yielded somewhat lower silt and clay percentages. The significance of this difference in methodology could not be ascertained due to the small N number in the comparison. The results of the dry sieve analyses, however, did yield results that were of importance in the data analyses, which are presented in the following sections. It was believed that wet sieving results may have yielded even stronger statistical results but would not have changed the overall significance of particle-size results from this study.

74. The original weight of sample used for particle-size analysis had to be a minimum of 10 g for accurate analytical results. Samples weighed to the nearest 0.1 mg were placed in a nest of U. S. Standard Sieves. These screens, in order from top to bottom, were # 18, # 35, # 60, # 120, # 230, and the catch pan, respectively. The sediment was then agitated in a Ro-tap Sieve Tapper for 10 min. Each fraction collected in the sieves was weighed and the percent weight of each size was calculated along with a total percent of silt plus clay in the catch pan. This fraction was further analyzed for silt and clay content using the FAST procedure (Duncan and Rukavina 1970) for 1975 samples and the Coulter Procedure (Coulter Electronics 1972) for the 1976 samples.

75. The CEC measurements of all 1975 wet sediment samples were completed. The methodology that was employed followed that of Ott and Toth (1970) or Engler*, except 5-10 g of sediment instead of 15-25 g was used. It should be noted that samples were incubated at 4° C prior to the first addition of 1 N NH_4OAc in order to retard losses due to

* Personal Communication, 1976, Dr. R. M. Engler, Project Manager, Environmental Impacts and Criteria Development, DMRP, WES, Vicksburg, Miss.

evaporation. Once the leaching process was completed with 1 N NH_4OAc , 80% EtOH, and 10% NaCl, the leachate was analyzed for ammonia according to U. S. EPA (1974) Methods Manual using the Selective Ion Electrode Procedure. Ammonia was determined potentiometrically using the ammonia probe and an Orion Model 701 pH Meter on the expanded millivolt scale.

76. In order to quantify the concentration of various sediment metals, dried sediment (1.000 ± 0.0005 g) was weighed into 125-ml Erlenmeyer flasks. While samples were on the electric hotplate, 20 ml of both concentrated hydrochloric and nitric acid were added and were allowed to boil down to a total volume of 5-10 ml. This process required about 6 hr of digestion time at a temperature of approximately 115°C . The above procedure was repeated for 5 days, yielding a total digestion time of 25-30 hr. The residue was then removed by filtering through $0.45\ \mu$ acid-washed membrane filters, and the volume diluted to 100 ml. This solution was directly aspirated into the spectrophotometer. The concentration mode was set to read directly the $\mu\text{g/g}$ of the solution. Mercury was measured using the manual cold vapor technique (U. S. EPA 1974). The alternate autoclave digestion was employed using 0.5 g of wet sediment rather than 0.2 g of dry sediment. The values were then corrected by dividing by the decimal dry weight.

77. All sediment metals analyses were run using analytical wavelengths as suggested by the manufacturer (Varian Techtron 1972). Other pertinent analytical instrument variables as well as typical detection limits and sensitivities are also presented in the above reference.

78. Sediment oxygen demand (SOD) determinations were obtained using a chamber designed and used for "Project Hypo" in 1970 (Lucas and Thomas 1972). Its triangular shape was chosen to maximize area of bottom sediment and minimize volume of water (Figure 16). In this way, oxygen depletion rates could be measured after a relatively short period of time without disturbing bottom sediments. The oxygen sensor used was a Yellow Springs Instruments Model 5739 Probe coupled to a YSI Model 54 ARC Oxygen Meter. A submersible pump was used to circulate chamber water to ensure a constant flow past the probe membrane.

79. Before lowering the chamber, DO and temperature profiles were taken to characterize the water column using another YSI Probe. This probe as well as the one used in the chamber was air-calibrated before use. The chamber was then lowered to the sediment-water interface after priming the pump. On the first day of using the chamber (7 June 1976), divers observed the chamber as it settled on the bottom. It was noted that the chamber settled with little disturbance of bottom sediments and a good seal of the baseplate with the sediment was easily obtained. Divers were not used for subsequent samplings on 17 June and 13 September 1976.

80. The DO content was noted at time zero and readings were taken every 5 min for 20-30 min. After a depletion rate was established, the chamber was raised and set down in a different location. Replicate measurements were made at both the reference and disposal sites.

81. Analytical quality control was maintained at a 20% level for the duration of the project for all parameters. In consideration of those variables where spikes could be used, the 20% quality control consisted of 10% replication and 10% recovery in order to verify precision and accuracy, respectively. Samples for quality control estimates were randomly selected. The actual technique for selection was parameter dependent. Generally, replicate analyses plus a spike of that same sample were made on every fifth or sixth sample of each set of analyses. A summary of the results of the quality control data is given in Table 7. It should be noted that the data presented represent quality assurance on environmental samples and not merely on the standard solutions used for calibration of the instrument and/or procedures.

Statistical Data Handling

82. All chemistry data were stored in auxiliary computer memory (IBM 370/158) in the form of two-dimensional tables of N columns and M rows using APL language. Each column in the table represented a station and each row represented the sample replicates from that station for one parameter to either lake water, interstitial water, interface water, or

sediment.

83. Tables were then subjected to statistical tests to determine their normality and homoscedasticity. A chi-square test was used to check for normality and a Bartlett's Test for multiple groups was employed to test for homoscedasticity. The table was assumed to be normal and homogeneous unless the Chi-square value and Bartlett's Chi value were significant at the 0.05α (alpha) level at the specific degrees of freedom. If the table was not normal and homogeneous, it was subjected to a transformation and then retested.

84. The normal and homogeneous (raw or transformed) data tables were then subjected to an analysis of variance test. The GLL used a one-way nested analysis of variance (ANOVA) design to analyze the data. This design was particularly suited to these data as the sampling scheme involved randomly selected replicate samples at stations which were nested within predetermined subareas.

85. The following comparisons were done within the data from each 1975 cruise:

- a. Reference Area vs. Harbor Dredgings Area
- b. Reference Area vs. River Dredgings Area
- c. Harbor Dredgings Area vs. River Dredgings Area

Additionally, comparisons were made between the predisposal and postdisposal sampling sites. The 1975 predisposal Reference, Harbor, and River sites were compared with the corresponding 1975 postdisposal sites as indicated below:

- | <u>PREDISPOSAL</u> | | <u>POSTDISPOSAL</u> |
|--------------------------|-----|-----------------------|
| a. Reference Area | vs. | Reference Area |
| b. Harbor Dredgings Area | vs. | Harbor Dredgings Area |
| c. River Dredgings Area | vs. | River Dredgings Area |

86. A Tectronix 4013 Computer Graphics Terminal was used to begin graphically displaying the data by August 1976. At this time, approximately one-half of the 1975 chemical data generated had been subjected to the aforementioned series of procedures. The computer graphics were employed originally as a method to condense and display the data. However, it readily became evident that the graphics could be used as an additional

statistical tool. The most useful statistically oriented graphic display appeared to be one employing means and corresponding confidence intervals of the three subareas mentioned previously. The mean and confidence intervals were calculated using these steps. First, the mean of the raw data within each subarea was calculated. The standard error was then computed for each subarea. A corresponding 95% confidence interval was then computed for each subarea. This confidence interval was based on the estimated standard error of the mean and the degrees of freedom. If the degrees of freedom were small (< 30), the T-distribution, not the normal distribution, was used to calculate the 95% confidence level.

87. The data were then graphically displayed with a solid line indicating means and intersection bars indicating each mean's confidence interval. As graphs were produced, they were compared to the nested ANOVA results. In the cases compared, the results from the ANOVA matched those given by the graphical display. Further ANOVA testing was based upon the results of the graphic displays. That is to say that obviously nonsignificant differences were not further tested via ANOVA.

88. One graphic data presentation showed both long-term (Reference and Disposal Sites at both predisposal and postdisposal dates) and short-term effects (Reference vs. Disposal Sites at the same date) for a parameter at one depth. The mean and confidence interval graph was used for the great majority of the data, and the nested ANOVA was employed to confirm and check the graphic results.

89. To summarize, the GLL used mean and confidence intervals that were displayed graphically to examine the impact of dredging and disposal as determined through chemistry parameters. For sediment and interstitial water in the 1975 phase, one graph consisted of the Reference Area, River Dredging Area, and the Harbor Dredging Area at all the cruises before and after disposal for the parameter at any one depth. For lake water in the 1975 study the graphs were done somewhat differently. Since no short-term effects (i.e., no difference between the reference water sites PW1, PW2, and the disposal sites PW3, PW4, or PW5 and PW6 at the same cruise) were found via ANOVA, only the longer term predisposal vs. postdisposal effects were displayed. A graph consisted of one mean and confidence interval for

all PW stations, regardless of location, for each cruise. A graph displayed both the surface and bottom values for one parameter.

90. In the 1976 phase, sediment, interstitial water, and interface water parameters were displayed in the same manner as the 1975 study. One graph showed the reference area and disposal area for all four 1976 cruises for a parameter at one depth. Lake water data from 1976 were handled in the same manner as the 1975 lake water data.

91. Other statistical handling of data via discriminant and multiple regression analyses were performed according to the Statistical Package for Social Sciences (SPSS) routines by Nie et al. (1970).

PART V: RESULTS

Aquatic Chemistry

92. The aquatic chemistry results have been divided into three more or less independent sections. The first section deals with the water chemistry data collected during all sampling events except disposal operations. The second section concerns the chemistry data gathered during disposal operations. The third section includes the results from the interface data collected in 1976.

93. These divisions within the aquatic chemistry results were based upon the fact that data from all sampling events except disposal operations were considered as a simple limnological survey. It was also observed that disposal operations had little or no direct effects on the results of the other water-quality samplings even when collections were completed within 24 hr of the cessation of disposal. Generally, interface water chemistries were found to be more a function of sediment characteristics and not the remaining overlying water column and are, thus, presented separately.

All sampling events except disposal operations

94. In general, the figures contained in the first section illustrate results, distinguishing only between surface and bottom collections. These figures also show the mean and associated 95% confidence interval for each parameter as measured at all stations within each event. This was possible since no statistical difference among parameters existed between stations sampled during each event. The only exceptions to the above were temperature, dissolved oxygen, specific conductance, and pH. For temperature and dissolved oxygen, representative stations in the reference area and disposal areas (two disposal sites in 1976) were selected and profiles were displayed. The actual figures for these data are presented later in this section of the report.

95. It should be noted that in situ profiles were made only for temperature, dissolved oxygen (DO), and specific conductance (Sp. Cond.).

The pH measurements were taken at three depths: a meter below the surface, middepth, and a meter above the bottom. In the following text the term "surface" will refer to the collection from a meter below the surface, while "bottom" refers to the sample taken a meter above the bottom. Alkalinity and Eh measurements were made on surface and bottom water collections at the on-site field laboratory. Split and preserved samples were returned to the GLL for analysis of remaining parameters. Temperature, DO, Sp. Cond., and pH were the only chemical measurements taken on 11-13 June and 19 October in 1975. Table 8 lists sampling dates and numerical identifications that have been used for figures presented in this section. In 1975, profiles were measured and samples collected at Stations PW1 through PW11. In 1976 only Stations PW1, PW2, PW3, PW5, and NDS were utilized to measure profiles and collect water samples. Since no statistical difference existed among the results between the stations within each survey, it had been postulated that this reduction in sampling sites would yield an adequate chemical limnological description of the study area.

96. Temperature and DO profiles. During the Initial Survey (11-13 June 1975) temperature profiles generally were uniform with depth (Figure 17). Surface temperatures varied from 17 to 20° C. This temperature range was observed throughout the water column with little change. There was no evidence of a thermocline, which had become established in other areas of the Central Basin. DO was near the saturation level at the surface, decreasing gradually to about 85% near the sediment-water interface (Figure 17). The concentrations ranged from 8.0 - 9.6 mg O₂/ℓ.

97. Later (9-11 July 1975) temperature profiles revealed the presence of a thermocline, 9-11 m below the surface, with the metalimnion continuing to the bottom (Figure 17). Temperatures at the surface were 23.0 - 24.0° C with bottom waters at 14.0 - 17.0° C. DO, ranging from 9.0 - 9.8 mg O₂/ℓ, at the surface was at saturation or supersaturation levels (Figure 17). Middepth waters were near saturation levels. At several stations, a reduction in oxygen at the bottom was evident. During the period, Station PW1 had the lowest recorded

dissolved oxygen, 4.2 mg O₂/ℓ and 40% saturation, 17 m below the surface.

98. During the 30-31 July 1975 sampling period there was no evidence of a thermocline. Surface temperatures were 24.0 - 25.0° C, slowly dropping through the water column to 22.0 - 23.0° C at the bottom (Figure 17). The DO concentrations ranged between 8.0 - 9.6 mg O₂/ℓ at the surface and middepth (Figure 17). All stations revealed an oxygen deficit at the bottom with values as low as 4.4 mg O₂/ℓ recorded.

99. A few hours after the completion of disposal on 14 August 1975, temperature profiles revealed a thermocline was present approximately 13 m below the surface. Temperatures decreased from 24.5° C at the surface to 13.0° C at the bottom (Figure 18). The DO concentrations at the surface ranged from 8.2 - 9.4 mg O₂/ℓ (Figure 18). These concentrations were maintained through the middepths, dropping off sharply at the thermocline. The lowest DO concentration recorded was 3.3 mg O₂/ℓ at Station PW4 at a depth of 16.5 m.

100. On 19-20 August 1975, 5 days after disposal, temperature profiles again revealed a thermocline present at a depth 13-14 m below the surface. Surface temperatures were 22.0 - 23.0° C, falling off sharply at the thermocline to a level of 13.0 - 14.0° C at the bottom (Figure 18). Figure 18 shows DO profiles that were typical of all stations during the 19-20 August 1975 sampling. An oxygen deficit at the bottom was evident at all stations, with the lowest concentration (3.0 mg O₂/ℓ, 30% saturation) recorded at Station PW5 in the disposal area.

101. Three samplings were made during the late summer and fall 1975 (12-14 September, 19 October, and 16-17 November). Figure 19 exhibits the unithermal conditions that were present during each of these collection phases. However, the mean temperature did decrease with each successive event (20.0° C in September, 14.0° C in October, and 10.0° C in November). The DO levels ranged from 80-90% saturation during each of these sampling periods (Figure 19). However, slight increases in DO concentrations were recorded for September (8.0 - 9.0 mg O₂/ℓ), October (9.0 mg O₂/ℓ), and November (> 10.0 mg O₂/ℓ).

102. The first sampling of 1976 on 21 April had temperature profiles which revealed no thermocline. Temperatures of 8.0 - 9.0° C at the surface were recorded, which gradually decreased to 5.7 - 6.3° C at the

bottom (Figure 20). The DO profiles consisted of concentrations greater than 14.0 mg O₂/ℓ at the surface, decreasing slightly at the bottom to 12.7 - 13.8 mg O₂/ℓ (Figure 20). Some of the stations showed a slight increase in the middepth regions; Stations PW1 and PW2 had values of 14.8 mg O₂/ℓ at 2-7 m below the surface. This translated to saturations of 119% at the surface, 123-125% in the middepth regions, and 101-109% at the bottom.

103. No thermocline was present during the May 1976 sampling (Figure 20). Surface temperatures varied between 11.0 - 11.5° C with a slight decline with depth to 10.4 - 10.8° C at the bottom. The DO profiles revealed a slight decrease in concentrations with depth (Figure 20). Values of 11.0 - 11.3 mg O₂/ℓ were measured at the surface and 10.5 - 10.7 mg O₂/ℓ at the bottom. This converts into saturation levels of 100-102% at the surface, and 94-97% at the bottom.

104. Five days after the 1976 disposal phase was completed (10-11 June 1976) temperature profiles showed weak thermal stratification (Figure 21). While a well-defined thermocline was lacking, in a few instances the temperature gradient approached 1° C/m of depth. Surface temperatures ranged from 18.0 - 19.0° C with a decrease to approximately 10° C at the bottom. The DO ranged from 10.0 - 11.0 mg O₂/ℓ at the surface, decreasing with depth to values of 8.2 - 9.2 mg O₂/ℓ at the bottom (Figure 21). This corresponded to saturation levels of 110% at the surface and 73% at the bottom. No significant difference was seen between the Reference and Disposal Areas with respect to DO during this sampling.

105. During the 30-day 1976 postdisposal sampling (7-8 July 1976) temperature profiles indicated that no thermocline was present (Figure 21), although stratification was present in other areas of the Central Basin. Temperatures recorded at the surface were approximately 21.5° C, 19.0 - 20.0° C in the middepth regions, and 18.0° C at the bottom. The DO was supersaturated at the surface with concentrations of 9.2 - 9.6 mg O₂/ℓ and saturated at the middepth region with concentrations of 8.6 - 9.2 mg O₂/ℓ (Figure 21). Bottom values exhibited an oxygen deficit. At Reference Stations PW1 and PW2, bottom oxygen concentrations were approximately 8.0 mg O₂/ℓ or 85% saturation. At Station PW3 (in the Disposal

Area) concentrations were at 7.3 mg O₂/ℓ or 77% saturation. At Station PW5 (also in the Disposal Area), DO concentrations were 5.6 mg O₂/ℓ with saturation levels of 53%. The 1976 disposal site, NDS, also showed a greater DO deficit as compared to the Reference Area. Values of 7.1 mg O₂/ℓ or 75% saturation were recorded at NDS.

106. Eh measurements. During 1975, Eh measurements were taken. It was determined that no statistical difference existed between surface and bottom water samples within and between events. All samples were oxidizing in nature.

107. pH measurements. During the initial sampling, 10-11 June 1975, pH was uniform within the water column with values ranging from 8.1 - 8.4. On 9-11 July 1975, pH ranged from 8.2 - 8.5 at the surface, with a slight increase through the middepths (8.4 - 8.7). The pH values decreased at the bottom (7.9 - 8.2). During the 30-31 July 1975 sampling period, the pH values were again uniform with depth and from station to station. At any given station, pH values varied only 0.3 - 0.4 units throughout the water column. The total range of pH values was 8.1 - 8.8.

108. On 14 August 1975, a few hours after disposal operations were completed, pH values ranged from 8.5 - 8.6 at the surface, decreasing to 8.1 - 8.2 at the bottom. A sampling 5 days later (19-20 August 1975) revealed surface pH values ranging from 8.3 - 8.5, while bottom values ranged from 7.8 - 7.9.

109. The pH values during the last three sampling periods in 1975 revealed very homogeneous conditions throughout the water column. Typical differences through the water column were 0.2 - 0.3 pH units. Values ranged from 8.0 - 8.5 during September and October. There was a decrease to 7.5 - 8.0 in pH during November.

110. During the April and May 1976 collections, pH values were quite similar at the surface (8.2 - 8.3) and at the bottom (8.1 - 8.2). The postdisposal collection in June revealed only a slight increase in pH at the surface (8.3 - 8.4). The bottom pH values showed a significant ($p = 0.031$) decrease in pH (7.7 - 8.1) as compared to the results from predisposal samplings. During the 7-8 July 1976 sampling, surface pH values ranged from 8.5 - 8.6 and bottom pH values were approximately 8.3.

111. Specific conductance. During the initial sampling, 10-11 June 1975, corrected specific conductance (Sp. Cond.) values revealed some variations. Surface readings generally ranged from 470-480 $\mu\text{mhos/cm}$. The typical values at the mid- and bottom depths increased slightly to 480-570 $\mu\text{mhos/cm}$. The Sp. Cond. values measured during this survey were suspected to be too high when compared to those gathered during the remainder of the study. During the 9-11 July 1975 sampling, Sp. Cond. measurements revealed fairly uniform conditions throughout the water column. Values generally varied from 270-380 $\mu\text{mhos/cm}$. During the 30-31 July sampling period, Sp. Cond. values, with little deviation from 300 $\mu\text{mhos/cm}$, were still uniform from station to station.

112. On 14 August 1975, the last day of disposal, Sp. Cond. values (280-310 $\mu\text{mhos/cm}$) were fairly uniform throughout the water column and from station to station. The exceptions to this were PW3 and PW4 in the Disposal Area. At PW3, a range of 612 $\mu\text{mhos/cm}$ at the surface to 792 $\mu\text{mhos/cm}$ at the bottom was recorded. Station PW4 had a range of 428-480 $\mu\text{mhos/cm}$. During the 19-20 August sampling, Sp. Cond. did not show any significant difference between the Disposal and Reference Areas. Values ranged from the high 200's to the upper 300's and increased slightly with depth.

113. The September and October samplings revealed uniform Sp. Cond. values throughout the water column. Values ranged from the upper 200's to the lower 300's. There was little change with depth or from station to station. No conductivity profiles were obtained during November due to a malfunctioning meter.

114. During the initial 1976 sampling on 21 April, profiles revealed that Sp. Cond. values ranged from 259-290 $\mu\text{mhos/cm}$ at the surface to 266-277 $\mu\text{mhos/cm}$ at the bottom. During the 1976 predisposal sampling, 15-16 May 1976, Sp. Cond. values exhibited little change with depth and between stations. Values of 288-298 $\mu\text{mhos/cm}$ were recorded at the surface while bottom values ranged from 298-303 $\mu\text{mhos/cm}$.

115. During the 5-day postdisposal sampling, 11-12 June 1976, Sp. Cond. values at the surface were approximately 280 $\mu\text{mhos/cm}$. At 6-12 m below the surface, values ranged from 300-312 $\mu\text{mhos/cm}$. At the bottom, values dropped to 294-302 $\mu\text{mhos/cm}$. Profiles taken during

the 30-day postdisposal sampling of 7-8 July 1976 did not reveal any substantial differences in Sp. Cond. between stations. Values of 277-283 $\mu\text{mhos/cm}$ were recorded at the surface. At most stations there was a slight increase in values with depth. Bottom Sp. Cond. values ranged from 291-298 $\mu\text{mhos/cm}$.

116. Alkalinity. Alkalinity measurements were taken during the 1975 sampling year. The bottom alkalinity values were significantly higher ($P = 0.016$) than surface values during thermally stratified conditions (Figure 22). During unstratified conditions the surface and bottom alkalinity values were uniform with depth. Surface alkalinity concentrations generally increased from the 9-11 July 1975 (pre-disposal) sampling (87.4 mg/l as CaCO_3) to a mean of 93.1 mg/l as CaCO_3 by 19-20 August 1975. The mean alkalinity then decreased to 89.1 mg/l as CaCO_3 in September and showed a yearly maximum in November (based on these collections) with a mean of 96.5 mg/l as CaCO_3 . The bottom alkalinity values decreased from the 9-11 July to the 30-31 July 1975 sampling (91.5 to 90.5 mg/l as CaCO_3 , respectively). The alkalinity means then increased significantly through the 14 August 1975 (last day of disposal) sampling to a maximum mean alkalinity concentration of 101.3 mg/l as CaCO_3 during the 5-day postdisposal sampling, 19-20 August 1975. The alkalinity then decreased in September to a mean of 89.0 mg/l as CaCO_3 , increasing again in November to a mean alkalinity of 96.1 mg/l as CaCO_3 .

117. Chloride concentration. Chloride (Cl^-) measurements were taken during the 1976 samplings. Lake water samples from both the surface and bottom regions showed a significant Cl^- increase, from a low mean of 21.6 mg Cl^-/l in samples taken on 21 April 1976 to 25.4 mg Cl^-/l in samples taken on 15-16 May 1976 (Figure 22). The Cl^- concentration, having a mean of approximately 25 mg Cl^-/l over the duration of the 1976 sampling period.

118. Turbidity. Turbidity was measured during the 1976 samplings. Turbidity measurements generally were slightly higher in the bottom samples than in the surface collections (Figure 22). During April, turbidity measurements had a mean of 1.8 NTU in the bottom collections and a mean of 1.2 NTU in the surface samples. The mean values then

increased significantly to a 1976 maximum mean of 6.0 NTU in the bottom and 4.4 NTU in the surface collections in May. Turbidity means then decreased to approximately 0.9 NTU in June and July.

119. Total suspended solids. Total suspended solids (TSS) were measured during the 1976 sampling. The TSS trends paralleled the pattern for turbidity. The maximum May measurements revealed a bottom mean of 11.4 mg/ℓ and a surface mean of 7.5 mg/ℓ in samples collected during this period (Figure 23). The April, June, and July collections showed means of approximately 1.1 mg/ℓ TSS.

120. Dissolved sulfate. Dissolved sulfate content, as measured during each study period in 1975 was very consistent. No appreciable change in sulfate levels occurred during and/or between any sampling period. The mean sulfate concentration encountered was approximately 23 mg SiO₂/ℓ. As a consequence, sulfate analysis was discontinued after the 1975 collections.

121. Silica concentrations. Silica concentrations were generally higher in the bottom water samples than in the surface water samples (Figure 23). The means in the surface ranged from 0.05 to 0.40 mg SiO₂/ℓ during the entire study. Silica decreased in 1975, from pre- to postdisposal, in the surface samples. During 1976 surface means generally increased from April to July.

122. Predisposal bottom silica mean concentrations were approximately 0.67 mg SiO₂/ℓ. On the last day of disposal operations, 14 August 1975, a slight increase in mean silica concentration was evident in the bottom samples (0.85 mg SiO₂/ℓ). A more pronounced increase was present in the bottom waters 5 days after disposal, 19-20 August 1975. Silica mean concentration in the bottom water samples had almost doubled to a mean of 1.55 mg SiO₂/ℓ from the previous sampling. The 30-day post-disposal sampling, 14 September 1975, showed more than a 50% decrease (0.35 mg SiO₂/ℓ) in silica in the bottom waters. The bottom silica concentrations exhibited further declines in the November collections. In 1976, the silica concentration in the bottom water displayed the lowest mean of 0.10 mg SiO₂/ℓ. The silica means then steadily increased to a mean concentration of 0.45 mg SiO₂/ℓ in the bottom depth samples during 7-8 July 1976.

123. Ammonia nitrogen. The ammonia nitrogen ($\text{NH}_3\text{-N}$) predisposal mean concentration was approximately 0.018 mg N/ ℓ (Figure 24). On the last day of disposal (14 August 1975), the $\text{NH}_3\text{-N}$ mean significantly decreased to approximately 0.004 mg N/ ℓ . The $\text{NH}_3\text{-N}$ means remained low throughout the remaining 1975 sampling periods. In April 1976, $\text{NH}_3\text{-N}$ means remained at those lower levels through the 7-8 July 1976 sampling, with the surface and bottom means fluctuating in an inverse pattern.

124. Total Kjeldahl nitrogen. The TKN was measured on all water samples in 1975. Predisposal TKN had a mean concentration of 0.088 mg N/ ℓ (Figure 24). The immediate effect of the disposal of dredged spoils was a twofold increase (0.150 mg N/ ℓ) of mean TKN concentrations as measured on 14 August 1975. Five days after disposal ceased (19-20 August 1975), TKN measured values peaked to 0.320 mg N/ ℓ . TKN levels in September and November exhibited a decrease, although never returning to predisposal levels.

125. Nitrate nitrogen. Nitrate nitrogen ($\text{NO}_3\text{-N}$) exhibited little variation during the study period (1975). Predisposal concentrations showed no difference between surface and bottom samples and had a mean of 0.0079 mg N/ ℓ . Immediately after disposal of dredged material (14 August 1975), the levels in the bottom waters were not altered. However, surface concentrations decreased more than one-half the previous values. The results from the September and November samplings showed a decrease of $\text{NO}_3\text{-N}$ in the bottom waters and, consequently, a return to homogeneous conditions in the water column with respect to this parameter.

126. Nitrite nitrogen. Nitrite nitrogen ($\text{NO}_2\text{-N}$) concentrations were low. Surface collections analyses exhibited a slightly higher level than those from bottom waters. The overall $\text{NO}_2\text{-N}$ mean for 1975 was 0.00112 mg N/ ℓ .

127. Orthophosphorus. The soluble orthophosphorus ($\text{PO}_4\text{-P}$) means for two 1975 predisposal surveys were 0.0010 mg P/ ℓ on 9-11 July and 0.0020 mg P/ ℓ on 30-31 July 1975 (Figure 25). $\text{PO}_4\text{-P}$ showed an increase to a mean of approximately 0.0040 mg/ ℓ on the last day of disposal which was statistically significant in the surface samples

($P = 0.027$). By 5 days after disposal ceased, PO_4-P concentrations had decreased to predisposal levels. Mean PO_4-P concentrations increased in September and had a mean of 0.0090 mg P/l in November. In April 1976 a low PO_4-P mean of 0.0010 mg P/l was observed. A peak mean concentration of 0.0085 mg P/l was noted in May. PO_4-P means decreased in the 1976 postdisposal sampling in June and July.

128. Total phosphorus. The 1975 predisposal P_T concentrations had a mean of 0.025 mg P/l. The apparent effect of disposal was the decrease of P_T to a mean of 0.005 mg P/l. Five days after the disposal operation had ceased, the mean P_T concentration increased to predisposal levels. The P_T mean concentrations then increased during the November sampling, which had a mean of 0.038 mg P/l. In 1976 P_T concentrations did not vary greatly. Five days after the 1976 disposal operation ceased, surface mean concentrations showed a decline to 0.016 mg P/l. Thirty days after disposal, the surface water mean returned to a predisposal level of 0.025 mg P/l (Figure 25)

129. Dissolved organic carbon. The DOC was measured in the collections obtained during the 1975 sampling events and in April and July 1976. The DOC in the water column appeared to be uniform within all samplings, and no statistical difference between surface and bottom concentrations were noted. A high DOC mean of 12.1 mg C/l was observed in the 9-11 July 1975 samples (Figure 26). By 30-31 July 1975, DOC concentrations dropped significantly ($P = 0.031$) to approximately 5.6 mg C/l. During July and continuing to the November sampling, DOC means increased with time from 4.7 to 8.1 mg C/l. The maximum DOC mean concentration (13.6 mg C/l) was noted during April 1976. The DOC values then decreased markedly to a mean of 4.9 mg C/l during the 7-8 July 1976 sampling.

130. Particulate organic carbon. The POC appeared to be uniform within all sampling periods. No statistical difference between surface and bottom concentrations were noted (Figure 26). An increase in POC means during July was observed. Values rose from 0.5 mg C/l in 9-11 July 1975 to 2.6 mg C/l in 30-31 July 1975. The mean POC concentration then decreased to about 0.5 mg C/l during the August samplings. A slight, yet significant ($P = 0.047$) increase (1.1 mg C/l) in POC from

August to November was noted. A maximum POC mean of 4.4 mg C/ℓ was observed during the April 1976 sampling. The POC mean concentration remained relatively high (2.6 mg C/ℓ) during the May 1976 collection. A decrease in POC was revealed by a mean of approximately 0.6 mg C/ℓ during the June and July 1976 samplings.

131. Heavy metals. Dissolved cadmium (Cd), copper (Cu), nickel (Ni) and lead (Pb) concentrations were below detectability for all Lake water samples taken during 1975. The detection limits, respectively, were 0.005, 0.010, 0.015, and 0.025 mg/ℓ.

132. Mercury (Hg) trends are displayed on Figure 27. There appeared to be no significant differences in Hg with depth within any sampling. It was believed the two 1975 predisposal samplings were contaminated with Hg Cl₂ from the previously used sample bottles. The first uncontaminated collections were during the last day of disposal (14 August); these samples had a mean concentration of 0.0019 mg Hg/ℓ. The concentration of Hg then increased through the 19-20 August 1975 sampling to a mean of 0.0047 mg Hg/ℓ during the September collection. The rest of the 1975 samplings showed considerably lower Hg concentrations, with the highest mean being only 0.0005 mg Hg/ℓ. The highest mean value for dissolved Hg concentration in 1976 was 0.0004 mg Hg/ℓ, measured during the July 1976 samplings. This, however, was not significantly higher than the other mean values of approximately 0.0002 mg Hg/ℓ, measured for the other 1976 collections.

133. The dissolved iron (Fe) concentrations in the samples taken during the 9-11 July 1975 sampling appear to be anomalies. Means of 0.0466 mg Fe/ℓ at the surface and 0.1336 mg Fe/ℓ at the bottom and the wide confidence intervals appear to support this conclusion (Figure 27). The means from this sampling, therefore, were not displayed. Mean Fe concentrations remained constant from the 30-31 July 1975 sampling to the last day of disposal (14 August 1975). Means were approximately 0.014 mg Fe/ℓ in the surface samples and 0.0085 mg Fe/ℓ in the bottom collections. Mean Fe concentrations increased during the 5-day postdisposal collection (19-20 August 1975) to a peak of about 0.034 mg Fe/ℓ. A decrease in Fe concentrations to a mean of approximately 0.010 mg Fe/ℓ during September was followed by an

increase to a mean of 0.027 mg Fe/ℓ in November. During 1976 Fe concentrations remained relatively constant. Generally, mean Fe concentrations ranged from 0.004 to 0.006 mg Fe/ℓ.

134. Dissolved zinc (Zn) concentrations showed a mean of 0.010 mg Zn/ℓ during the 9-11 July 1975 sampling (Figure 27). A lower mean of 0.007 mg Zn/ℓ was recorded during the 30-31 July 1975 sampling. Mean Zn concentrations made successive increases on the last day of disposal, 14 August, and on the 19-20 August sampling, reaching a mean of 0.010 mg Zn/ℓ. Zinc values decreased in September to a mean of 0.007 mg Zn/ℓ, increasing again in November to a mean of 0.010 mg Zn/ℓ. In April 1976, Zn concentrations reached a peak mean of 0.018 mg Zn/ℓ. During May and June 1976, Zn means were lower than the previous sampling. Means in the range of 0.001 to 0.003 mg Zn/ℓ were observed. The zinc concentration once again increased to 0.012 mg Zn/ℓ from the June-July sampling.

135. Generally, dissolved manganese (Mn) concentrations were significantly higher in the bottom collections versus the surface samples (Figure 27). The mean Mn concentrations initially decreased from the 9-11 July 1975 sampling (0.012 mg Mn/ℓ) to the 30-31 July sampling (0.006 mg Mn/ℓ). Commencing with the predisposal sampling (30-31 July 1975), Mn bottom concentrations increased from 0.010 to 0.038 mg Mn/ℓ as measured during the 5-day postdisposal, 19-20 August. An increase in the surface Mn concentrations was not noted until the 30-day postdisposal sampling, 14 September 1975, by which time the bottom concentration had declined. The November sampling indicated mean Mn values (0.004 mg Mn/ℓ) had returned to predisposal levels. The low Mn values continued into April, May, and June of 1976 when means of 0.002 mg N/ℓ were reported. A marked increase (0.023 mg Mn/ℓ) in concentrations in the bottom collections during the 30-day postdisposal (1976) was noted, while the surface mean concentration (0.002 mg Mn/ℓ) remained low.

Disposal operations

136. Following the dredging of the Ashtabula River and Harbor, the GLL monitored the Disposal Sites in order to ascertain any changes in water quality as a result of the open-lake depositions. Two separate disposal operations at three sites were monitored.

137. The deposition of Harbor materials at D2 and River materials

at D8 were investigated in August 1975 following dredging operations of the Markham. During this phase of the project five vessels were used in the two-part investigation. Four vessels were anchored downcurrent of the Disposal Site and the fifth boat followed the surface turbidity plume resulting from the disposal. Figure 8 shows the positions of the anchored vessels during the disposal monitoring. The first part of the work was to use only transmissivity in attempts to track the turbidity plume. These data showed that only the vessel anchored approximately 50 m from the Disposal Site (A1) was directly influenced by the turbidity plume. Whether the lack of any significant turbidity plume at the other vessels (A2 through A4) was a function of rapid settling, shifting currents, and/or positioning could not be determined. On the days following the above study, the same vessels were rearranged closer to the Disposal Site down-current of the Disposal Site. Water bottle samplings were initiated at fixed time intervals and depths as deemed appropriate, based on the transmissivity results.

138. All chemical analyses of these water bottle collections confirmed the transmissivity results. Only in the samples gathered from the vessel at A1, was there any evidence of a turbidity plume. The collections from the moving vessel, which followed the plume, also showed values believed to be indicative of a plume from the disposal operation. The data from these samples, however, because of the lack of information as to their location, the depth, and time of collection in reference to the disposal, were of little value. Since all values found within this sampling scheme were within the limits of the data found in the 1976 monitoring effort, no further data analyses were attempted. The only supported conclusion from the 1975 monitoring was that although the disposal operation disrupted the thermocline (Figure 28), it did reestablish rapidly and seemed to serve as a barrier to dispersion of the disposed material. As was seen in the transmissivity data, the thermocline did serve as an upper limit for the dispersion of the coarser grained materials suspended in the water column.

139. In May 1976 the dredge Hoffman was working in the Ashtabula River. Following dredging operations on 24, 25, and 26 May, the GLL

monitored open-lake disposals at NDS. Using the previously described continuous monitoring system aboard the Dambach, the staff of the GLL investigated the deposition of four loads of material on each of the three days. Different types of dredging and disposal techniques were used in attempts to determine what, if any, differences resulted from these variations. These techniques included dredging with or without overflow, disposal with or without flushing, dredge arms up or down during disposal, and stationary or moving disposal. During this phase of the study the Dambach was tethered with 50 m of line directly to the buoy marking the Disposal Site. The positioning of the Dambach on each sampling day is shown in Figure 10. The monitoring system employing pumped water from three depths (1, 14, and 17 m below the surface on 24 May and 1, 16, and 17 m below the surface on 25 and 26 May) was used to determine when samples for subsequent chemical analyses should be collected. Along with this event sampling, fixed time sampling also was conducted as previously mentioned. The only problem that has arisen as a result of this sampling design was the difficulty in ascertaining the distance between the dredge Hoffman and the R/V Dambach during each monitored disposal.

140. Monitoring also was completed following the third and fourth disposals on 25 May and the first and second disposals on 26 May by means of the John Carroll University team, under contract to the GLL. The purpose of this monitoring effort was to determine the dispersion of the turbidity plume and the rate of change of the chemical intensity of the plume as a function of distance. The position of the John Carroll University vessel on various days and/or disposals is also shown in Figure 10.

141. All water samples collected were delivered periodically to the land-based laboratory for splitting, preservation, and/or on-site analysis. All methods of analysis were either EPA- or Corps-approved techniques.

142. Specific conductance. Conductivity measurements via the continuous monitoring system showed no significant changes at any depth except for a small peak at the surface following disposal 1 on 26 May, and at 14 m after disposals 3 and 4 on 24 May. Means and 95% confidence limits are presented in Table 9.

143. Surface conductivity values taken from the bottle sampling also exhibited no significant change as a result of disposal operations. Conductivity measured on the 14 m samples from 24 May also showed no effects of disposal. The 16 samples collected on 25 and 26 May, however, did parallel the turbidity peaks in that they returned to ambient conditions in 15 to 20 min after deposition. At the 17 m depth, the only change seen on 24 May was after disposal 3. This might have been due to a stationary disposal with flushing. On 25 and 26 May in the bottom depth samplings, peaks paralleled turbidity with respect to returning to ambient within 15 or 20 min. As illustrated in Figure 29, the 17 m depth increases were generally much larger than the increases seen at 16 m. The previously reported (via personnel communication with WES) increases in conductivity occurring prior to turbidity peaks were believed to be anomalies. These initial increases were concluded to be merely a function of lag time in turbidity measurements.

144. Obvious differences existed between the continuous monitoring data and the laboratory results for conductivity. This paradox was believed to be a function of the sensitivity of the continuous monitoring conductivity instrument. The lowest range of this device was in m mhos/cm while the laboratory instrument was accurate in the low μ mhos/cm range. It was this latter accuracy which was needed to detect differences due to disposal.

145. Turbidity. Turbidity measurements via the continuous monitoring system proved to be the most reliable on-site variable for plume definition. Surface turbidity measurements showed no significant changes as a result of disposal except for one small peak after the first disposal on 26 May. Surface means (\pm 95% confidence limits) for the 3 days were 4.6 ± 0.4 , 4.1 ± 0.4 , and 3.9 ± 0.4 NTU, respectively.

146. Turbidity measurements at 14 m on 24 May, after the third and fourth disposals, did show some variance. These changes, however, were insignificant relative to the changes found at the 17 m depth but did imply some effects of disposal. The mean and 95% confidence limit at 14 m for turbidity was 4.6 ± 0.4 NTU. At the 16 m depth on both 25 and 26 May, turbidity paralleled the disposal operations with sharp peaks usually occurring within 2 min of time zero (release of dredgings)

and returning to ambient within 20 min postdisposal (Figure 30).

147. At a depth of 1 m above the bottom (17 m) turbidity peaks again paralleled the disposal operations. Peaks occurred within 2 to 5 min after disposal, depending mostly on the distance between the Dambach and the hopper dredge. Generally, turbidity returned to ambient within 15 or 20 min. However, on 24 May after disposals 1 and 4, return time was approximately 80 min. Peaks after each disposal were usually multinodal. This was believed to be a function of the initial release of materials and physical back-flushing as a result of the initial shock produced. Interface water being forced away from the Disposal Site was believed to be of minor importance. If this water were moving as a single water mass, an initial temperature decrease should have been observed. However, this was not seen.

148. Generally, turbidity values were highest in the samples from the 17 m depth. This was particularly true after disposal 3 on 26 May. The notable exception to this trend was observed after disposal 4 on 25 May, when the reverse was noted. This condition was believed to be a function of the dredged material during this disposal having been collected from an upriver area. Figure 30 illustrates typical results obtained through the continuous monitoring system from the 17 m depth.

149. Turbidity results as obtained from the collected pumped samples from all three days of sample collection agreed well with the continuous monitoring data for turbidity (Figure 31). However, in-lab analysis of the same samples consistently yielded lower results than the continuous monitoring data. This discrepancy was believed to be the result of dilution during sampling. The peaks were generally short-lived and the amount of water in the monitoring system was small in comparison with the time and volume collected for analysis at any one time. The above-mentioned discrepancy and sampling error tends to make the values seen during the peaks appear to be conservative. Based upon differences in turbidity, peak values determined from collected samples might actually have been 25-45% higher than those presented in this report.

150. Dissolved oxygen. The DO data was collected from in situ

probes attached to the pump lines from 14 or 16 m and 17 m collection depths. Resulting data from both depths on all days showed a slight increase in oxygen concentrations immediately after disposal. This was believed to be a result of the forced downwelling of surface waters having higher O₂ content. Following these increases there were significant declines in oxygen concentration usually between 0.2 and 0.6 mg O₂/ℓ (Figure 31). These decreases, although short-lived, did produce a steadily declining oxygen content over the period of the day. This decrease was believed to be the result of the more or less continuous oxidation of the dredged materials (known to be reducing in character) that were passing through the water column and/or due to entrained water.

151. pH measurements. Surface collection pH values on both 24 and 25 May and the 14 m depth samples on 24 May showed no changes as a result of disposal. Mean and 95% confidence limits were 8.27 ± 0.01 , 8.47 ± 0.02 , and 8.25 ± 0.01 pH units, respectively. On 26 May, however, surface waters did respond to disposal, with decreases in pH after each disposal operation. Similar declines were noted in the 16 m depth samples gathered on both 25 and 26 May. After each disposal on all three days, the bottom waters showed significant pH decreases ranging from 0.1 to 0.6 pH units (Figure 32). The decreases in pH seen in the 17 m depth samples were greater than those from the 16 m depth. These, in turn, were greater than the corresponding surface decreases. The bottom water pH data shows the consistent binodal deflection due to the second flush of dredged materials. These reductions in pH were believed to be a function of the mixing of lower pH interstitial waters and sediment with the lake water.

152. Total suspended solids. The concentration of suspended solids showed a high degree of variability over the sampling periods on all 3 days. Although this variability did not correlate directly with disposal, it was believed to be a result of disposal. The mean and 95% confidence limits for suspended solids from surface collections on 24, 25, and 26 May and for the 14 m depth samples on 24 May, were 7.8 ± 1.1 , 6.9 ± 1.2 , 6.2 ± 1.0 , and 8.2 ± 1.0 mg/ℓ, respectively. The suspended solids content at 16 m (on 25 and 26 May) and 17 m on all

three days and after each disposal paralleled the turbidity peaks.

153. Generally, the suspended solids concentrations peaked within approximately 2 min and returned to ambient within 25 min. The 16 m depth sample peaks generally were very sharp in comparison with the broader peaks seen in the 17 m depth collections. The range of suspended solids results was 0.1 to > 2500 mg/ℓ. Except after disposal 2 on 26 May, the 17 m sample values were greater than those from the 16 m depth. Figure 32 illustrates typical peaks in suspended solids data for samples from a depth of 17 m.

154. Particulate organic carbon. The POC results for collections from the 1 m depth on all three days showed only a small degree of correlation with the turbidity results as did the results from the 14 m depth samples from 24 May. Mean and 95% confidence limits for the collections taken on the above days and/or depths were 0.53 ± 0.14 , 0.57 ± 0.13 , 0.80 ± 0.16 and 0.48 ± 0.16 mg C/ℓ, respectively. At both the 16 m and bottom depth samples, POC correlated with turbidity results. Both peaked simultaneously and returned to ambient levels within 25 min (Figure 33). On 25 May at these same depths after disposal 3, only small POC peaks were found relative to the turbidity peak as was the case following disposals 3 and 4 on 26 May. These small POC peaks were believed to be a function of the dredged material during these disposals since these materials were dredged from the mouth of the river. Generally, the POC increases in the bottom water (17 m) collections were larger than those found in the 16 m depth samples.

155. Alkalinity. Alkalinity, as an indicator of inorganic carbon, was measured on all samples collected after disposals 1 and 4 on 25 May. Surface alkalinity showed no change relative to disposal operations. The surface mean (and 95% confidence limit) alkalinity was found to be 89.7 ± 1.0 mg/ℓ as CaCO₃. Both the 16 m and 17 m depth collections correlated with turbidity (Figure 33, from 17 m depth alkalinity data) with bottom values slightly greater than the 16 m values after both disposals. Alkalinity was seen to return to predisposal levels within 15 min.

156. Ammonia nitrogen. In the 1, 14 or 16 and 17 m depth samples

after each disposal on all three days (except at the 1 m depth after disposal 1 on 26 May) significant increases, if not sharp, well-defined peaks in $\text{NH}_3\text{-N}$ concentrations were observed. Generally, multi-nodal peaks were noted after each disposal operation, during which time other large peaks not corresponding directly to the disposal times were also seen. Returns to ambient conditions generally were prolonged in comparison to turbidity. The results from disposal 4 on 25 May exhibited a particularly large peak that was attributed to this load of dredged material being collected from an up-river area. Generally, the magnitude of the $\text{NH}_3\text{-N}$ concentration increases in the samples were directly proportional to the collection depth. Changes in $\text{NH}_3\text{-N}$ concentration at each depth relative to disposal operations are seen in Figure 34 for the 1, 16, and 17 m depth collections, respectively.

157. Release of NH_3 was seen but did not follow the turbidity peaks. Since $\text{NH}_3\text{-N}$ was measured in the soluble form, this result was expected. The NH_3 seemed to mix with the disposal site water and remained in the water column considerably longer than the particulate or suspended materials. In some instances, an initial short-lived decrease in $\text{NH}_3\text{-N}$ concentration was noted. This was attributed to sediments sorbing some aqueous NH_3 (NH_4^+) while passing through the water column.

158. Orthophosphorus. Despite considerable variation in $\text{PO}_4\text{-P}$ concentrations, increases were observed in samples from all three depths after each disposal. These increases did not correlate directly with turbidity but were believed to be the result of disposal operations. In the 16 and 17 m depth collections, secondary peaks were often greater than the initial peaks. As was the case with $\text{NH}_3\text{-N}$, the release of $\text{PO}_4\text{-P}$ appeared much longer-lived than the increases seen for the particulate variables. The range of $\text{PO}_4\text{-P}$ concentrations was $3 \mu\text{g P}/\ell$ to $23 \mu\text{g P}/\ell$ with a return to stable conditions that were lower than the ambient predisposal levels (approximately $7 \mu\text{g P}/\ell$) between 25 and > 90 min after the disposal. These results implied not only a release but a sorption of PO_4 to the particulate materials prior to settling. These PO_4 decreases also were seen to occur in the

elutriate results as presented later in this report. The return to pre-disposal levels for both $\text{NH}_3\text{-N}$ and $\text{PO}_4\text{-P}$ was believed to be primarily a function of currents transporting these nutrients out of the sampling area rather than to the settling of particulate matter. Figure 35 illustrates the aquatic response to disposal with respect to $\text{PO}_4\text{-P}$ in the 16 and 17 m depth collections, respectively.

159. Total phosphorus. Surface water showed P_T increases as the result of all disposal operations. On 25 May, the P_T increases after disposals 3 and 4 were approximately three times larger than the peaks after disposals 1 and 2. This implied a greater impact on water quality at the 1 m depth following dredging operations with no overflow. A return to ambient conditions at the surface (1 m depth) occurred between 15 and > 90 min.

160. As was the case with surface waters, the 14 and 16 m depth regions also exhibited a response to disposal with respect to P_T . There were significant increases in P_T after all disposal operations. Generally, the increases in the collections from the 16 m depth were greater than those seen in the surface samples. This particularly was true following disposals 1 and 4 on 25 May. Generally within 30 min P_T levels had returned to predisposal concentrations. Some disposals, however, did not show any return to ambient levels within the 90 min between depositions.

161. Peaks in P_T concentration in the 17 m depth samples as well as those from other depths exhibited trends that parallel bottom turbidity peaks. The P_T increases in the 17 m depth collections were greater than those from the 16 m depth, except after disposal 4 on 25 May. The two disposal operations on 26 May with overflow during dredging (disposals 1 and 2) produced peaks larger by a factor of two over the results from disposals following no overflow during dredging. Return to ambient levels ($\sim 25 \mu\text{g P}/\ell$) generally occurred after 15 or 20 min. Conditions following some disposals, however, showed no return to predisposal levels within the 90 min period between depositions. Figure 36 illustrates the conditions at 1, 16, and 17 m for P_T after disposal operations on 26 May.

162. Silica concentrations. Although 1 m depth SiO₂ concentrations were somewhat variable over the period of collection, increases were seen in response to disposal operations (Figure 37). The changes as indicated by the 14 or 16 and 17 m depth samples followed the general trends found in the turbidity data, with peak SiO₂ concentrations found after each disposal and a return to ambient between 20 and > 90 min (Figure 37). Generally, the return time at the 16 and 17 m depths was prolonged for loads collected with overflow. Generally, the greatest SiO₂ concentration increases were seen at the 17 m depth.

163. Chloride concentrations. Despite increases of Cl⁻ ion in the standard elutriates (as presented in a later section), no change in Cl⁻ concentration attributed to disposal was found at any collection depth. Means and 95% confidence limits for the Cl⁻ results are presented in Table 10.

164. Heavy metals. The results from heavy metals analyses for Fe showed sporadic multimodal increases that did not correspond directly to disposal operations but did show the greatest concentration increases in conjunction with the turbidity peaks (Figure 38). This especially was obvious after the disposals 1 and 4 on 24 May (Figure 38). Generally, the return to ambient levels occurred rapidly (within 25-30 min). Although the soluble form of Fe was measured, its rapid oxidation from Fe⁺² - Fe⁺³ caused this variable to follow the return to ambient patterns as seen with the particulate rather than the soluble parameters.

165. Findings from analyses of Hg concentrations in the collected water samples during disposal did show an increase to levels much higher than those normally found in Lake water. These short-lived but distinct increases were seen in collections from all depths after each disposal, except after disposal 1 on 25 May and from the 16 m depth after disposal 4 on 26 May. Increases rarely occurred in direct conjunction with turbidity. The elevated concentrations were believed to be the result of disposal operations. Figure 39 illustrates Hg levels during each disposal as measured

from 1, 16, and 17 m collections, respectively, on 26 May 1976. As was the case with $\text{NH}_3\text{-N}$ and $\text{PO}_4\text{-P}$, the lack of a strong correlation between Hg and turbidity was thought to be a function of the soluble forms of Hg, possibly including the methyl and dimethyl Hg forms. Generally, the greatest increases in Hg concentrations were associated with increasing depth.

166. All 12 disposal operations produced elevated Mn concentrations ranging from the detectability limit of $1.0 \mu\text{g Mn}/\ell$ to nearly $100 \mu\text{g Mn}/\ell$. Generally, the results from the 16 and 17 m depth samples paralleled the turbidity peaks with respect to time while concentrations in the 17 m samples were greater by a factor of approximately two than those found in the collections from the 16 m depth (Figure 40). Usually a return to predisposal levels was seen within 30 min.

167. As was seen with Mn, the Zn concentrations increased after each disposal operation. Generally, Zn results produced multinodal peaks with considerable variance in concentration between disposals. These increases, as illustrated in Figure 40, were believed to be related to disposal operations. The time required for Zn concentration to return to predisposal levels was questionable due to the variability in the data but was believed to occur between 15 and > 90 min, depending on the dredging techniques used and/or the distance of the dredge from the Dambach.

168. JCU data - May 25. As was previously mentioned, the John Carroll University research vessel (JCU vessel) also was used during disposal monitoring. On 25 May the JCU vessel was located approximately 100 m west of NDS for water quality monitoring after disposals 3 and 4, using a flow-through turbidimeter for water pumped from a depth of 17 m.

169. Turbidity peaks were seen at 165 and 245 min into the sampling period which were only slightly different times than seen at the Dambach (Figure 41). The turbidity maximum after disposal 3 at the JCU vessel was 94 NTU, while at the Dambach the maximum was 540 NTU. Immediately after disposal 4, the maximum turbidity readings at the JCU vessel and the Dambach were 220 and 190 NTU,

respectively. These different turbidity maxima were believed to be primarily a function of the path of the dredge. During disposal 4, the Hoffman was equidistant from both the JCU vessel and the Dambach, while during disposal 3 the distance from the JCU vessel to the dredge was approximately twice the length between the dredge and the Dambach. The difference in distance that the plume traveled in reaching the JCU vessel was approximately 50 m. Assuming that the decrease in turbidity with distance was 8.9 NTU/m. Relating this to suspended solids (from the previously stated regression analyses), the rate of change with distance was 22.0 mg/l/m of suspended solids.

170. Soluble nutrients after disposal 3 peaked at 16 min postdisposal that represented a 14 min delay compared to the peak time seen at the Dambach. This implied that the water mass containing the soluble forms of various materials did disperse but at a much slower velocity than the turbidity plume (> 70 cm/sec; Danek et al. in preparation). The velocity of this water mass was estimated at 6.0 cm/sec, which was only slightly greater than the prevailing bottom currents.

171. Concentrations of SiO₂ found in samples collected by the crew of the JCU vessel showed approximately a 25% loss over 50 m, while NH₃-N content showed an approximate loss of 12%. Concentrations of PO₄-P in these samples were seen to decrease as a function of sediment sorption as the turbidity plume moved through the area. After disposal 4, no appreciable differences were seen in the turbidity or time to reach maximum turbidity at the two vessels. SiO₂ results showed no significant concentration peaks either at the JCU vessel or the Dambach. The NH₃-N concentrations peaked at 9 and 27 min after this disposal operation. The 9 min peak corresponded to a peak at the R/V Dambach. The 27 min peak was not well quantified at the Dambach but was observed. These data for the JCU vessel exemplified the multinodal character in concentration increases as the result of disposal. The 27-min peak at the JCU vessel might also have been a prop wash effect due to the path of the dredge after this particular disposal.

172. Although turbidity maxima were essentially the same during the fourth disposal, the $\text{NH}_3\text{-N}$ data from the JCU vessel collections were approximately 50% that of the concentration found from the Dambach collections. No significant changes in $\text{PO}_4\text{-P}$ levels were seen at the 9-min peak, but after 27 min an increase of approximately 50% for $\text{PO}_4\text{-P}$ concentration was noted at the JCU vessel relative to the Dambach data.

173. JCU data - May 26. On 26 May for disposal 1, the JCU vessel was located approximately 75 m southeast of the Dambach. After this deposition, the maximum turbidity (800 NTU) and time to reach the maxima were only slightly more than those observed at the Dambach (Figure 42). SiO_2 concentration was seen to peak at essentially the same time at both vessels, but the JCU vessel data were 22% less than the values as collected by the Dambach. This difference implied a rate of change for SiO_2 of only $2 \mu\text{g}/\ell/\text{m}$. This was believed to be in the same order of magnitude of the rate of change of submicron particle settling. The $\text{NH}_3\text{-N}$ concentrations were observed to peak at 4 and 12 min after disposal with only the 4-min peak appearing at the Dambach. This 4-min peak showed a 65% reduction in concentration over the 75 m, which translated to a rate of change for $\text{NH}_3\text{-N}$ of $7.2 \mu\text{g N}/\ell/\text{m}$ due to dispersion and/or sorption and subsequent settling. The 12-min peak was believed to be more of a function of prop wash from the Hoffman than an effect of disposal. Concentration maxima for $\text{PO}_4\text{-P}$ as measured from both vessels were seen at 7 min after the first disposal. The data from the JCU vessel samples, however, showed a 50% loss in the bottom depth collections and a 33% loss in the surface collections for $\text{PO}_4\text{-P}$ while the samples from the 16 m depth showed decreasing $\text{PO}_4\text{-P}$ concentrations believed to be the result of sorption of $\text{PO}_4\text{-P}$ by suspended sediments or precipitation with soluble Fe.

174. Prior to disposal 2 on 26 May, the JCU vessel was repositioned 150 m southeast of the Dambach. At this greater distance from the disposal site, the turbidity maximum was delayed by approximately 3 min and the turbidity peaks were 150 NTU less than at the Dambach (or a

rate of change of turbidity of 1 NTU/m). These results in comparison to the previous data showed that the rate of change of the turbidity plume with distance was not linear but appeared to be more hyperbolic in nature. SiO₂ concentrations were approximately 50% less than those seen at the Dambach at the corresponding maxima, while NH₃-N concentrations showed a difference of approximately 70% or a rate of change for NH₃ of 6.8 µg N/ℓ/m. A comparison of the rates of change of NH₃-N implied that dispersion as a result of prevailing and/or induced currents and not settling was the major factor in the time required for the return of predisposal levels to be recognized. The PO₄-P concentrations after this second disposal operation were seen to steadily increase in the surface samples from both collection points. The rate of change of PO₄-P intensity at 17 m where significant increases over ambient conditions were seen, was approximately 20% over the 75 m between vessels, or approximately 0.05 µg P/ℓ/m. For all practical limnological considerations, this rate of change for PO₄-P was believed to be negligible.

Sediment-water interface

175. Sediment-water interface samples were taken in 1976 during predisposal collections on 15 and 16 May as well as during post-disposal samplings on 10 and 11 June and 7 and 8 July. The samples were collected at 4 reference stations (C1 through C4) and 16 disposal site stations (SD1 through SD16). Stations SD6, SD7, SD10, and SD11 were termed "central disposal stations" since they were located in the center of the disposal quadrant and received the majority of the dredged material during disposal operations. The following parameters were measured for all interface samples collected: pH, DO, and the soluble fraction of SiO₂, PO₄-P, NH₃-N, TOC, Fe, Hg, Zn, and Mn.

176. pH measurements. The pH values were generally lower in the interface samples than in the water column above. The pH means decreased from predisposal through postdisposal samplings in 1976 at the Reference Stations (Figure 43). The means were 7.78 in May, 7.73 in June, and 7.58 in July. The disposal site pH values exhibited no significant change from predisposal to postdisposal samplings. The respective pH means were 7.82, 7.92, and 7.88 in May, June, and July.

An inspection of the data from the Central Disposal Site Stations shows a slight increase between the Reference and Disposal Stations. The pH means were 7.70, 7.99, and 7.90 for the May, June, and July samplings, respectively, at the Central Disposal Site Stations.

177. Dissolved oxygen. The DO means at the Reference Stations and at the Disposal Stations followed similar trends (Figure 43). The pre- to the 5-day postdisposal sampling revealed little change in the means. A significant decrease in DO was noted between the June and the July postdisposal samplings. The means at the Reference Stations were 10.3, 10.9, and 7.8 mg O₂/ℓ in May, June, and July, respectively. The means at the Disposal Stations in May, June, and July were 10.3, 10.5, and 7.6 mg O₂/ℓ, respectively. When DO concentrations were converted to percent saturation, the mean for each sampling at the Reference and Disposal Areas again followed similar patterns. The means in May, June, and July at the Reference Areas were 98.3, 111.1, and 83.5%, respectively. The respective means at the Disposal Sites were 98.4, 107.6, and 80.7% in May, June, and July, respectively. A close inspection of the data from the Central Disposal Stations revealed a mean of 102.5% for the June sampling, indicating a possible oxygen reduction had occurred as a result of the disposal of dredged material. This difference in percent saturation was not seen in the July sampling between the data from the Reference Area and the Central Disposal Area.

178. Silica concentrations. Silica concentrations at the interface revealed the same trends as exhibited in the analyses of the bottom water collections (Figure 44). Although both the interface and bottom water silica concentrations increased with time, the interface means were substantially lower. The silica means at the Reference Stations were 0.450 mg SiO₂/ℓ in May, 1.101 mg SiO₂/ℓ in June, and 1.564 mg SiO₂/ℓ in July. The means at the Disposal Site Stations were 0.400 mg SiO₂/ℓ, 0.917 mg SiO₂/ℓ, and 1.254 mg SiO₂/ℓ, in May, June, and July, respectively.

179. Ammonia nitrogen and orthophosphorus. Ammonia and orthophosphorus results showed similar trends for the interface water means

(Figure 44). The concentrations measured were slightly higher than those found in the bottom waters. A significant increase in both the ammonia and orthophosphorus was observed at the Disposal Sites with a simultaneous decrease at the Reference Sites, 5 days after disposal operations had ceased. These increases in $\text{NH}_3\text{-N}$ and $\text{PO}_4\text{-P}$ concentrations were characterized, however, by high variance between replicate samples. The means in the samples collected were 0.142, 0.054, and 0.071 mg N/ ℓ for ammonia and 0.0010, 0.0023, and 0.0028 mg P/ ℓ for orthophosphorus, respectively, during the May, June, and July samplings, respectively, at the Reference Sites. At the Disposal Sites during the May, June, and July samplings, the respective means in the collected samples were 0.116, 0.202, and 0.047 mg N/ ℓ for ammonia, and 0.0155, 0.0300, and 0.034 mg P/ ℓ for orthophosphorus.

180. Total organic carbon. TOC concentrations were generally higher in the interface samples than in the overlying water column. Total organic carbon means in the samples collected at the Reference Stations remained constant from pre- to 5-day postdisposal, increasing significantly ($P = 0.027$) at the 30-day postdisposal sampling (Figure 44). The means were 20.9, 21.2, and 25.2 mg C/ ℓ in May, June, and July, respectively. At the Disposal Site a significant increase ($P = 0.019$) in organic carbon was observed in the samples collected from the pre- to postdisposal samplings. Means of 14.3, 23.3, and 24.1 mg C/ ℓ were noted from the Disposal Site samples in May, June, and July, respectively. It was observed that a significant difference ($P = 0.037$) in TOC means between the Reference and Disposal Sites during the May sampling was not observed during the postdisposal samplings.

181. Heavy metals. Dissolved metal concentrations in the interface water samples were generally much higher than those found in the water column above. The overall mean concentrations of all the interface samples for iron, 0.032 mg Fe/ ℓ ; manganese, 0.089 mg Mn/ ℓ ; and zinc, 0.078 mg Zn/ ℓ , were approximately 5, 12, and 9 times greater, respectively, than the concentrations found in the overlying water column. Iron (Figure 45) and mercury interface water concentrations remained fairly constant throughout the study. The means at the Reference Sites

were 0.042, 0.034, and 0.038 mg/ℓ for iron, and 0.0002, 0.0004, and 0.0002 mg/ℓ for mercury during the May, June, and July samplings, respectively. The respective means during the May, June, and July collections at the Disposal Site were 0.036, 0.031, and 0.023 mg Fe/ℓ and 0.0004, 0.0003, and 0.0002 mg Hg/ℓ. There was a significant increase in zinc concentrations ($P = 0.049$) and a significant decrease in manganese concentrations ($P = 0.039$) in samples between the pre- and postdisposal collections (Figure 45). The concentration for both metals then returned to predisposal levels by the July sampling. The Reference Site means were 0.049, 0.198, and 0.045 mg/ℓ for zinc, and 0.131, 0.049, and 0.178 mg/ℓ for manganese during the May, June, and July samplings, respectively. The means during the May, June, and July collections at the Disposal Site were, respectively, 0.057, 0.116, and 0.046 mg Zn/ℓ and 0.173, 0.016, and 0.053 mg Mn/ℓ.

Elutriate Chemistry

182. Sediments, Dredge Site waters, and Disposal Site waters were collected for preparation of standard elutriates (Keeley and Engler 1974) on 31 July 1975 and again on 15 May 1976. In 1975, three River and three Harbor collections were gathered in triplicate. In 1976, five duplicate sets of samples were collected from the River. Analyses of the standard elutriates included all applicable interstitial water variables for each year (as shown in Table 11 and 12).

183. Data from both 1975 and 1976 were subjected to Kruskal-Wallis non-parametric analysis of variance. The results were shown to have no statistically significant difference within the 1975 Harbor and River data or within the five sets of the 1976 River data. In light of these results, the mean elutriate concentrations for all parameters measured from the two areas for 1975 and from the River for 1976 were calculated and are presented in Tables B11 and B12, respectively.

184. With only a few exceptions, all variable concentrations

in the elutriates were greater than those found in the Disposal Site water. However, assuming a 10-fold dilution of the elutriate upon open-lake deposition, it was seen in 1975 that only TKN, NH₃-N, and Mn increased significantly. This situation was found with both the Harbor and River elutriates. In 1976, NH₃-N, Fe, and Mn increases were observed in the elutriates. It should be noted that TKN measurements were not made in 1976.

185. From the elutriate results, it was concluded that both areas which were dredged, consisted of contaminated materials. The degree of contamination was higher, however, in the River sediments.

186. Using the EPA bulk sediment chemistry criteria, these dredged materials, both Harbor and River, also would be classified as contaminated, with the degree of contamination greatest in the River area.

187. In September 1976, five duplicate Ponar grabs were collected for elutriate analyses. These samples were collected in attempts to answer the specific question of the time dependency of elutriate preparation. The results of this work are presented in Appendix C'.

Interstitial Water Chemistry

Total dissolved organic carbon (TOC-d)

188. The TOC-d analysis was performed on sediment interstitial water which had been extracted from cores collected during the course of the project. The 9-11 July 1975 sampling (-37 days on figures) will not be considered for the results of any variable, since it was felt that this sampling was not representative of predisposal conditions. This decision was based primarily on that fact that only 4 stations (with 4 replicates each) instead of the normal 16 stations (with 4 replicates each) were collected during this sampling.

189. Figure 46 illustrates the TOC-d trends seen in the samples extracted from the first, second, and third sections of cores. The TOC-d concentrations generally increased with depth. Although the absolute mean concentrations were different, the TOC-d trends, for

each respective section, from the Reference Site and Harbor and River Sites within the Disposal Area were generally similar. However, an intensive examination of the data from the Reference Stations C1-C4 and the Disposal Stations D2 and D8, at the center of the Harbor and River Sites, respectively (Figure 46), reveals an increase in TOC-d, in the first section, from the D8 River Disposal Site, with a corresponding decrease in the Reference Stations and D2 (Harbor Disposal Site collections) during the 5-day postdisposal sampling. The second section also shows a decrease in the TOC-d mean trends at D8 from those seen at the Reference Stations for both the 5- and 30-day postdisposal sampling (Figure 46).

190. The temporal trends of mean TOC-d found in the interstitial water during 1976 are depicted in Figure 47. In Section 1 the mean TOC-d concentrations showed a general increase at both the Reference Site and NDS. However, the amount of change was greatest at the NDS. By the 30-day postdisposal sampling, the mean TOC-d concentrations in two areas were significantly different ($P = 0.033$). The second section values also increased in mean TOC-d concentrations from the pre- to postdisposal samplings. In the second section data, the reverse pattern was seen with decreasing significance with time between the Reference Site and NDS mean TOC-d concentrations. The Section 1 isopleth (Figure 48) indicated a general increase in TOC-d concentrations over the Disposal Area from pre- to postdisposal samplings. The isopleth showing the Section 2 (Figure 49) TOC-d distributions reveal low concentrations in the central and northwest sectors of the 1976 Disposal Area and high concentrations in the northeast and southeast sectors during the predisposal sampling. The 5-day postdisposal sampling indicates a reversal of this trend with highest TOC-d concentrations in the central and northwest sectors, and lowest concentrations in a narrow strip between the central and northwest sector. These lows continued into the northeast sector of the Disposal Area. The 30-day postdisposal sampling reveals a general TOC-d decrease from the central sector to the perimeter of the Disposal Site.

Orthophosphorus

191. Interstitial water phosphorus ($\text{PO}_4\text{-P}$) during 1975 showed the same seasonal and disposal trends for both the first, second, and third section of the cores. Reference, Harbor, and River Disposal Site samples had $\text{PO}_4\text{-P}$ levels that were statistically indistinguishable during all sampling events except the Spring of 1976 (Figure 50). Generally, after the disposal operation, interstitial $\text{PO}_4\text{-P}$ decreased markedly and remained low until the Spring of 1976, when concentrations in all sections and localities were seen to increase, particularly at the Reference Site. Since the same basic pattern was seen in both the Reference Site and NDS data, the changes that were observed were not believed to be a function of disposal.

192. Interstitial $\text{PO}_4\text{-P}$ concentrations in both the Harbor and River areas to be dredged had higher mean concentrations than their respective Lake Disposal Site sediments. Postdisposal results, however, did not reflect these higher concentrations, lending credence to the validity of the measured increase in aqueous $\text{PO}_4\text{-P}$ concentrations found during disposal monitoring.

193. Interstitial $\text{PO}_4\text{-P}$ extracted from the 1976 cores collected in the Reference and NDS Areas showed no difference between areas or with depths of sample during predisposal. Reference Site $\text{PO}_4\text{-P}$ data remained relatively constant from pre- to 30-day postdisposal with no significant difference between these sampling periods. At NDS, a significant drop ($P = 0.018$) in interstitial $\text{PO}_4\text{-P}$ concentrations was seen (Figure 50). This decrease, despite the higher concentrations in the sediment to be dredged, again implies the loss of interstitial $\text{PO}_4\text{-P}$ during the actual dredging and/or disposal operations. The 30-day postdisposal sampling showed a slightly higher mean concentration but this was found to be insignificantly different from the two previous collections. This indicated a very rapid return to predisposal conditions within the interstitial water matrix.

Ammonium nitrogen

194. Interstitial ammonium ($\text{NH}_4^+\text{-N}$) concentrations in the cores

from all areas in 1975 showed a general increase with depth. Predisposal results, except in the first section, exhibited significantly higher ($P = 0.021$) values at the Disposal Sites. As a result of deposition of dredged materials, the NH_4^+-N concentrations were seen (from the 5-day postdisposal collection) to decrease significantly ($P = 0.038$) in the first section (Figure 51) at the Harbor Disposal Site. Changes in the first section, at the River Site, and in the second section, at both Disposal Sites, paralleled the Reference Site collection changes. Interstitial NH_4^+-N data from the third section showed no change as a function of disposal.

195. Generally during 5- and 30-day postdisposal sampling, the second section data resembled the predisposal data from the first section. However, from that period on, the data followed changes seen at the Reference Site and within 90 days, again exhibited the general predisposal NH_4^+-N levels. This information implied that a rather rapid reestablishment of conditions within the interstitial water matrix and/or erosion of the disposal mound did occur.

196. The 1976 interstitial ammonium data also showed increasing concentrations with depth. At the Reference Site, in the first and second core sections, the NH_4^+-N levels indicated no significant difference with time. At NDS, interstitial NH_4^+-N in the first section showed no significant change as a result of disposal. Second section concentrations were seen to decrease markedly 5 days after disposal (Figure 52). This decrease was believed to be the result of deposition, where the second section during this sampling was actually the first section from the previous collection. This situation, however, had disappeared by 30 days after disposal through either reestablishment of predisposal interstitial equilibria and/or erosion of the mound.

197. As was the case with the 1975 data, the initial River material to be dredged contained NH_4^+-N in the interstitial phase that was approximately four to five times greater than those levels.

found in the samples collected at the Disposal Site, even immediately after disposal. This implied a loss or release of $\text{NH}_4^+\text{-N}$ to the water column, either during dredging and/or disposal operations.

Total dissolved Kjeldahl nitrogen (TKN-d)

198. The TKN-d in the interstitial water from the 1975 cores showed the increasing concentration with core depth as did the $\text{NH}_4^+\text{-N}$ values. In the first section of the cores from the Reference Sites, a slight decrease in TKN-d concentrations was seen over the entire sampling period (Figure 53) while the River Disposal Site exhibited no significant change as a function of disposal and/or time. The first sections of cores from the Harbor Disposal Area showed a decrease in concentration from samples collected during the 5-day postdisposal. This was assumed to be due to losses of $\text{NH}_4^+\text{-N}$ and some soluble organic nitrogen as a result of disposal. There was a return to predisposal levels by 30-day postdisposal.

199. Interstitial TKN-d in the second sections of the Reference Site cores followed the same pattern as seen with the data from the first sections. In the results from the 5-day postdisposal sampling, it was noted that both Disposal Sites (Harbor and River Areas) increased (significantly at the River Site; $P = 0.021$) as a result of disposal. This change is believed to be a function of the increased dissolved organic nitrogen from the dredged materials and was particularly important in light of the decreasing pattern seen in the data from the Reference Site cores (Figure 53) and the loss of $\text{NH}_4^+\text{-N}$. The 30-day postdisposal sampling results revealed that interstitial TKN-d in the second section had essentially returned to predisposal levels. The results from the third section of cores from 1975 from all three areas and sampling periods showed no significant changes in the concentration of TKN-d in the interstitial water environment. No interstitial TKN-d measurements were made on the 1976 samples.

Chloride concentrations

200. Interstitial water from the sections of all cores collected at NDS in 1976 were analyzed for chloride ion (Cl^-) concentration.

No statistically significant differences were found as a result of disposal operations between samplings or between the Reference and Disposal Sites. The Disposal Sites did, however, exhibit slightly higher concentrations in both the first and second sections throughout this phase of the project (Table 13). Concentration at NDS, 30-days postdisposal, did increase significantly. This increase, to a lesser degree, also was seen at the Reference Site. The elevated Cl^- ion concentrations were believed to be a result of equilibrium changes in the sediment, possibly as a function of increasing temperatures, rather than as a result of the disposal of dredged materials.

Heavy metals - 1975

201. Cadmium, nickel, lead, and copper. Concentrations of Cd, Ni, Pb, and Cu were measured in the interstitial water of the samples taken in 1975 only. They were no longer measured in 1976 because these parameters exhibited insignificant changes between and within samplings in 1975. Lead concentrations in the first and second sections of the cores are illustrated in Figure 54 and were indicative of the changes that occurred for these four metals. Pb was the only metal of the four that exhibited any apparent difference between areas or samplings. The only general trend seen for all four metals was that after disposal, the samples from the Reference Site usually contained the lower metal concentrations.

202. The Reference Site samples remained at about the same concentration while the Harbor and River Area samples showed maximum concentrations occurring at different times. The River Area reached what appeared to be a maximum in concentration 5 days after disposal, which then began to decrease back to Reference Site values by 90 days after disposal. The Harbor Area samples appeared to reach a maximum in concentration 30 days after disposal.

203. The data inferred that there was some type of inherent difference as a function of the different sediment types and/or dredged materials that affected the rate of dissolution of metals within the sediment. The changes in concentration of these heavy metals in the interstitial water did not result in any observed changes of concentration in the sediment due to the large concen-

tration gradient between the solid and liquid phases of the sediments.

204. Iron, manganese, and zinc. Iron, manganese, and zinc concentrations in the interstitial water samples taken in 1975 at the Reference Site, generally increased with increasing depth in the core. This seemed to correspond to the relative changes in Eh throughout the core. Iron concentrations in the third sections were higher than those in the first sections for all of the 1975 samplings. Manganese concentrations followed the same pattern but to a lesser extent. Zinc concentrations were only slightly higher in the third sections. These patterns appear to be related to redox potential and the variety of possible chemical forms, and the relative abundance of each metal in the sediment as well as in the interstitial water. At the Reference Site, the mean concentrations of Fe in the interstitial water ranged from 3 to 13 mg/l throughout 1975. Mn ranged from 1.6 to 3.1 mg/l and Zn ranged from 0.1 to 0.5 mg/l. Fe and Mn concentrations in samples taken 30 days after disposal exhibited significant differences in metal concentrations between all three sections. For all three metals there was a large increase in concentration five days after disposal at the Reference Site. Assuming that this area was not affected by disposal operations, this occurrence was considered to be a natural phenomena. All of these trends for the Reference Site are illustrated in the Fe data on Figure 55.

205. In the first sections of the cores taken 5 days after disposal, there was an increase in Fe and Mn concentrations at the Reference Site and not at the two Disposal Sites (Figure 55). Between 5 and 30 days after disposal, concentrations decreased slightly for Mn and Zn at both disposal sites and then returned to approximately the same values observed during the predisposal samplings. For the same time period, Fe concentrations decreased in the samples from the River Disposal Site, while concentrations in the samples from the Harbor Disposal Site remained the same. The concentrations of Fe in the samples from the River Disposal Site had returned to predisposal levels by 90 days after disposal. It seemed that disposal had little effect on the iron concentration in the interstitial water. This primarily could have been

due to the relatively small differences initially found between the interstitial water concentrations of the original Harbor and River sediment and the predisposal sediment at each disposal site.

206. The concentrations in the second sections of the samples from the two disposal sites follow the same trends as those of the Reference Site samples (Figure 55). Again, no effects of disposal were discernable for Fe or Mn. Zinc concentrations, however, increased in the samples from both disposal sites 30 days after disposal. By 90 days after disposal the concentrations in the samples from the River Disposal Site had decreased back to predisposal levels. The concentrations in those samples from the Harbor Disposal Site were seen to decrease after 90 days.

207. In a pattern similar to that found for the Reference Site samples, Fe and Mn concentrations in samples from both Disposal Sites throughout 1975 were usually higher in the third sections than in the first sections. Zn concentrations were highly variable for the Disposal Site samples and had no pattern with respect to depth in the core. These trends in variation of concentration with depth were the only major ascertainable conclusions from the Fe, Mn, and Zn interstitial water data.

208. Mercury. Trends for Hg concentration in interstitial water are displayed in Figure 56. There was no differentiation of concentration according to depth in the Reference Site samples and very little in the Disposal Site samples. The Reference Site samples showed an increase in mercury concentrations 5 days after disposal. This corresponded to a decrease in sediment mercury concentration (presented later in this report).

209. The first and second sections of the Disposal Site samples exhibited the same pattern as the Reference Site samples, indicating a naturally occurring phenomena. The River Disposal Site samples had decreased in Hg concentration in the interstitial water by 30 days after disposal. The Harbor Disposal Site samples required an additional 60 days to reach the same concentrations. This was the opposite trend compared to the concentrations of Hg in the sediment. The

changes in sediment Hg are discussed in a later section of this report.

Heavy metals - 1976

210. Iron, manganese, and zinc. Figure 57 illustrates the changes in Fe, Mn, and Zn concentrations in the interstitial water of Reference Site samples collected in 1976. Fe concentrations remained essentially the same in the samples from the first two samplings with slight decreases in the samples from the last sampling. As in 1975, the first sections of the cores had lower concentrations than the deeper core sections. Mn followed the same concentration trends as Fe. However, the differences in concentration between the two sections were smaller and insignificant. Examination of Zn concentrations (Figure 57) indicated that the data were of questionable value. Concentrations measured in collections from the first sampling were much less than those measured previously. The second and third samplings yielded results with typical values; however, the third sampling produced concentrations that varied to a large extent with unusually large confidence intervals. Except for the one set of Zn values, the concentrations of Fe, Mn, and Zn fell within the same range as those measured in 1975. The order of concentration (Fe > Mn > Zn) between the upper and lower sections also was the same in 1976 as in 1975.

211. The study region was divided into the Inner, Central Disposal Site Stations (SD6, SD7, SD10, and SD11) and outer, peripheral (SD1-SD5, SD8, SD9, and SD12-SD16) areas. A comparison of interstitial water metal concentrations using these areas is found in Figure 58. For all three metals, the inner area during the predisposal sampling contained slightly higher concentrations in the interstitial water than the outer area. Throughout 1976, NDS samples exhibited the same differentiation of concentration with depth as discussed for the Reference Site samples.

212. Fe and Mn concentrations in the samples from the inner area taken 5 days after disposal decreased in the first sections and increased in the second sections compared to the data from predisposal collections. The values from the samples from the outer area increased in both sections. Zn concentrations increased in both sections of the samples from both areas. These initial differences in metal concentrations of the interstitial

water correlated directly with the simultaneous differences in metal concentrations in the sediment. The Fe and Mn concentrations in the interstitial water of the original River material were much higher than any of those measured after disposal. This implied decreases in concentrations which could have resulted from dilution caused by the mixing of sediments and/or release of the interstitial water while in the hopper dredge. During disposal this water could have produced the concentration peaks observed during the on-site monitoring. The sediment then would have had to reestablish new interstitial water concentrations based on the metal concentrations available from the sediment along with the existing physicochemical conditions (Eh, pH, etc.).

213. Changes in Fe, Mn, and Zn concentrations did not correspond directly to the pattern of changes in sediment from 5 to 30 days after disposal. Instead, they appeared to return fairly rapidly to the pre-disposal concentrations found in their respective core sections and areas. The only exception was Mn, which followed the pattern of manganese concentrations in the sediment.

214. Mercury. The Hg concentrations in the interstitial water remained relatively constant with respect to depth and time throughout 1976. Most values deviated only slightly from the overall mean of 0.0003 mg/ℓ. No natural variation or effects of disposal were observed for these samples.

Sediment Chemistry

pH measurements

215. The analyses of the first section of sediment cores collected during the predisposal operations in 1975 (9 July and 30 July 1975) exhibited no significant differences in pH data from the 9 July sampling (n = 16); but when all the stations were sampled (total n = 64) on 30 July, the Harbor Disposal Site Area (D2) was found to have a significantly lower pH (P = 0.037) than the Reference and River Disposal Sites, which were essentially equal. The results from the first sections of cores collected during the 5-day postdisposal sampling showed a significant increase (P < 0.001) from predisposal collections and from data from the Reference and River Disposal Sites

during the same time period, that were again essentially equal (Figure 59). This increase of approximately 1 pH unit was attributed to the indigenous difference between the initial Harbor material to be dredged (mean pH = 7.33) and the Lake sediments found at the Harbor Disposal Site (mean pH = 6.49). The lower organic carbon content in the initial Harbor material to be dredged also was believed to play a role in influencing these results. The lack of any significant change in the River Disposal Site was also a function of the original Lake and River pH values, which were essentially equal.

216. By 13 September (30-day postdisposal) pH values at the Harbor Disposal Site had returned to the predisposal levels. This significant decrease in pH was believed to be a function of mixing, erosion, and/or compaction of materials. The November results again showed no difference between the Reference, Harbor Disposal, and/or River Disposal Sites. Resampling of these same sites in April and July of 1976 yielded results that showed no changes between areas in April and a slightly elevated pH at the Harbor Disposal Area in July. This increase was found to be insignificant from the previous results from the Harbor Area but was significantly ($P = 0.042$) different from both the Reference and River Disposal Site data during the same period. The increase of only 0.45 pH units from the Reference Site data was believed to be primarily an artifact of the small number of samples collected during the July sampling ($n = 4$).

217. The pH trends in the results from the second and third sections of the 1975 cores paralleled the first section data. Changes at these depths of the core were found to a lesser extent, however, than those observed in the first section. No pH gradient with depth of core was found in any of the three areas investigated.

218. The sediment pH data from 1976 cores showed no significant difference within or between samplings at the Reference Site and/or NDS at either depth of the core. The mean pH for the first sections of the cores from both the Reference and Disposal Areas were 6.70 in May, increasing to 6.80 in June and 6.82 in July. Unlike the 1975

results, no pH effects were seen as a result of the 1976 disposal operations.

Percent water content

219. During both predisposal samplings, the percent H₂O content in the 1975 cores from all three areas were approximately equal in respective sections of the cores. The percent H₂O content decreased slightly with increasing depth of core section. The 5-day postdisposal data showed a significant ($P < 0.001$) decrease for both samples from the Harbor and River Disposal Areas in contrast with the predisposal data, while the results from the Reference Site showed no significant variation with time and/or depth of core. The deposition of low percent H₂O content sediments from the Harbor (36.7%) and River (48.1%) areas, assuming no severe loss of material integrity due to mixing or compaction within the hopper, was believed to be the primary reason for this observed reduction. This pattern was found in both the first and second sections of the core. In the second section, however, the decrease at the River Disposal Site was markedly less than that of the samples from the Harbor Disposal Site (Figure 60). This was attributed to be a function of the original percent H₂O content of the River material scheduled for dredging. The percent H₂O data collected between 30-day postdisposal and July of 1976 from both the Harbor and River Disposal Areas remained low and significantly ($P = 0.041$) less than those from the Reference Area. Some indications of a return to predisposal conditions were evident in the July 1976 data.

220. Cores collected from the Reference Site and NDS in 1976 were divided into two sections, and each section was analyzed for percent H₂O content. The first section data showed no difference between the two areas sampled during predisposal (16 May). Both areas showed an approximate 5% decrease with section depth. A noteworthy decrease ($P < 0.001$) was seen in the Disposal Site data from predisposal to both postdisposal collections with some indications of return to predisposal levels seen in the 8 July 1976 data. This reduced percent H₂O content during postdisposal

collections was directly attributed to dredging and disposal operations.

221. Unlike the first section percent H₂O data, those from the second sections during postdisposal collections were seen to increase rather than decrease. This implied that overall, the second section Disposal Site mean percent H₂O content during the 5-day postdisposal was increased to the level originally found in the first sections of the cores. These data suggested that only approximately 10 cm of dredged material was deposited at NDS (Figure 61). Danek et al. (in preparation), however, reported a mound greater than 10 cm. This apparent contradiction lead to a closer examination of the data. When the four Central Disposal Site stations (SD6, SD7, SD10, and SD11) were grouped, the percent H₂O content data exhibited the same basic trends of decreasing values in postdisposal collections (Figure 62) with no change in the Reference Site data with respect to time of sampling. These data suggested that the dredged material at the Central Disposal Site stations was at depths between 20 and 40 cm, which was in agreement with the Danek et al. (in preparation) results. The data also showed that the second sections of the cores had considerable amounts of dredged material in the Central Disposal Site stations and lesser amounts in the peripheral collection sites.

Total organic carbon

222. Percent total organic carbon (TOC) analysis was performed on sediment cores taken during the duration of the project. The 10 June 1975 collection generally is not discussed since it was sampled using a K-B corer at only four stations.

223. Figure 63 reveals the mean trends in TOC for cores taken at the Reference, Harbor Disposal, and River Disposal Sites. No significant difference existed in mean TOC between the results from samplings at the Reference Sites. The means of collections ranged from 2.26 to 2.70% TOC at the Reference Stations. The effect that Harbor dredged material had when disposed in the Lake is reflected by a sharp and significant ($P = 0.003$) decrease in mean TOC between pre- and 5-day postdisposal results. The TOC then leveled off and

remained constant through the 90-day postdisposal collection date. The first section TOC mean content began to show a gradual increase from the 90- to 325-day (8 July 1976) postdisposal sampling. The first section samples taken from the River Disposal Sites showed an increase in mean TOC from the pre- to 5-day postdisposal. Although the increase was not statistically supported when all River Disposal Site stations were included (D7-D12), a closer examination of the data solely from the center of the River Disposal Site station, D8, (Figure 63) indicated a much greater increase in TOC from the pre- to the 5- and 30-day postdisposal samplings. The mean TOC then decreased to the 90-day postdisposal sampling, eventually returning to predisposal levels by the 1976 postdisposal collections at D8.

224. The second section mean TOC trends are illustrated in Figure 64. At the Reference Sites, no significant difference for mean TOC with time of collection was observed. At the Harbor Disposal Site, a significant ($P = 0.021$) decrease (from predisposal) in mean TOC did not occur until the 30-day postdisposal sampling. However, a slight decrease in mean TOC with an increased confidence interval was noted between the pre- and 5-day postdisposal collections. The remainder of the samplings exhibited TOC means lower than predisposal concentrations. Insignificant differences in mean TOC content existed between pre- and 1975 postdisposal samplings at the River Disposal Site. An intensive examination of the data from Station D8 in the River Disposal Site Area, however, revealed drastically increased TOC levels from pre- to 30-day postdisposal sampling (Figure 64). Both Harbor and River Disposal Areas illustrated an increase in TOC between the 1975 and 1976 postdisposal collections that was believed to be due to naturally occurring phenomenon.

225. The third section mean TOC trends were also shown in Figure 64. The Reference Site data mean TOC concentrations revealed no significant difference between samplings, except for the two 1976 postdisposal samplings. At the Harbor Disposal Site, a significant decrease in TOC was observed between the pre- and 5-day postdisposal

collections. An increase in TOC was noted between the analyses of the 5- and 30-day postdisposal samples. This was followed by another sharp decrease in TOC by the 90-day postdisposal sampling. Values had returned to predisposal levels by the 1976 postdisposal collections at D2. The River Disposal Site showed insignificant differences between the pre- and 1975 postdisposal for TOC means. (No third sections were obtainable from the 5- and 245-day postdisposal core samples.) A significant increase in TOC mean was noted in the final postdisposal sampling in 1976. Except for the decrease in TOC at the Harbor Site 5 days after disposal, changes seen in the third sections of the cores were not attributed to deposition of dredged materials.

226. Figure 65 illustrates the vertical distribution of mean TOC at the Reference, Harbor, Disposal, and River Disposal Sites, respectively. The Reference Site data showed a general decrease in TOC with depth. The collections from the Harbor Disposal Site revealed a general decrease in TOC with depth during the predisposal sampling. Thereafter, a complex vertical pattern was observed. The vertical distribution of TOC at the River Disposal Site showed a decrease with depth during predisposal operations and the 5-day postdisposal sampling. The remainder of the study revealed second section TOC means generally greater than the first section TOC means. This illustration implied that the dredged material extended to depths of > 20 cm at the Harbor Disposal Site and that the material underwent compaction and/or erosion. Due to the near equality of TOC content between the dredged material from the River and the indigenous material at the River Disposal Site, estimates of depth of the mound were not obtainable using the TOC results.

227. The TOC means did not significantly vary between samplings for Section 1 at the Reference Site during the 1976 phase of the project (Figure 66). At NDS, the analyses of the postdisposal samplings revealed a mean increase in TOC in the first section, that was significantly ($P = 0.041$) greater during the 30-day postdisposal collection. Figure 66 also shows that no significant variation occurred in the samples from the Reference Site during the course of the project with respect to TOC in the second section of the cores. A significant

($P = 0.007$) increase in TOC was noted in the data between the pre- and post-disposal samplings at NDS from the second section. In the collections from both the Reference and Disposal Sites (SD1-SD16), a general vertical decrease in TOC with depth was revealed (Figure 66). These data implied that the first section was made up of dredged material and the second section during postdisposal may also have contained small amounts of dredged material. The lack of any further disposal definition in TOC data was again a function of the near equality of TOC content between the dredged materials and the indigenous Lake sediment.

Total phosphorus

228. All sediment cores collected in 1975 were analyzed for P_T after sectioning. All first section P_T data from predisposal collections were seen to be essentially equal (approximately 800 mg P/kg).

229. Reference Site cores retained the same P_T levels (within 95% confidence limits) through September. In November, however, P_T concentrations in the collections from the Reference Site increased significantly ($P = 0.012$). This increase was believed to be a function of the settling of plankton, which were assumed to have peaked after fall turnover (Vollenweider et al. 1974).

230. Results of collections from 5-day postdisposal showed that P_T decreased significantly ($P < 0.001$) in the first section of cores at both the Harbor and River Disposal Sites. This was believed to be a function of the deposition of dredged materials of lower P_T content (Figure 67). The P_T levels in the Disposal Site collections from subsequent sampling remained less than those from the Reference Site, but showed some indication of return to predisposal conditions as a result of what primarily was believed to be erosion and/or compaction. Second and third section P_T data showed only minimal effects of deposition. Reference Site results from the second section, also illustrated in Figure 67, indicated no difference between P_T concentration with time. The data from the Harbor Disposal Site in both lower sections revealed a decreased P_T concentration 5 days after disposal ($P = 0.026$) and a tendency to return to predisposal

levels by November (90-day postdisposal). At the River Disposal Site, a decrease (not statistically significant) in mean P_T in the results from the second section was observed. These results implied an impact on sedimented P_T from disposal operations and also that the mound at the Harbor Disposal Site (> 25 cm) showed levels that were greater than the River Disposal Site (10-15 cm). Both sites appeared to be affected by erosion of the dredged material.

Total organic nitrogen

231. Total sediment organic nitrogen (TON) results as seen in Figure 68 parallel the changes observed in P_T data. TON, as with P_T , showed a decreasing concentration with depth of core, statistically equivalent predisposal concentrations in the Reference, Harbor Disposal, and River Disposal Sites, no change in TON at the Reference Site with time, and a significant ($P < 0.001$) decrease as the result of deposition at both Disposal Sites in the first section and at the Harbor Site in the second section from the 5-day postdisposal sampling data. TON levels also indicated a general trend towards predisposal values. This may have been a function of erosion and/or compaction and possibly increased utilization as a food source, as seen in the 30- and 90-day postdisposal data.

Cation exchange capacity

232. Wet sediment samples from the Ashtabula River and Harbor as well as cores from the Reference, Harbor Disposal, and River Disposal Sites from pre- and 5-day postdisposal samplings were analyzed for CEC, according to the method of Ott and Toth (1970), which is a modification of the soil chemistry method of Jackson (1958). The results of these analyses indicated that the Reference Site and the predisposal Harbor and River Site data were essentially equal with respect to CEC and that the CEC at the Reference Site was insignificantly different between sampling dates. The 5-day postdisposal results at the Disposal Sites exhibited increased CEC values at both areas.

233. The length of time required to analyze the above samples was considerable. The GLL communicated with the personnel at WES and suggested some possible alterations in the design and/or method were needed with respect to CEC analysis. The end result of these discussions was to change the method to that of Engler (1976)* rather than drop the CEC analyses altogether. This new method, although faster and more reproducible, was not comparable to that of Ott and Toth, regardless of various attempts at normalization. Regardless, the results of CEC suggest that deposition of dredged materials did increase the exchange capacity of the sediments at both Disposal Sites but more so, however, at the River Disposal Site. A return to predisposal CEC levels is not ascertainable but was believed to have occurred, or to be occurring, as a result of erosion. The differences in the increases seen at the River and Harbor Disposal Site were believed to be a function of the original CEC levels in harbor and river materials (approximately 50 and 200 meq/100 g, respectively) prior to dredging and open-lake deposition.

Heavy metals

234. Sediment samples for the Ashtabula Harbor and River as well as the Reference, Harbor Disposal, and River Disposal Sites were analyzed for Cd, Cu, Fe, Hg, Mn, Ni, Pb, and Zn in 1975 and for Cu, Fe, Hg, Mn, and Zn in 1976. The long-term effects of deposition of dredged materials on the lacustrine environment were best illustrated in the results of Cu analyses from the 1975 site collections. The other metals concentrations except for Hg, followed the same general trends as seen with Cu data with only slight variation.

235. Heavy metals concentrations in sediments scheduled for dredging in 1975 were characterized by significantly ($P = 0.010$) higher concentrations in the River area compared to the Harbor area. Sediments from both areas, however, were significantly ($P = 0.006$) lower in heavy metals content than the sediments at their respective lake disposal sites. Evaluations of the 5-day postdisposal results indicated that these dredged materials retained

* Personal Communication, 1976, Dr. R. M. Engler, Project Manager, Environmental Impacts and Criteria Development, DMRP, WES, Vicksburg, Miss.

their concentration integrity during the disposal operations. Generally, the values found in the first sections of the cores taken during this sampling were essentially equal to those seen in the original Harbor and River material. It was, therefore, concluded that the first sections of the cores were composed entirely of dredged material.

236. Variance in concentrations of the Reference Site data were only slight and seldom statistically significant. This relative consistency indicated that natural changes in the sediment environment had a proportionately small effect on the concentrations of heavy metals in the sediment. Most of the variance in these data was attributed to the natural heterogeneity of this geographic area and/or to the sampling procedure. Ni concentrations in the first sections of cores from the Reference Site varied the least (60 to 61 $\mu\text{g/g}$) while Zn results yielded the greatest variation (315 to 425 $\mu\text{g/g}$). The remaining metals varied within approximately 3 to 8% from their respective mean concentrations.

237. Many heavy metals concentrate near the sediment-water interface producing surface enrichment. Below that there is an exponential decrease and subsequent leveling off of concentration to background concentrations. Since the collected samples were sectioned according to lithology or into predetermined lengths, much of the surface enrichment was not seen in the metals results. Generally, the metals concentration in the first and second sections were statistically indistinguishable. However, in the third sections, the results were significantly lower than in the first section (for all metals, $P < 0.012$). These values imply the surface enrichment that also was noted by Rosengrant (1975) in other samples collected in the Central Basin of Lake Erie near Ashtabula, Ohio.

238. As was the case with numerous other parameters, the results from the first predisposal collection of cores (9 July 1975) will not be discussed due to the small number of samples collected and the use of a K-B Corer for their acquisition. The second predisposal sampling data exhibited concentration of heavy metals at the Reference and Disposal Sites that were similar.

Samples collected during the 5-day postdisposal collections showed significantly ($P < 0.001$) lower concentrations of all metals in both the first and second sections (Figure 69). The first core sections appeared to have consisted entirely of dredged materials while the second sections, with slightly higher concentrations relative to the first sections, were believed to have contained dredged materials as well as some original Lake sediments. Second section data indicated that, for most metals, the River Disposal Site samples contained significantly higher concentrations ($P = 0.043$) than did the Harbor Disposal Site samples. This was believed to be a function of the differences in particle-size composition of the original dredged materials. The silty nature of the River dredgings more closely resembled the natural Lake materials, and were believed to be physically mixed upon deposition. During each disposal, the surface sediments encountered currents greater than the determined erosion velocities, 15-20 cm/sec (Danek et al. in preparation). Under these conditions, the silty River materials were believed to be deposited, remixed, and resettled after each disposal. Eventually, dredged materials covered this mixed layer, producing the observed concentration gradients.

239. At the Harbor Disposal Site, the larger particles that characterize these dredgings would have been less likely to erode and resuspend, allowing the formation of a barrier to mixing between the dredged material and the natural Lake sediments. This aspect of disposal operations was believed to have resulted in the observation of lower concentrations of metals in the second sections of the Harbor Disposal Site cores. This phenomenon also could explain the results of the sediment trap data (Danek et al. in preparation) where metals concentrations in the traps were of lower levels than those in the surrounding sediments.

240. Third section heavy metals data exhibited no consistent patterns of concentration and no apparent effects of disposal at either the River or Harbor Disposal Sites.

241. After the sudden decreases in heavy metals concentrations in the data from the first and second sections of the cores as a result of disposal at both sites (5-day postdisposal), the data appeared to reflect the effects of erosion. Analyses of samples from the 30- and 90-day postdisposal collections yielded results that were slightly higher than data from the previous collection. This implied that there was a gradual return in metals content to predisposal levels. Samples from the collections made in April and July of 1976, however, suggested a leveling off at the lower metals concentrations. These results indicated the combined effects of sedimentation of new material during winter stagnation plus the erosion of the dredged materials at the Disposal Sites.

242. Unlike the other metals, Hg concentrations in the indigenous Lake sediments were low. It was assumed that the changes in the Hg content that occurred at the Reference Site were naturally occurring changes. Any similar changes occurring simultaneously at the Disposal Sites were assumed to be at least partially a result of natural fluctuations.

243. The original Harbor material contained less Hg than the original Lake sediment (0.129 and 0.465 $\mu\text{g/g}$, respectively) while the River material had a higher Hg content than the indigenous lake sediment (0.775 and 0.390 $\mu\text{g/g}$, respectively). The data presented in Figure 70 indicated that the patterns for Hg concentration changes at both Disposal Sites followed the same general pattern as those for the other metals. Immediately after disposal, a significant decrease was seen at the Harbor and River Disposal Sites ($P = 0.013$ and $P = 0.009$, respectively) followed by a gradual increase through the 90-day postdisposal collection. Following the latter, there appeared to be somewhat of a leveling off. Closer examination of these data, however, revealed that unlike the other metals, the Hg concentrations in the cores taken 5 days after disposal did not resemble those from the original dredged materials. The Harbor material had apparently increased from 0.129 to 0.250 $\mu\text{g/g}$, while the River material

decreased from 0.775 to 0.290 $\mu\text{g/g}$. These results indicated that there had been a release of approximately 0.5 μg of Hg per gram of dredged materials from the River. During disposal monitoring, marked increases were noted in the amount of Hg in the aquatic environment. The increases seen in Harbor materials were believed to be a function of two factors: first, the mixing of sediments of higher concentration as previously discussed and, secondly, the sorption of aqueous mercury during either dredging and/or disposal operations. Since the aqueous Hg levels generally returned to ambient between disposal operations, it appeared as though sorption that did occur was the result of interactions between the Harbor sediments and the heavily sediment-laden Harbor water, which had been mixed in the hoppers during the dredging operations. Examination of Figure 70 also revealed that for both the first and second core sections, the Hg concentrations from the River Disposal Site and the Harbor Disposal Site had returned to predisposal levels by 30 and 90 days after disposal, respectively.

244. Variations in Hg concentration with depth of core section at the Reference Site generally revealed slightly higher concentrations in the upper strata of the core (Figure 71). Both the Harbor and River Disposal Site data, however, exhibit the highest values in the third section of the cores after disposal. These results implied that the third sections were primarily composed of original Lake materials.

245. The metals concentrations from samples collected at the Reference Site in 1976 remained statistically indistinguishable as a function of time of collection. Figure 72 illustrates the Cu concentrations at the Reference Site during the 1976 sampling periods. All of the metals results, including those for Hg, followed similar patterns. Cu concentrations in the first section varied the least with respect to time and Fe and Mn showed the greatest variance. The mean concentrations of the first section data were always greater than the means of the second section data for all metals.

246. The preliminary evaluations of the data from the NDS cores,

with all 16 stations grouped together yielded erroneous observations for the first sections of the cores. With this grouping, there appeared to be little change in Fe concentrations, slight increases for Mn, and slight decreases in Zn and Cu values. (Hg results will be discussed later in this section of the report.) These observations can be seen in Figure 73, using Cu and Mn concentrations as examples. Assuming that 5 days after disposal the whole disposal area was covered with dredged material, the concentrations in the first sections of the cores should have been similar to those found in the River samples prior to dredging. The mean Cu concentration in these River samples was 31 $\mu\text{g/g}$, while the overall first section mean concentration was 38 $\mu\text{g/g}$ at NDS during postdisposal. Similarly, the mean Fe concentration was 33,400 $\mu\text{g/g}$ in the River samples and 36,100 $\mu\text{g/g}$ for the first section of the cores at NDS after disposal. Although these data are in agreement, the results of 1975 work suggested that these differences in mean concentrations were greater than would be expected. The concentration of Mn in the second sections of the cores from the 5-day postdisposal samplings were also higher than expected. A reexamination of these data resulted in the establishment of the previously mentioned preliminary grouping of stations. The inner stations or Central Disposal Site stations at NDS (SD6, SD7, SD10, and SD11) were grouped together since it was felt that these stations would best reflect the effects of disposal. The remaining peripheral stations also were grouped together and are again referred to as the outer area. After the data were regrouped and replotted, it was apparent that there was a natural spatial distribution of metal concentrations during the predisposal sampling that markedly affected the plots of the overall NDS mean concentration vs. time.

247. The inner area contained higher concentrations of all metals than did the outer area during the predisposal period. It also was determined that, relative to the area (inner or outer), the dredged materials from the River were of either greater or lesser concentration than the values found in the indigenous Lake materials relative to the two (inner or outer) areas. As a consequence, the variables were

classified into one of three groups. The first group consisted of Cu, Fe, and Zn. This group was characterized by lower metal concentrations in the dredged material than in the predisposal sediments of the inner area, and metal concentration equal to or slightly lower in the dredged material than in the outer area. The second grouping consisted only of Mn. In this grouping, the dredged materials were again lower in concentration relative to the inner area, but somewhat higher than the values found in the outer area. Hg formed the third group, and although it will be discussed later, the concentrations observed in the analysis of the dredged materials from the River were higher than those found in either area of the Lake at NDS.

248. In the inner and outer area groupings, it was found from the 5-day postdisposal sampling that the mean Cu concentration in the first section cores from the inner area was 35 $\mu\text{g/g}$ compared to 31 $\mu\text{g/g}$ in the dredged River sediments; and the mean Fe concentrations in the first sections of the inner area were 33,900 $\mu\text{g/g}$, compared with 33,400 $\mu\text{g/g}$ in the River material (Figure 74). These results implied that the first section of the cores was composed entirely of dredged material. In the outer area groups, it was found that the first section results were greater than the concentrations in the dredged material. The mean Cu and Fe concentrations in the first section of the outer area from the 5-day postdisposal sampling were 41 and 37,500 $\mu\text{g/g}$, respectively. These data suggested that some dredged material was present in these peripheral stations (Figure 74).

249. Second section core concentrations from the 5-day postdisposal collections in the inner area were higher than those concentrations found in the first sections of the cores. These results were attributed to core penetration into the natural Lake sediments. These natural sediments, with much higher concentrations, therefore, were mixed with the dredged materials, which resulted in the observed lower mean concentrations. In the outer area, the values found in the second sections of the cores also were greater than in the first sections, which again suggested original Lake sediments. However,

these concentrations were even greater than for the natural Lake sediment levels observed in the outer area. These data, therefore, offered evidence for the movement and mixing of the natural Lake material as well as previously deposited dredged material. These displacements were believed to be a consequence of accelerated current forces during each disposal operation. It was surmised that these forces, through erosion and resuspension processes, had moved some of the natural Lake sediment and the lighter (smaller grain size) dredged materials from the inner area to the outer area, with the end result being the slightly elevated concentrations found in the outer area results from the second section of the cores.

250. No significant changes in concentrations for either Cu, Fe, Mn, or Zn were noted between the 5- and 30-day postdisposal collections, and yet all metals followed the same trends in their respective core sections and areas (inner or outer). It was assumed after a review of physical variables measured (Danek et al. in preparation) that compaction and erosion could have occurred during this 25-day period. The first sections of the cores were believed to have compacted proportionally more than did the second sections; however, second section metals concentrations exhibited greater changes. If 3 to 5 cm of compaction (based on field measurement of core lengths) were assumed, the second sections of the cores collected would then be 3 to 5 cm deeper in the natural Lake sediment. Since the natural sediments in the inner area were of higher concentration, the mean metals content would increase slightly by the 30-day postdisposal sampling. Since the predisposal concentration in the outer area was lower, the 30-day postdisposal means in this area would have decreased slightly. This hypothesis appeared to be applicable for the outer area, but not the inner area. The discrepancy in the inner area results was attributed to the small number (four) of stations in the inner area, mixing of sediments, and variation in actual sampling location.

251. Changes in spatial distribution and alterations in the shape of the disposal mound at NDS are illustrated by the first

section concentration contours for Cu, Fe, Mn, Zn, and Hg during predisposal and 5-day and 30-day postdisposal samplings. The predisposal contours exhibited similar distribution patterns for all five metals in the first and second section of the cores (Figures 75 and 76, respectively). These results suggested that naturally occurring physical phenomena were responsible for the initial metal concentration distributions.

252. The first sections of cores taken during the predisposal sampling showed a pattern of relatively high concentration of metals in the northern and central stations (SD2, SD3, SD6, and SD7). The concentrations decreased in the surrounding areas. Two areas of low concentrations appeared between Stations SD8 and SD9 and Stations SD12 and SD14. No samples were obtained near Station SD13 due to the shale in that area. The second sections showed a general discontinuity between the western and eastern halves of the Disposal Site. The eastern half consisted primarily of low concentrations, with the shale area in the southeastern corner of the area. The western half consisted of highly variable concentrations. There appeared to be a pocket of higher concentration near the southern central area (near Station SD15).

253. The effect of disposal on the first sections of cores was seen in the contours of metal concentrations in samples taken 5-days postdisposal (Figure 77). Cu, Fe, and Mn results exhibited a decrease in concentration due to the presence of dredged material. Due to the large variance in concentrations between replicate samples, the Zn contour did not reflect the location of the dredged material.

254. The concentration contours of the 30-day postdisposal sampling again showed the concentric pattern of decreasing values towards the center of the Disposal Area (Figure 78). The northern stations (SD1-SD4) had increased in concentration with the values approaching those originally found in that area.

255. The concentration contours of the second sections of the core samples taken 5 days after disposal were indicative of the consequences of disposal on the original Lake sediment. Pockets of high concentrations appeared to emanate from the northeasterly path

of the hopper dredge. This pattern was illustrated in Figure 79. The contours of the 30-day postdisposal sampling data from second core sections appeared to retain only a small resemblance to the 5-day postdisposal sampling. The values were somewhat uniform, with only a few pockets of high or low concentrations (Figure 80).

256. In September of 1976 the NDS Area was sampled on two transects that dissected the area into four equal quadrants. Thirteen stations along these transects were sampled in duplicate with each of the cores divided into 2-cm sections for the first 20 cm and 4-cm sections from depths of 20 cm to the end of the core. The primary objective of this phase of the project was to more accurately determine the depth of the mound of dredged material at that time. Due to the mixing of the dredged material and the Lake sediments, it was difficult to determine the precise interface between these materials. Using second-section core data from the 30-day postdisposal sampling and predisposal results, the probable locations of the interface were estimated. Results from each core were then aligned with the interface level on other cores and the vertical profiles for both Fe and Cu on a north-south plane (Figure 81) and a west-east plane (Figure 82) were constructed. Cu and Fe concentrations at the interface of the dredged material and the original Lake sediments ranged from 40 $\mu\text{g/g}$ to 50 $\mu\text{g/g}$ and 35,000 $\mu\text{g/g}$ to 40,000 $\mu\text{g/g}$, respectively. These illustrations suggest a very irregular topography that also was represented by Danek et al. (in preparation). The layering and degree of sorting as observed in the radiographs (Danek et al. in preparation) also are visible in these exhibits. Pockets of high and low metal concentrations, as a result of disposal, also were visible. These data suggest a thin layer of approximately 2 cm at the sediment-water interface where the concentrations were slightly higher. These results were believed to be consistent with the lower settling velocities of the finer grained dredged materials of higher metals concentration.

257. Since all 1976 (except for those collected in September)

sediment core samples were divided into 10 cm lengths for the first sections, the data from the top five sections from the September sampling were grouped together and Cu and Fe contours were constructed (Figure 83). The same general pattern as found in the 30-day post-disposal first section data was seen in the September results. Concentrations were, however, slightly less from this later sampling data, which was believed to be a function of further erosion processes over the two-month period between collections.

258. From the approximations of depth of dredged materials in each core from the September collection, a contour map of the depth of the mound was produced (Figure 84). Based upon these results, a volume of 15,000 m³ of dredged material was present at NDS in September of 1976. A contour map based on survey rod and sediment trap data (Danek et al. in preparation) exhibited the same basic distribution of dredged material immediately after disposal with a volume of 18,000 m³. The apparent decrease of 3,000 m³ between June and September can be accounted for if the sum of erosion and/or compaction processes averaged between 2 and 3 cm over the entire area. Assuming that near the center of the mound compaction alone could have reduced the height of the mound as much as 5 cm, this apparent loss of dredged material was believed to have been probable.

259. The Hg concentrations at the Reference Site remained constant throughout the 1976 sampling (Figure 85). The lack of evidence of naturally occurring variations in the 1976 sampling data was believed to be a function of collection dates, as well as the fact that the majority of the collections were within the spring limnological period. First-section core Hg data, regardless of whether obtained from the Reference, inner area, or outer area Disposal Sites, consistently had mean concentrations greater than those found in the second sections of the core. This depth gradient, however, was often not statistically significant.

260. As with the 1975 data, mean Hg concentrations in the dredged material from the River were much higher than in the original Lake sediments (1.29 and 0.321 µg/g, respectively). As was the case with the other metals, the Hg data was grouped into the inner area

and the outer area. Both these areas exhibited lower Hg content prior to disposal than was found in the River materials.

261. Data from postdisposal collections in the first sections of the cores showed an increase to mean values of 0.553 and 0.499 $\mu\text{g/g}$ in the inner area and outer area, respectively. These results implied a 0.735 and 0.790 μg loss of mercury per gram of dredged material at the inner area and outer area, respectively, as a result of disposal operations. The 1975 mercury data suggested that this loss was higher than would have been expected. A loss of approximately 0.75 $\mu\text{g Hg/g}$ would be lowered somewhat, however, if one considered the mixing of the dredged material and the natural Lake sediments. Based upon this mixing process, the initial postdisposal, first-section Hg concentrations would be between 0.321 and 1.29 $\mu\text{g/g}$. In light of the changes found in concentrations of the other metals (Fe, Cu, and Mn), the first section of the cores collected 5 days after disposal was composed of 10-25% natural Lake sediment and 75-90% dredged material. Assuming the above percentages were correct, the resultant sediment would have contained not less than 1.06 $\mu\text{g/g}$ of Hg for inner area samples. The amount of Hg apparently lost through disposal operations, therefore, was computed as 0.507 μg of Hg per gram of dredged material. This estimate of release in 1976 operations was in excellent agreement with the 1975 results.

262. The mean Hg concentration in the first section of cores from the inner area was slightly higher than that from the outer area (0.553 and 0.499 $\mu\text{g/g}$, respectively) for the 5-day postdisposal collections. This difference was believed to be a function of the greater amounts of dredged material in the inner area. The effects of the mixing processes in the outer area, as seen with the other metals data, were not as apparent in the measured Hg levels. The second section of cores collected 5 days after disposal as a result of the mixing processes contained less Hg than in the sediments from the first sections of the cores, but more than was found in the predisposal sediments (Figure 86).

263. The changes in Hg concentration between the 5- and 30-day

postdisposal collections were statistically insignificant. Hg concentrations in the outer area in both sections followed the same general patterns as seen in the other metals data. This was believed to be a function of compaction and/or erosion. The inner area Hg concentrations in the first section of the cores also followed the same patterns as the outer metals data. Second core section inner area Hg concentrations, however, increased markedly. These data suggest that the Hg concentrations in the cores from the inner area were distributed evenly within the core and no longer exhibited the Hg gradient with depth.

Grain-size distribution

264. Particle-size distributions were determined on each core section collected during the entire project. Samples from the 1975 Disposal and Reference Sites were analyzed for five distinct sand fractions, total silt, and total clay. These analyses were completed using the dry sieving techniques of Duncan and Rukavina (1970). Samples from the 1976 Disposal and Reference Sites were analyzed for grain sizes of -1ϕ units to $+9 \phi$ units using a Coulter Counter for sizes $> 4 \phi$ units. Sizes $+4 \phi$ to $+7 \phi$ units were grouped as total silt and sizes $+8 \phi$ and $+9 \phi$ units were grouped as total clay for comparison with the 1975 results.

265. The basic triangular diagram for illustration of particle-size data is shown in Figure 87.

266. Grain-size distribution for the sediment cores from the Reference Sites for pre- and postdisposal periods in both 1975 and 1976 were determined and are illustrated in Figures 88-94 using only the lower sections of the basic diagram since all data points fall within these sections.

267. Reference Site samples were generally classified as silty sands with some samples composed of sandy silt. Differences between replicate samples illustrated the relative error in sampling and overall heterogeneity of the bottom materials.

268. Predisposal sample results from both the 8-10 July and 30 July to 1 August 1975 collection periods are illustrated in Figure 88. Sediments from all cores and sections were classified as silty sands or sandy silts, except for the first section of the core from D5 and the second and third sections of the core from D2, which were classified as a sand sediment. Generally, Reference and Disposal Site (from predisposal collections) data were clustered together. This cluster, however, was seen to disperse with depth of core section.

269. Data resulting from the grain-size analyses of 5-day postdisposal cores showed a slight but significant change ($P = 0.041$) in overall percent compositions of the sediments at the River and Harbor Disposal Sites for the predisposal data. Sediments were still classified, however, as silty sands or sandy silts for all three sections of the cores (Figure 89). Second section data, with the exception of those from Station D3, fell into the silty sand classification. The difference in composition in these postdisposal sediments was due mainly to a smaller percent clay content with some small and generally insignificant changes in the sand and silt content between the pre- and postdisposal collections. Due to the small amount of sediments available for cores taken during this collection period, the third section data for particle size were limited to only four stations (with four replicates). The differences in textural composition between pre- and 5-day postdisposal results in this section were attributed to the deposition of sandy and silty River and Harbor materials, respectively.

270. Sediment cores from the 30-day postdisposal collection varied only slightly from the previous samplings with respect to particle size distribution and were again classified in the silty sand to sandy silt range. First section results again showed the lower clay content as a consequence of disposal operations and were seen to remain statistically different ($P = 0.039$) from the predisposal data (Figure 90). Second and third section results exhibited a rather wide range of values that was somewhat similar to the second section predisposal data. However, the findings continued

to exhibit a slightly lower percent clay content. Second section data from D1 and D8 were classified as sand sediments, as was the third section of the core from Station D4. The broader classification range from the 30-day postdisposal sampling results was attributed to erosion of the disposal mound and the sampling of the irregular bottom believed to be composed of various sized mounds of mixed dredged and original sediment material. Particle size distributions from the 90-day postdisposal sampling and the two 1976 sampling periods (April and July 1976) showed little deviation from the previously observed results. First section results from three samplings are illustrated in Figure 91. In comparison of these data it appeared that the composition, with respect to particle size distributions, was returning to predisposal levels. Results from most stations exhibited a mean grain size in the very fine sand to coarse silt ranges. Most analyses indicated that the collected material was poorly sorted to very poorly sorted, except for those from Station D5 (from predisposal collection) which fell into the moderately sorted classification.

271. As previously mentioned, sediment samples from the 1976 collections at NDS and Reference Sites were analyzed for 11 phi (ϕ) sizes. For general geological classification, the phi sizes were grouped to yield total percentages of sand, silt, and clay.

272. The mean percent compositions of NDS cores from the predisposal collections, for both the first and second core sections, were classified as silty sands. The only exceptions to this classification during this period of time were SD5 (first and second section) and SD14 in the first section of the core that was classified as sand. Figure 92 illustrates that predisposal sediments were clustered in a similar manner to the 1975 predisposal data. The results of the 5-day postdisposal collection for first section cores for particle size analyses, however, exhibited a significant deviation ($P = 0.027$) from the predisposal results. Second section data were statistically indistinguishable from the predisposal results (Figure 93). Sediment cores from the 30-day postdisposal collections analysed for grain-size distribution showed similar results (Figure 94); first section data were significantly different

($P = 0.029$) from the predisposal results, but the second section data remained unchanged.

273. An examination of the individual phi sizes for first and second sections of the 1976 sediment cores indicated that the predisposal cores contained a larger percentage by weight of particle sizes of -1, 0, and +1 ϕ units. Immediately after disposal, these same phi size percentages decreased significantly ($P = 0.050$, 0.021 , and 0.011 , respectively) and remained essentially unchanged through the 30-day postdisposal sampling (Figure 95). These data suggested that the entire top 10 cm of the cores was composed of dredged materials and that small amounts of dredged materials were found within the second sections. In consideration of mixing processes as well as the similar geological classifications of the dredged materials and the original Lake sediments, the approximation of a 10-cm depth of mound was considered to be a conservative estimate.

274. Predisposal sediments from NDS exhibited significantly higher ($P \leq 0.041$) mean percent composition of sizes +2, +3, and +4 ϕ units in the second sections of the cores relative to the first sections. Results from the analyses of core sections collected 5 days after disposal exhibited a reversal in this trend. Values from the second section decreased significantly ($P = 0.021$, 0.050 , and 0.037) for phi sizes +2, +3, and +4, respectively, between the pre- and 5-day postdisposal samplings. Subsequent increases were seen in the first section data, suggesting the influence of disposal operations and a depth of the mound of at least 10 cm. As was the case during the previous sampling, the results from +2, +3, and +4 ϕ unit grain-size analyses remained unchanged through the 30-day postdisposal collection period (Figure 96).

275. Percent composition of sizes +5, +6, and +7 ϕ units for the first and second core sections during predisposal samplings was statistically indistinguishable. After deposition of dredged materials, however, the percent composition of all three size ranges increased significantly ($P = 0.021$, 0.017 , and 0.015 , respectively). Second section composition data also increased for the +7 ϕ size

particles ($P = 0.011$); while those in the +5 and +6 ϕ size remained statistically unchanged. Again, the 30-day postdisposal collection results for sediment cores showed no change from the 5-day postdisposal sampling in either the first or second sections of the cores (Figure 97).

276. The data for clay size particles (+8 and +9 ϕ unit sizes) showed no difference between the first and second sections of the cores gathered during the predisposal sampling. The 5-day postdisposal collection resulted in a significant increase in the second sections of the cores for both the +8 and +9 ϕ unit sizes ($P = 0.009$, $P = 0.021$, respectively). There was essentially no change in the first-section data for either of the two size ranges. Regarding the data from the 30-day postdisposal sampling, the second section means for +8 and +9 ϕ decreased and, as was found for the samples gathered during predisposal, were indistinguishable from the first section results (Figure 98).

277. During the examination of the data in the phi sizes considered to be silt and clay particles (+4 to +9 ϕ units), the +5 ϕ range (medium silt) exhibited the greatest percent by weight of the total silt and clay percentage. Within the sand fraction sizes (-1 to +3 ϕ units) the major percentage was variable; but generally the largest percent fell within the range of +1 to +2 ϕ units. In general, medium to fine sand (+1 to +2 ϕ units, respectively) was the dominate grain size by weight. Most core sections were very poorly sorted.

278. Particle-size data from the 1976 collections at NDS were plotted on the sampling grid, and contours were constructed in an attempt to illustrate more fully the effects of the deposition of dredged materials. The results for first and second section core data are presented in Figures 99 and 100, respectively. These illustrations indicate that there was a complex set of forces affecting the sediments, both during and after disposal operations. The major change, however, as evident in these illustrations, was due to disposal itself. It was found that the dredged materials

contained various sized particles. It was believed that these materials essentially fell as a single mass at NDS during each individual disposal. It also was reasoned that the dredged material mixed with the original Lake sediments. The end result was a surface layer of essentially all dredged materials, an intermediate area of mixed sediments, and the original Lake sediments. The physical impact of each single mass of dredged material striking the Lake bottom created extreme bottom currents that pushed quantities of the original Lake bottom materials from the center of the Disposal Area to peripheral areas of the study site. The mixing and induced currents, as a result of disposal operations, produced textural changes in the area. Changes with time after deposition, contributing to the variations in grain-size distribution, were believed to be primarily a function of compaction and/or erosion. As a consequence of these two naturally occurring forces, the composition of the sediments at the Disposal Sites appeared to be approaching those found prior to the disposal operations. The particle-size data suggested that, in time, there would be little distinction between the sediments in the Disposal Site and those in the surrounding areas.

Sediment oxygen demand

279. Utilizing previously acquired information, including the redox potential of dredged materials and the oxygen demand in the standard elutriate preparations, coupled with the history of anoxia in the Central Basin of Lake Erie, an attempt was made to ascertain the effects of deposition of dredged materials on the sediment oxygen demand (SOD) rates in the Ashtabula region of Lake Erie.

280. On 7-8 June, 17 June, and 13 September 1976, diver-assisted SOD determinations were made at the Reference and Disposal Sites. On the latter two sampling dates, additional off-the-mound Reference Sites also were used. These sites were within the general NDS Area, but were located approximately 250 m east and west of the Disposal Site. Generally, ten replicate measurements

were taken at the Disposal Site and six replicate measurements were made at the Reference Site. Prior to the initiation of the actual SOD determinations, temperature, conductivity, and DO profiles were completed as were Secchi disc measurements. The results of these profiles are presented in Figure 101. The aquatic environment on 7-8 June exhibited stratified conditions for temperature, conductivity, and DO. The Secchi disc was 2.75 m, implying a euphotic depth of approximately 8.3 m. The 17 June data showed unstratified conditions with a Secchi disc reading of 2.5 m (euphotic depth of approximately 7.5 m). The profiles of 13 September revealed unithermal, unstratified conditions with a Secchi disc measurement of 2.6 m (euphotic depth estimated at 7.8 m). Van Dorn water bottle samples also were collected just above the Lake bottom at NDS and the Reference Site. The collections were analyzed for plankton enumeration. The results of these analyses verified the absence of any photosynthesizing algae in the bottom waters. Generally, the initial oxygen conditions within the chamber were slightly greater than or equal to the bottom water concentrations shown on these profiles.

281. The SOD data from the three sampling periods are illustrated on Figure 102. The SOD at NDS was from approximately three to five times greater than found at the Reference Sites. Using one-way analysis of variance, it was seen that no differences existed within the Reference Site results. Disposal Site data from 17 June were statistically different ($P = 0.013$) from the 7 June data. This difference was believed to be a function of so-called "organic rains" from the May phytoplankton biomass maxima and wind-induced perturbations of the newly deposited and yet relatively unconsolidated bottom materials at NDS. These perturbations were believed to be the result of two consecutive days during which bottom currents were $> 15-20$ cm/sec. The latter being defined as the threshold velocity for sediment erosion at this site (Danek et al. in preparation). The significantly higher ($P < 0.001$) SOD rates at NDS were believed to be both a direct and indirect result of disposal operations.

The presence of more labile organic carbon and increased numbers of total macroinvertebrates, especially tubificids, as a result of disposal were believed to be the primary factors influencing these higher SOD levels.

Heavy Metal Content of Benthic Macroinvertebrates

282. A total of 153 benthic macroinvertebrates samples were analyzed for heavy metals content. The five major taxa collected were Oligochaeta, Chironomidae, Isopoda, Sphaeriidae, and Gastropoda. The results of this study are summarized in Table 1, Appendix A'.

Heavy Metal Content of Fish

283. A total of 163 fish of 14 species were collected at 6 sites 10 days before, and 5 and 30 days after the 1975 and 1976 dredged material disposal operations. The fish captured were analyzed for Hg, Fe, Pb, Cd, Cr, Ni, Cu, and Mn and the results are contained in Appendix B'.

Time Dependency of Standard Elutriate Test Preparations

284. A study was conducted to clarify one aspect of the standard elutriate test, namely the dependency of the results on the time of preparation. This study was accomplished by comparing the results of analyses from on-site versus inlab preparations of elutriates. Elutriates were prepared immediately (time 0) and 6 and 77 days following the initial elutriate preparation. Variables measured were chloride, total organic carbon, ammonia, soluble reactive phosphorus, and the metals Fe, Cd, Mn, Cu, Zn, Ni, Hg, and Cr. The results of this experiment are summarized in Appendix C'.

PART VI: DISCUSSION

Aquatic Chemistry

All events except disposal operations

285. In determination of the effects of dredged material disposal on aquatic chemistry, it was important to distinguish naturally occurring limnological events and those from disposal effects. Therefore, a chronological discussion of each sampling period will be made to evaluate what was believed to be impacting the observed chemical trends.

286. Predisposal - 1975. Since no thermal structure was evident during the 11-13 June 1975 sampling, the water columns within the study areas were fairly uniform with respect to the chemical parameters measured.

287. The low DO and pH values observed during the 9-11 July 1975 sampling at the bottom of the water column were typical of hypolimnetic waters of Lake Erie. The higher concentrations of alkalinity, SiO_2 , TKN, DOC, dissolved Fe, dissolved Zn, and dissolved Mn in the bottom samples appeared to have been the result of the resuspension of the surface sediments into the bottom waters. The occurrence of an internal seiche (upwelling) may have provided the needed energy (Danek et al. in preparation).

288. The loss of a thermal structure on 30-31 July 1975 may have been due to an internal seiche depressing (downwelling) the thermocline. The fact that the rest of the Central Basin was stratified at this time, that the study area was stratified during the previous sampling, and that the temperatures were similar to epilimnetic temperatures lent support to this postulation. The uniform conditions with depth in pH, conductivity, alkalinity, all the nutrients (except SiO_2), and all the metals (except Mn) were further evidence for the possibility of a downwelling event during this sampling. Although SiO_2 was not uniform with depth, the decrease in bottom and the increase in the surface concentrations from the previous sampling revealed a trend towards uniformity. The Mn concentrations also showed

near uniform levels. The DO decline at the bottom implied that the disruption of the thermal stratification was only temporary. The minor peak in POC observed during 30-31 July was coincident with a small increase in chlorophyll-a, phytoplankton numbers, and primary productivity rates.

289. Postdisposal - 1975. On 14 August 1975, the last day of disposal, an oxygen decline was noted at all stations below the thermocline. The greatest decrease was observed at Station PW4, located just east of the Harbor Disposal Site. The general lowering in the bottom pH values from the previous sampling may have been caused by the mixing of disposed dredged material with the bottom waters and/or the reestablishment of a thermal structure with resultant and expected lower pH values in the hypolimnetic stratum. The unusually high specific conductance measured at Stations PW3 and PW4 appeared to be a result of disposal. The significant increase in alkalinity from pre- to postdisposal (14 August) may have been caused by the mixing of disposal sediments with the water column. However, the expected increase in alkalinity during the summer possibly masked the actual effect of disposal on this parameter. The significant increase in bottom SiO₂ concentrations between pre- and postdisposal in 1975 was attributed to the deposition of dredged material. It was not believed that the natural expected increase in SiO₂ during the summer months could completely explain the magnitude of change between the pre- and postdisposal samplings. The decrease in NH₃-N after disposal may have been a function of disposal. NH₃-N may have been sorbed to particles, settling through the water column. The TKN was largely organic in nature since NH₃-N was low. The deposition of dredged spoils appeared to account for the postdisposal increase in TKN. The decrease in NO₃-N during the 14 August sampling was believed to be related to the thermal structure. A decline in the nitrate concentration in the epilimnion during the summer is an often observed trend. The increase in PO₄-P which was significant in the surface samples was related to the disposal operations. P_T results revealed a significant decrease between predisposal and the last day of disposal samplings. It was

possible that the particulate phase of P_T may have complexed and precipitated by oxides of Fe and Mn during disposal. The lower POC concentrations observed during the 14 August sampling appeared to be a function of the reestablishment of a definite thermal structure creating more physically stable conditions that were conducive to settling. The increase of Mn in the bottom waters between the pre- and postdisposal samplings was related to the disposal activities. It is generally believed that Mn is released from the sediment before iron or zinc. This was well illustrated in the elutriate tests.

290. During the 19-20 August sampling, which was 5 days after disposal, deposition was believed to be responsible for the DO depletion, which was most pronounced at Station PW5. The expected decline during summer stagnated conditions complicated the quantification of the effects solely due to disposal.

291. The low pH values at the bottom depths were probably due to the reestablishment of a thermocline and/or a lag effect of disposal. The organically rich dredged spoils may have undergone decomposition, which increased CO_2 concentrations and lowered the pH in the hypolimnion. The peak alkalinity concentrations noted at the bottom during the 19-20 August sampling was believed due to either the continued effect of dredged material and/or the natural alkalinity increase in hypolimnetic waters during the summer (Hutchinson 1957). SiO_2 concentrations continued to increase at the bottom depths from the previous sampling. This was attributed to disposal activities. NH_3-N concentrations remained low, probably due to the same factors as noted during the 14 August sampling. TKN appeared to increase again during the 19-20 August sampling due to disposal operations. By 5 days after disposal, phosphorus (PO_4-P and P_T) concentrations returned to predisposal levels. A statistical difference in DOC levels was observed between the predisposal (30-31 July) and the postdisposal sampling (19-20 August). This increase in DOC may have been induced by a lag effect due to disposal of dredged material. The evaluation of the preceding values was complicated by the expected increase in DOC during the summer (Wetzel 1975). Fe which showed

no release into the aquatic system on the last day of disposal peaked during the 19-20 August samplings. Zn concentrations in the water samples continued to increase, as did Mn concentrations in the bottom waters. The heavy metal increases appeared to be related to disposal activities. However, a complicating factor was the fact that these fluctuations could be natural since the observed concentrations were similar to literature values for many natural waters. During the 14 September, 19 October, and 16-17 November samplings, most of the chemical parameters measured showed homogeneous conditions in the water column. These conditions appeared to be a function of the breakdown of stratified conditions and turnover. The increase in Hg from August to September may have indicated a slight release of dissolved Hg from the sediments shortly after disposal. However, these increases in Hg were not statistically supported. The increase in POC, PO₄-P, and P_T from August to November was attributed to the breakdown in the thermal gradient, turnover and a major storm which may have caused resuspension of bottom sediments prior to the November sampling.

292. The decrease in pH during the 16-17 November collections was believed to be an effect of the resuspension of bottom sediments during the storm prior to sampling. The increase in alkalinity, Fe, and Zn during the November sampling also was attributed to the severe storm. The TKN levels appeared to have been kept above pre-disposal concentrations due to fall turnover.

293. During the 21 April 1976 collection, the chemical parameters measured exhibited concentrations that were generally uniform with depth. The mid-depth increase in DO may have been a function of photosynthetic activity. The maximum carbon (DOC and POC) and zinc concentrations levels noted were coincident with elevated plankton numbers and primary productivity rates. The April sampling followed increased levels of precipitation, runoff, and resuspension generally associated with late winter and early spring. The results of this sampling reflected these conditions.

294. Predisposal - 1976. The 1976 predisposal samplings on

15-16 May 1976 revealed homogeneous concentrations with respect to depth to most chemical parameters. A slight decrease in DO was noted with depth. Maximum turbidity, suspended solids, phytoplankton numbers, and primary productivity rates were measured in the May collections. Elevated levels of Cl^- , $\text{PO}_4\text{-P}$, and POC also were noted. The exact reasons for the above high concentrations could not be completely elucidated other than attributing them in part to spring mixing, increased runoff, and increased biotic productivity.

295. Postdisposal - 1976. The weak thermal structure observed during the 10-11 June 1976 sampling gave support to a DO depletion and a lower pH in the bottom waters. It could not be determined how much of an impact disposal had on the above conditions. The slight increase in Mn concentrations at the bottom appeared to be directly related to disposal.

296. The decline of DO in the bottom waters near the disposal sites during the 7-8 July 1976 sampling appeared to be a result of the disposal of dredged materials. The slight increase of Hg, Zn, and bottom Mn concentrations may reveal a delayed effect of disposal. However, the lack of a thermocline resulting in possible mixing conditions complicated the interpretation of these changes. SiO_2 increased in the water samples from this postdisposal collection. However, the expected summer increase in dissolved reactive silica minimized any recognizable effects of disposal. It is important to note that the detection limits of Cd, Cu, Ni, and Pb are in the ranges typical of naturally occurring concentrations. Therefore, disposal operations did not appear to have an impact on these metals. Although 10-fold increases in Mn concentrations were noted during postdisposal collections, these concentrations were not out of the range of naturally occurring Mn concentrations in the Great Lakes. It was seen that metals were released to the water column during disposal. However, the availability of oxygen should have facilitated the formation of insoluble metal oxides and hydroxides. Thus, any solubilized metals were believed to have been precipitated and/or occluded on the vast amount of suspended particles also present in the water column.

297. The slightly higher turbidity, suspended solids, alkalinity, SiO₂, and Mn concentrations in the bottom collections, as compared to the surface samples, were expected trends attributed to the resuspension of superficial bottom sediments.

298. Since the water column is a dynamic environment with new water masses more or less continuously flowing through the study area, it was difficult to determine any long-term effects of disposal of dredged materials. Dredged material generally settled quickly and/or became well dispersed by currents soon after disposal. While there were identifiable short-term effects, long-term effects were not readily apparent.

299. It is paramount to recognize the difference between the two disposal operations in 1975 and 1976. In 1975, the Markham deposited 114,602 m³ of material at the Alternate Disposal Site, 85,340 m³ at D2 (Harbor Disposal Site) and 48,141 m³ at D8 (River Disposal Site) over a 14-day period from 4-17 August. Although the Alternate Disposal Site was used solely from the 14th to the 17th, it was important to note that deposition near the study area was taking place when the last day (14 August) of disposal sampling was made. The total dredged materials deposited amounted to 248,083 m³. In 1976, the Hoffman deposited 47,772 m³ of dredged materials over a 17-day period from 20 May - 4 June 1976. The first post-disposal sampling in 1976 was six days later on 10-11 June 1976. The above differences in the two disposal operations were reflected in the apparent greater effects of disposal on the aquatic environment during 1975.

300. Table 14 is a summary of those chemical variables that were affected by open-lake disposal of dredged materials. It is apparent that disposal effects were short-lived. By 30 days after disposal, no effects could be directly related to dredged material deposited in the study area. However, how the short-term effects differed from the naturally occurring processes could not be answered through this study. The fact that DO depletions in the bottom waters was noted at all disposal sites in July of 1976 could have significant ramifications. The accumulated dredged materials could be a concen-

trated source of toxicants and nutrients if this area would ever go anoxic since the solubilization of these chemicals is accelerated when the DO level is $< 1.0 \text{ mg O}_2/\ell$ (Burns and Ross 1972).

Disposal operations

301. As the result of an extensive monitoring program during open-lake disposal of dredged materials, it was ascertained that all measured variables, except chloride, did change as a result of the disposal operations. Most variables, including nutrients, heavy metals, and general water quality indicators, were significantly increased in concentration at 1, 14 or 16 and/or 17 m depths as the result of open-lake disposal. However, pH and DO values decreased.

302. These responses to disposal, except for SiO_2 , $\text{NH}_3\text{-N}$, and $\text{PO}_4\text{-P}$, were generally short-lived. A return to ambient conditions or predisposal levels was generally seen to occur within 30-45 min after disposal. The response of most variables correlated well with turbidity. The return to ambient was believed to be primarily a function of settling. Soluble nutrients, however, were released to the water column and remained in solution. These variables, including $\text{PO}_4\text{-P}$ and $\text{NH}_3\text{-N}$ as well as other dissolved constituents were seen at elevated levels at distances of 200 m from the Dambach at times when no increases were seen at NDS. A return to ambient was prolonged and attributed primarily to dilution and the movement of these waters out of the study area. Their effects on the aquatic environment outside the immediate study area were not investigated directly.

303. Concentration maxima or minima of the measured variables were generally greatest immediately after disposal but consistently showed a multinodal pattern. This pattern was believed to be the result of the initial shock and subsequent secondary and tertiary flushings resulting from the disposal. It was believed that interface water played only a minor role in the various responses to the deposition of dredged materials.

304. The magnitude of the maxima or minima as a result of disposal was believed to be a function of primarily the distance of

the dredge from the monitoring vessel(s). Other factors investigated that did not appear to affect the response due to disposal were having the dredge stationary compared to moving (low speed) when disposal occurred and disposal with dredge arms up or down. If any effects did result from these disposal variations, they were masked by the effects of distance of the dredge from the monitoring vessel(s). Some variables did appear to be influenced by flushing during disposal, particularly in the upper water column. Dredging operations with or without overflow were seen to have different effects. Disposal following dredging operations without overflow impacted the 1 m depth area to a larger degree than did the overflow dredgings. These results are believed to be a function of the dredged materials being comprised to a larger extent of the more buoyant, smaller-grained materials when no overflow was employed.

305. Following dredging operations with overflow, parameters measured on collections from the 14 or 16 and 17 m depth regions exhibited significantly larger maxima or minima, while those from the 1 m depth showed little or no effect. These results also were believed to be based on grain size. When overflow techniques are used during dredging, the hoppers fill with less buoyant, larger grained materials that when discharged had more of a tendency to act as a single mass. The latter appears to generate a larger shock wave when the load struck the bottom of the Lake.

306. The dispersion of the sediment turbidity plume (or rate of change/m) displayed a hyperbolic rate of change with distance. The area affected by the turbidity plume extended to at least 175 m from the Disposal Site. The 17 m depth or bottom depth region was affected for the entire distance (\geq 175 m) the turbidity plume traveled away from the Disposal Site. The upward extent of the plume at distances $>$ 50 m away from the Disposal Site appeared to be bounded by the thermocline or a depth of approximately 2 m or 3m above the sediment-water interface.

Sediment-water interface

307. Predisposal. Both univariate and multivariate analyses routines were used to aid in handling the data of the interface water

chemistry results. Analysis of variance of the data from predisposal collections illustrated no significant differences between variables (probabilities ranged from 0.124 to 0.665), implying that the information from the Disposal and Reference Sites was statistically equivalent prior to disposal operations with respect to interface water concentrations for the variables considered.

308. Postdisposal. Both the 5- and 30-day postdisposal results for interface water chemistry were subjected to discriminant analyses in order to identify the areas impacted by deposition of dredged materials. In this work, the Reference group consisted of Station C1 through C4, and the Disposal group consisted of the stations in the Central Disposal Site (inner area), SD6, SD7, SD10, and SD11. The third group of stations consisted of those areas within the overall Disposal Site as determined by the discriminant analyses,

309. The results from the discriminant analyses of the 5-day postdisposal collection information illustrated little impact of deposition, except within the inner area. The variables considered in this analysis were (in order of discriminating power) pH, TOC, Zn, Mn, DO, Fe, and Hg. Use of other variables in combination with the above list of variables did not increase the discriminating power of the computer-derived functions used to differentiate the areas and, thus, were not included. It was determined that during this collection time, the Reference group was significantly different from both the Central Disposal group and the Outer Disposal group, defined in this analysis as SD4 and SD5 ($F = 66.2$ and 65.7 , respectively; F needed at 0.05 level was 9.01). However, the Central Disposal group data were not different from that of the Outer Disposal group ($F = 6.03$). Figure 103 illustrates these discriminant results which suggested that Stations SD4, SD5, SD6, SD7, SD10, SD11, SD14 and SD15 were impacted by deposition. These results were in excellent agreement with the expected impact area with respect to the path of the hopper dredge.

310. The 30-day postdisposal data subjected to multivariate analyses yielded results quite similar to the 5-day postdisposal

results. These data were grouped as before, except that during this analysis the Outer Disposal group consisted of SD8 and SD9. As during the previous discussion, the Reference Site group was significantly different from the Central Disposal group ($F = 14.9$; F needed at the 0.05 level was 9.01), which was in turn also different from the Outer Disposal group ($F = 10.8$). These results suggested that the data from stations in the outer areas of NDS were more similar to those from the Reference Site than to the Central Disposal group results. The F -value of the Reference group and the Outer Disposal group data did indeed reflect this situation ($F = 5.8$; F needed at the 0.05 level was 9.01). The variables, in order of discriminating power used in the above analysis were Zn, Mn, Fe, TOC, and DO. Figure 103 also illustrates these results and suggests an impact of deposition in Quadrants SD2 through SD7 and SD10, SD11, and SD15.

311. Comparison of the results from these two analyses suggests that this impact of deposition of dredged materials on the concentrations of interface water variables was greatest during the 5-day postdisposal period and that the impact decreased somewhat with time after deposition. It also was seen that, with respect to the interface water concentrations, the dredged materials appeared to move via erosion in a north-northwest direction relative to NDS.

Elutriate Chemistry

312. As previously mentioned, the elutriate results from the Harbor and River collections in 1975 and the River sampling again in 1976 did not exhibit a significant difference within the respective replicate groups of analyses. With few exceptions, all measured variables showed higher elutriate concentrations than the values in the water at NDS. Based on an assumed 10-fold dilution upon deposition, however, sediments were seen to be contaminated with respect to TKN, $\text{NH}_3\text{-N}$, and Mn from both the Harbor and River samples in 1975 and $\text{NH}_3\text{-N}$, Fe, and Mn from the River samples in 1976. Accordingly, the two areas would have been classified as potentially

a contaminating source with respect to elutriate analyses, with the degree of potential contamination greater from the River samples. These results were confirmed by the bulk chemical analyses of these same samples using the EPA criteria.

313. The resulting data from the elutriate study indicated that the TKN increases were essentially a function of the release of interstitial $\text{NH}_4\text{-N}$ to the water-sediment mixture. In the elutriate samples the $\text{NH}_3\text{-N/TKN}$ ratio was 0.80 and 0.76 for the River and Harbor area samples, respectively. In 1976 this ratio was believed to be as high or higher since the samples for elutriate analyses were concentrated in the middle of the River channel. The exact ratio, however, was indeterminate since TKN was not measured in 1976.

314. From the aquatic chemistry results during disposal monitoring and the elutriate results, it was seen that the elutriate test was not an adequate tool for characterizing dredged materials with regard to potential release of contaminants upon open lake disposal. It was believed that the elutriate results were more characteristic of the material within the hopper dredge. It does not, however, adequately reflect the impact of disposal on the open-lake environment for all the measured parameters. Those parameters that showed a potential release from the elutriate tests did show maxima or minima during open-lake disposal. However, other important variables ($\text{PO}_4\text{-P}$, Hg, etc.) that did not show marked release potentials in the elutriate test were seen to increase significantly during the monitoring of disposal operations. It is recommended that additional studies be undertaken to modify existing and/or develop new elutriate monitoring procedures in order to find more environmentally meaningful tests for ascertaining the potential for release of various parameters from sediments to be dredged.

315. These same elutriate data can also be used, for calculation of the mixing zone required to dilute the water associated with the dredged material in the hopper to acceptable levels after discharge. It is also possible to calculate the bottom area required for this dilution process and, therefore, determine whether or not the designated disposal area is adequate for this required mixing volume.

316. Guidelines for these calculations as set forth in the WES Report D-76-17 (Anon 1976) were used to estimate a mixing zone for the dredged materials from the Ashtabula River.

317. By definition, a mixing zone is that volume of water at a disposal site required to dilute contaminant concentrations associated with a discharge of dredged materials to an acceptable level. The first step in these calculations, after the elutriate analyses were completed, was to derive the dilution factor (D) required to accomplish the above. This factor was calculated according to the following equation:

$$D = \frac{C_e - C_s}{C_s - C_a} \quad (1)$$

where C_e , C_s , and C_a were the concentration of a given constituent in the elutriate, water quality criteria concentration and ambient concentration, respectively, for that same constituent. The total volume (M) required to accomplish this dilution (D) was calculated according to the following equation:

$$M = DV_d \quad (2)$$

where V_d is the volume of dredged material for a particular discharge. After calculation of the required volume (M) of disposal site water that would be necessary for dilution of the discharge, the next step in implementing the mixing zone concept was to characterize the shape associated with the dilution volume. The general shape that appeared to be most applicable to discrete discharge operations is that of a conical frustrum whose volume (M) was defined by:

$$M = \frac{d}{3} A_b + \frac{A_b A_t}{3} + \frac{A_t^2 d}{3} \quad (3)$$

where d is the height of the frustrum and A_b and A_t are the areas of

the lower and upper frustrum, respectively.

318. Disposal operations monitored by the GLL were categorized as stationary and/or moving discharges with prevailing currents. In light of these categorizations, the above equation becomes:

$$M = \frac{\pi}{3} d^1 R^2 + Rr + r^2 \quad (4)$$

for a stationary discharge and

$$M = \frac{\pi}{3} d^1 R^2 + Rr + r^2 + d^1 V T (R + r) \quad (5)$$

for a moving discharge.

When these equations are solved for R, the bottom radius of the mixing zone is transformed to:

$$R = -r \pm (r^2 - 4 (r^2 - 3 M/\pi d^1))^{\frac{1}{2}} \div 2 \quad (6)$$

for a stationary discharge and

$$R = - (r + 3VT/\pi) \pm ((r + 3VT/\pi)^2 - 4(r^2 + 3VT/\pi - 3M/\pi d^1))^{\frac{1}{2}} \div 2 \quad (7)$$

for a moving discharge, where d^1 is the depth at the disposal site, v is the velocity of the discharge vessel, T is the time required for discharge and r is the radius of the initial surface mixing area. This value r is intended to approximate the initial mixing area at the surface that will occur at a disposal site. This area was estimated for Ashtabula disposals, to be equal to the area of the openings of the hopper dredge Hoffman. This value was calculated to be an area of 110.2 ft².

319. In order to calculate the area of the mixing zone after the value of R is determined, an estimate of the horizontal transport distance as a result of the prevailing currents must be calculated.

This horizontal transport distance (X) can be estimated by:

$$X = \frac{d}{V_s} V_w \quad (8)$$

where V_s is the settling velocity of the discharged material and V_w is the prevailing bottom current velocity at the disposal site. Having calculated this value (X), the mixing area can be computed:

$$A = \frac{\pi}{2} R^2 + r^2 + (R + r) X \quad (9)$$

for a stationary discharge and

$$A = \frac{\pi}{2} R^2 + r^2 + 2 RVT + (R + r) X \quad (10)$$

for a moving discharge.

320. The above equations were used to calculate a mixing zone (R and A) for unionized $\text{NH}_3\text{-N}$ and Mn from the data acquired at Ash-tabula. Table 15 lists the data used in these calculations and the source of this information.

321. In order to determine the effect of variance within some of these terms on the equations, each individual term was doubled and the remaining terms were held constant. The results of this process indicated that for stationary and moving discharges with a prevailing current, R, and, consequently, A increased markedly if either the elutriate concentration and/or the volume of dredged material increased. It also was observed that both R and A decreased markedly with increased water quality criteria or increased depth and remained essentially unchanged with regards to changes in the other terms of the equations.

322. Using both the unionized $\text{NH}_3\text{-N}$ and dissolved Mn data, the bottom radius of the mixing zones were calculated to be 21.4 ft (6.5 m) and 54.5 ft (16.6 m), respectively. These results suggest small

mixing zones that are not consistent with the results of disposal monitoring. The on-site observed results suggest a much larger R and A would actually be required to accomplish the actual dilution. Since the four terms which seem to affect the value of R and A (C_e , V_d , C_s , and d) were defined or experimentally determined, it could be concluded that the elutriate concentrations as measured did not adequately describe the potential release of unionized $\text{NH}_3\text{-N}$ or dissolved Mn, volumes of dredged materials as measured on the dredge were in error, and/or that the above equations were not appropriate for determining the area required to dilute the hopper mixture to the established water quality criteria.

Interstitial Water Chemistry

Predisposal - 1975

323. In attempts to ascertain the differences in the data from the Reference and the Disposal Sites prior to deposition, a one-way analysis of variance was completed. The results of this test indicated that first sections of cores from the predisposal collection (8-10 July and 30 July - 1 August 1975) had significantly different $\text{PO}_4\text{-P}$, Hg, and Fe concentrations ($P = 0.015$, 0.026 , and 0.027 , respectively) in the interstitial waters of the Disposal Site cores as compared with those same parameters from the Reference Site cores. The Disposal Site samples had higher mean Hg and Fe concentrations and lower mean $\text{PO}_4\text{-P}$ contents. Second-core section results were markedly different for $\text{NH}_3\text{-N}$ and Hg between the two geographic areas. Both of the above parameters exhibited higher concentrations at the Disposal Sites. Results from third section core samples were not treated via analysis of variance because of the lack of data, since not all the cores were sufficiently long to have a third section. This same situation also was found in the third section results during other sampling periods. These data, therefore, had to be ignored in the following discriminant analyses as well.

324. Data from the 5-, 30-, and 90-day postdisposal samplings

for both the first and second core sections were all subjected to discriminant analyses using the SPSS program (Nie et al. 1970). The initial step in this analyses was to remove from the matrix any variable that correlated with any other variable at a level of $r \geq 0.90$. This step was necessary to reduce dimensionality (Mattson et al. 1977) and allow the interprogram matrix inversion.

325. Results of analyses of data from both the Harbor and River Disposal Areas were grouped since on a univariate basis these two disposal areas were generally indistinguishable. In these multivariate routines, results from the Reference Sites (C1 through C4) were grouped as the first known group; Station D2 and D8 were grouped as the second known group (Inner Disposal Area); and the discriminant program selected the proper group designation for the remaining unknown stations. In most cases, a third group of stations (referred to as the Intermediate Area) was defined and the analysis was repeated.

5-day postdisposal - 1975

326. Discriminant results from the analysis of a 5-day postdisposal data from the first-core sections for interstitial water ranked (in order of discriminating power) Fe, $\text{NH}_3\text{-N}$, Hg, and Zn. Discriminant scores based on calculations with those variables from the Reference, Inner Disposal, and Intermediate (composed of some peripheral stations) Areas showed that all three areas were statistically different. The F-values for Reference vs. Inner Disposal Area, Reference vs. Intermediate Area, and Inner Disposal vs. Intermediate Area were 26,191, 11,752, and 2,380, respectively. (F-value at the 0.05 level was 225). The unknown stations were then classified. The disposal operations impacted all Disposal Site stations except D6 and D12, which were 300 m down-current of the Disposal Sites.

327. Second section interstitial water data for the 5-day postdisposal collection yielded discriminant results which ranked Fe, Hg, TKN, $\text{PO}_4\text{-P}$, Cd, Ni, and Pb as the variables with discriminating power relative to the Reference and Disposal Areas. F-values (19.2 needed for 0.05 level) indicated that significant

differences existed between the Reference and Inner Disposal Groups ($F = 70.9$) as well as the Disposal and Intermediate groups ($F = 110.5$) but not between the Reference and Intermediate Area groups ($F = 18$). Generally, it was observed that interstitial water concentrations from the second core sections were not impacted by disposal operations except at the D2 and D8, which were defined as Disposal Site stations.

30-day postdisposal - 1975

328. Discriminant analyses of interstitial water results from the first section of cores collected during the 30-day postdisposal sampling yielded Mn, Hg, Pb, Ni, Cd, $\text{NH}_3\text{-N}$, and TKN as variables with discriminating power. These statistics also showed that the Reference group data were essentially indistinguishable from those for the Intermediate group but different from those of the Inner Disposal group ($F = 330$ with 225 needed at the 0.05 level). Classification of unknown stations showed that the impact of disposal by 30 days after deposition was only evident at the center of the Disposal Sites. Second-section interstitial water values showed the same basic results when subjected to this multivariate technique. The F-value between the Reference and Inner Disposal Areas was 5535 with only 225 needed at the 0.05 probability level. This implied that these two areas were different. However, the results from the Reference and Intermediate groups were again indistinguishable. The only areas showing impact of disposal were the central sites of the Harbor and River Disposal Sites, D2 and D8, respectively.

90-day postdisposal - 1975

329. By 90 days after deposition, impacts of disposal essentially were not detectable except in the first sections of cores from D2 and D8. The results from the discriminant analysis of first core section interstitial water illustrated that, again, the only areas impacted were the center sites of the Disposal Areas. From this analysis it also was concluded that the Reference Site group results were still different ($F = 43,968$, 230 needed at 0.05 level) from those for the Inner Disposal group based on the use

of Pb, TKN, $\text{NH}_3\text{-N}$, Zn, Mn, and Cu as discriminating variables. Second section discriminant results, however, showed no differences between areas and suggested a multivariate return to predisposal levels.

330. Other interstitial water data from postdisposal samplings of the 1975 Harbor and River Disposal Sites (April and July 1976) were not subjected to statistical analyses because of the reduced sampling design and re-equilibration of concentration seen in the 90-day postdisposal analysis.

Predisposal - 1976

331. As was the case with the 1975 Disposal Sites data, the 1976 interstitial water results were used for discriminant analyses following the same steps as was used for the 1975 results, except that in this analyses of the 1976 data, the Reference Site group consisted of values from C1 through C4; and the Inner Disposal Site group consisted of results from the stations previously defined as the Inner Area or Central Disposal Site (SD6, SD7, SD10, and SD11).

332. At NDS in 1976, interstitial water chemistry concentration from both the first and second sections of sediment cores were indistinguishable from the Reference Site core sections collected during the predisposal sampling period. Based on the univariate analysis of variance determinations, probabilities of difference between the two areas ranged from 0.177 to 0.688, and 0.108 to 0.685 for the first and second sections, respectively.

5-day postdisposal - 1976

333. Interstitial water data from the first core section of the 1976 5-day postdisposal collection showed $\text{NH}_3\text{-N}$ and $\text{PO}_4\text{-P}$ as the variables with discriminating power. The Reference group results were statistically different from those of the Inner Area group and the Intermediate Area group ($F = 5.92$ and 11.07 ; F at the 0.05 level was 5.14). It was also found that the Inner Area was different from the Intermediate Area ($F = 7.40$). Discriminant results suggested that the entire area sampled (all SD stations except for those in the

shale area) was impacted by disposal operations. Stations SD8, SD15, and SD16 were impacted to a lesser degree than the other NDS sites. These three stations were located west and southwest of the actual disposal site and, hence, these results were not considered unusual.

334. Interstitial water data for the second core sections during this same postdisposal period classified the unknown stations using Fe, NH₃-N, TOC, Zn, and Cl data as determinants for discrimination between stations. In this analysis, the only significant demarcation of areas was between the Reference Sites and the Inner Area Sites (F = 9.28 with 6.39 being the required F-value at the 0.05 level) and the Inner Area Sites and the Intermediate Area group (F = 13.03). Classifications of unknown stations showed that disposal operations impacted most of the area sampled. Generally, the areas affected at these core depths (> 10 cm) were in the path of the hopper dredge. Figure 104 illustrates the station classifications via discriminant analyses of both the first and second-section interstitial water results from core collections during the 5-day postdisposal sampling.

30-day postdisposal - 1976

335. As was the case with the 5-day postdisposal sampling, all three areas were significantly different from each other in the first core sections during the 30-day postdisposal period. (Reference group vs. Inner Area group, F = 61.70; Reference group vs. Intermediate group, F = 12.97; Inner Disposal group vs. Intermediate group, F = 10.24 with an F-value of 6.39 required at the 0.05 level.) These differences were based on classifications of interstitial water content from the cores from the respective areas using NH₃-N, Mn, Fe, TOC, and Cl as the variables with discriminating capability. The classification of stations from this analysis as seen in Figure 104 suggested an overall reduction in the total area affected by deposition. Again, this change towards predisposal interstitial water concentration was seen as a relatively rapid reequilibration and possibly a shift of sediments in basically a north-south direction.

336. Second core section interstitial water results from the

1976 30-day postdisposal sampling showed that the only difference between areas was between the Reference Site and the Inner Area Site ($F = 6.47$ with an F -value of 5.59 required at the 0.05 level). The only variable used to discriminate these areas was Cl^- concentration. Classification of stations from this section also indicated an overall reduction in the impacted area.

337. The data as well as the results of discriminant analyses for the 1975 and 1976 interstitial water chemistry results suggested that the overall effect of deposition was only detectable during a short time period after the conclusion of disposal operations. These results also implied that the system returned to predisposal interstitial water levels between 30 and 90 days in the second section of the cores and within approximately 90 days in the first section of the cores. No distinct patterns or shifts in areas of impact were ascertained. It was believed that the changes in the interstitial water concentrations were primarily a function of the reestablishment of equilibria within the sediment-interstitial water system. These findings indicated that the original sediment, upon which dredged materials were deposited, would have undergone only minimal changes in concentration within the interstitial waters of that original sediment. Subsequently, if the dredged materials were removed via erosion, which appeared to have occurred at Ash-tabula, the interstitial water chemistry in the original sediment just below the sediment-water interface would be quite similar to predeposition conditions.

Sediment Chemistry

338. Generally, it can be said that the most apparent effects of disposal were seen in the sediment environment. It also was found that this matrix was the most complex and difficult with which to work, particularly in light of initial lack of suitability of the Reference Site stations as controls for the Disposal Site stations.

339. The results of analysis of sediment samples from the

various sections of the cores from all areas and collection periods were handled in essentially the same manner as previously described for the interstitial water data.

Predisposal - 1975

340. The 1975 predisposal data for both first and second core sections were investigated via one-way analysis of variance. It was found that in a comparison of Reference and Disposal Sites data that the areas were significantly different with respect to Cd, CEC, P_T , Hg, and Zn ($P = 0.009, 0.028, 0.006, 0.028,$ and $0.042,$ respectively) in the first sections and CEC, P_T , and clay ($P = 0.017, 0.016,$ and $0.001,$ respectively) in the second sections. Based on these results and general heterogeneity of variance found in sediment chemistry results, the predisposal data also were subjected to discriminant analysis. The results of this data evaluation confirmed that indeed the Reference Site stations and the Disposal Site stations were different ($F = 48,813,$ F needed at 0.05 level was 230). The stations that were statistically different on a multivariate basis were D5 and D6 in the first core sections and D1, D4, and D5 in the second core sections from the proposed Harbor Disposal Site. At the proposed River Disposal Site, significant differences ($F = 48.8$ with F of 6.94 required at the 0.05 level) were found at Stations D7, D10, and D11 in both core sections plus D9 and D12 in the second sections. As was the case with interstitial water, no discussion is offered for third section results from any collection period. Other stations at both Disposal Site sections were essentially equal to the Reference Site stations in a multivariate sense. These results were based upon discriminant analysis using P_T , pH, 0ϕ grain particle size, percent silt, $+1 \phi$ grain size, CEC, Zn, Ni, and TON data for the first core section and P_T , Mn, and clay for the second core sections. As previously explained, other parameters measured on the same samples added no further strength to the capability of discriminating power for classification of stations.

341. Station differences within and between the Reference and Disposal Sites in both a univariate and multivariate consideration

complicated further evaluation of discriminant analysis for the other samplings. After the discriminant scores and classifications were made, rankings were made of the changes in the individual stations and sites in general, relative to the known station groups (Reference group, C1-C4; Inner Area group, D2 and D8, and any Intermediate group deemed essential by the statistical routines) between sampling events.

5-day postdisposal - 1975

342. The results of sediment chemistries from the 5-day post-disposal collections were subjected to discriminant analysis. The analysis showed that first section data at both the Harbor and River Disposal Sites were affected by deposition with the exception of those from D6. Stations D5, D7, D10, D11, and D12 were only moderately affected while the remaining sites were heavily affected. The evidence of only moderate effects at D5 was believed to be a function of the path of the hopper dredge and at D7, D10, and D11 was believed to be a function of the finer grained materials deposited at the River Disposal Site. It was particularly noteworthy that D12 exhibited moderate affects of disposal despite the fact that this station was located 300 m down current of the center of the Disposal Site. These results were based upon the use of TON, Cd, +2 ϕ grain size, CEC, P_T , +3 ϕ grain size, Cu, TOC, Zn, Ni, Pb and % H₂O as discriminating variables and a Reference group that was statistically different from the Inner Area group (F = 869 where F at the 0.05 level was 230).

343. Second core section data from the 5-day postdisposal collections yielded results based upon the Reference group different from the Inner Area group (F = 16,489, F = 230 at 0.05 level), and the Intermediate group (F = 7,921). The classifications were based upon the following variables listed in order of highest discriminating ability: Cu, TON, Fe, TOC, Ni, Pb, P_T , +3 ϕ grain size, CEC, and +1 ϕ grain size. The classifications of the stations in the study areas were seen to illustrate the impact of disposal on all Disposal Site stations except D5 and D6 at the Harbor Disposal Site and D11 and D12 at the River Disposal Site. The only stations

seen to be heavily affected were the two center site Stations D2 and D8 plus Station D1. Again, these results were believed to be primarily a function of the path of the dredge Markham. Only moderate or no effects of disposal at second section depths were considered as expected results. In general, the effects of disposal were greatest on the first core sections.

30-day postdisposal - 1975

344. Discriminant analysis of data from the first section core collected during the 1975 30-day postdisposal event yielded three mutually different areas. The Reference Site was different from both the Inner Area of the Disposal Site and Intermediate Area as was the Inner Area group from the Intermediate Area group ($F = 9571, 299, \text{ and } 6122$, respectively, with an $F = 19.3$ required for significance at the 0.05 level). Classifications, based on Fe, % H₂O, Zn, Ni, Pb, clay, TON, P_T, TOC, and +2 ϕ grain size composition as discriminating variables, showed slight changes in the conditions at Disposal Sites relative to the previous sampling. At the Harbor Disposal Site, Station D3 values were seen to shift from heavily to only moderately affected and D5 was found to exhibit no effects of disposal operations by this time. At the River Disposal Site, Stations D9 and D10 were seen to change from heavily to moderately affected and moderately affected to no effect, respectively, between the 5- and 30-day postdisposal samplings.

345. Second section sediment chemistry data from cores collected 30 days after disposal again indicated that the Reference Site was significantly different from the Inner Area of the Disposal Sites and the Intermediate Areas ($F = 748 \text{ and } 726$, respectively, with $F = 230$ at the 0.05 level). Based upon Cu, Fe, Ni, clay, 0 ϕ grain size, and CEC, stations from the Harbor Disposal Site were classified. No change was seen in the results between this sampling period and those from the 5-day postdisposal collection period. At the River Disposal Site the classifications showed that Stations D9 and D10, previously considered as moderately affected, were no longer different from the predisposal results. Station D11, however, was

classified as moderately affected. This situation implied a significant change since D11 during the previous collection period was considered to be unaffected by disposal operations. Changes seen in the first section discriminant results were consistent with those found in the second section analysis at all stations and/or areas between the 5- and 30-day postdisposal collections.

90-day postdisposal - 1975

346. Sediment chemistry data from the 90-day postdisposal collections from the River Disposal Site in first core sections showed the continued erosion of the disposal mound. Again, the Reference Site group results were significantly different than those from the Inner Area of the Disposal Site and Intermediate Area groups ($F = 108$ and 59.5 with $F = 19.3$ at the 0.05 level), at both the Harbor and River Disposal Sites. Using Fe, CEC, % H₂O, pH, silt, +1 ϕ grain size, and P_T data for discrimination of the station groups, the derived classifications showed that conditions at Stations D10, D11, and D12 had returned to predisposal levels on a multivariate basis. The first core section data from the River Disposal Site during the 90-day postdisposal sampling showed no apparent change in the classifications from the previous sampling. These classifications possibly are somewhat misleading, however, since the second section data from this area showed all stations except D2 had returned to predisposal levels. Second section data from the River Disposal Site showed the same basic trend except that Station D7 was still classified as being moderately affected by disposal operations. These second section classifications were based on pH, P_T , and Hg with all three known groups being significantly different from one another (F varying from 12.9 to 79.2 with a required F -value at the 0.05 level of 9.28). As was the case during the previous sampling period, changes in the first sections of the cores were consistent with those seen in the second section from the 90-day postdisposal chemistry data.

347. Sediment chemistry results from the other postdisposal collections could not be compared to the above results due to the reduced number of stations, replicates, and mandated changes in

section depths used during the extrusion procedure. Generally, it was found that disposal operations impacted, at least moderately, the entire Disposal Sites.

348. The results of discriminant analysis of sediment chemistry data from the 1975 areas illustrate a multivariate assessment of the erosion of the disposal mound (Figure 105). It was seen that the total process of return to predisposal conditions required a longer period of time than 90 days. Generally, the changes in the distribution of dredged materials occurred between the 5- and 30-day post-disposal samplings. Compaction processes may be a significant factor in this time range. Sediment transport, as an erosion process, exhibited a southwest to northeast trend relative to the illustrated station configuration at both the Harbor and River Disposal Sites.

Predisposal - 1976

349. Evaluation of sediment chemistry data from the 1976 samplings at NDS was complicated in the same manner as found with the 1975 results. Concentrations of various sediment parameters from the first core section of the predisposal sampling revealed significant differences between NDS and the Reference Sites for 8 of the 20 parameters. These parameters included Zn, Cu, percent silt, and +2, +4, +5, +6, and +9 ϕ grain-size fractions ($P = 0.024$, 0.021 , 0.012 , 0.035 , 0.049 , 0.019 , 0.019 , and 0.026 , respectively). In the second core sections from this same collection period, 10 of the 20 variables had significantly different concentrations at NDS relative to the Reference Site. These variables were Hg ($P = 0.008$), Zn ($P = 0.048$), percent water ($P = 0.041$), percent clay ($P \leq 0.001$), and -1 ϕ ($P = 0.036$), +2 ϕ ($P = 0.002$), +6 ϕ ($P = 0.044$), +7 ϕ ($P = 0.005$), +8 ϕ ($P = 0.001$), and +9 ϕ ($P \leq 0.001$) grain-size fractions. In both the first and second section results, each of the above variables had their higher concentration at the Reference Site (C1-C4), except for the +2 ϕ grain-size fraction. These same data (sediment chemistries from predisposal) were subjected to discriminant analysis. The results of this analysis confirmed the univariate differences between the two

sites at both the surface and bottom sections of the cores. In the first section evaluation, the Reference, Inner Area, and Intermediate Area Disposal station groups were mutually different from one another ($F \geq 13,516$ with an F-value at the 0.05 level of 239 required for significance). Variables used in the classification were Cu, TOC, Zn, and +4, +5, +2, and +6 ϕ grain-size fractions, Mn, clay, +8 ϕ grain-size fractions, % H₂O, pH, and 0, +4, +5, and -1 ϕ grain-size fractions, and Hg (in order of discriminating power). The results showed that stations SD5 to SD11 were different from the Reference Site Stations C1-C4. The analyses of second section predisposal chemistry results again showed the three known groups (Reference, Inner, and Intermediate areas) to be mutually different from one another ($F \geq 12.43$ with $F = 5.19$ at the 0.05 level). Classifications, based on +9, -1, and +6 ϕ grain-size fractions, Hg, and +2 and +3 ϕ grain-size fractions (in order of discriminating power) depicted Stations SD1, SD3, SD5, SD7-SD11, and SD14 as significantly different than the Reference stations, C1-C4. As was the case with the 1975 results, these findings had to be considered in the subsequent analysis of both the 5- and 30-day postdisposal results.

5-day postdisposal - 1976

350. Sediment chemistry results of first core section from the 5-day postdisposal collection showed that essentially all of the 160,000 m² area within NDS was affected by the disposal operations. In this analysis, the Reference Area group was significantly different from the Inner Area group at the Disposal Site at less than the 0.05 level ($F = 525$). The derived classifications were based upon the +7 ϕ grain-size fraction, Fe, % H₂O, Cu, Hg, and +3, +1, +5, and +9 ϕ grain-size fractions, TOC and the 0 ϕ grain-size fractions (in order of discriminating power). These classifications depicted only SD9 as not being affected by disposal. Stations SD1-SD5, SD8, and SD11 were moderately impacted by disposal while all other stations sampled were heavily affected. These findings suggested the greatest effects of disposal operations were along

the path of the hopper dredge.

351. Discriminant analysis of second core section results from the 5-day postdisposal sampling showed that at depths of > 10 cm, effects of disposal also were present. Using the clay, and +8, +9, +3, +2, and +6 ϕ , grain-size fractions, Hg, Mn, TOC, % H₂O, percent silt, and +1, +4, +5, and 0 ϕ grain-size fractions data (in order of discriminating power), the NDS stations were classified. Stations SD1, SD5, and SD9 showed no effects of disposal, and SD6 was shown to be heavily affected by deposition. All other stations sampled were moderately impacted by the disposal operations.

30-day postdisposal - 1976

352. Results from the 30-day postdisposal collection showed a significant reduction in the overall area under the effects of disposal in both the first and second core sections. The discriminant analysis of first section data again exhibited mutually distinct groups of stations which were statistically different ($F \geq 158$ with $F = 19.3$ at the 0.05 level). Unknown station classifications based on Cu and 0 and +3 ϕ grain-size fractions, percent silt, and +4, +5, and +6 ϕ grain-size fractions, Mn, % H₂O, and pH (in order of discriminating power) were completed. These findings suggest that only the Inner Disposal Area at the Disposal Site had remained heavily impacted by disposal. At this time, the other areas still affected by disposal operations were those quadrants located essentially north and northwest of the Central Disposal Site stations (Inner Area group). Second core section data were used to classify unknown stations based upon three mutually different groups of stations ($F \geq 15.8$ with $F = 5.14$ at the 0.05 level) and the use of +2 ϕ grain-size fraction, % H₂O, +4 ϕ grain-size fraction, Mn, Cu, Hg, TOC, clay, -1 ϕ grain-size fraction, pH, and the 0 ϕ grain-size fraction (in order of discriminating power) data. Stations were classified such that the effects of disposal at this time in the second core sections were seen as only moderate and were located in quadrants north and northeast of the Central Disposal Sites stations.

353. The overall effects of disposal operations on the NDS

area are illustrated in Figure 106. As can be seen in this figure, the effects of deposition were severe in terms of changes in sediment chemistry parameters during the 5-day postdisposal period. By 60-days postdisposal, however, changes that indicated approach to pre-disposal conditions had occurred. It was believed that these changes were primarily the result of erosion and compaction processes and that the sediment transport was in a southwest to northwest direction. These results were consistent with the observations at the 1975 Disposal Sites. Generally, the effects of disposal on the sediment environment were initially strong. These effects were dissipated by 30-days postdisposal, and in the case of deposition of river dredgings may have totally disappeared by some period of time greater than 90 days after disposal.

Sediment oxygen demand

354. As previously illustrated, the SOD rates at the Disposal Site were three to five times greater than at the Reference Sites. These elevated demands ($\Delta = 1.26 \text{ gm O}_2 / \text{m}^2 / \text{day}$) were multiplied by the estimated area covered by dredged materials ($13 \times 10^4 \text{ m}^2$) and by 100 days. The latter time period was assumed to be the relative temporal duration of thermal stratification in the Central Basin of Lake Erie. These calculations indicated that an additional oxygen demand, as the result of disposal of approximately $16 \times 10^3 \text{ Kg of O}_2$ was experienced. A comparison of this quantity of O_2 demand to the total content of the hypolimnion (which ranges from approximately 300 to $12 \times 10^6 \text{ Kg O}_2$ depending on the time of year), indicates that maximum increase in demand as a function of deposition was 0.14%. If it is assumed that the area covered by dredged materials to the volume of dredged materials in m^3 is relatively constant (which was believed to be a conservative assumption due to controlled disposal at Ashtabula) and that the increases in SOD rates at Ashtabula are somewhat representative of conditions that might occur at other disposal sites located in the Central Basin of Lake Erie, the percentage of O_2 depletion due to open-lake disposal would be $\geq 1.0\%$. These data appear to suggest that only minimal effects on the total hypolimnetic oxygen content would be experienced. In consideration of water

mass movements, this $\geq 1.0\%$ effect of disposal may be an understatement. Water mass movements at NDS (Danek et al. in preparation) were found to be essentially confined to the nearshore region and to periodically oscillate over the disposal mound. The low current velocities at 1 m off the bottom ($\leq 3-8$ cm/sec) and the parallel-to-shore movement may trap some bottom water over the disposal site and then transport this water (which would remain in the nearshore area of the Central Basin for the entire period of stratification) to an adjacent disposal site at Conneaut or Fairport, Ohio. This additive oxygen stress situation could produce a much greater demand on some nearshore water than is indicated in the estimate of only $\geq 1.0\%$ of the total hypolimnetic oxygen demand, being due to disposal operations. It also was noteworthy that historically, the hypolimnetic anoxia in the Central Basin of the Lake has always begun in the nearshore region on the United States side of the Lake.

Metals in Benthic Macroinvertebrates

355. The mean metals concentrations indicated decreases in all metals concentrations in the benthic organisms collected from the Disposal Sites from before and after disposal. Zn concentrations increased then decreased in going from before to 5 to 30 days after disposal. There also appeared to be a slight decrease between the 5- and 30-day postdisposal results for Cu, Zn, and Fe. Comparison of confidence intervals and subsequent one-way analysis of variance indicated that for Cd, Cu, Zn, and Fe, there were significant differences in tissue concentrations over the study period. Cd concentrations were different in the Oligochaeta ($P = 0.044$) between the 5-day postdisposal and the predisposal results. Both the 5- and 30-day postdisposal organism concentrations of Cu were lower than the predisposal results ($P = 0.018$ and 0.009 , respectively). Fe and Zn results showed a significant decrease between the predisposal and the 30-day postdisposal results ($P = 0.02$ and 0.040 , respectively), but not between predisposal and the 5-day postdisposal results in the Oligochaeta. Except for the Zn levels in the organisms from the 5-day postdisposal collection, the metals contents during postdisposal collections were indistinguishable from the concentrations observed in the organisms from the River stations. Therefore, it appeared as though the postdisposal samplings consisted primarily of organisms displaced from the River by the dredging and disposal process.

356. Table 5, Appendix A', illustrates the relationship between the weight of the organisms and their total metals content. The mean weight in milligrams of the organism was calculated using the number of organisms in each sample and the weight of wet samples subjected to digestion. The relative order of weight per single organism was Gastropoda > Isopoda > Sphaeriidae > Chironomidae > Oligochaeta. The number of nanograms of metal per organism based on mean weight was calculated using the mean metals concentration for Table 2, Appendix A', and the calculated mean weight. Gastropoda had the highest mean weight and also contained the largest amounts of most metals. Samples of Oligochaeta had the smallest mean weight and contained the lowest amounts of metals. Although these results are based on a relatively small number of organisms, these data were useful in estimating the amount of metals in major taxa and the approximate amount of metals that possibly could be ingested by a predator consuming an "average" organism of each taxon.

Metals in Fish

357. Comparison of pre- and postdisposal Reference Area fish showed a statistically significant difference in Pb for the 1975 disposal. The mean value for Pb during Pre-disposal 1975 was 9.3 $\mu\text{g/g}$, with a range of 6 fish samples from 3.0 to 23.0 $\mu\text{g/g}$. The mean value was significantly lower for Pb during postdredging 1975 with a value of 1.7 $\mu\text{g/g}$ with a range of 11 samples from < 1.0 to 9.0 $\mu\text{g/g}$. It might also be mentioned that there was a significant difference between pre- and postdisposal 1975 with respect to Fe ($P = 0.0127$), with a decrease in mean concentration from 171 to 46 $\mu\text{g/g}$, respectively. The other metals analyzed showed no significant difference. However, all decreased in mean concentration with respect to postdisposal 1975. Reference Area perch showed a significant difference with respect to Pb ($P = 0.0413$) for the 1975 disposal season.

358. Most fish captured in the disposal areas for 1975 showed a statistically significant increase with respect to Fe, Cd, Ni, and Mn after the dredged material disposal operation ($P = 0.0421, 0.018, 0.028, \text{ and } 0.0286$, respectively). Mean concentrations for Hg, Cd, and Ni doubled after disposal in 1975. For Hg, the mean concentration went from 0.18 to 0.38 $\mu\text{g/g}$. Cd and Ni followed similar patterns with a 0.7 to 1.7 $\mu\text{g/g}$ and 1.6 to 3.8 $\mu\text{g/g}$

increase, respectively. Pb, Cr, and Cu also increased after disposal. It should be mentioned that the mean weights of fish caught at the Reference Area decreased after disposal from 165.7 to 55.0 g. However, the fish collected in the Disposal Areas exhibited an increase in mean weight after disposal (80.3 to 153.8 g).

359. For the 1976 phase of the study, no fish were collected in the Reference Area prior to the disposal operation. Therefore, samples collected after the 1976 disposal at the Reference Area were compared to pre-disposal 1975 Reference data. This comparison showed no significant differences between metals.

360. The Disposal Area was sufficiently sampled to show a significant difference from pre- to postdisposal conditions in 1976 with respect to Fe ($P = 0.001$). Fe mean concentrations in fish increased also for Cd, Cr, Cu, and Mn. However, these were not statistically significant. Mean weight decreased from 150.7 to 115.3 g. Hg and Pb followed similar patterns in decreasing, while Ni mean concentration ($3.8 \mu\text{g/g}$) did not change.

Time Dependency of Standard Elutriate Test Preparations

361. The following tabulation summarizes the results obtained for the various parameters studied.

<u>Parameter</u>	<u>Elutriate Concentration</u>
Chloride	Increase with time
Total organic carbon	Data nonhomogeneous
Ammonia	Decreased with time
Soluble reactive phosphorus	No difference observed with time
Cd, Cr, Hg, Ni	No difference observed with time
Cu	Data nonhomogeneous
Fe	No difference observed with time
Mn	No difference observed with time
Zn	No difference observed with time

PART VII: CONCLUSIONS

362. Deposition of dredged materials in the open-lake environment was seen to present immediate effects on almost all measured parameters from the aquatic environment. Generally, these effects were very short termed, with a return to ambient predisposal conditions for suspended or particulate constituents within 90 min of disposal. Soluble variables ($\text{PO}_4\text{-P}$, $\text{NH}_3\text{-N}$, etc.) exhibited that longer periods of time were required to return to the predisposal levels. Rates of return to predisposal conditions were believed to be a function of settling velocities for particulate variables and/or the time needed to carry the dissolved constituents out of the study area via the prevailing currents. Most disposal monitorings exhibited multinodal peaks suggesting an initial release plus secondary water mass movements associated with the turbidity plume. Although the total monitoring effort showed short-lived effects, the fate of the soluble nutrient transported out of the study area was not determined. For reasons based primarily on the design of on-site monitoring, the effects of various dredging or disposal techniques (except for overflow) could not be ascertained. Dredging with overflow produced greater effects on the bottom waters, while dredging without overflow generated more profound surface water effects.

363. Water chemistry results from periods other than the actual disposal monitoring showed only slight short term effects. Parameters which exhibited a definite effect from disposal were specific conductance, soluble SiO_2 , TKN, P_T , and $\text{PO}_4\text{-P}$, and Mn. Parameters that showed some minor effects of disposal included Temperature, DO, pH, Alkalinity, $\text{NH}_3\text{-N}$, DOC, POC, Hg, Fe, and Zn.

364. Interface water concentrations were impacted by disposal operations. These impacts were seen to dissipate somewhat after a period of time > 5 days after disposal with some residual effects still evident at 60 days after deposition. The results of discriminant analysis of interface data suggested the transport of sediments in a north-northeast direction.

365. Currently employed elutriate test procedures were judged to be of limited value for evaluating the potential release of contaminants from the proposed dredged materials. Comparison of elutriate and on-site monitoring data yielded incompatible results. Those parameters which yielded increases in the elutriate samples did appear with elevated concentrations during disposal monitoring. The reverse, however, was not true. All parameters that showed maxima or minima during disposal monitoring were not seen in the elutriate test results.

366. Interstitial water concentrations were found to be impacted at all Disposal Site stations. However, chemical conditions returned to predisposal levels in a relatively brief period of time (30 to 90 days). It was believed that the rather short-lived effects of deposition on this aspect of the ecosystem were primarily a function of the characteristic of the interstitial water to reestablish the equilibria present during the predisposal sampling and to the erosion and/or compaction of the disposal mound. Sediment transport, indirectly affecting this phase of the system, occurred in a northeasterly direction.

367. The benthic environment, as defined by sediment chemistry data, was found to be the most affected geographic component of the study. All areas of the Disposal Sites in 1975 and 1976 were covered to some degree by dredged materials. Generally, the physical and chemical changes in the sediments were a function of erosion and, to a lesser extent, compaction. Return to ambient predisposal levels was seen for some variables by periods of time \geq 90 days and less than 1 year. Other variables, however, remained affected by disposal operations for periods of time greater than one year.

368. SOD rates as a function of disposal operations exhibited significantly higher values (three to five times greater at the Disposal Site compared to the Reference Site) which may or may not be a consideration relative to anoxia problems within the Central Basin of Lake Erie. With time, the SOD of the Disposal Sites, also approached those of the Reference Sites. Generally, the erosion characteristics due to sediment transport were seen to occur in a northerly

direction.

369. Oligochaeta analyzed for Fe, Mn, Zn, Cu, Cd, and Hg showed apparent decreases in metals concentrations after the disposal operations. These decreases, which were statistically significant during one and/or both of the postdisposal samplings for Cd, Cu, Zn, and Fe, were believed to be primarily a function of the transfer of organisms from the River Dredged Sites to the Disposal Sites. These organisms exhibited significantly lower concentrations of the above metals than were measured in the indigenous Lake organisms.

370. The small number of organisms available for analyses necessitated the results being expressed on a wet-weight basis. Therefore, precautions should be made when comparing these metal-benthic data to other bulk sediment data of this and/or other studies in which results are reported on a dry-weight basis.

371. Generally, the disposal operation for 1975 had an apparently greater impact on the fish with respect to the increase in heavy metal concentration than did the 1976 disposal. All the mean metal concentrations during the 1975 season of Hg, Fe, Pb, Cd, Cr, Ni, Cu, and Mn increased with the Fe, Cd, Ni, and Mn data being statistically significant. If fish are concentrators of trace elements from their external environment, then perhaps the disposal operation had an influence on such accumulations.

372. From these data it was noted that the magnitude of metal concentrations of fish show a resemblance to the concentrations found in the sediments of the study area; that is, $Fe > Mn > Cu > Cd$. The heavy metals in the benthic macroinvertebrates from these areas followed a similar pattern. It should be noted that the heavy metal concentrations in the dredged material were lower than those in the "natural" Lake sediment. Likewise, the heavy metals in the macroinvertebrates from the dredged areas were lower than those in Lake Erie off Ashtabula.

373. With respect to the time dependency of the standard elutriate test, the elongation of the confidence intervals for chloride, copper, and mercury elutriate concentrations indicated a possible reproducibility problem with time. It appeared that the changes in the elutriate, Dredge, and Disposal Site water levels for total organic carbon, ammonia, soluble reactive phosphorus, copper, and zinc were affected by the decomposition of particulate organic matter.

LITERATURE CITED

American Public Health Association (APHA). 1971. Standard methods for the examination of water and wastewater, 13th Edition. American Public Health Association. New York, N.Y. 874 pp.

_____. 1975. Standard methods for the examination of water and wastewater, 14th Edition. American Public Health Association. New York, N.Y. 1193 pp.

Anon. 1976. Ecological evaluation of proposed discharge of dredged or fill material into navigable waters. Miscellaneous Paper D-76-17. Environmental Effects Laboratory, U.S. Army Engineer Waterways Experiment Station. Vicksburg, Miss.

Beckman Instruments. 1967. The measurement of oxidation. Reduction potentials, Bulletin 99-D. Beckman Instruments Inc. Fullerton, California.

_____. 1974. Model 915A total organic carbon analyzer. O15-082355. Beckman Instruments Inc. Fullerton, California. 46 pp.

Brannon, J.M., Engler, R.M., Rose, J.R., Hunt, G., and Smith, Isaac. 1976. Distribution of manganese, nickel, zinc, cadmium, and arsenic in sediments and in the standard elutriate. Miscellaneous Paper D-76-18. Environmental Effects Laboratory, U.S. Army Engineer Waterways Experiment Station. Vicksburg, Miss.

Burns, Noel M. and Curtis Ross. 1972. Project Hypo. U.S. Environmental Protection Agency Technical Report TS-05-71-208-24. Washington, D.C. 182 pp.

Coleman Instruments. 1969. Coleman model 33 carbon hydrogen analyzer. 33-900 Operating Directions. Coleman Instruments, Division of Perkin-Elmer Corp. Maywood, Ill. 38 pp.

Coulter Electronics. 1972. Instruction and service manual for the Coulter model TA. Coulter Electronics, Inc. Haleah, Fl. 84 pp.

Danek, L.J., G.R. Arthur, P.P. Paily, R.G. Johnson, J.F. Yohn, F. deLibero, and F.T. Lovarn. In preparation. Aquatic disposal field investigations, Ashtabula River Disposal Site, Ohio - Appendix B: Investigation of the hydraulic regime and physical nature of bottom sedimentation. Prepared by NALCO Environmental Sciences, Northbrook, Ill., under contract to U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Duncan, G.A. and N. Rukavina. 1970. F.A.S.T.-fast analysis of sediment texture. Proc. 13th Conf. Great Lakes Res. Internat. Assoc. Great Lakes Res. 241-281 pp.

Engler, R.M., J.M. Brannon, and J. Rose. 1975. A practical selective extraction procedure for sediment characterization. U.S. Army Engineer Waterways Experiment Station, Office of Dredged Material Research. Vicksburg, Miss.

Federal Water Quality Administration (FWQA). 1969. Chemistry laboratory manual bottom sediments. U.S. Department of Interior.

Hatch, W.R. and W.L. Ott. 1968. Determination of sub-microgram quantities of mercury by atomic absorption spectrophotometry. Anal. Chem. 40, 2085.

H.F. Instruments Limited. 1975. Instruction manual, model DRT-1000 nephelometric turbidimeter. Bolton, Ontario. Canada. 20 pp.

Hutchinson, G.E. 1957. A treatise on limnology, Vol. 1. John Wiley and Sons, Inc. London, England. 1015 pp.

Jackson, M.L. 1958. Soil chemical analysis. Prentice Hall, Inc. Englewood Cliffs, N.J.

Keeley, J.W. and R.M. Engler. 1974. Discussions of regulatory criteria for ocean disposal of dredged material elutriate test rationale and implementation guidelines. Miscellaneous Paper No. D-74-14, March 1974. U.S. Army Engineer Waterways Experiment Station. Vicksburg, Miss.

Lucas, A.M. and N.A. Thomas. 1972. Sediment oxygen demand in Lake Erie Central Basin. 1970. Project Hypo. U.S. Environmental Protection Agency Technical Report TS-05-71-208-24. Washington, D.C.

Mattson, J.S., C.S. Mattson, M.J. Spencer, and S.A. Starks. 1977. Multivariate statistical approach to the finger printing of oils by infrared spectrometry. Anal. Chem. 49(2):297-302.

Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bendi. 1970. Statistical package for social sciences (SPSS). McGraw-Hill Inc. New York, N.Y. 675 pp.

Orion Research Incorporated. 1970. Instruction manual sulfide ion electrode. Silver ion electrode, model 94-16. Cambridge, Mass. 28 pp.

_____. 1973. Orion ionalyzer, Instruction Manual. Platinum Redox Electrode. Cambridge, Mass. 9 pp.

_____. 1976. Instruction Manual, Halide Electrodes, Cambridge, Mass. 28 pp.

Ott, A.N. and S.J. Toth. 1970. Characterization of bottom sediments: cation exchange capacity and exchangeable cation status. Environmental Science and Technology 4(11):935-939.

Rosengrant, L.E. 1975. Distribution of heavy metals in sediment cores from the Central Basin of Lake Erie. Presented at the 18th Conference on Great Lakes Research. Internat. Assoc. Great Lakes Res. Albany, N.Y.

Sweeney, R.A., R. Foley, C. Merckel, and R. Wyeth. 1975. Impacts of the deposition of dredged spoils on Lake Erie sediment quality and associated biota. J. Great Lakes Research 1(1):162-170.

Technicon Industrial Systems. 1974. Technical Publication No. TS1-0268, document support package. Technicon Autoanalyzer II. Tarrytown, N.Y.

U.S. Army Corps of Engineers. 1976. Third Annual Report: Dredge Material Research Program. Environmental Effects Laboratory, U.S. Army Engineer Waterways Experiment Station. Vicksburg, Miss.

U.S. Environmental Protection Agency (U.S. EPA). 1974. Methods of Chemical Analysis of Water and Wastes. Methods Development and Quality Assurance Research Laboratory. National Environmental Research Center. Cincinnati, Ohio.

Varian Techtron. 1972. Analytical Methods for Flame Spectroscopy. Varian Instruments. Sidney, Australia.

Vollenweider, R.A., M. Munawar, and P. Stadelmann. 1974. A Comparative Review of Phytoplankton and Primary Production in the Laurentian Great Lakes. JFRB Canada 31:739-762.

Wetzel, Robert G. 1975. Limnology. W.B. Saunders Co., Philadelphia, Pa. 743 pp.

TABLE 1

Sediment Chemistry Mean Values (%) in the Reference Area from the
Initial Survey (11-12 June 1975) in Lake Erie off
Ashtabula, Ohio

<u>Station Number</u>	<u>H₂O</u>	<u>IOC</u>	<u>Clay</u>	<u>Silt</u>	<u>Total Sand</u>	<u>Greatest Sand Fraction (mm)</u>	<u>Sediment Type</u>
B1	76.5	2.52	46.1	22.3	31.6	0.250 - 0.125	Loam
B2	67.5	2.19	41.7	27.2	31.1	0.250 - 0.125	Loam
B3	68.7	2.29	48.4	22.9	28.8	0.250 - 0.125	Loam
B4	65.7	1.91	42.7	25.6	32.1	0.250 - 0.125	Loam
B5	67.0	2.10	49.4	24.8	26.0	0.250 - 0.125	Loam
B6	61.6	1.83	44.4	28.6	27.0	0.250 - 0.125	Loam
B7	59.0	1.95	48.3	26.4	24.9	0.250 - 0.125	Loam
B8	49.8	1.49	42.5	37.2	20.2	0.125 - 0.062	Loam
B9	52.9	1.63	46.8	28.4	24.8	0.250 - 0.125	Loam

TABLE 2

Sediment Chemistry Mean Values (%) in the Disposal Area from the
Initial Survey (11-12 June 1975) in Lake Erie off
Ashtabula, Ohio

Station Number	H ₂ O	TOC	Clay	Silt	Total Sand	Greatest Sand Fraction (mm)	Sediment Type
B10	64.1	2.00	38.1	5.7	50.5	0.250 - 0.125	Clayey sand
B11	N O	S A M P L E	C O L L E C T E D		F O R	A N A L Y S I S	Rock (shale)
B12	N O	S A M P L E	C O L L E C T E D		F O R	A N A L Y S I S	Rock
B13	57.5	1.65	28.3	13.9	63.3	0.250 - 0.125	Clayey sand
B14	N O	S A M P L E	C O L L E C T E D		F O R	A N A L Y S I S	Rock
B15	N O	S A M P L E	C O L L E C T E D		F O R	A N A L Y S I S	Rock
B16	N O	S A M P L E	C O L L E C T E D		F O R	A N A L Y S I S	Rock
B17	60.4	1.51	25.4	11.8	62.9	0.250 - 0.125	Clayey sand
B18	67.9	2.23	76.0	8.5	15.5	0.250 - 0.125	Clay
B19	N O	S A M P L E	C O L L E C T E D		F O R	A N A L Y S I S	Rock
B20	N O	S A M P L E	C O L L E C T E D		F O R	A N A L Y S I S	Rock
B21	64.1	2.02	60.0	11.7	28.2	0.250 - 0.125	Sandy clay
B22	61.4	1.80	52.8	12.6	34.5	0.250 - 0.125	Sandy clay
B23	N O	S A M P L E	C O L L E C T E D		F O R	A N A L Y S I S	Rock
B24	58.6	1.69	46.6	13.9	39.2	0.250 - 0.125	Sandy clay
B25	61.6	1.90	65.0	13.3	21.4	0.250 - 0.125	Sandy clay
*B26	39.7	1.00	49.8	15.4	34.5	0.125 - 0.062	Sandy clay

* NOTE: B26 was collected from the alternate disposal area.

TABLE 3

Water Chemistry Mean Values from the
Initial Survey (11-12 June 1975) in Lake Erie in the vicinity of
Ashtabula, Ohio

<u>Station Number</u>	<u>Alkalinity (mg/ℓ)</u>	<u>TKN (mg/ℓ)</u>	<u>NH₃-N (mg/ℓ)</u>	<u>NO₃-N (mg/ℓ)</u>	<u>Ortho-P (mg/ℓ)</u>	<u>Total P (mg/ℓ)</u>	<u>Total Solids (mg/ℓ)</u>	<u>Suspended Solids (mg/ℓ)</u>
SPW1	85.2	0.164	0.073	0.114	0.014	0.033	205	7.78
SPW2	84.5	0.410	0.073	0.050	0.016	0.031	216	9.78
SPW3	84.0	0.177	0.054	0.099	0.015	0.033	186	9.78
SPW4	84.0	0.145	0.053	0.225	0.016	0.020	184	4.44
SPW5	84.6	0.148	0.031	0.102	0.020	0.046	204	4.89
SPW6	83.3	0.145	0.052	0.158	0.017	0.042	185	6.45
SPW7	82.7	0.212	0.068	0.203	0.027	0.036	196	4.45

TABLE 4

Station Descriptions for Collection Sites in
Lake Erie at Ashtabula, Ohio

<u>Station Number</u>	<u>North Latitude</u>	<u>West Longitude</u>	<u>Depth (m)</u>
PW1 B1 C1	41°56'55"	80°50'00"	17.5
PW2 B7 C3	41°56'02"	80°50'00"	16.0
PW3 B13 D2	41°57'46"	80°46'32"	16.0
PW4 D6	41°57'41"	80°46'09"	16.0
PW5 B24 D8	41°56'53"	80°46'56"	15.0
PW6 D12	41°56'49"	80°46'31"	15.0
PW7	41°57'43"	80°49'27"	17.0
PW8	41°55'21"	80°48'46"	13.5
PW9	41°55'21"	80°47'33"	13.0
PW10	41°56'13"	80°46'13"	14.0
PW11	41°57'46"	80°44'46"	16.0
SPW1	41°58'38"	80°47'10"	20.0
SPW2	41°57'20"	80°48'22"	16.0
SPW3	41°57'20"	80°47'10"	16.0
SPW4	41°57'20"	80°46'07"	15.0
SPW5	41°56'09"	80°49'23"	16.0
SPW6	41°56'09"	80°47'10"	14.5
SPW7	41°56'09"	80°44'57"	12.0
B10	41°57'46"	80°47'44"	16.5
B3	41°56'53"	80°48'50"	16.5
B5	41°56'28"	80°49'25"	16.5
B9	41°56'02"	80°48'50"	15.0
B22	41°56'53"	80°47'44"	14.5
B25	41°56'53"	80°46'32"	15.0
D1	41°57'48"	80°46'32"	16.0
D3	41°57'44"	80°46'32"	16.0
D4	41°57'46"	80°46'34"	16.0
D5	41°57'46"	80°46'30"	16.0
D7	41°56'54"	80°46'56"	15.0
D9	41°56'52"	80°46'56"	15.0
D10	41°56'53"	80°46'58"	15.0
D11	41°56'53"	80°46'54"	15.0
C2	41°56'53"	80°49'52"	17.5
C4	41°56'00"	80°49'52"	16.0
B2	41°56'55"	80°49'25"	17.0
B4	41°56'28"	80°50'00"	16.5
B6	41°56'28"	80°48'50"	61.0
B8	41°56'02"	80°49'25"	15.5
B11	41°57'46"	80°47'22"	16.5
B12	41°57'46"	80°46'56"	16.0
B14	41°57'29"	80°47'44"	16.0
B15	41°57'29"	80°47'22"	16.0

(CONTINUED)

TABLE 4 (CONCLUDED)

<u>Station Number</u>	<u>North Latitude</u>	<u>West Longitude</u>	<u>Depth (m)</u>
B16	41°57'29"	80°46'56"	16.0
B17	41°57'29"	80°46'32"	16.0
B18	41°57'12"	80°47'44"	15.0
B19	41°57'12"	80°47'22"	15.0
B20	41°57'12"	80°46'56"	15.0
B21	41°57'12"	80°46'32"	15.0
B23	41°56'53"	80°47'22"	14.5
SD1	41°57'51"	80°47'49"	16.0
SD2	41°57'51"	80°47'44"	16.0
SD3	41°57'51"	80°47'40"	16.0
SD4	41°57'51"	80°47'36"	16.0
SD5	41°57'48"	80°47'36"	16.0
SD6	41°57'48"	80°47'40"	16.0
SD7	41°57'48"	80°47'44"	16.0
SD8	41°57'48"	80°47'49"	16.0
SD9	41°57'44"	80°47'49"	16.0
SD10	41°57'44"	80°47'44"	16.0
SD11	41°57'44"	80°47'40"	16.0
SD12	41°57'44"	80°47'36"	16.0
SD13	41°57'41"	80°47'36"	16.0
SD14	41°57'41"	80°47'40"	16.0
SD15	41°57'41"	80°47'44"	16.0
SD16	41°57'41"	80°47'49"	16.0
NDS B10	41°57'46"	80°47'44"	16.0

TABLE 5

Variables Determined for Lake Water,
Interstitial Water, and Sediment Chemistry
on Samples Collected in Lake Erie off Ashtabula, Ohio

<u>Sample Type</u>	<u>1975</u>	<u>1976</u>
Lake Water	Alkalinity	SS
	SO ₄	pH
	SiO ₂	PO ₄
	NH ₃ -N	Total-P
	TKN	NH ₃ -N
	NO ₃ -N	SiO ₂
	NO ₂ -N	POC
	PO ₄ -P	Fe
	Total-P	Mn
	DOC	Hg
	POC	Zn
	Cd	Cl
	Cu	Turbidity
	Fe	DO (profile)
	Mn	Temperature (profile)
	Hg	Conductivity (profile)
	Ni	% Transmission (profile)
	Pb	
	Zn	
	pH	
	Eh	
	DO (profile)	
	Temperature (profile)	
	Conductivity (profile)	
	% Transmission (profile)	

(CONTINUED)

TABLE 5 (CONCLUDED)

<u>Sample Type</u>	<u>1975</u>	<u>1976</u>	
Interstitial Water	TOC	TOC	
	TKN	NH ₄ -N	
	NH ₄ -N	PO ₄ -P	
	PO ₄ -P	Fe	
	Fe	Mn	
	Mn	Hg	
	Hg	Zn	
	Cd	Cl	
	Cu		
	Ni		
	Pb		
	Zn		
	Sediment	pH	pH
		Eh	Eh
% H ₂ O		% H ₂ O	
TOC		TOC	
% Clay		NH ₄ -N	
% Silt		Fe	
Sand Fractions		Mn	
TON		Hg	
NH ₄ -N		Cu	
Total-P		Zn	
CEC		Grain size (-1 to 9 φ units)	
Cd			
Cu			
Fe			
Hg			
Mn			
Ni			
Pb			
Zn			

TABLE 6

Sampling Schedule for Water and Sediment
Collections in Lake Erie Off Ashtabula, Ohio
Relative to Open-Lake Disposal of
Dredged Material

<u>Period</u>	<u>1975 Disposal</u>	<u>1976 Disposal</u>
Background	11-12 June 1975 (Initial Survey)	15-16 May 1976 (River Cores)
	24 June 1975 (Harbor and River Cores)	
Predisposal	9-11 July 1975	21 April (Water Chemistry Only)
	30-31 July 1975	15-16 May 1976
Disposal	4-14 August 1975	24-26 May 1976
Postdisposal	14 August 1975	10-11 June 1976
	19-20 August 1975	7-8 July 1976
	14 September 1975	
	16-17 November 1975	
	21 April 1976	
	15-16 May 1976 (Water Chemistry Only)	
	7-8 July 1976	

TABLE 7

Summary Table of Quality Control Data
for Laboratory Analyses of
Environmental Replicates and Spikes

<u>Sample Type</u>	<u>Variable</u>	<u>% Coefficient of Variation</u>	<u>% Recovery</u>
Lake Water	PO ₄ -P	2.0	99.0
	NH ₃ -N	3.3	99.6
	TKN	5.3	99.4
	P _T	4.2	100.1
	NO ₃ -N	4.6	100.9
	NO ₂ -N	4.7	102.1
	SiO ₂	1.1	99.5
	POC	18.0	96.2
	DOC	3.2	96.2
	Cl	1.5	97.1
	Conductivity	0.6	-
	Turbidity	9.3	-
	Suspended Solids	2.3	-
	SO ₄	1.9	101
	Hg	0.2	99.1
	Fe	4.0	98.7
	Mn	1.0	101
	Zn	2.0	98.3
	Pb	4.0	96.1
	Ni	4.0	95.8
Cu	1.0	99.8	
Cd	1.0	95.3	

(CONTINUED)

TABLE 7 (CONCLUDED)

<u>Sample Type</u>	<u>Variable</u>	<u>% Coefficient of Variation</u>	<u>% Recovery</u>	
Interstitial Water and Interface Water	PO ₄ -P	2.0	99.0	
	NH ₄ -N	3.3	99.6	
	TKN	5.3	99.4	
	TOC	3.2	96.2	
	Metals	Same as that listed for Lake Water		
	Cl	1.8	97.3	
Sediment	% H ₂ O	2.5	-	
	TOC	3.6	98.3	
	NH ₄ -N	9.1	83.6	
	TON	2.7	101	
	Sand (F.A.S.T.) (COULTER)		10.7	-
			1.4	-
	Silt (F.A.S.T.) (COULTER)		12.1	-
			1.4	-
	Clay (F.A.S.T.) (COULTER)		6.9	-
			5.5	-
	PT	3.4	102	
	CEC	10.9	-	
	Hg	4.4	89.0	
	Fe	0.4	-	
	Mn	1.3	88.0	
	Zn	1.9	86.0	
	Pb	2.7	92.0	
	Ni	1.7	93.0	
	Cu	1.4	94.4	
	Cd	8.2	90.0	

TABLE 8

Sampling Dates for Collection of Samples
in Lake Erie Off Ashtabula, Ohio,
and Numerical Identifications Used for Graphic Displays

<u>Sampling Dates</u>	<u>Descriptions</u>	<u>Numerical Identifications</u>
11-13 June 1975	Initial Survey 1975	Not displayed
9-11 July 1975	Predisposal 1975	-37
30-31 July 1975	Predisposal 1975	-14
14 August 1975	Last day of Disposal 1975	0
19-20 August 1975	5-Day Postdisposal 1975	5
14 September 1975	30-Day Postdisposal 1975	31
October 1975	60-Day Postdisposal 1975	Not displayed
16-17 November 1975	90-Day Postdisposal 1975	92
21 April 1976	250-Day Postdisposal 1975 Predisposal 1976	248
15-16 May 1976	Predisposal 1976	272
10-11 June 1976	5-Day Postdisposal 1976	298
7-8 July 1976	30-Day Postdisposal 1976 and 325-Day Postdisposal 1975	326

TABLE 9

Conductivity Results from
the Continuous Monitoring System
Aboard the R/V Dambach During Disposal Operations
on 24, 25, 26 May 1976

<u>Date</u>	<u>Depth (m)</u>	<u>$\bar{x} \pm 95\%$ Confidence Interval ($\mu\text{mhos/cm at } 25^\circ \text{ C}$)</u>
24 May	1	312 \pm 1
	14	307 \pm 2
	17	309 \pm 2
25 May	1	346 \pm 4
	16	309 \pm 2
	17	309 \pm 4
26 May	1	349 \pm 1
	16	311 \pm 2
	17	317 \pm 5

TABLE 10

Results of Chloride Analysis for Samples
Collected on 24, 25, and 26 May 1976

<u>Date</u>	<u>Depth (m)</u>	<u>$\bar{x} \pm 95\%$ Confidence Interval (mg/l)</u>
24 May	1	24.5 \pm 0.6
	14	23.5 \pm 0.5
	17	23.9 \pm 0.6
25 May	1	33.4 \pm 0.6
	16	23.4 \pm 0.4
	17	23.6 \pm 0.7
26 May	1	34.1 \pm 0.3
	16	23.2 \pm 0.5
	17	24.1 \pm 0.6

TABLE 11

Mean Results of Chemical Analyses of Ashtabula
River and Harbor Elutriates, and Disposal and
Dredge Site Water

31 July 1975

Parameter	Disposal Site Water (mg/l)	Dredge Site Water		Elutriate Water	
		Harbor (mg/l)	River (mg/l)	Harbor (mg/l)	River (mg/l)
TOC	7.63	13.3	8.1	10.9	15.0
TKN	0.084	0.98	0.65	23.2	42.8
NH ₃ -N	0.016	0.69	0.24	14.4	38.3
NO ₂ -N	0.006	0.021	0.009	0.01	0.01
NO ₃ -N	0.095	0.085	0.122	0.06	0.06
PO ₄ -P	0.0045	0.017	0.017	0.008	0.013
Fe	0.029	0.021	0.017	0.022	0.033
Mn	0.006	0.007	0.006	0.61	0.64
Hg	0.0002	0.0005	-	0.0006	0.0004
Cd	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.010	< 0.010	0.012	< 0.010	0.011
Ni	< 0.015	< 0.015	< 0.015	< 0.015	< 0.015
Pb	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
Zn	0.007	0.010	0.020	0.007	0.017

TABLE 12

Mean Results of Chemical Analyses of
Ashtabula River Elutriates, Disposal Site
and Dredge Site Water

<u>Variable</u>	1976		
	Disposal Site Water (mg/l)	Dredge Site Water (mg/l)	Elutriate Water (mg/l)
	<u>1976</u>	<u>1976</u>	<u>1976</u>
TOC	8.01	20.6	49.9
NH ₃ -N	0.014	0.029	6.94
PO ₄ -P	0.005	0.011	0.009
Fe	0.006	0.015	0.229
Mn	0.005	0.001	0.851
Zn	0.009	0.008	0.014
Hg	0.002	0.0050	0.0024

TABLE 13

Mean Interstitial Water Chloride Concentration
and Associated 95% Confidence Interval
for Sediments Collected at
Reference and Disposal Sites in 1976

<u>Date</u>	<u>Section</u>	<u>Reference Site</u>			<u>Disposal Site</u>		
		<u>Mean</u>	<u>95% Confidence Interval</u>		<u>Mean</u>	<u>95% Confidence Interval</u>	
15-16 May	1	37.4	±	4.2	41.8	±	3.2
	2	41.4	±	5.2	46.0	±	3.9
7-8 June	1	41.4	±	5.7	52.9	±	3.6
	2	50.6	±	5.3	60.4	±	5.6
7 July	1	69.7	±	20.1	102.2	±	19.0
	2	72.6	±	23.3	101.1	±	17.3

TABLE 14

<u>Postdisposal Dates</u>	<u>Variables Affected by Disposal</u>	
	<u>Pelagic Chemistry</u>	<u>Variables Possibly Affected</u>
	<u>Variables Affected</u>	
14 August 1975	Conductance, Silicate, TKN	Temp., DO, pH, Alkalinity, NH ₃ -N, DOC, Mn
19-20 August 1975	Silicate, TKN	DO, pH, Alkalinity, NH ₃ -N, DOC, Hg, Fe, Zn
14 September 1975	-	Hg
*19 October 1975	-	-
16-17 November 1975	-	-
10-11 June 1976	Mn	DO, pH
7-8 July 1976	-	DO, Silicate, POC, Hg, Zn, Mn

* Only Temp., DO, pH, and Specific Conductance measured on this sampling date.

TABLE 15

<u>Data for Mixing Zone Calculations</u>			
<u>Term</u>	<u>Source</u>	<u>Unionized NH₃ Values</u>	<u>Mn Values</u>
C _e	GLL	0.083 mg/ℓ	0.851 mg/ℓ
C _s	EPA	0.020 mg/ℓ	0.050 mg/ℓ
C _a	GLL	0.001 mg/ℓ	0.003 mg/ℓ
V _d	WES	4.31 x 10 ² yd ³ (3.30 x 10 ² m ³)	4.31 x 10 ² yd ³ (3.30 x 10 ² m ³)
r	CORPS (Buffalo District)	5.92 ft (1.80 m)	5.92 ft (1.80 m)
d ¹	NALCO	55.1 ft (16.8 m)	55.1 ft (16.8 m)
V	WES	0.01 ft/sec (3.05 cm/sec)	0.01 ft/sec (3.04 cm/sec)
T	CORPS	180 sec	180 sec
V _w	NALCO	0.1-1.0 ft/sec (0.03-0.30 m/sec)	0.1-1.0 ft/sec (0.03-0.30 m/sec)
V _s	WES	10 ft/sec (3.05 m/sec)	10 ft/sec (3.05 m/sec)
D	-	3.32	17.04
M	-	1.43 x 10 ³ yd ³ (1.09 x 10 ³ m ³)	7.34 x 10 ³ yd ³ (5.61 x 10 ³ m ³)
R	-	21.4 ft (6.52 m)	54.5 ft (16.6 m)
A	-	868-1000 ft ² (80.6-92.9 m ²)	4950-5250 ft ² (459-488 m ²)

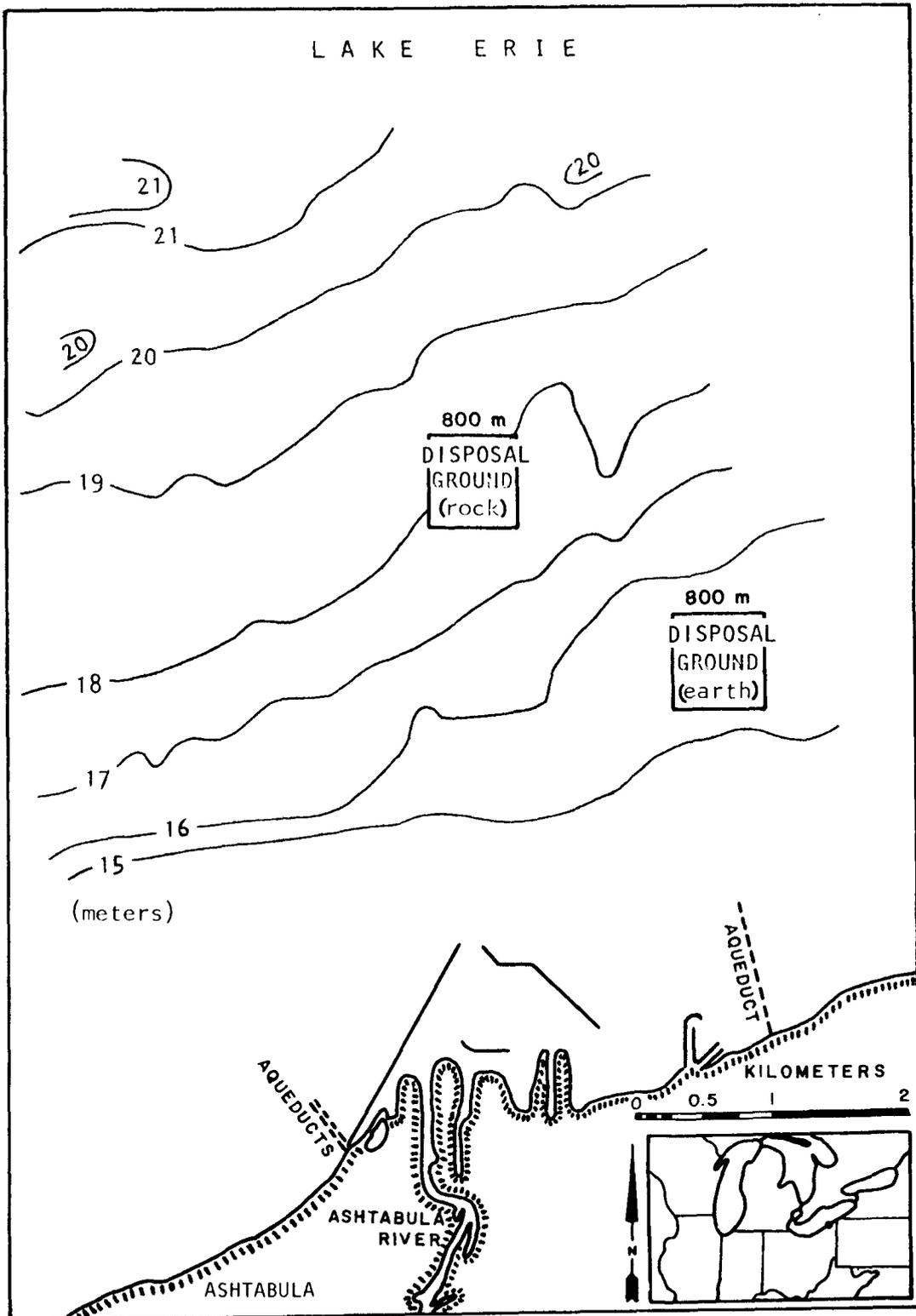


Figure 1. Earth and rock disposal sites for dredged materials collected from Ashtabula River and Harbor

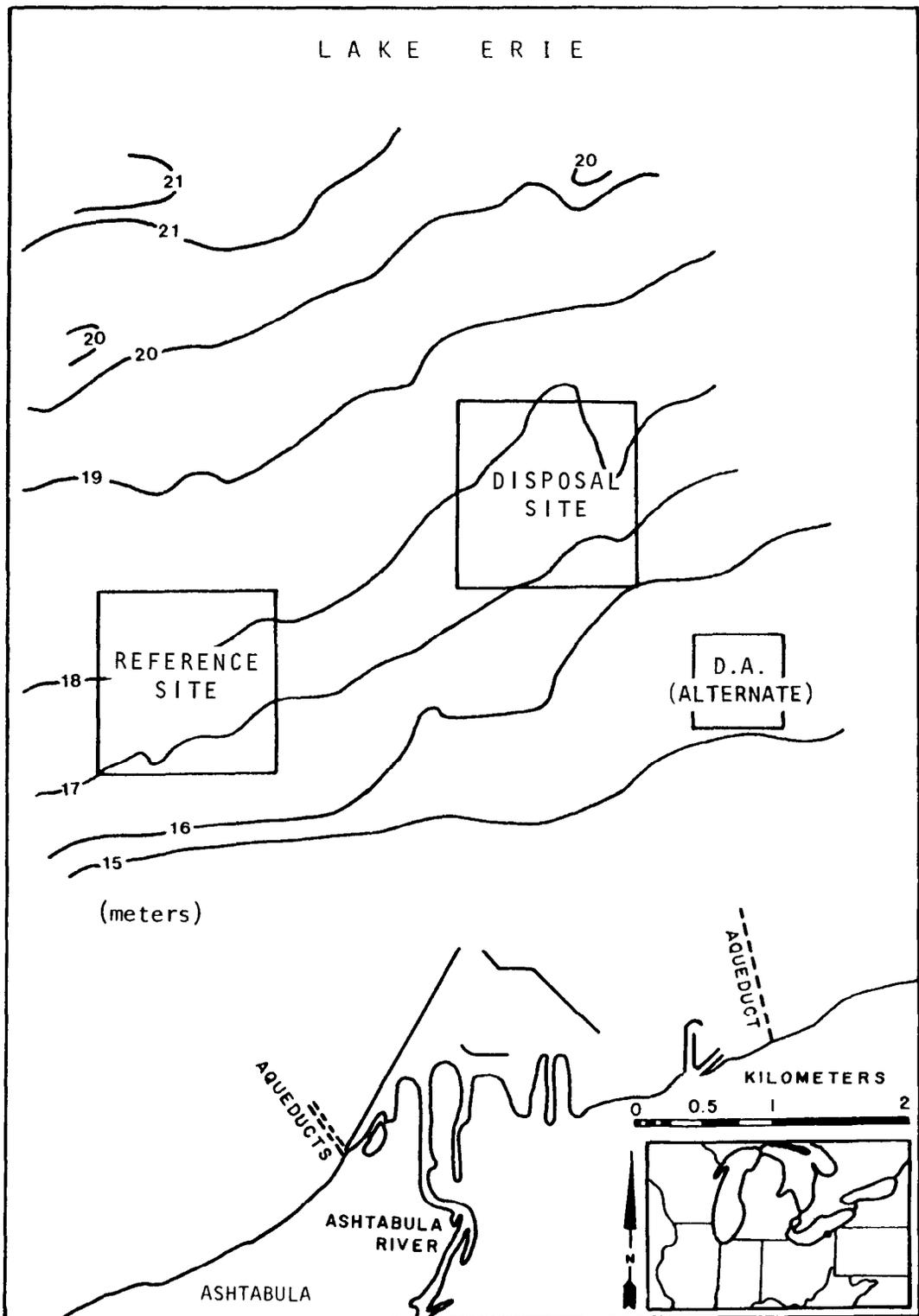


Figure 2. Reference and disposal sites for use during GLL studies of open-lake disposal of dredged materials from the Ashtabula River and Harbor. The alternate disposal area (D.A.) was not used in the investigation phases of the study

L A K E E R I E

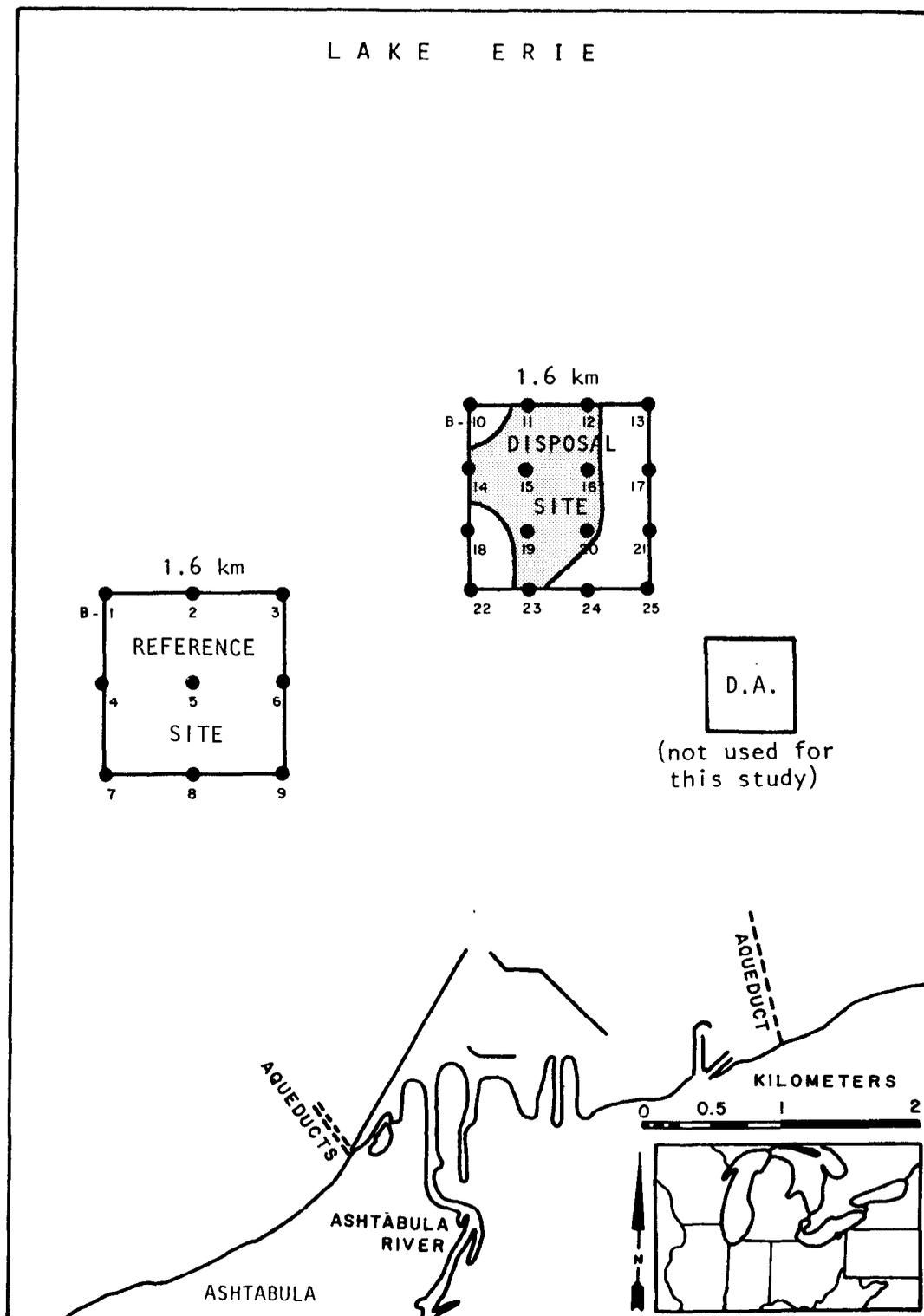


Figure 3. Station locations (B1-B25) for duplicate Ponar grabs collected during GLL initial survey, 11-12 June 1975. The shaded area within the disposal site represents the spatial distribution of fragmented Ohio shale

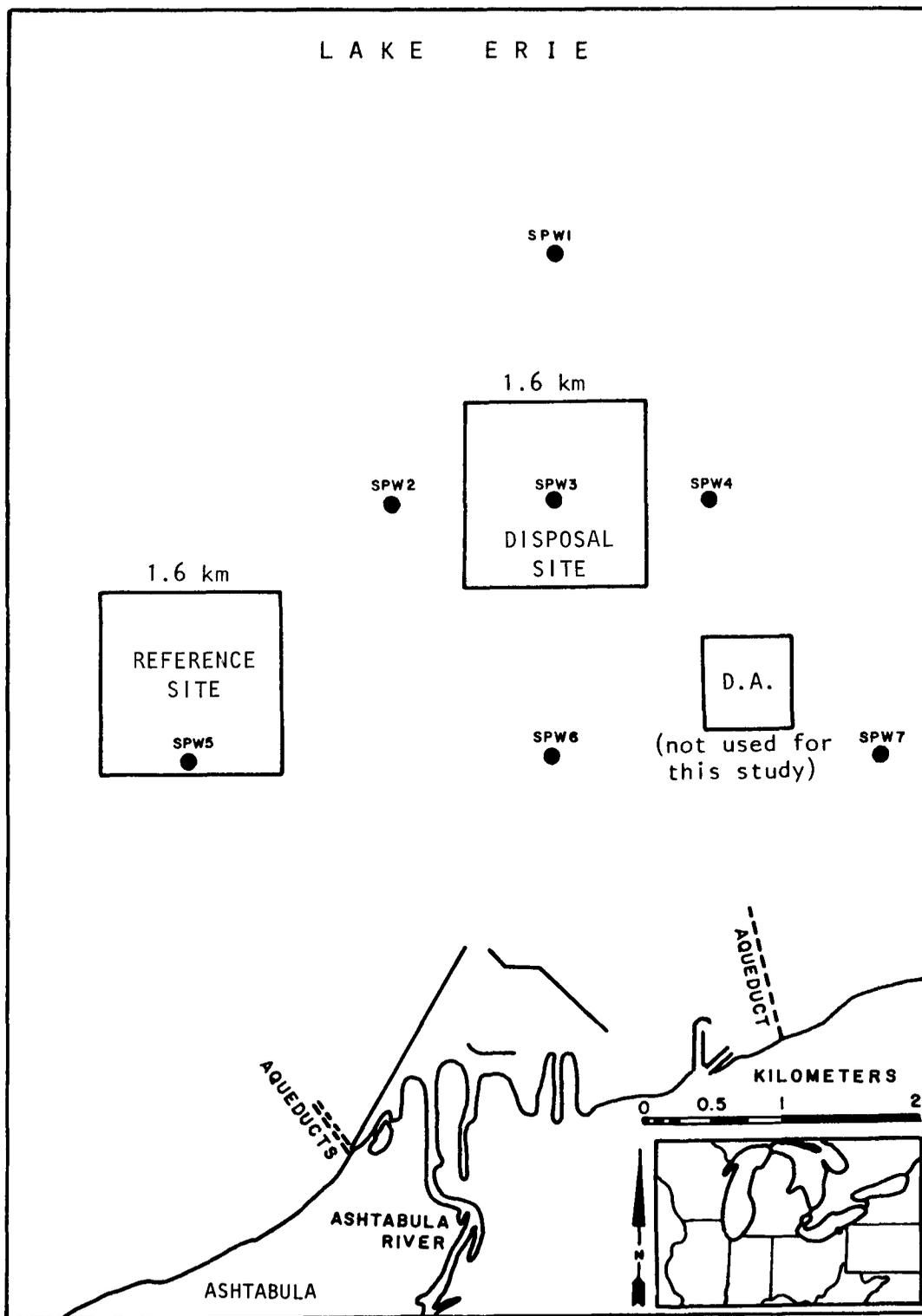


Figure 4. Station locations (SPW1-SPW7) for triplicate middepth water sample collections during GLL initial survey, 11-12 June 1975

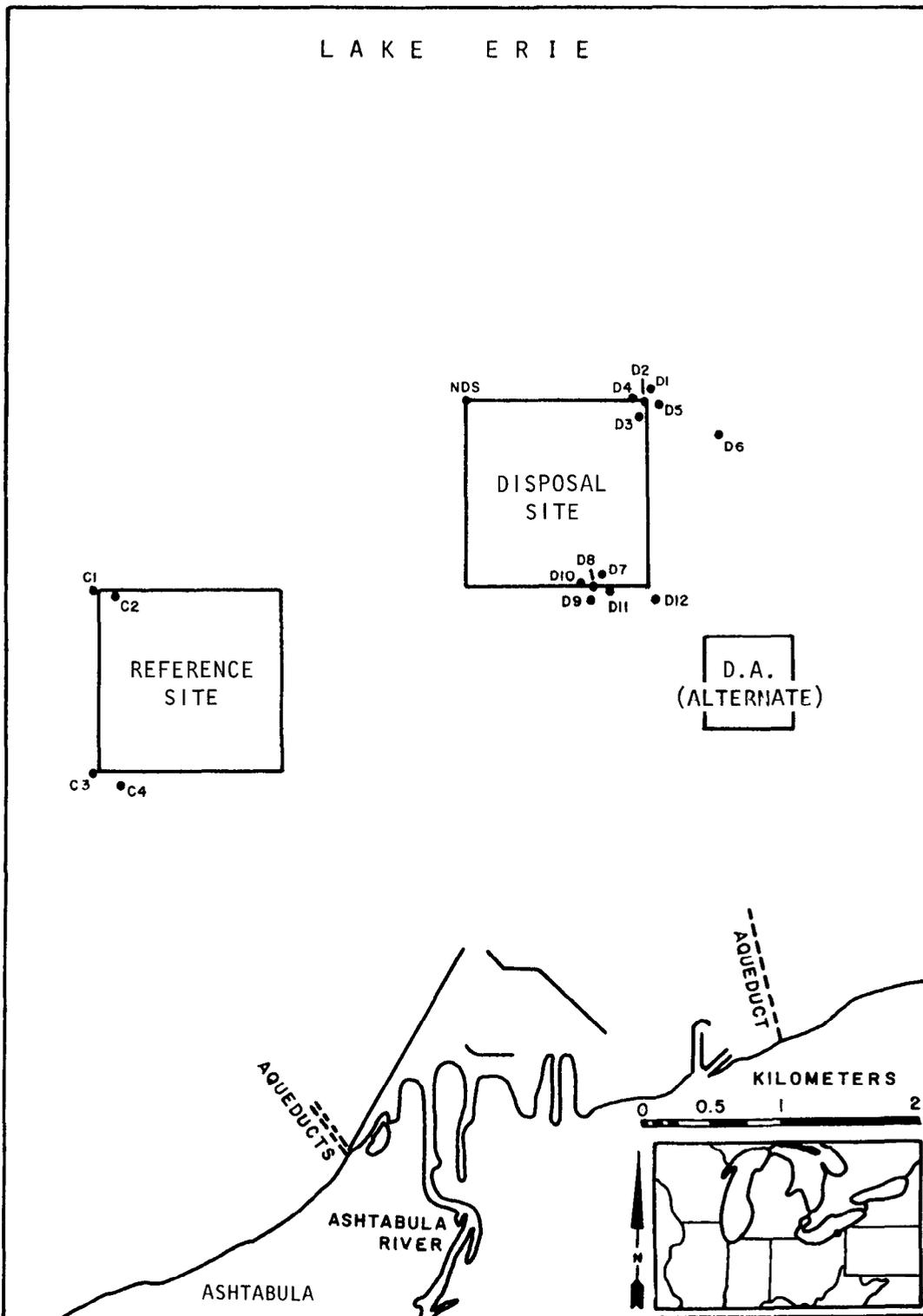


Figure 5. Station locations for reference site stations (C1-C4) and disposal site stations (D1-D6 and D7-D12) for deposition of Ashtabula Harbor and River dredgings, respectively, during 1975. The northwest disposal site (NDS) was the site of 1976 deposition studies

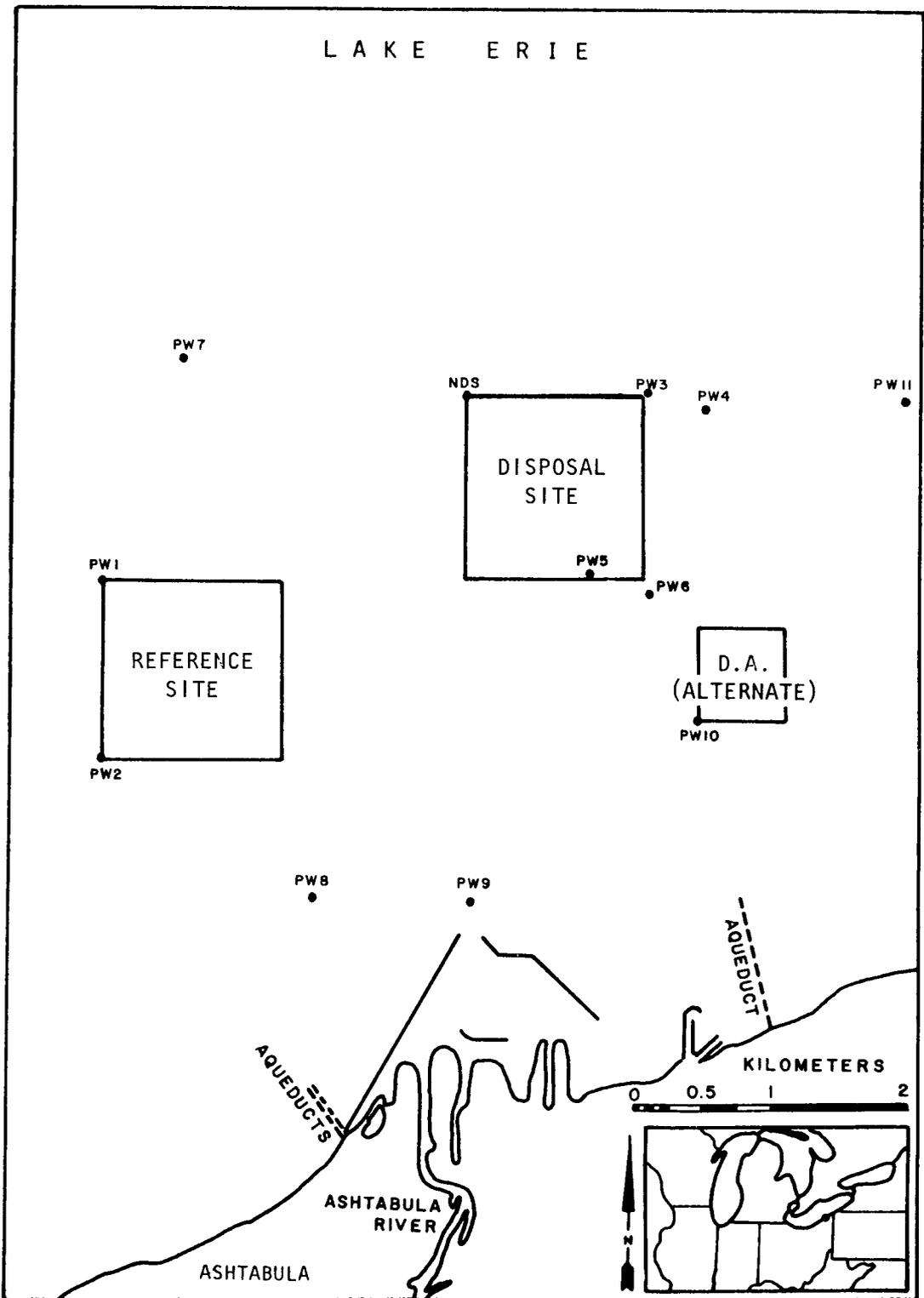


Figure 6. Station locations (PW1-PW11) for water sampling at Ashtabula, Ohio. The northwest disposal site (NDS) was a site for water sampling during 1976 only

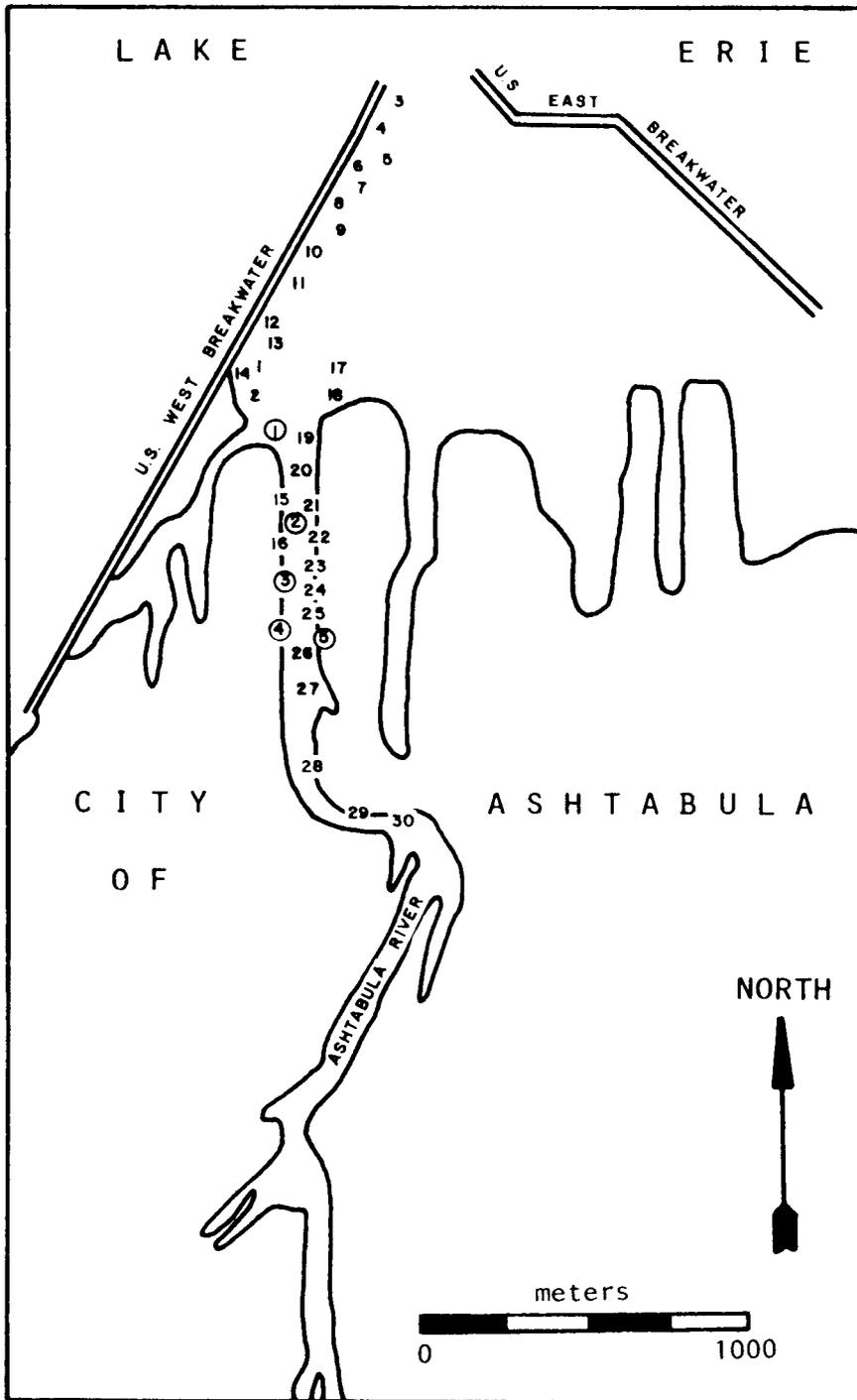


Figure 7. Station locations (1-30) for collection of duplicate K-B cores for chemical and biological analyses of materials to be dredged

■ MARKER BUOY

--- PATH OF MOVING VESSEL

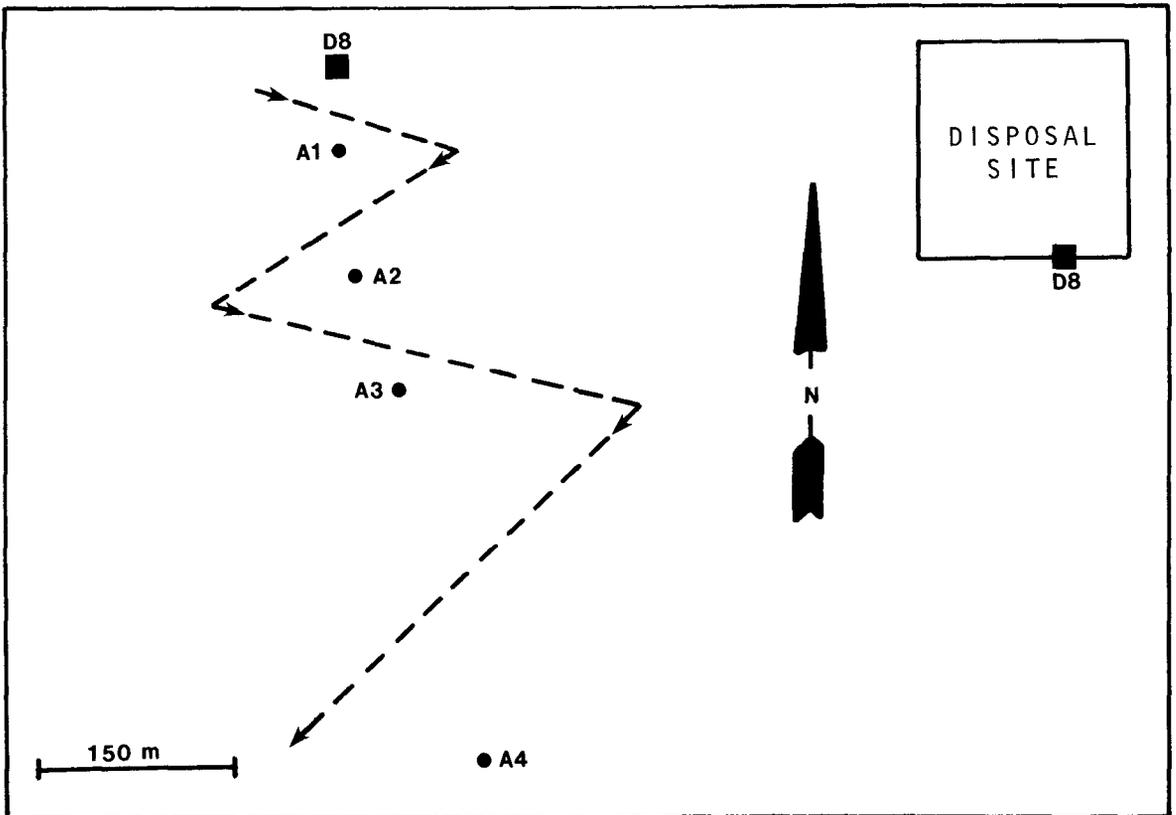
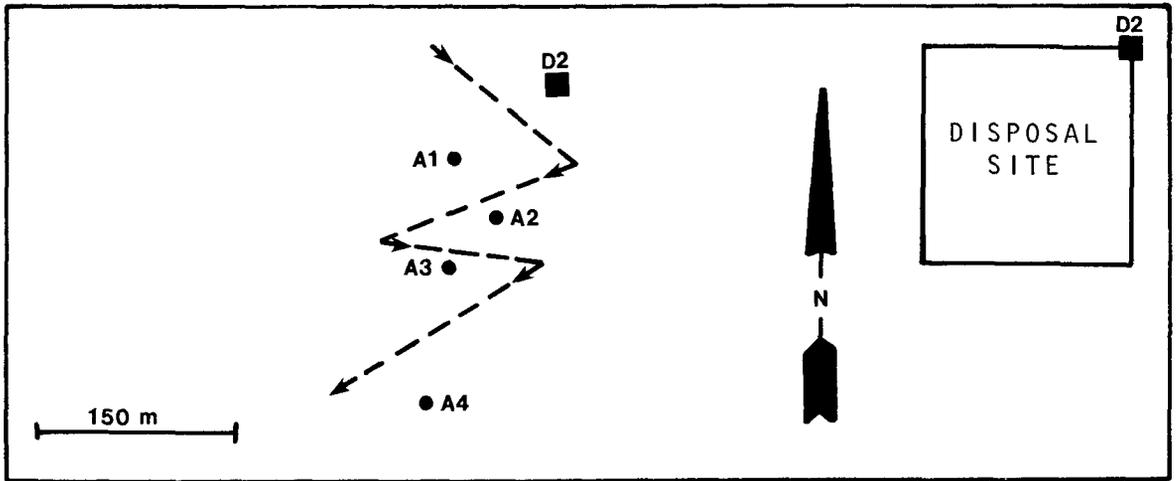


Figure 8. Anchored vessel locations and path of moving vessel relative to marker buoys at disposal sites D2 and D8 during disposal monitoring in 1975

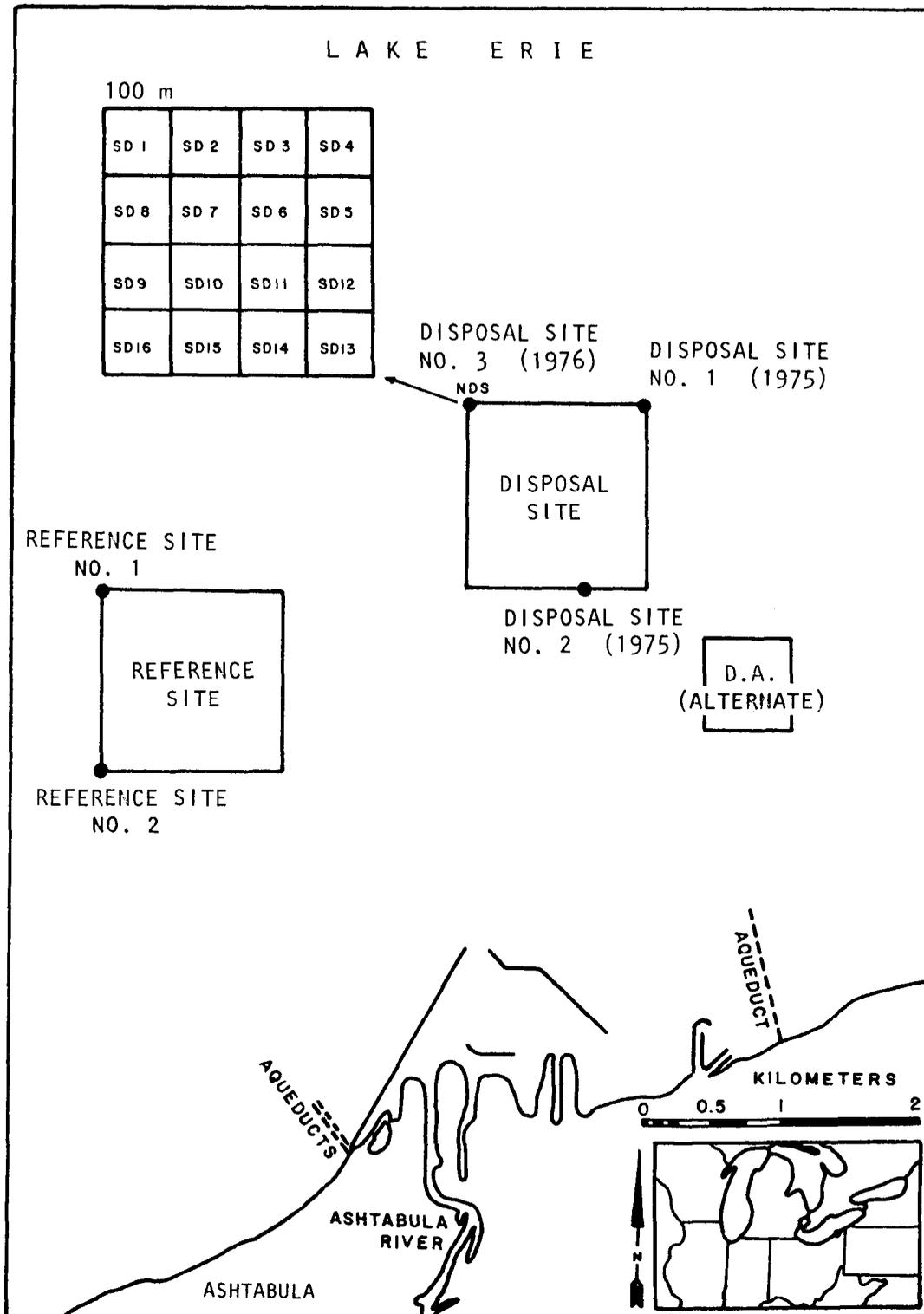


Figure 9. Station locations for reference sites and disposal sites (SD1-SD16) for deposition of material dredged from Ashtabula River in 1976

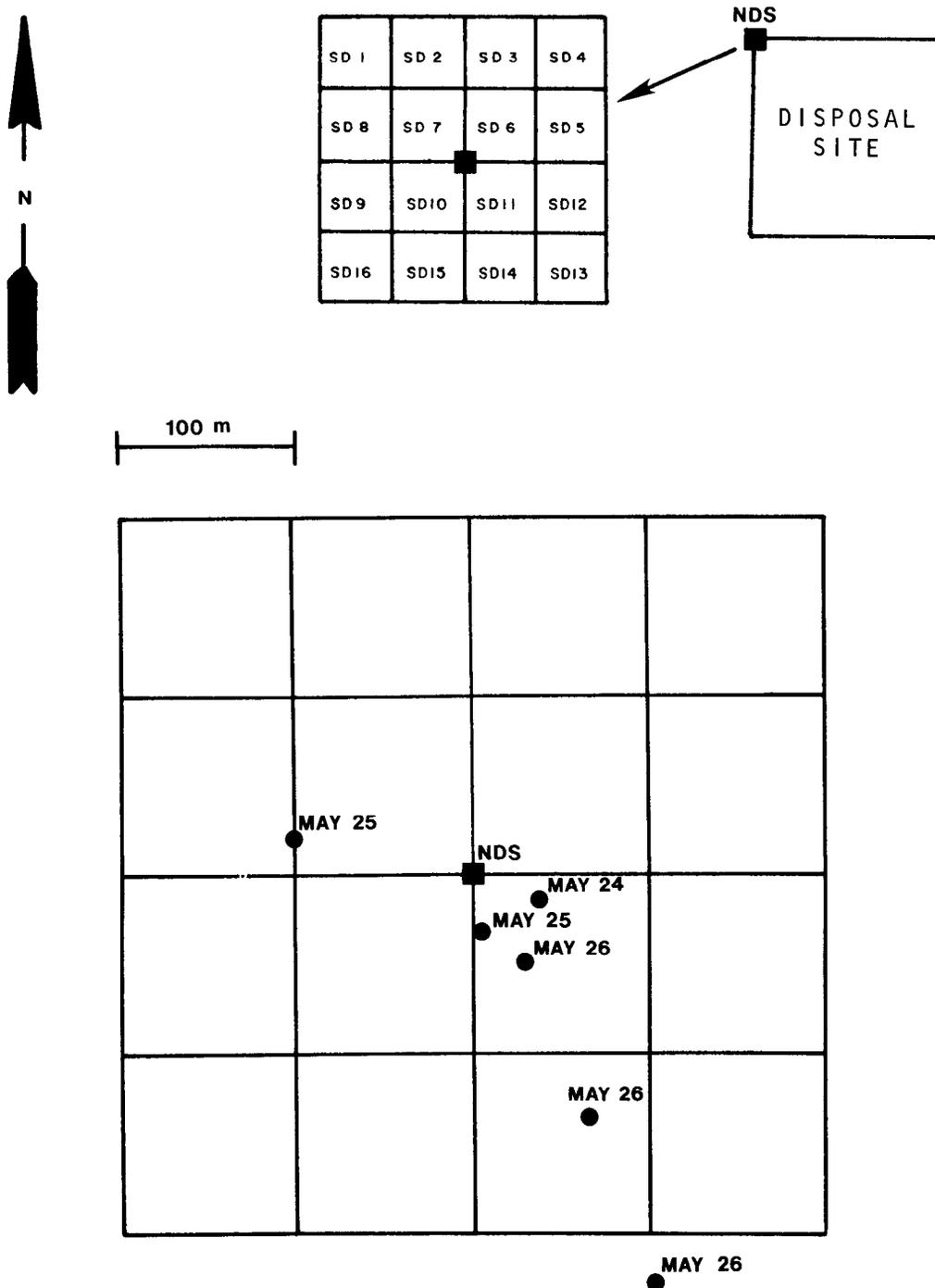
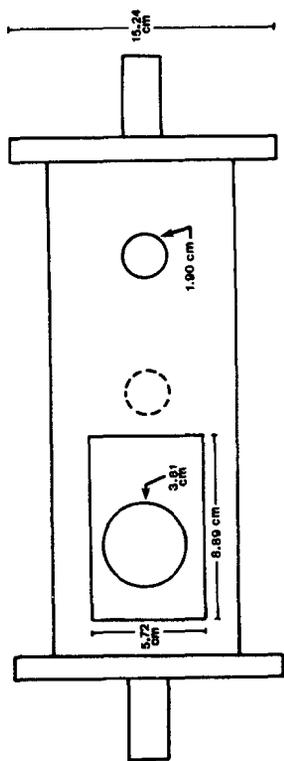
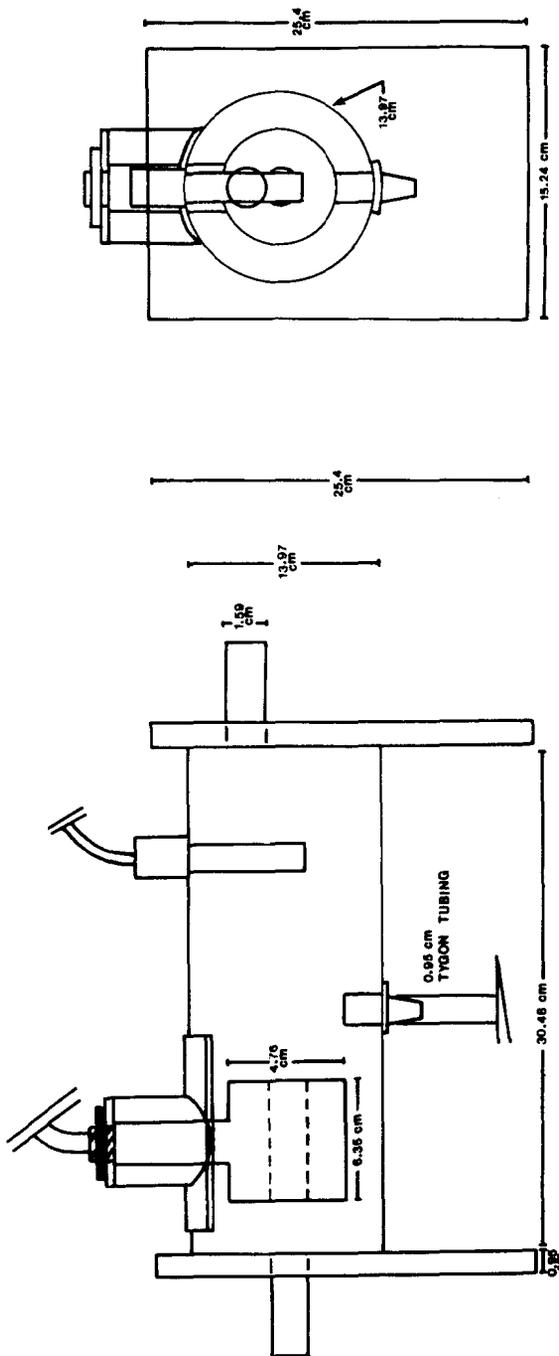


Figure 10. Locations of anchored vessels relative to the northwest disposal site (NDS) during disposal operations on 24, 25, and 26 May 1976



TOP VIEW



FRONT VIEW

SIDE VIEW

Figure 11. Schematic diagram of flow-through cells for the continuous monitoring of water quality for conductivity, turbidity, and pH or chloride ion concentrations during disposal operations on 24, 25, and 26 May 1976

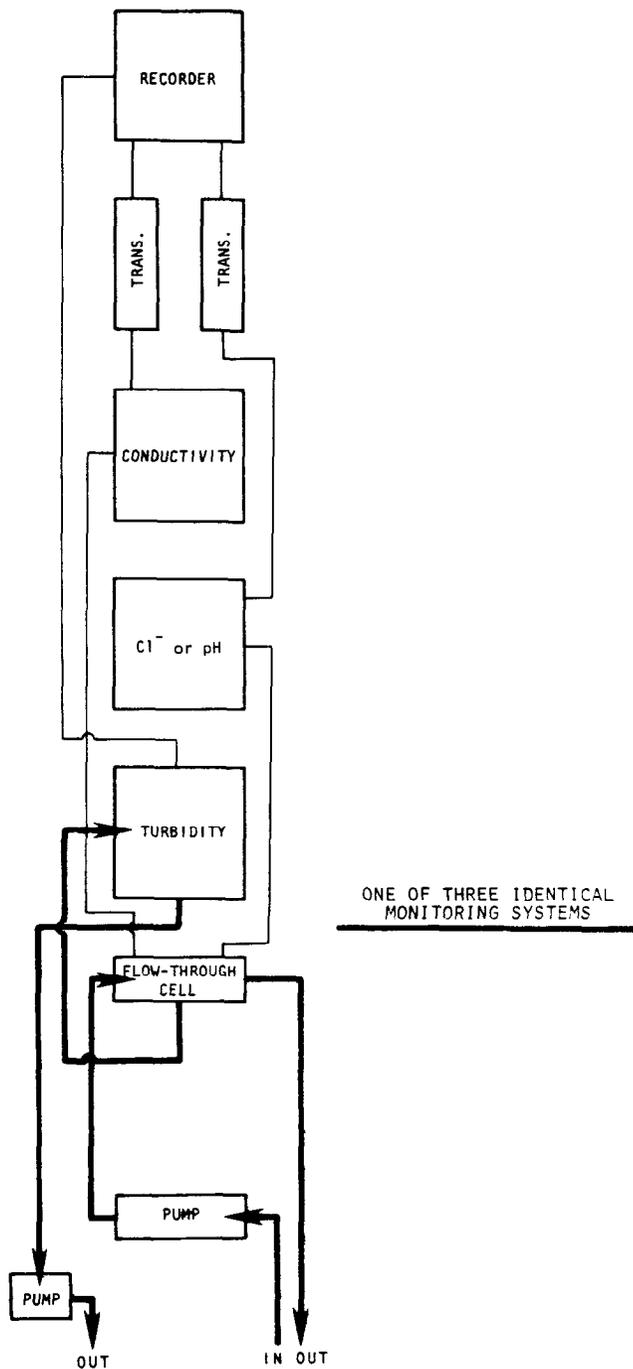


Figure 12. Schematic diagram of electrical signal and sample flow for the continuous monitoring of water quality for conductivity, turbidity, and pH or chloride ion concentrations during disposal operations on 24, 25, and 26 May 1976

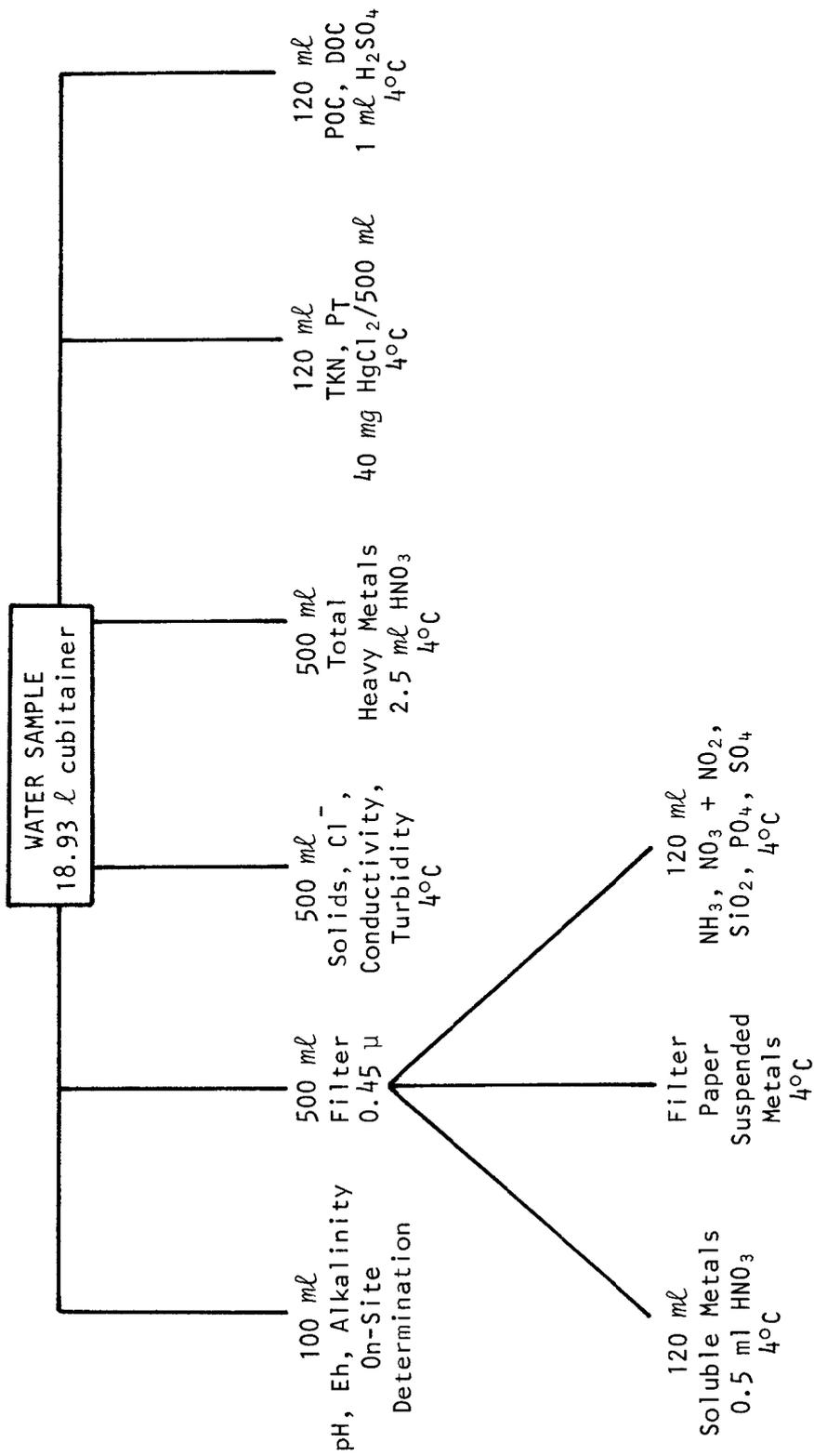


Figure 13. Schematic diagram for water sample splitting and preservation

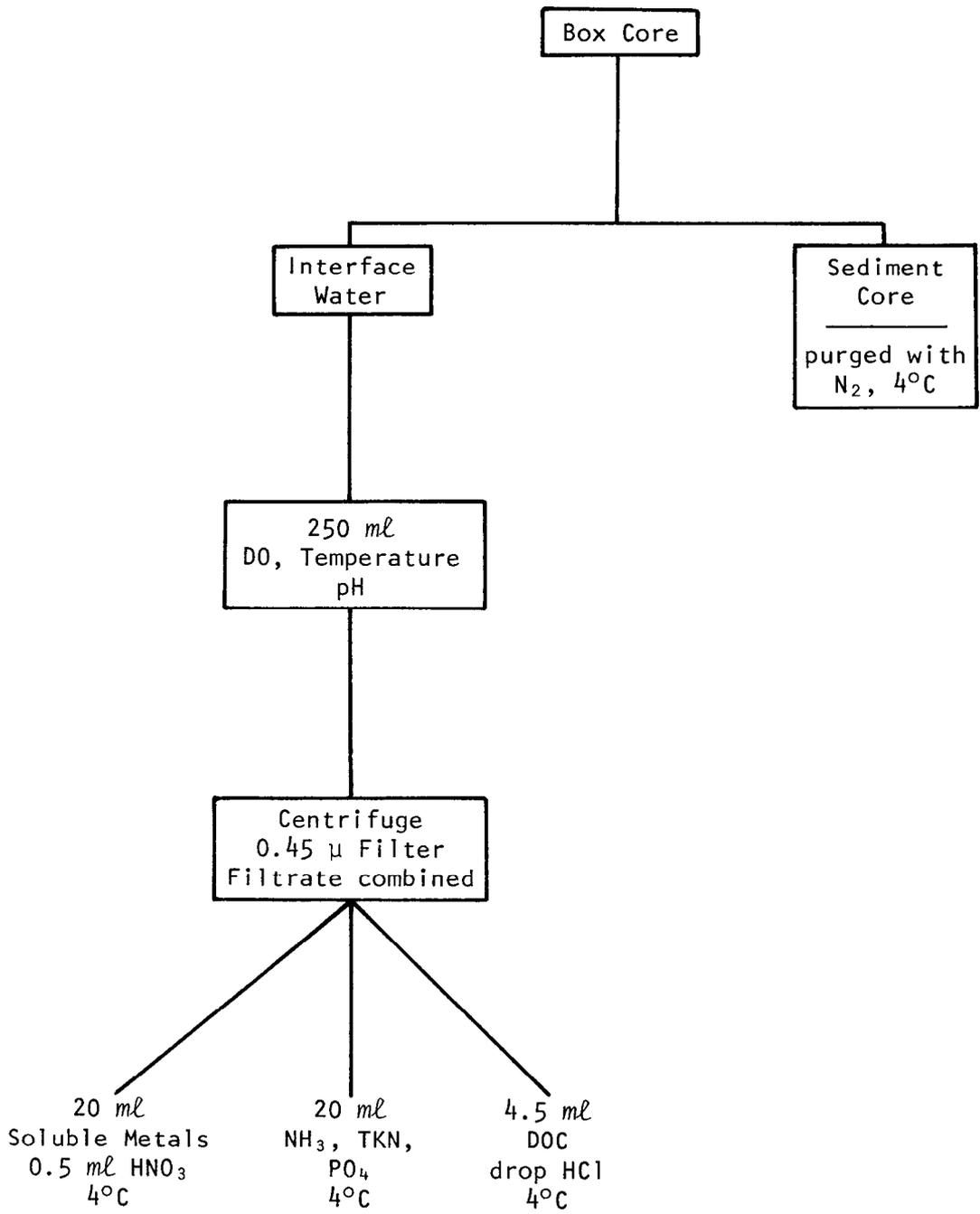


Figure 14. Schematic diagram for sediment and interface water sampling from box cores collected at all reference and disposal site stations

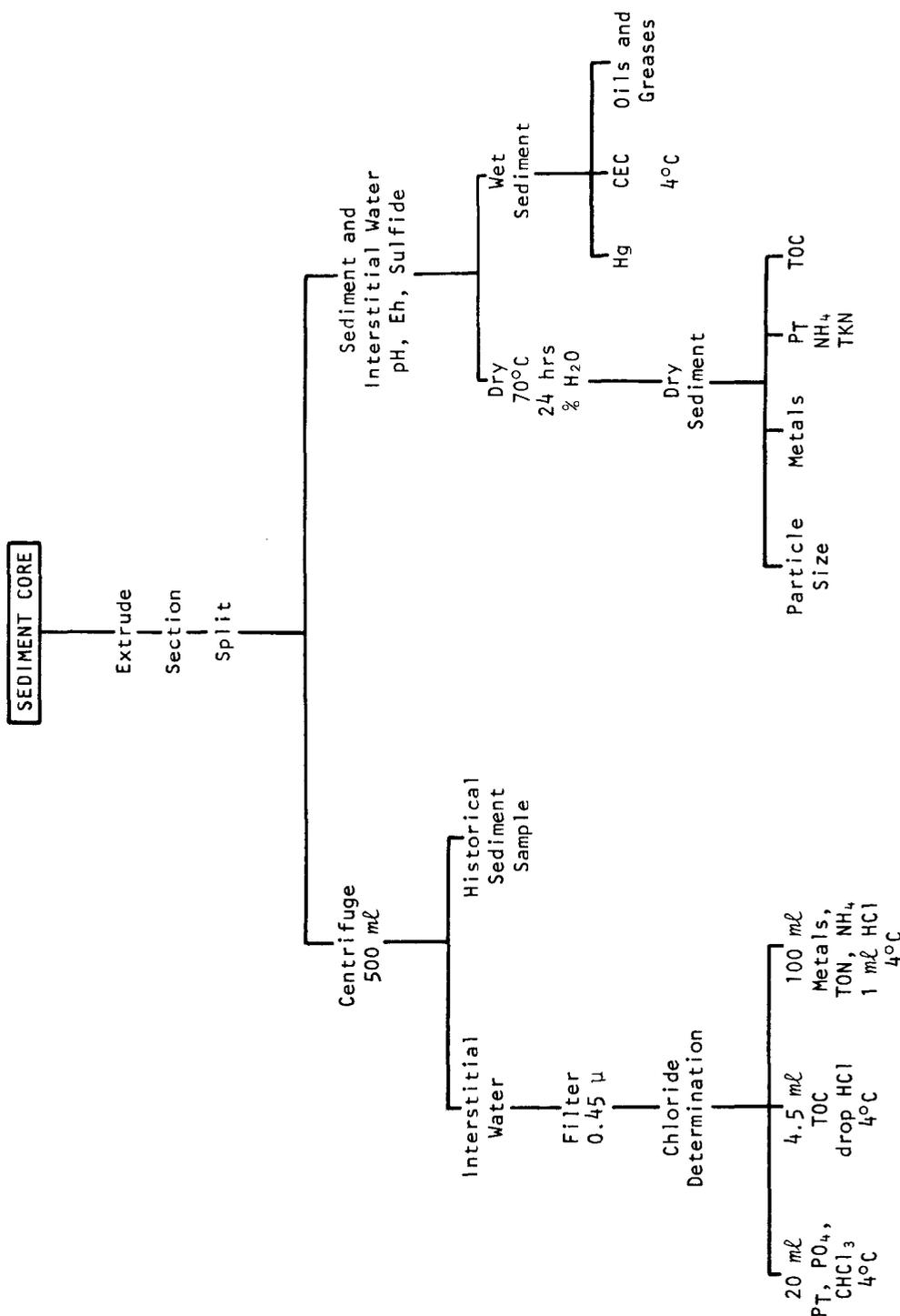


Figure 15. Schematic diagram for core extrusion and interstitial water extraction from all sediments collected at reference and disposal site stations

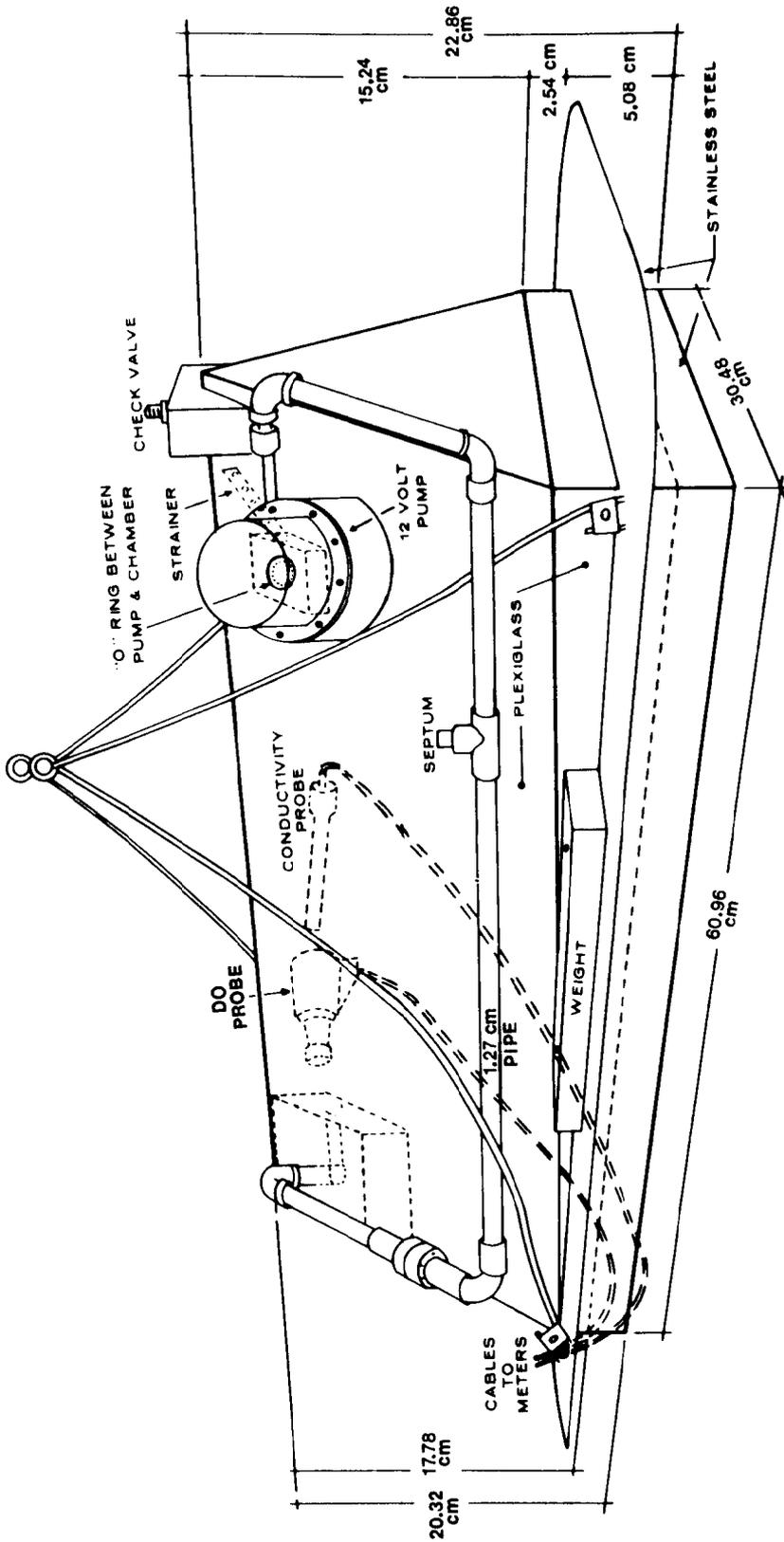


Figure 16. Sediment oxygen demand chamber. (From Lucas and Thomas 1972)

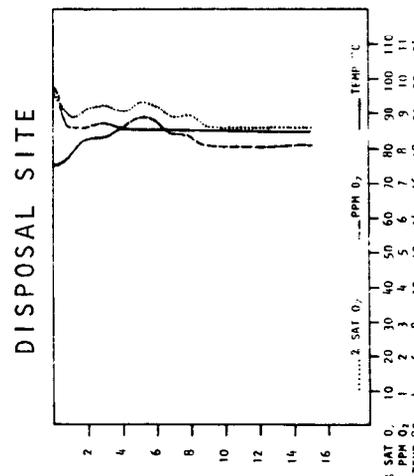
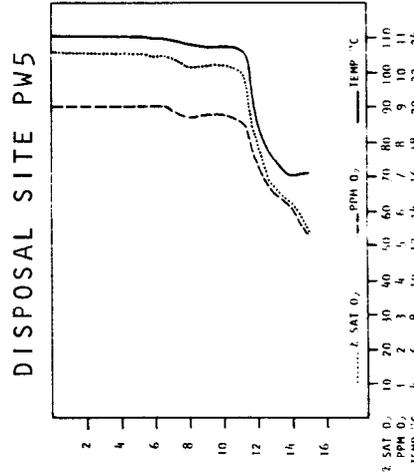
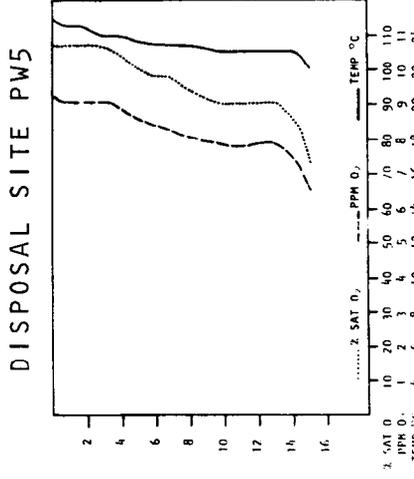
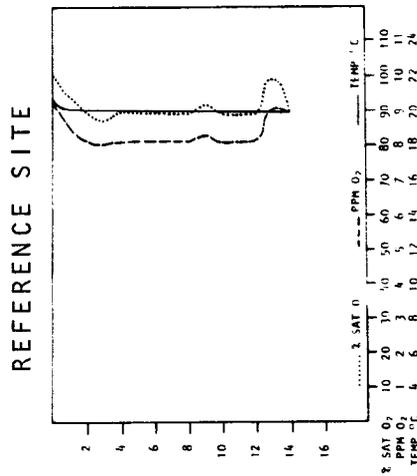
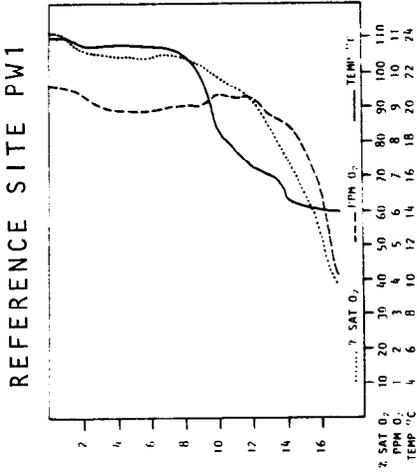
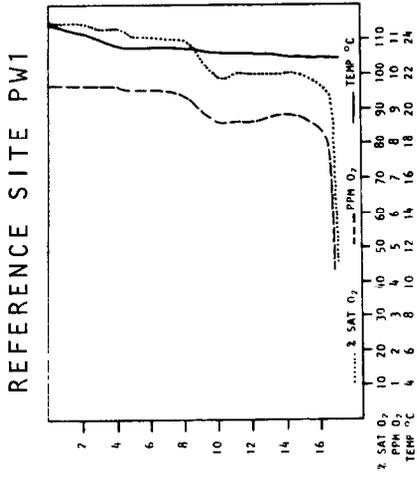
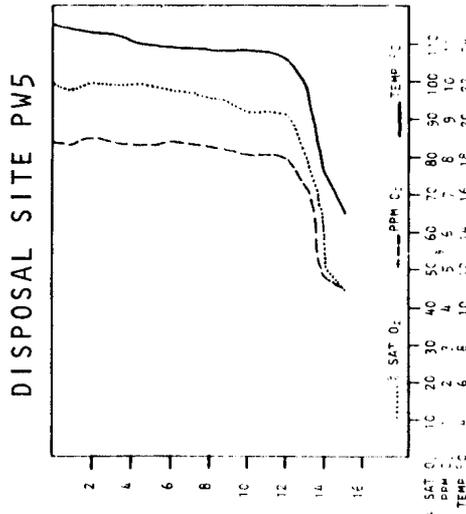
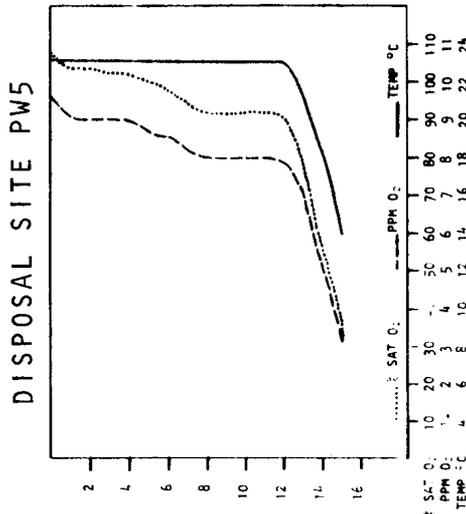
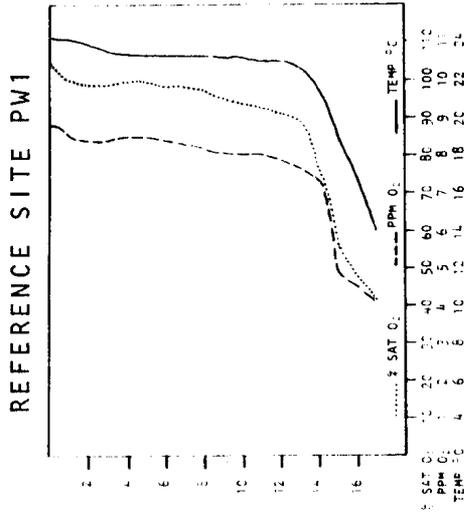
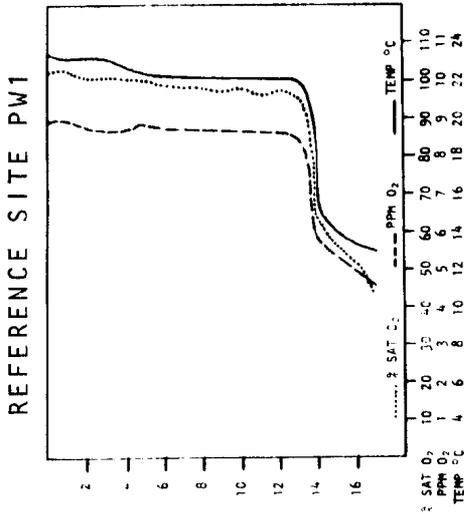


Figure 17. Representative oxygen and temperature profiles from the reference and disposal sites during predisposal collections of 1975 (initial survey, 11-13 June, 9-11 July and 30-31 July)

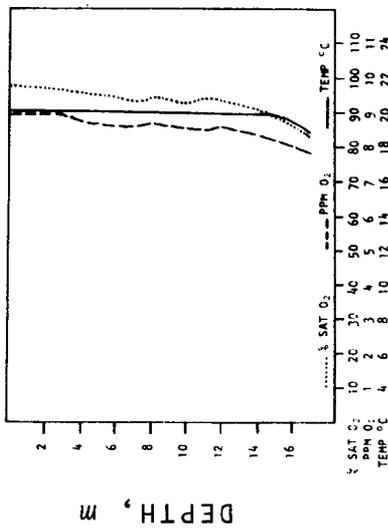


14 August 1975

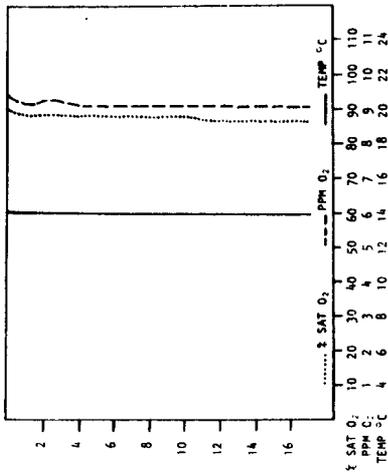
19-20 August 1975

Figure 18. Representative oxygen and temperature profiles from the reference and disposal sites during immediate postdisposal collections of 1975 (14 August, 19-20 August)

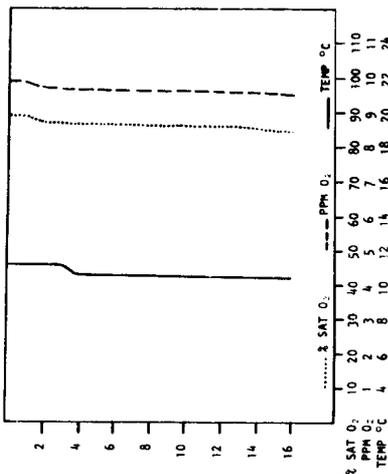
REFERENCE SITE PW1



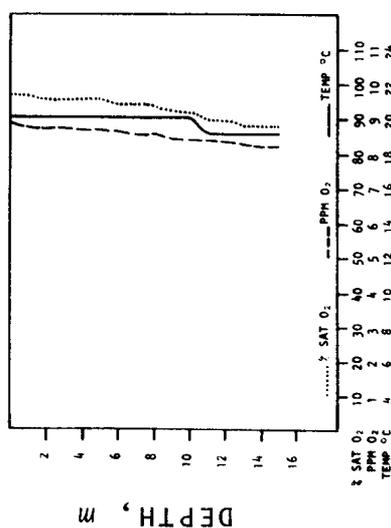
REFERENCE SITE PW1



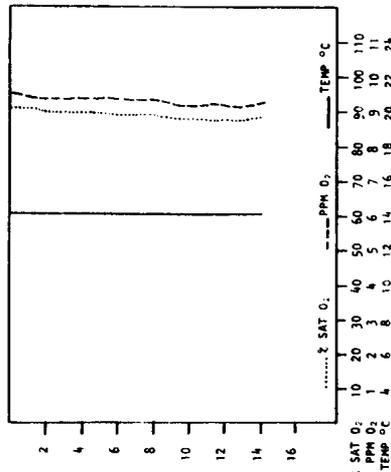
REFERENCE SITE PW1



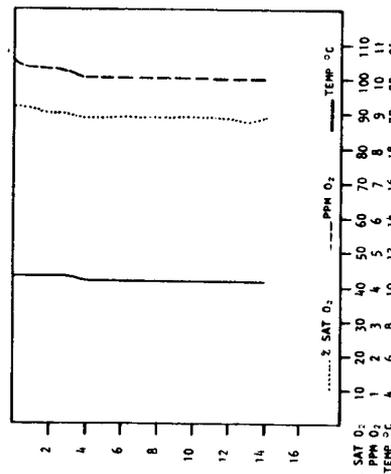
DISPOSAL SITE PW5



DISPOSAL SITE PW5



DISPOSAL SITE PW5

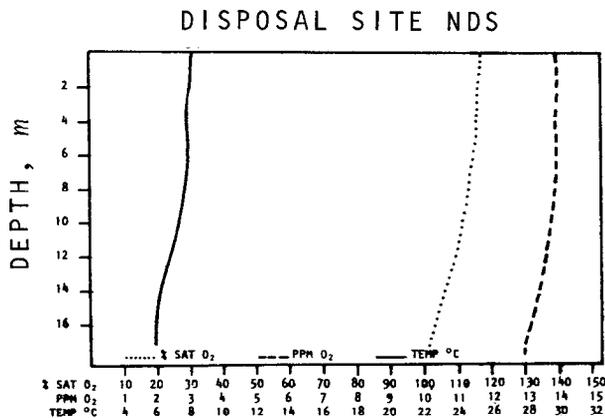
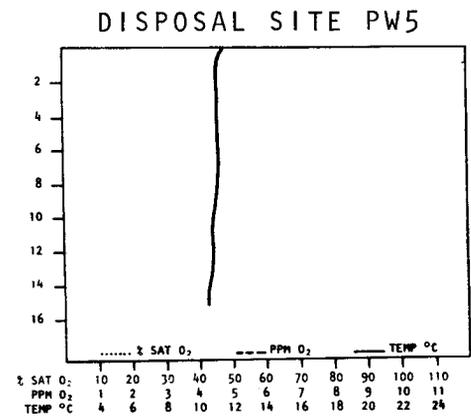
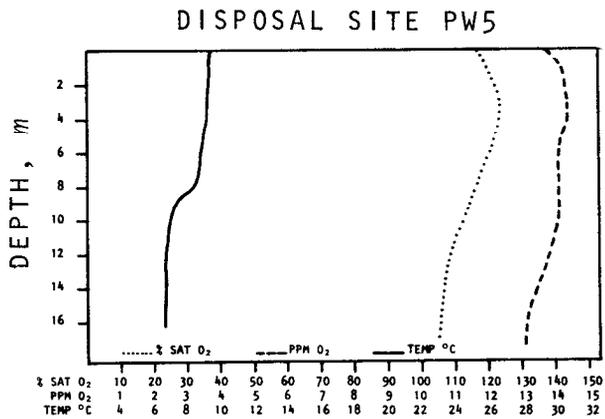
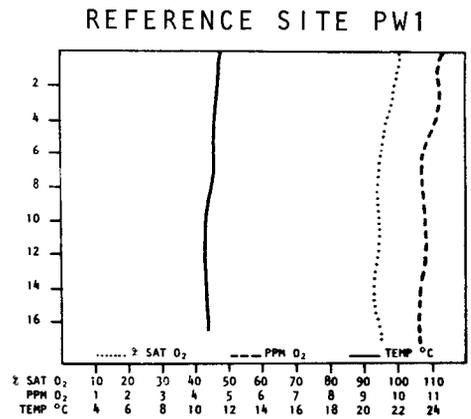
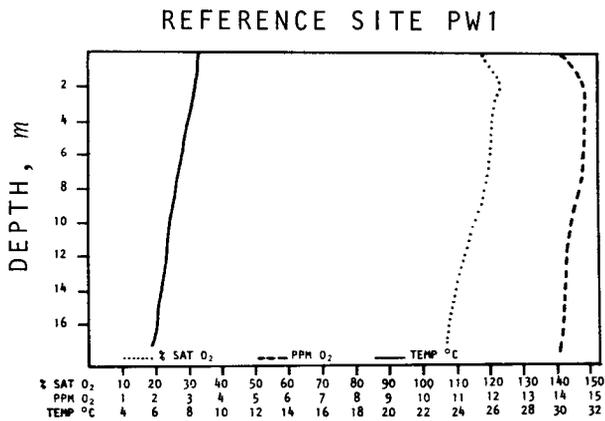


12-14 September 1975

19 October 1975

16-17 November 1975

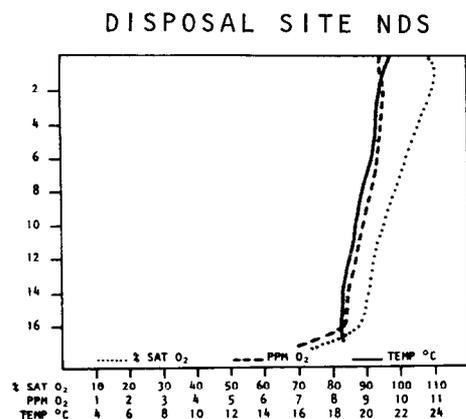
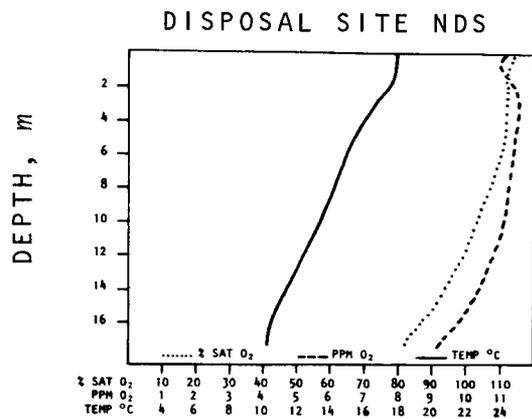
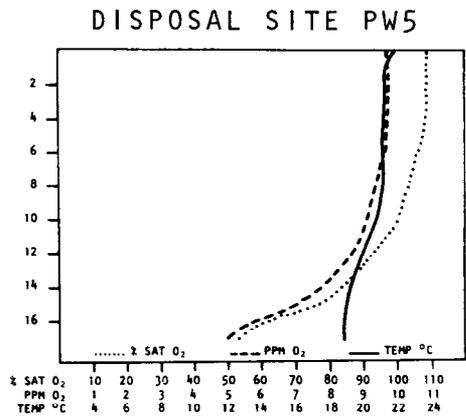
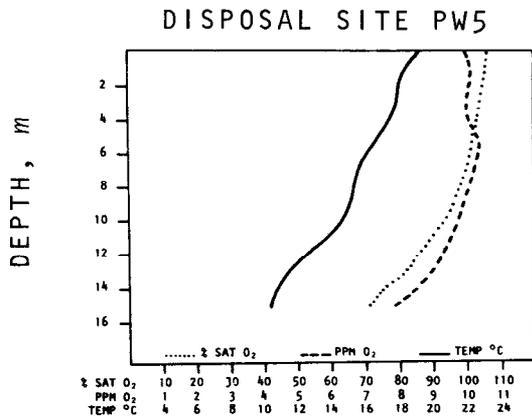
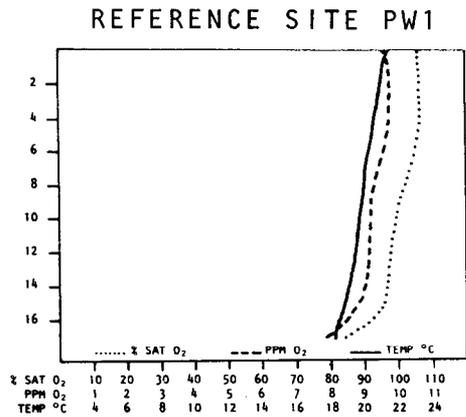
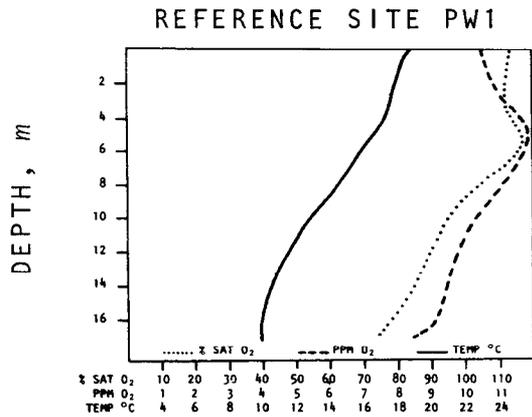
Figure 19. Representative oxygen and temperature profiles from the reference and disposal sites during September, October, and November postdisposal collections of 1975 (12-14 September, 19 October, and 16-17 November)



15-16 May 1976
 No profiles for NDS
 because of
 equipment failure

21 April 1976

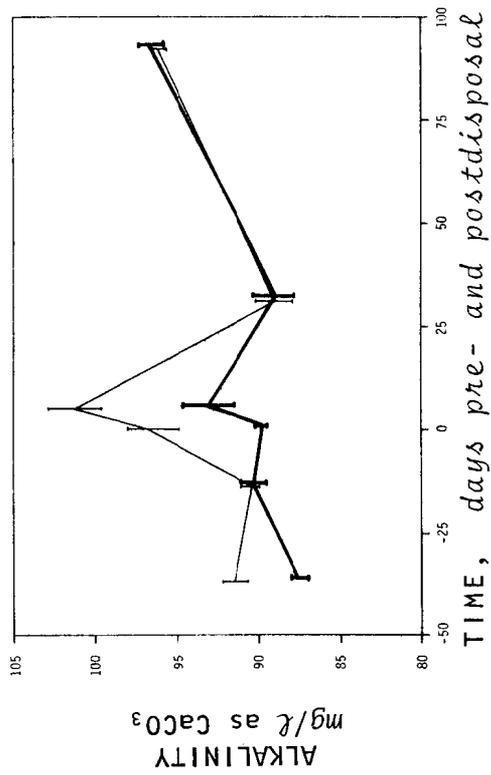
Figure 20. Selected oxygen and temperature profiles from the reference and disposal sites during the 21 April 1976 and 15-16 May 1976 collections



10-11 June 1976

7-8 July 1976

Figure 21. Representative oxygen and temperature profiles from the reference and disposal sites during 1976 postdisposal collections (10-11 June and 7-8 July)



1 m

17 m

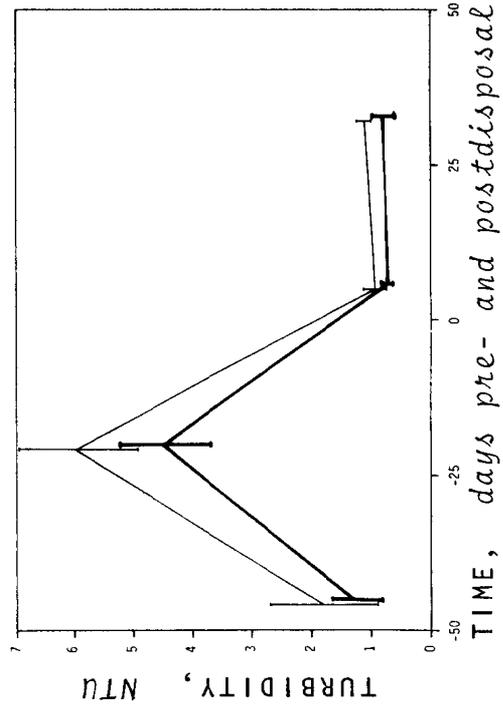
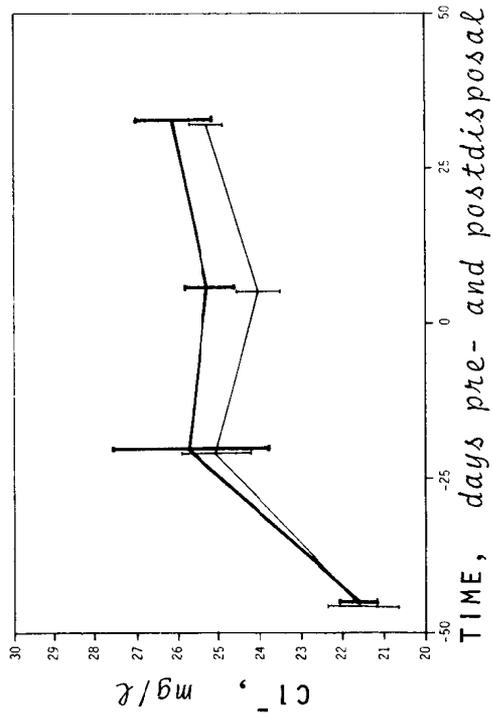


Figure 22. Mean and 95 percent confidence intervals for alkalinity (mg/L as CaCO₃) in 1975 and chloride ion concentration (mg/L) and turbidity (NTU's) in 1976 from surface plus 1 meter and bottom minus 1 meter depths from all collection periods relative to disposal operations

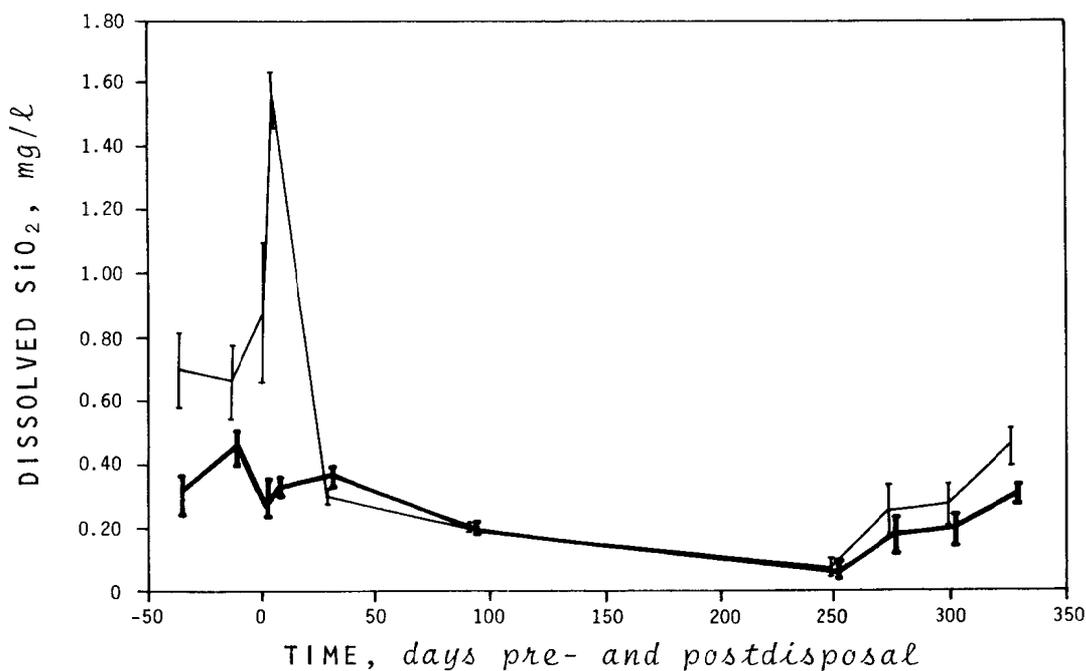
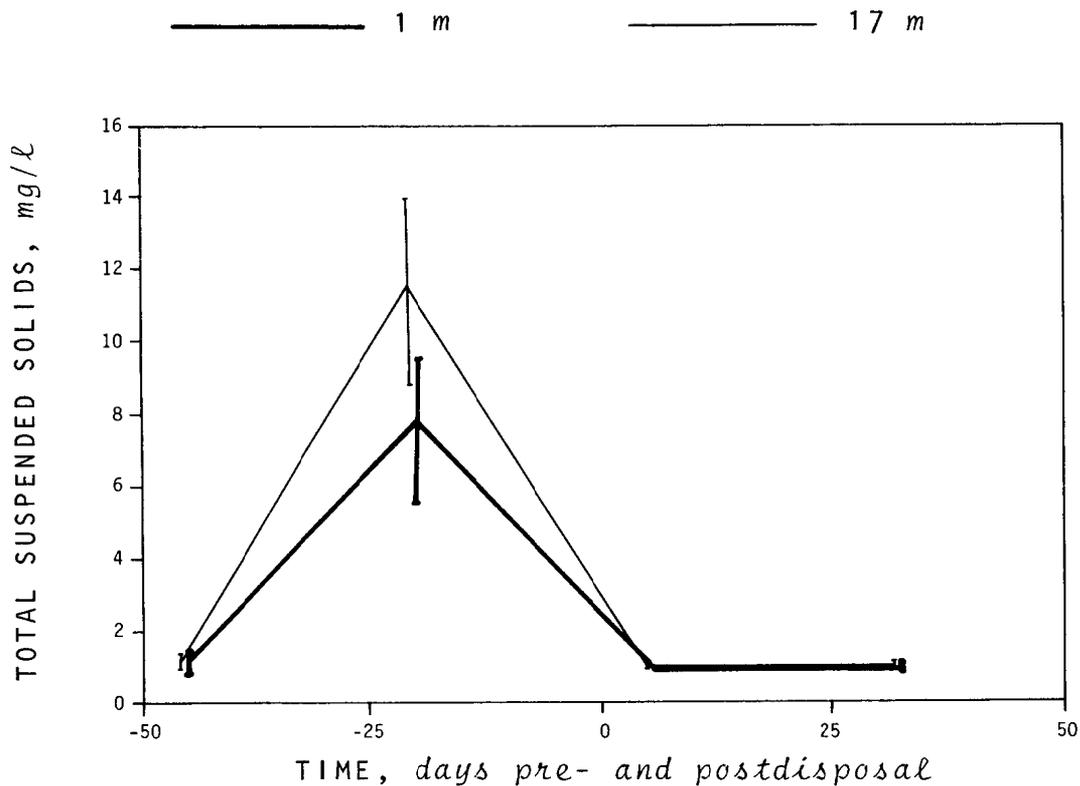


Figure 23. Mean and 95 percent confidence intervals for total suspended solids (mg/l) in 1976 and dissolved silica (mg/l) in 1975 from surface plus 1 meter and bottom minus 1 meter depths for all collection periods relative to disposal operations

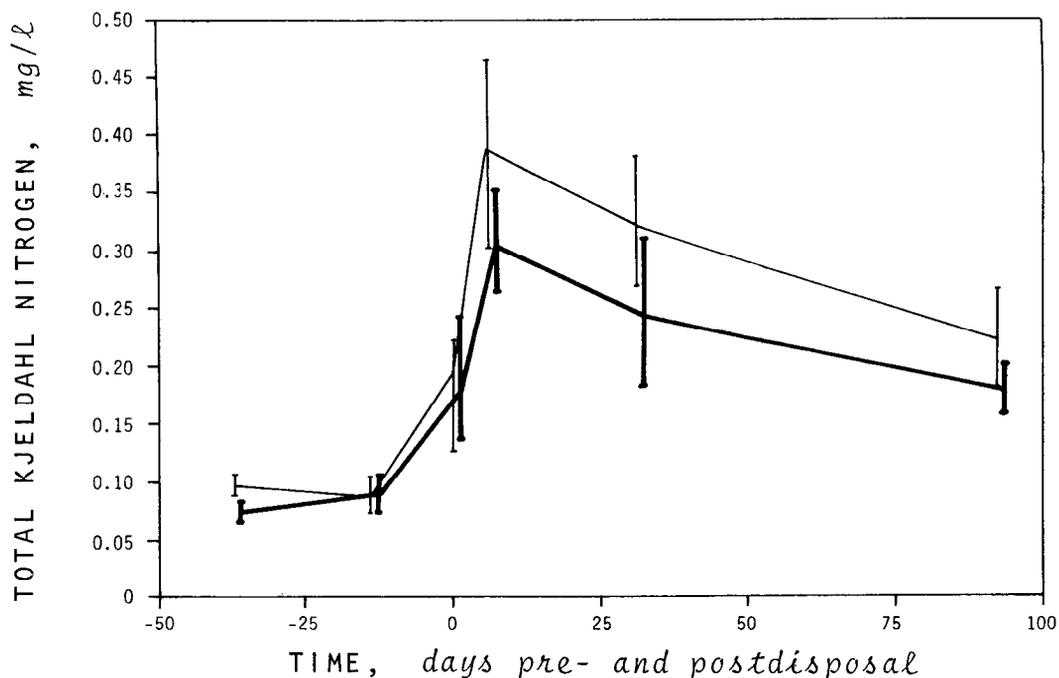
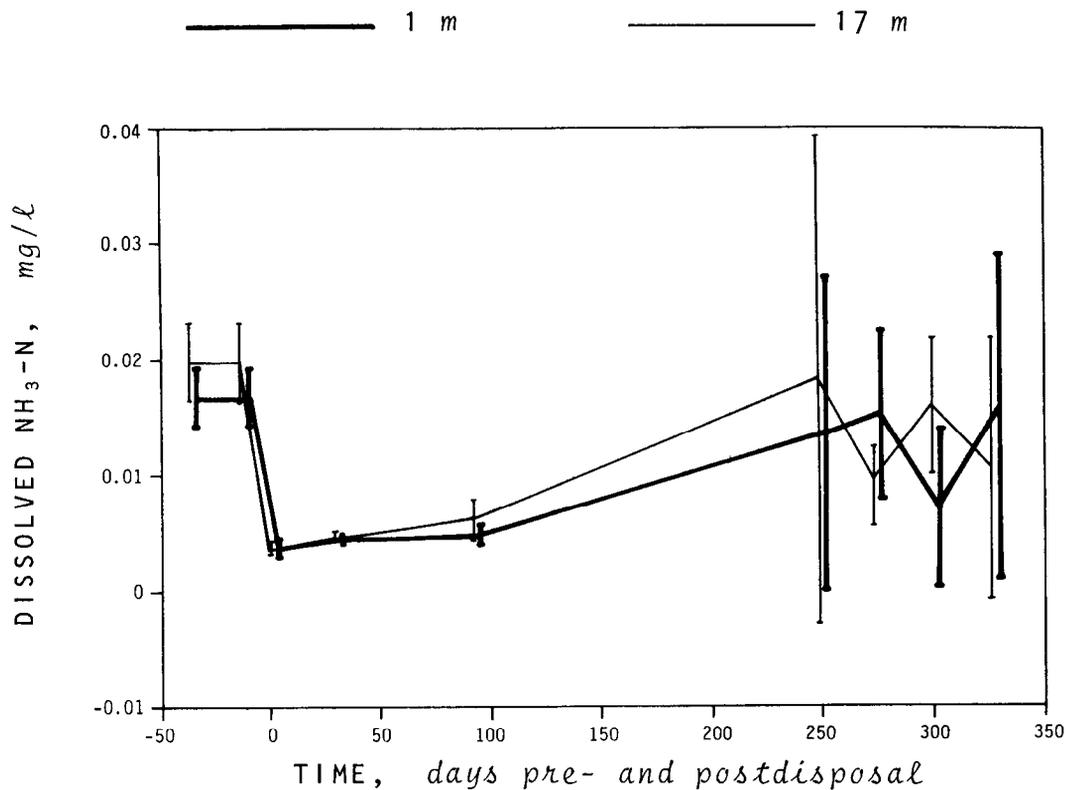


Figure 24. Mean and 95 percent confidence intervals for soluble ammonia nitrogen (mg/l) in 1975 and 1976 and total Kjeldahl nitrogen (mg/l) in 1975 from surface plus 1 meter and bottom minus 1 meter depths for all collection periods relative to disposal operations

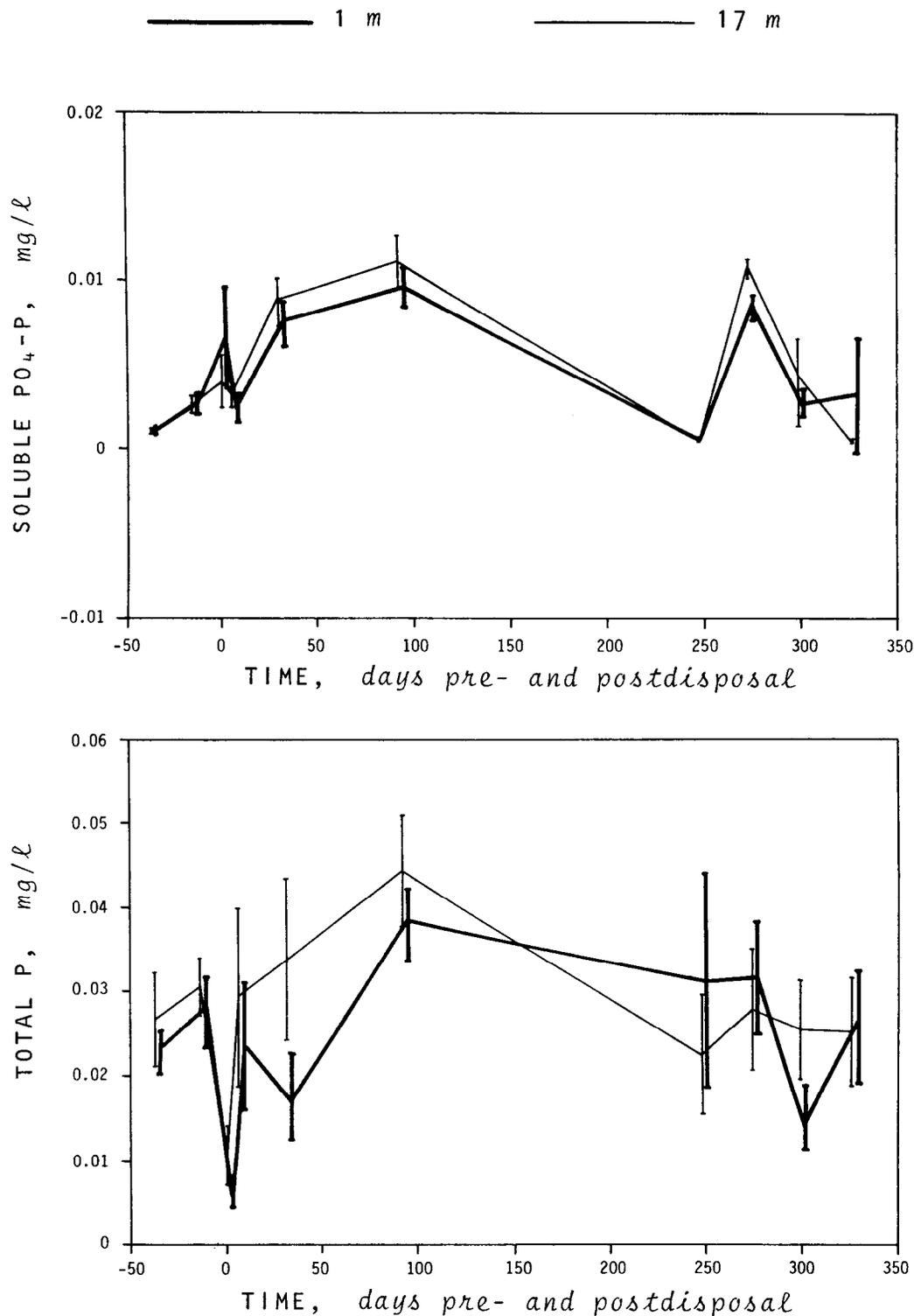


Figure 25. Mean and 95 percent confidence intervals for soluble orthophosphorus (mg/l) and total phosphorus (mg/l) in 1975 and 1976 from surface plus 1 meter and bottom minus 1 meter depths for all collection periods relative to disposal operations

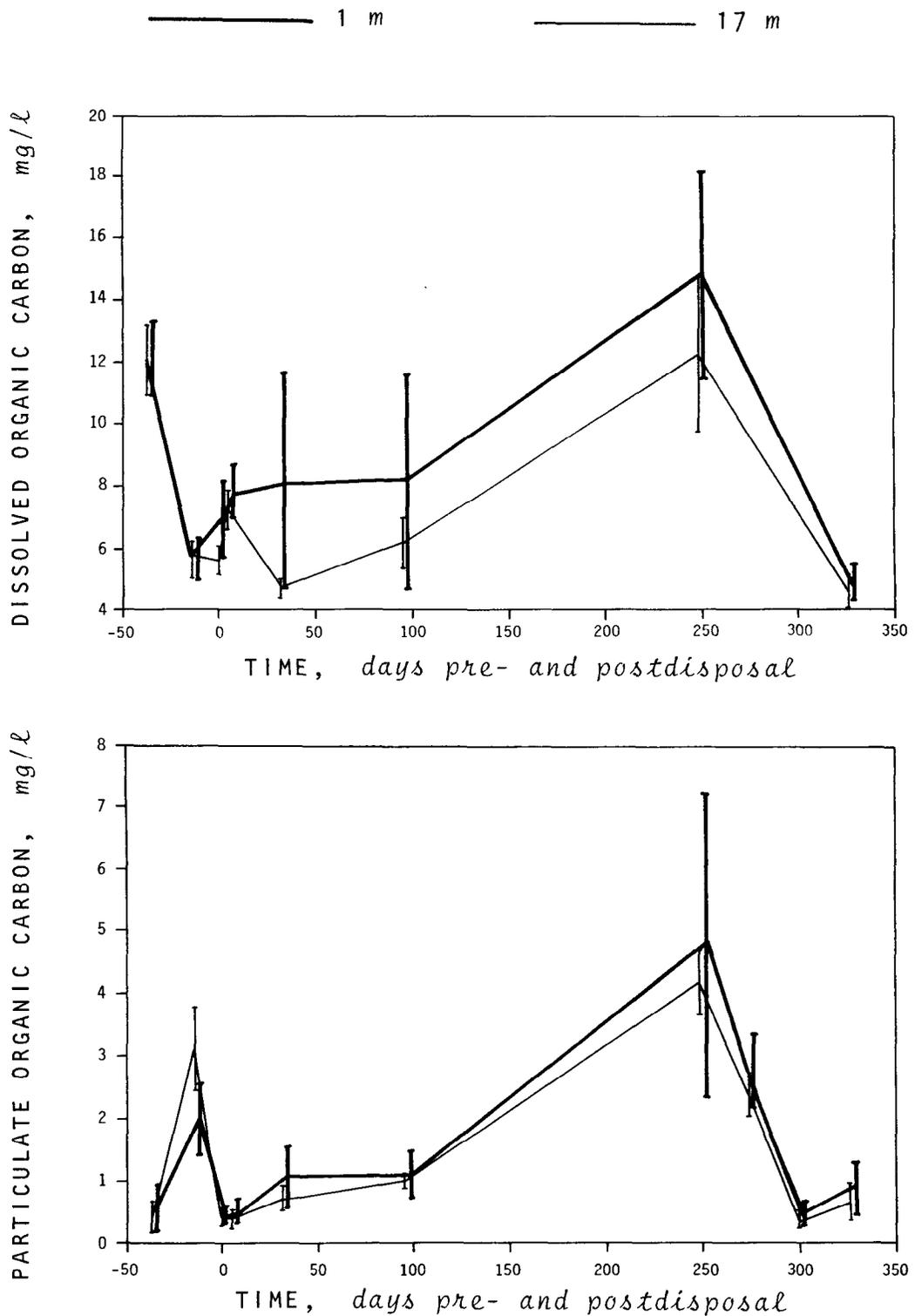
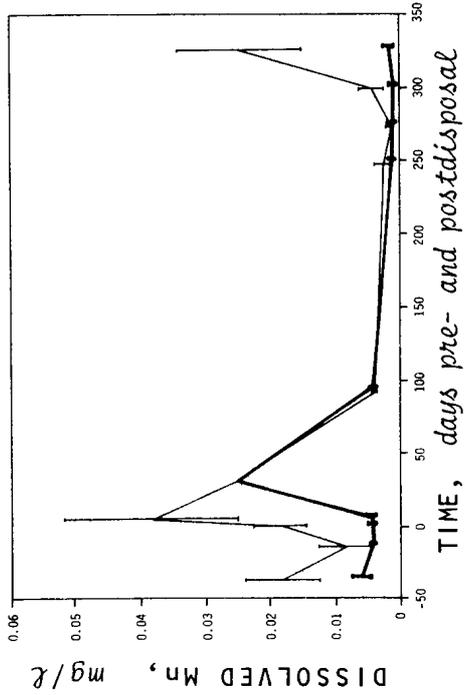
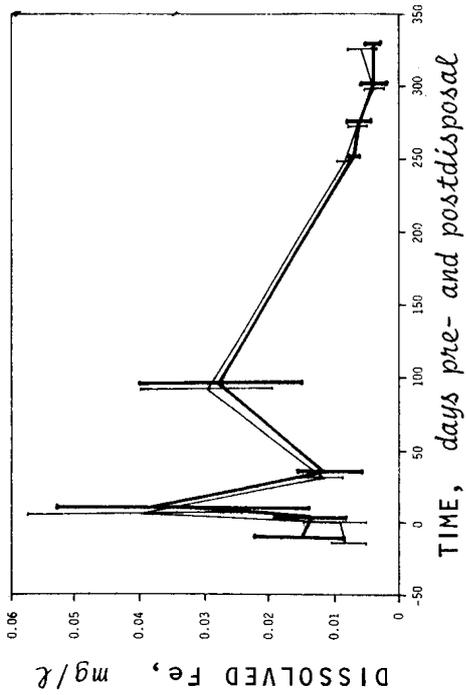


Figure 26. Mean and 95 percent confidence intervals for dissolved organic carbon (mg/l) and particulate organic carbon (mg/l) in 1975 and 1976 from surface plus 1 meter and bottom minus 1 meter depths for all collection periods relative to disposal operations

17 m



1 m

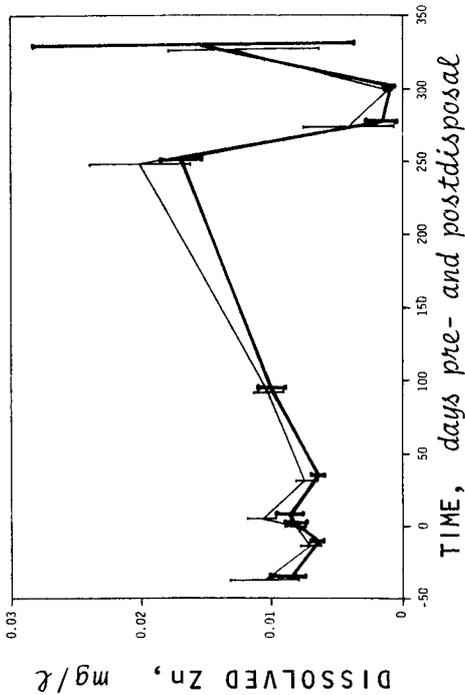
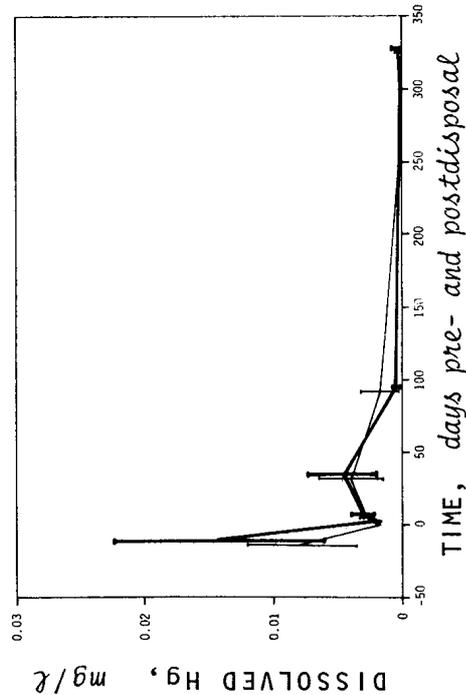


Figure 27. Mean and 95 percent confidence intervals for dissolved mercury (mg/L), iron (mg/L), zinc (mg/L), and manganese (mg/L) in 1975 and 1976 from surface plus 1 meter and bottom minus 1 meter depths for all collection periods relative to disposal operations

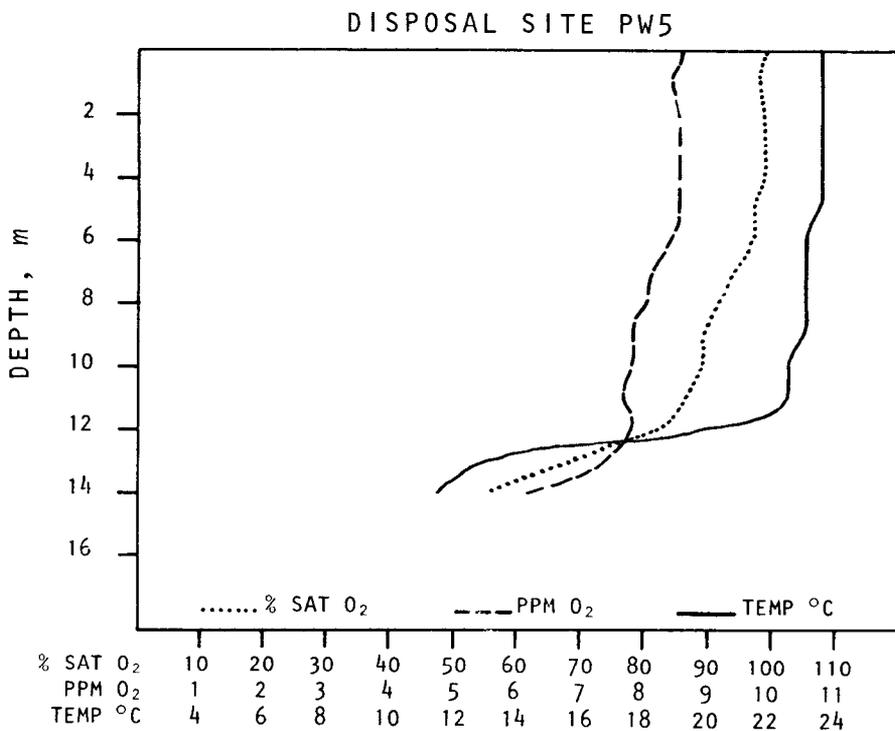
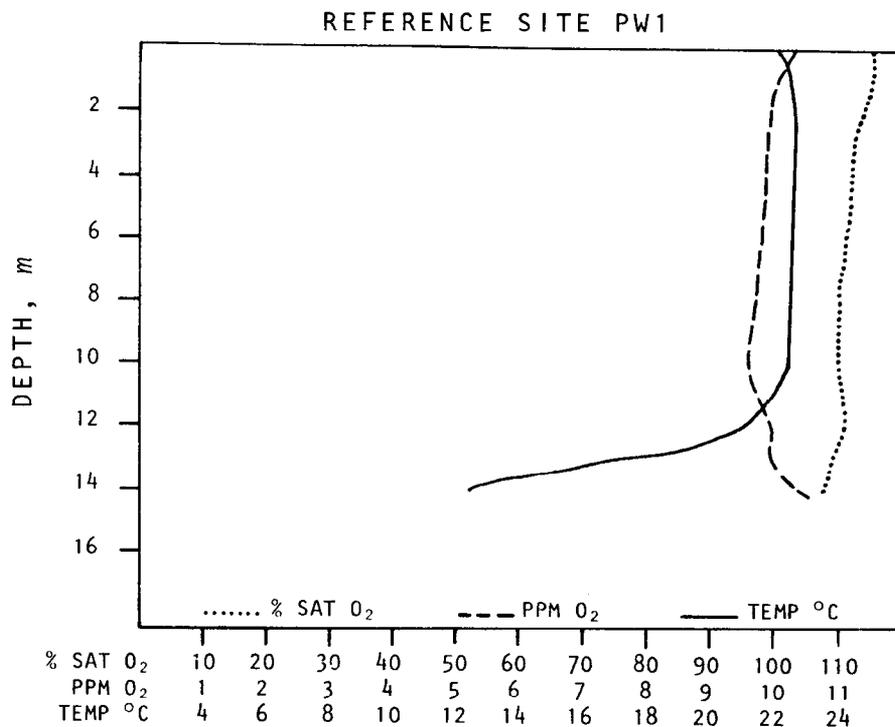


Figure 28. Representative oxygen and temperature profiles from the reference and disposal sites immediately after cessation of disposal in 1975

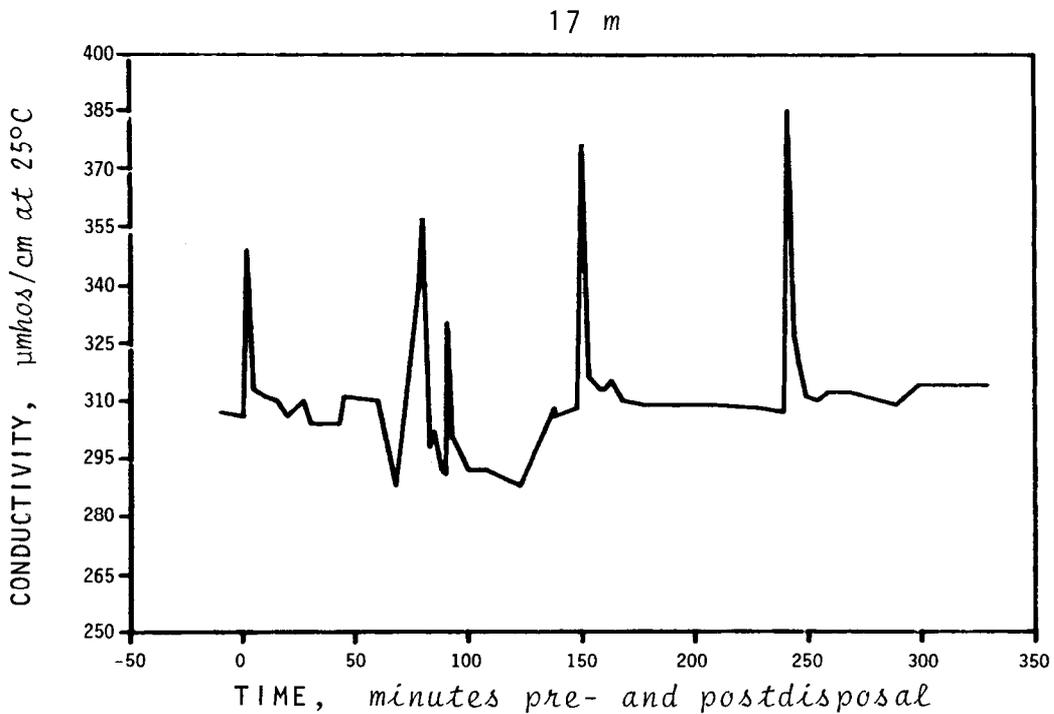
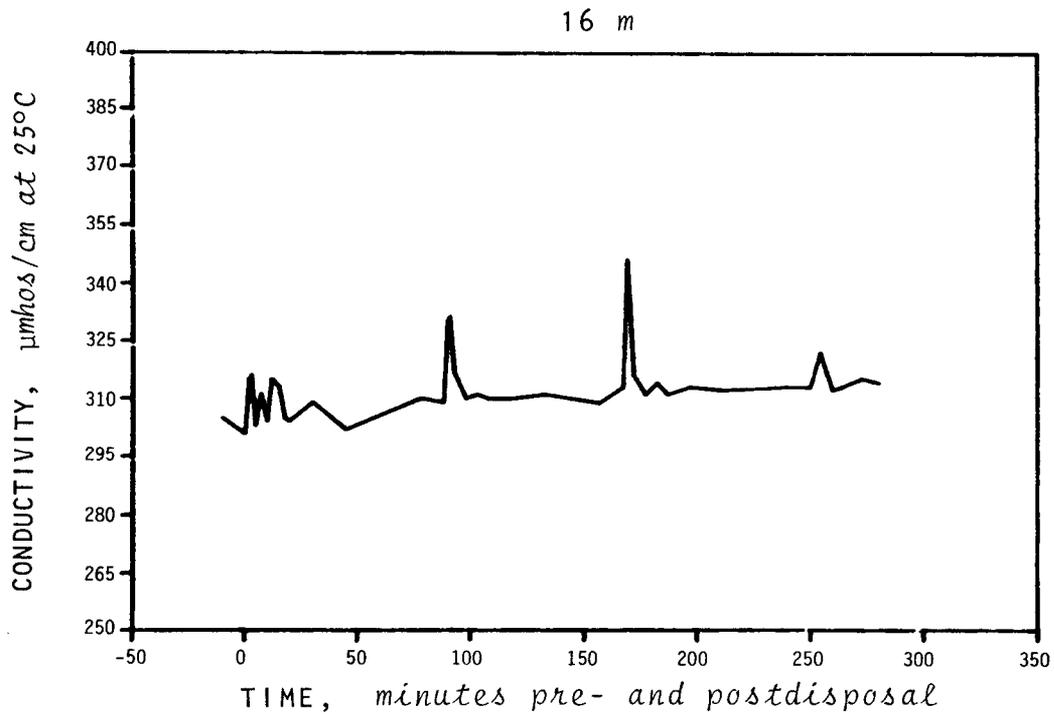


Figure 29. On site water quality monitoring for specific conductance ($\mu\text{mhos/cm}$ at 25°C) at the 16 m depth on 26 May 1976 and the 17 m depth on 25 May 1976 relative to the first disposal of each day (time=0) at NDS

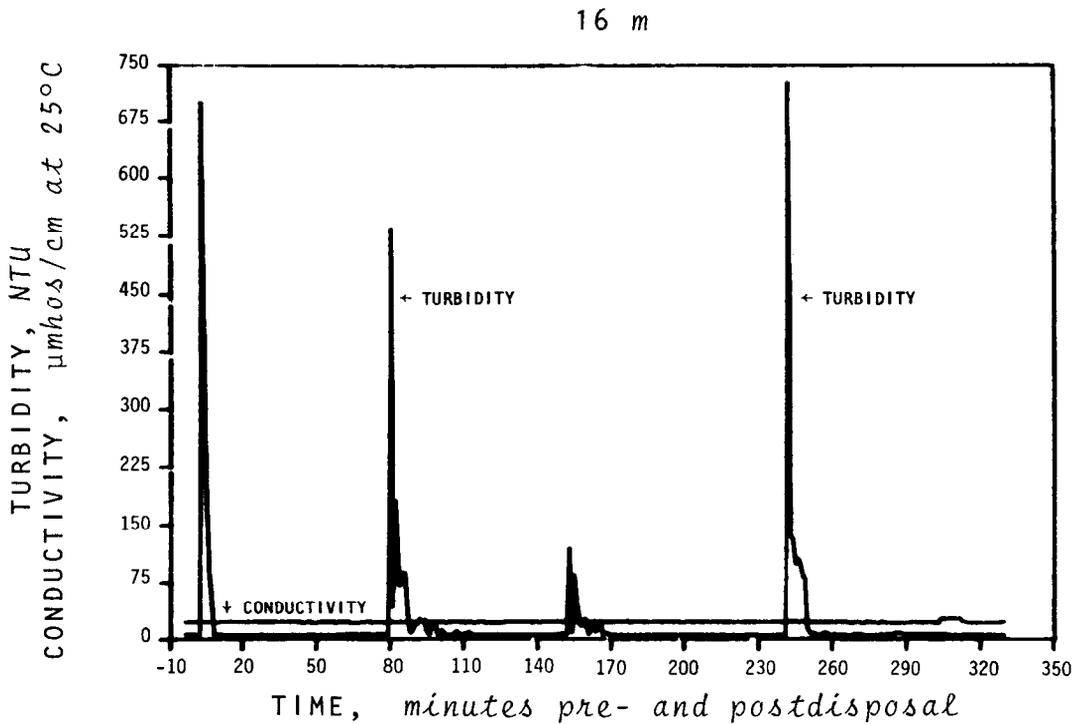
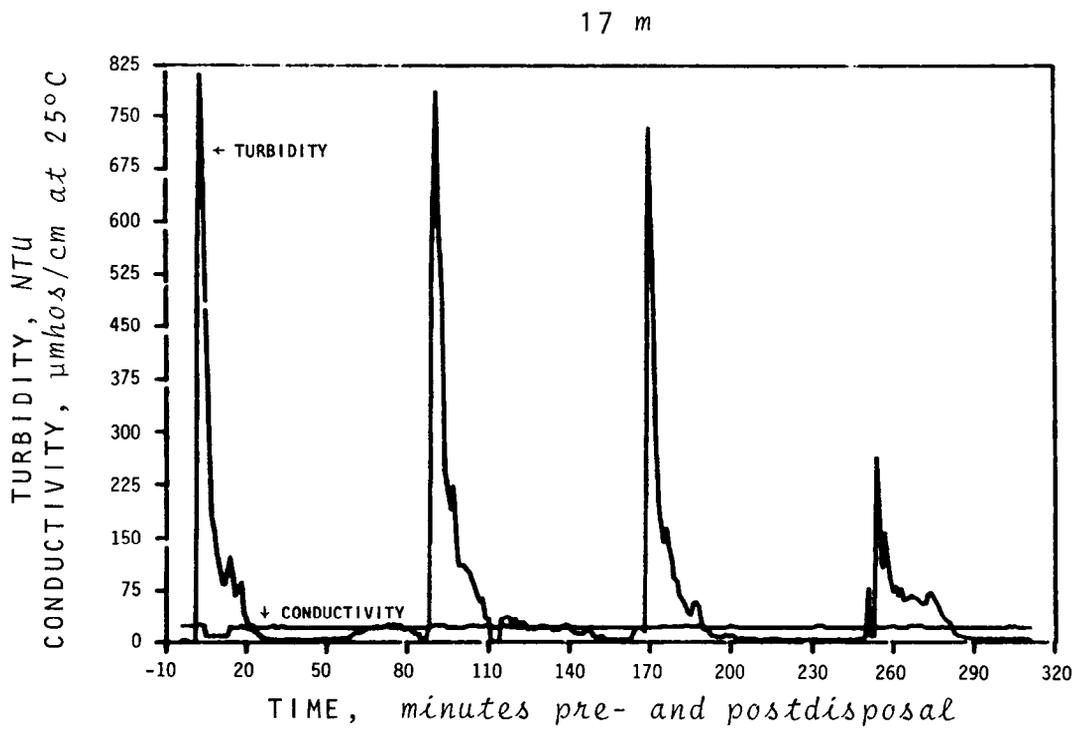


Figure 30. On site water quality monitoring for turbidity (NTU's) at the 16 m depth on 25 May 1976 and the 17 m depth on 26 May 1976 relative to the first disposal of each day (time=0) at NDS

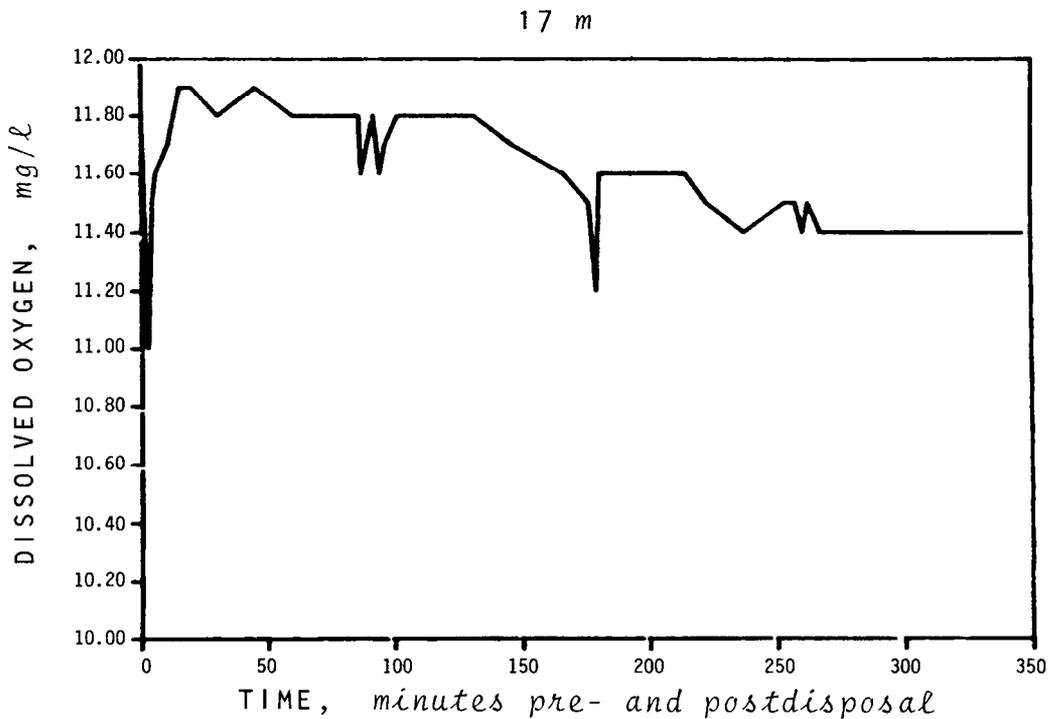
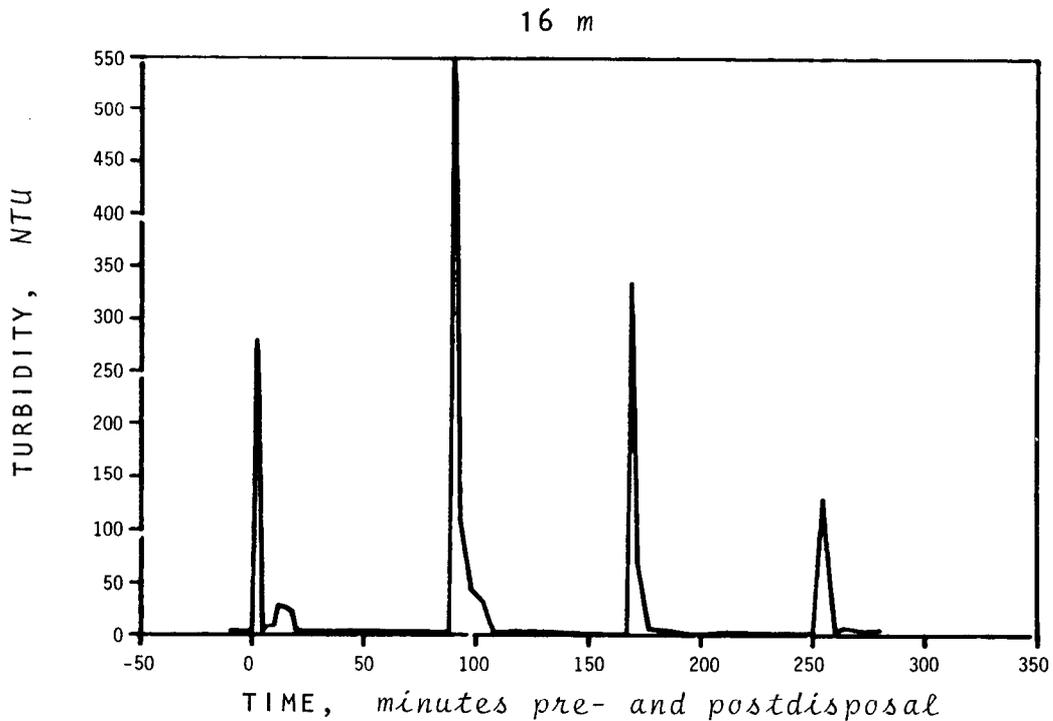


Figure 31. Laboratory determined turbidity (NTU's) from the 16 m depth on 26 May 1976 and changes in dissolved oxygen (mg/l) concentration at the 17 m depth on 24 May 1976 relative to the first disposal of each day (time=0)

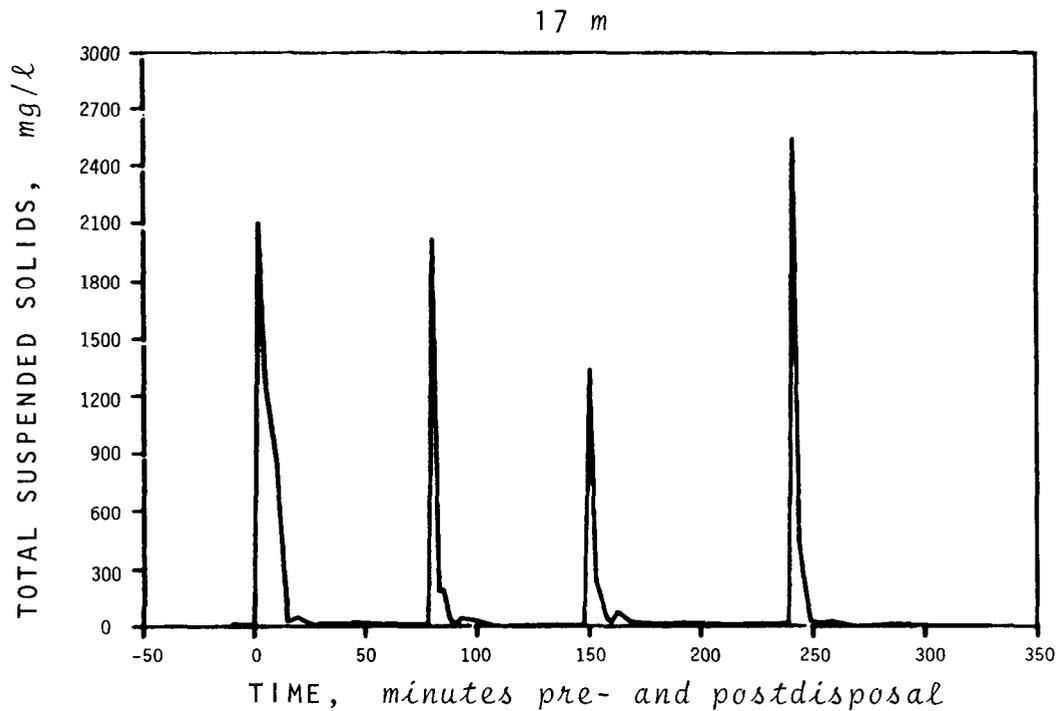
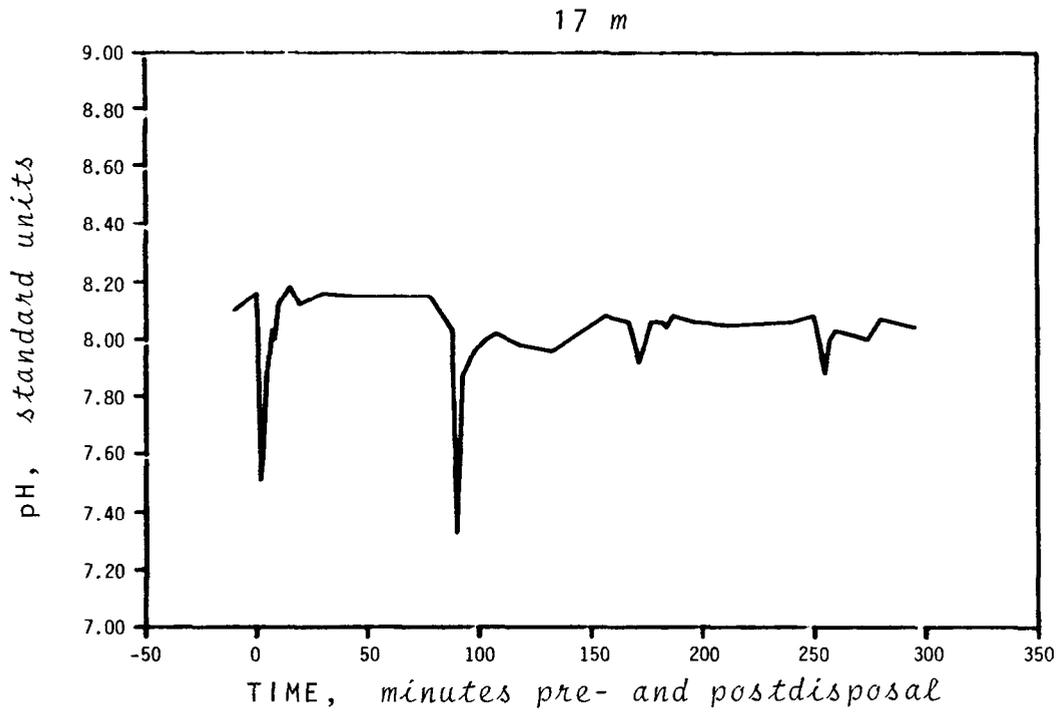


Figure 32. pH (standard units) and total suspended solids (mg/l) concentrations at the 17 m depth from 25 and 26 May 1976, respectively, relative to the first disposal of each day (time=0) at NDS

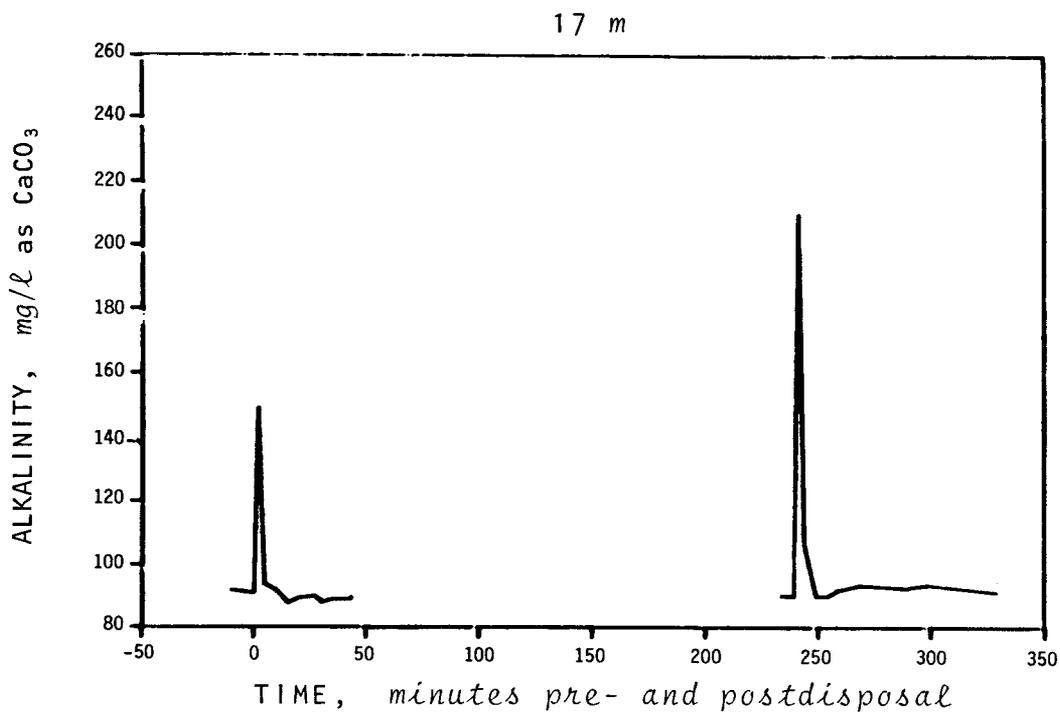
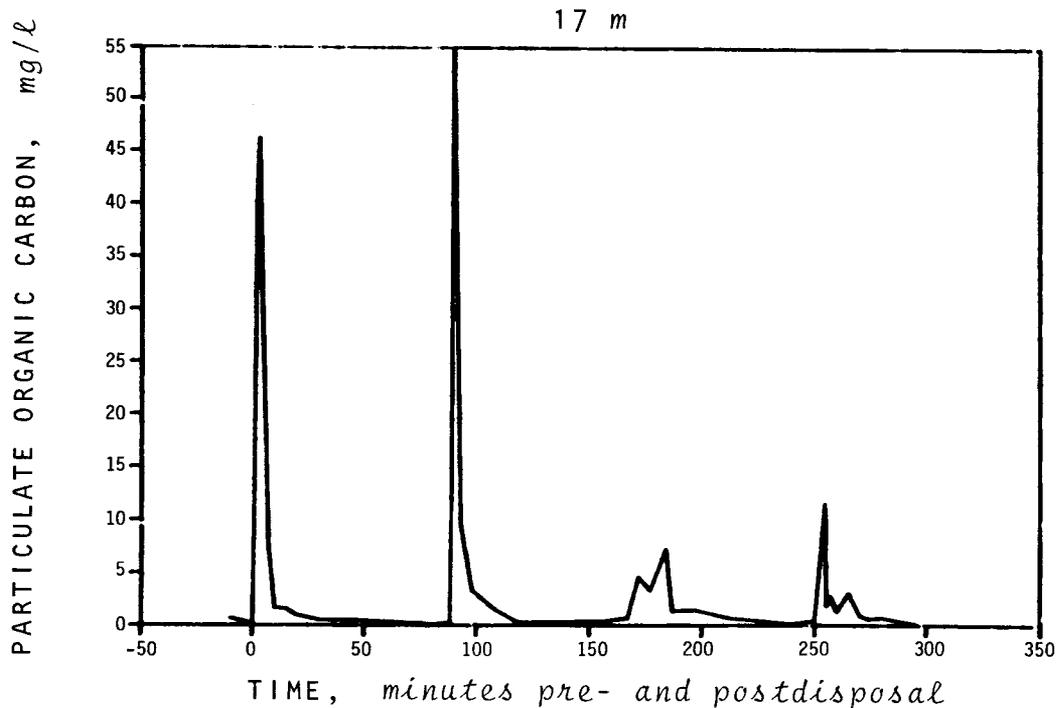


Figure 33. Particulate organic carbon (mg/ℓ) and alkalinity (mg/ℓ as CaCO_3) content at the 17 m depth on 26 and 25 May 1976, respectively, relative to the first disposal of each day (time=0) at NDS

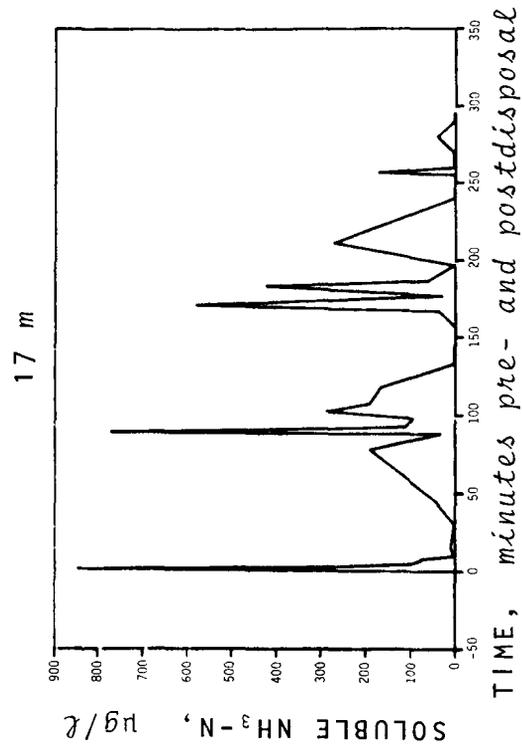
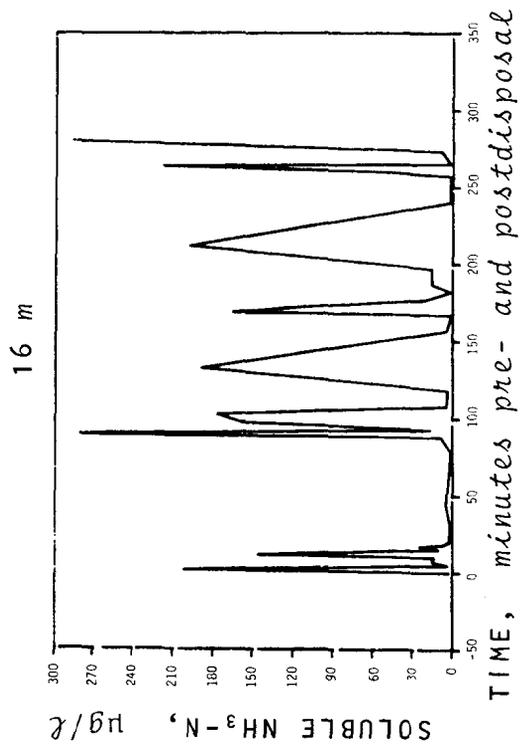
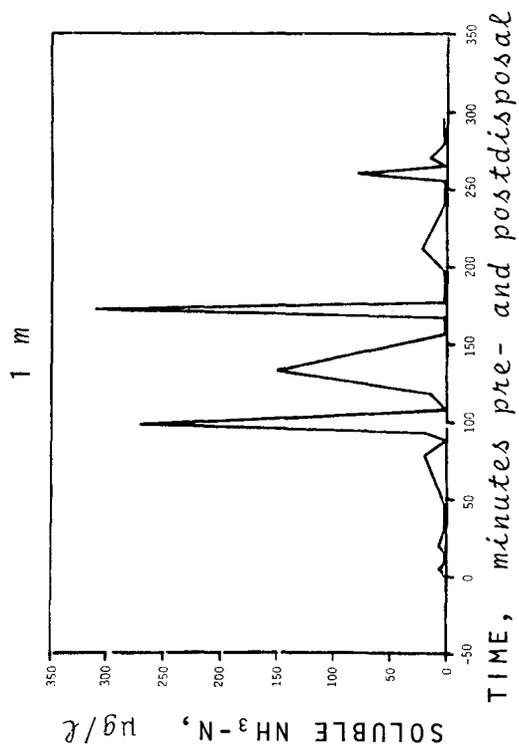


Figure 34. Soluble ammonia nitrogen concentrations ($\mu\text{g/l}$) at 1, 16 and 17 m depths on 26 May 1976 relative to the first disposal of the day at NDS

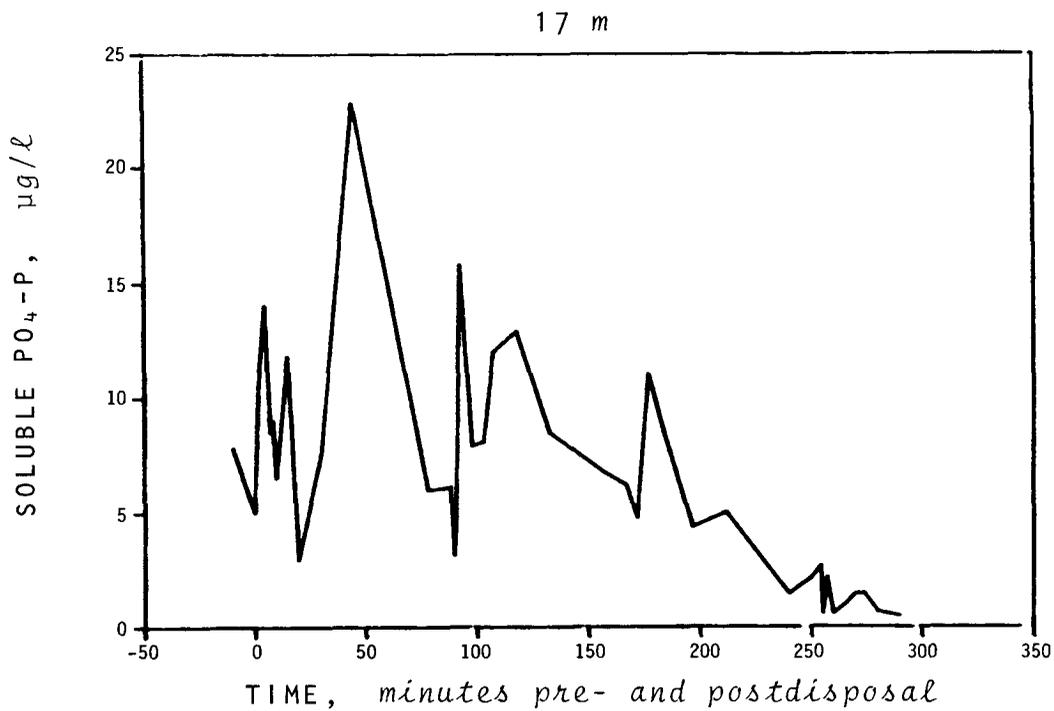
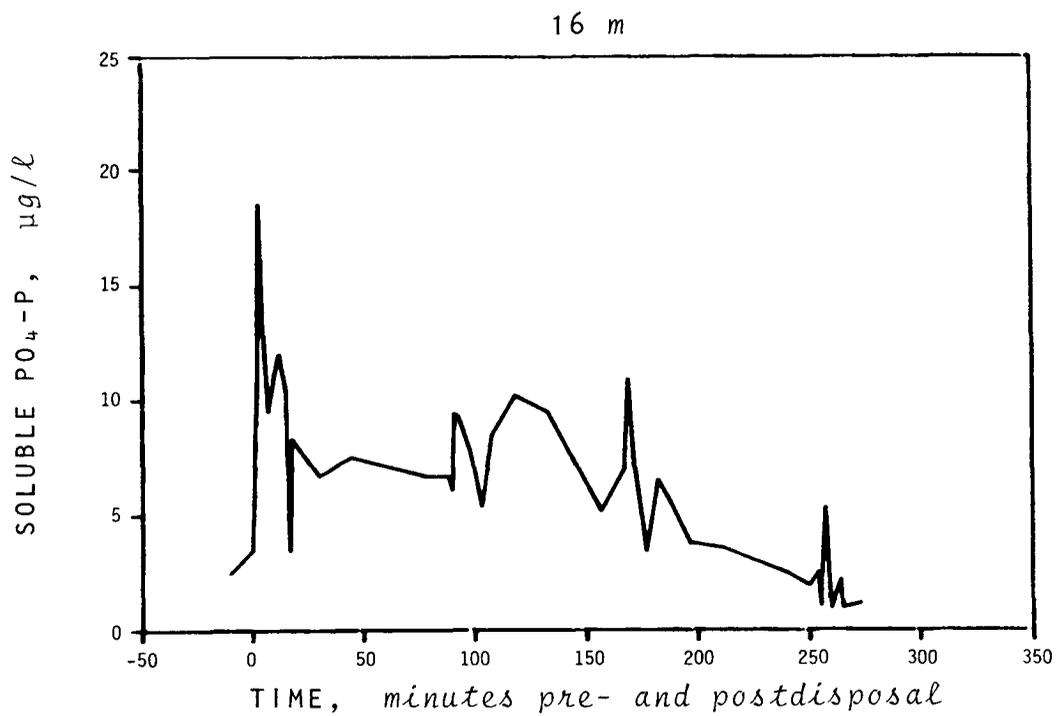
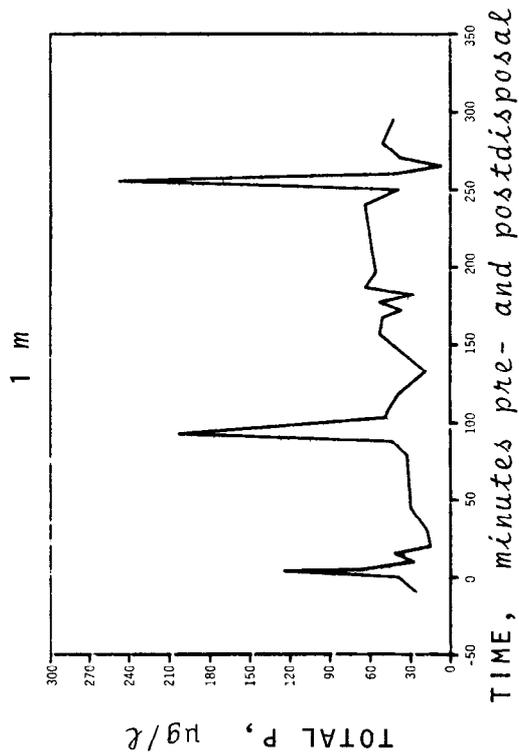
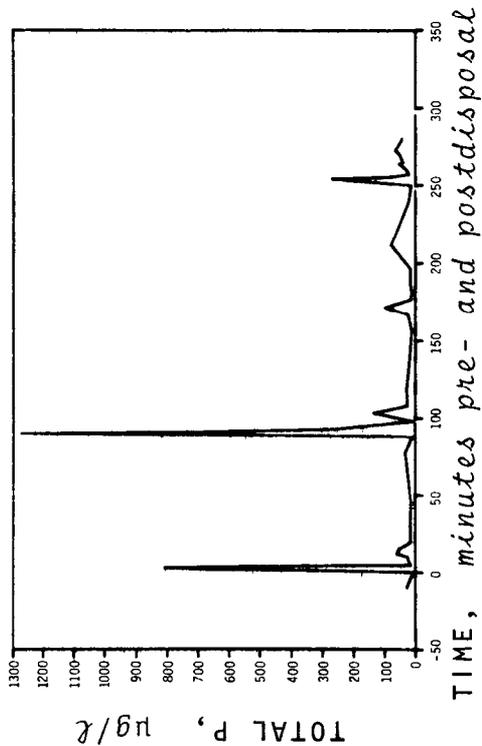


Figure 35. Soluble orthophosphorus concentrations ($\mu\text{g}/\ell$) at 16 and 17 m depths on 26 May 1976 relative to the first disposal of the day (time=0) at NDS



16 m



17 m

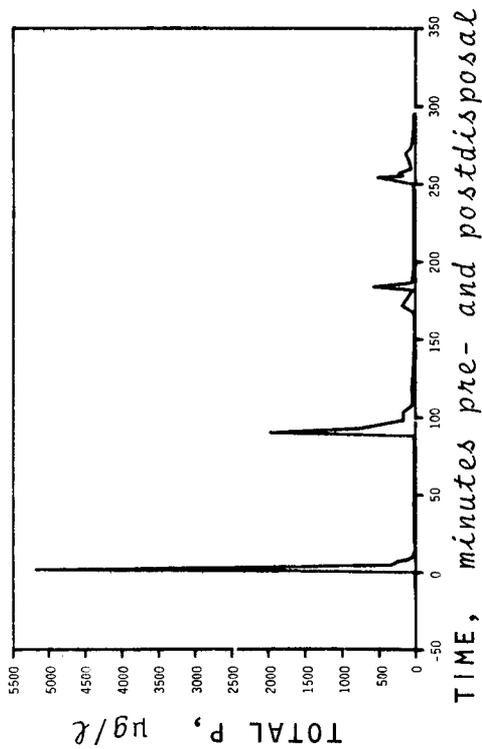


Figure 36. Total phosphorus concentrations ($\mu\text{g}/\text{l}$) at 1, 16 and 17 m depths on 26 May 1976 relative to the first disposal of the day (time=0) at NDS

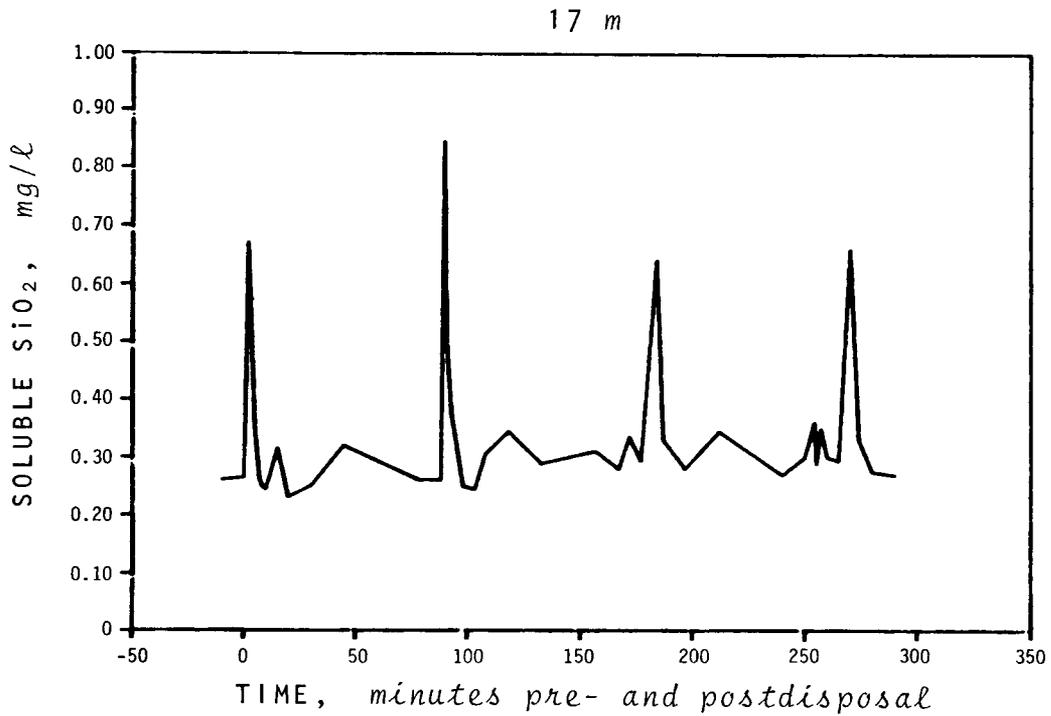
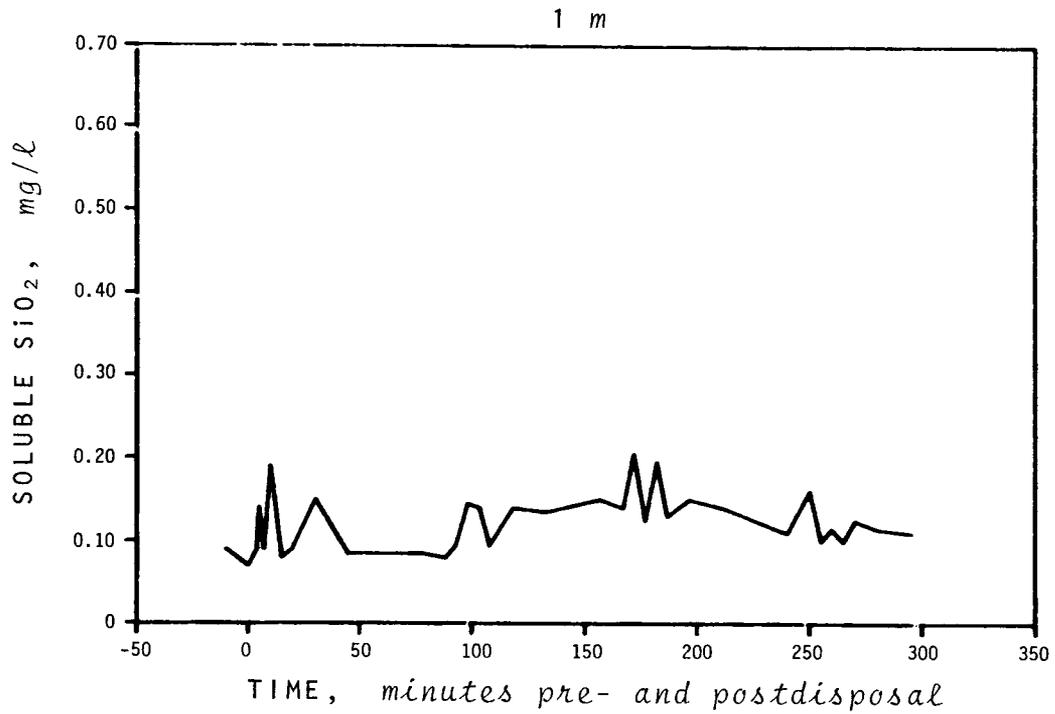


Figure 37. Soluble silica concentrations (mg/l) at 1 and 17 m depths on 26 May 1976 relative to the first disposal of the day (time=0) at NDS

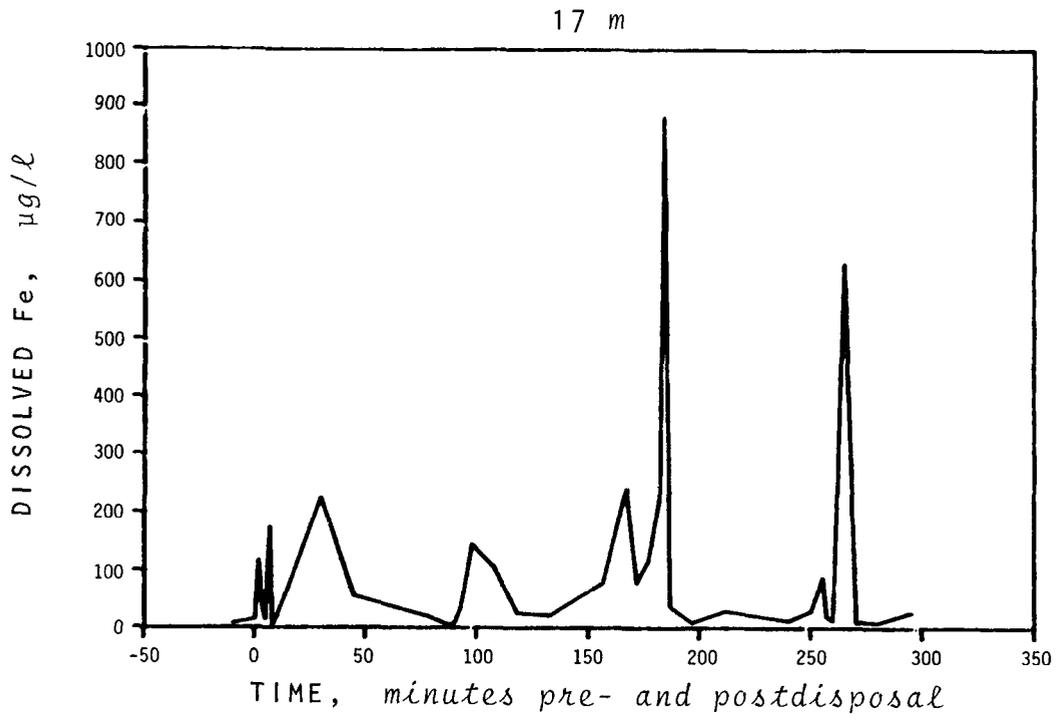
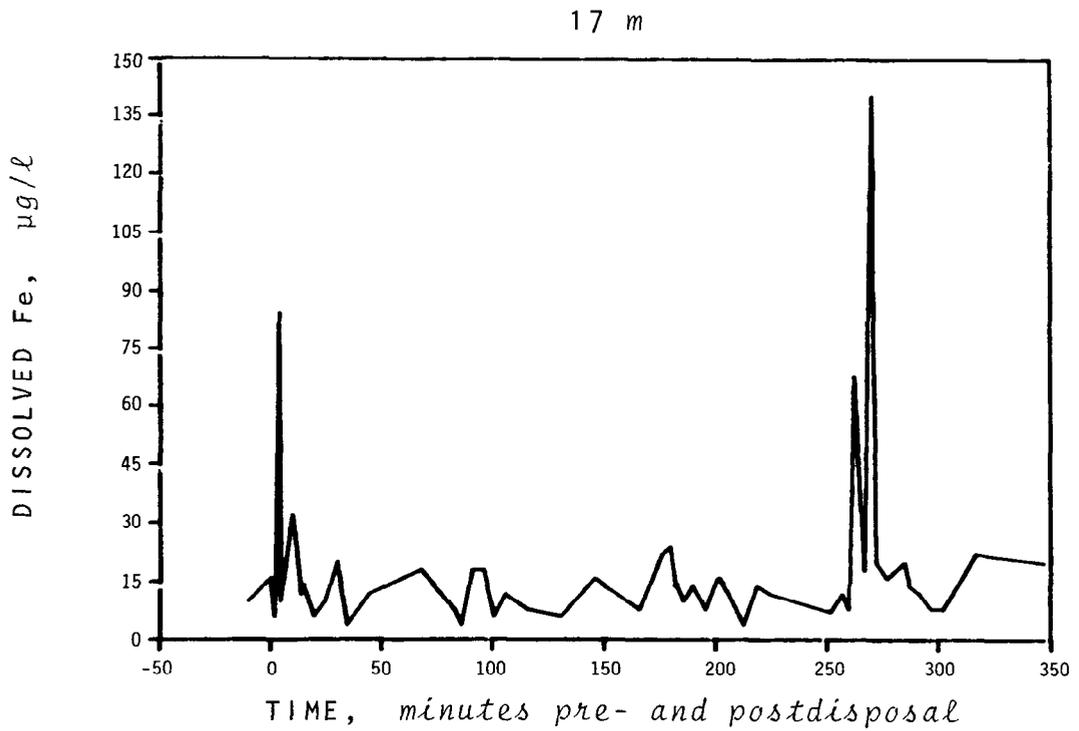


Figure 38. Dissolved iron concentrations ($\mu\text{g}/\ell$) at the 17 m depth on 24 and 26 May 1976 relative to the first disposal of each day (time=0) at NDS

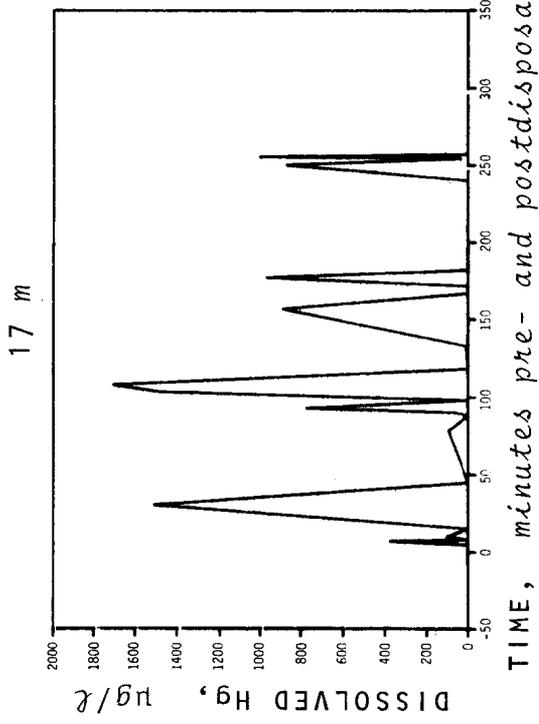
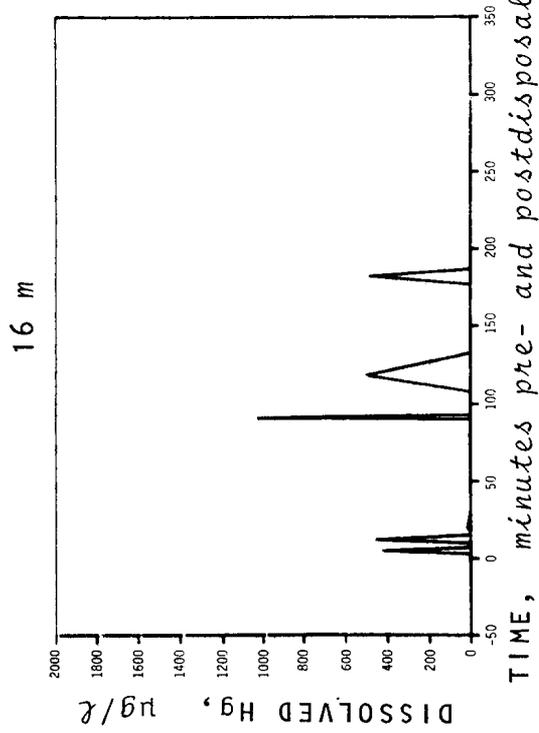
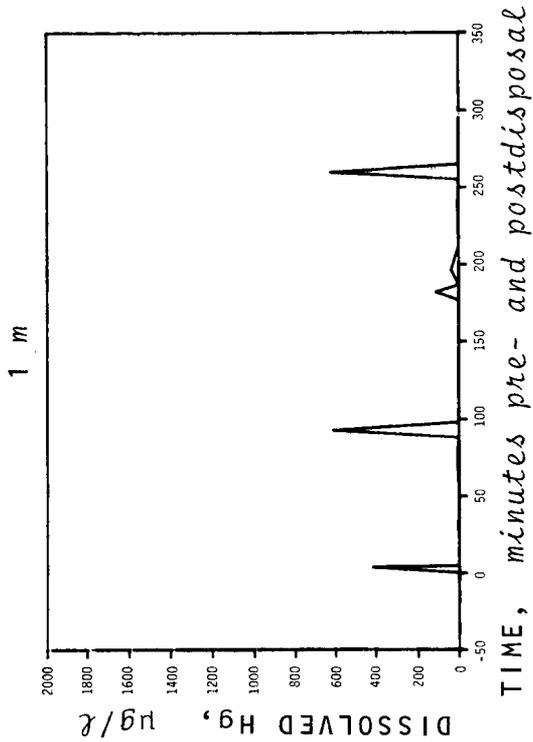


Figure 39. Dissolved mercury concentrations ($\mu\text{g}/\ell$) at the 1, 16 and 17 m depths on 26 May 1976 relative to the first disposal of each day (time=0) at NDS

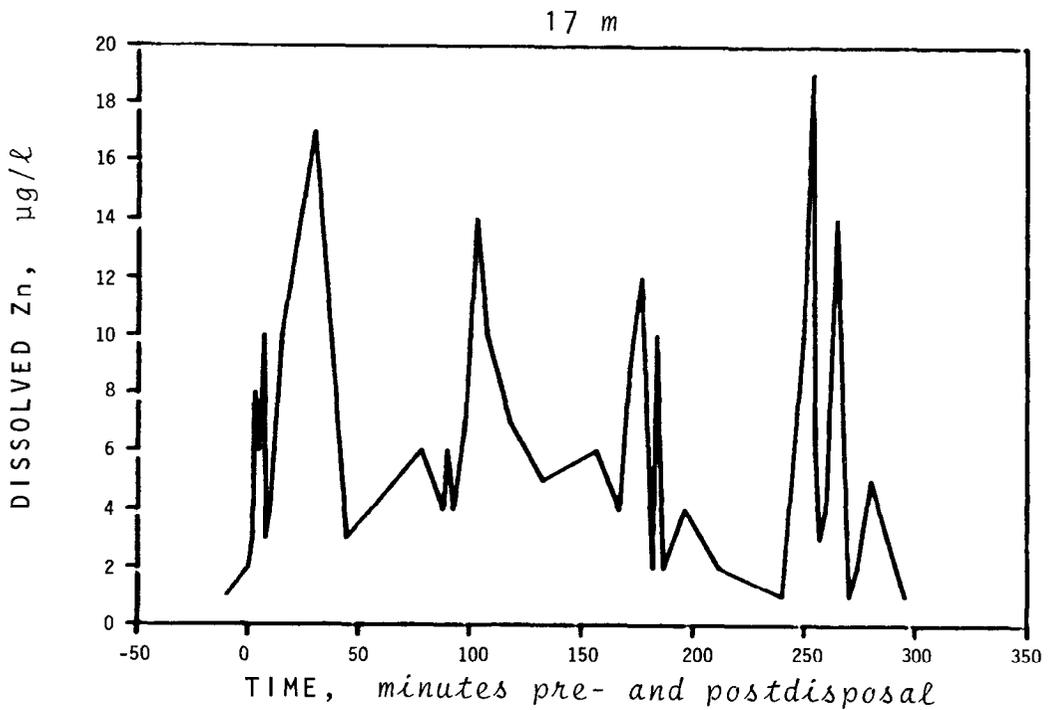
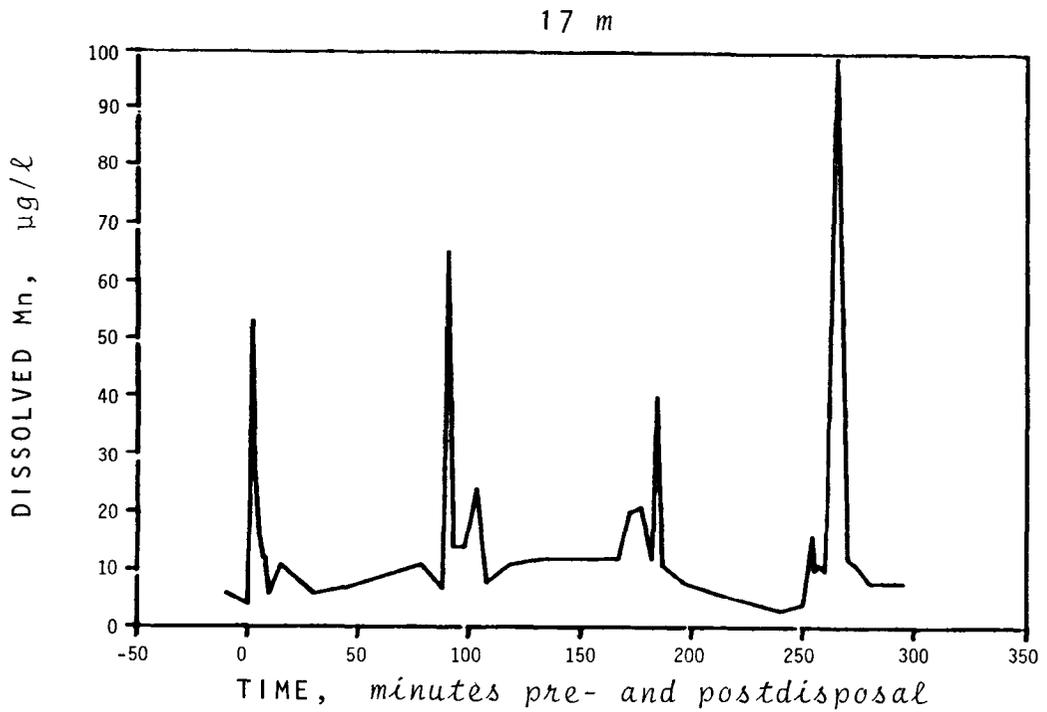


Figure 40. Dissolved manganese and zinc concentrations ($\mu\text{g}/\ell$) at the 17 m depth on 26 May 1976 relative to the first disposal of the day (time=0) at NDS

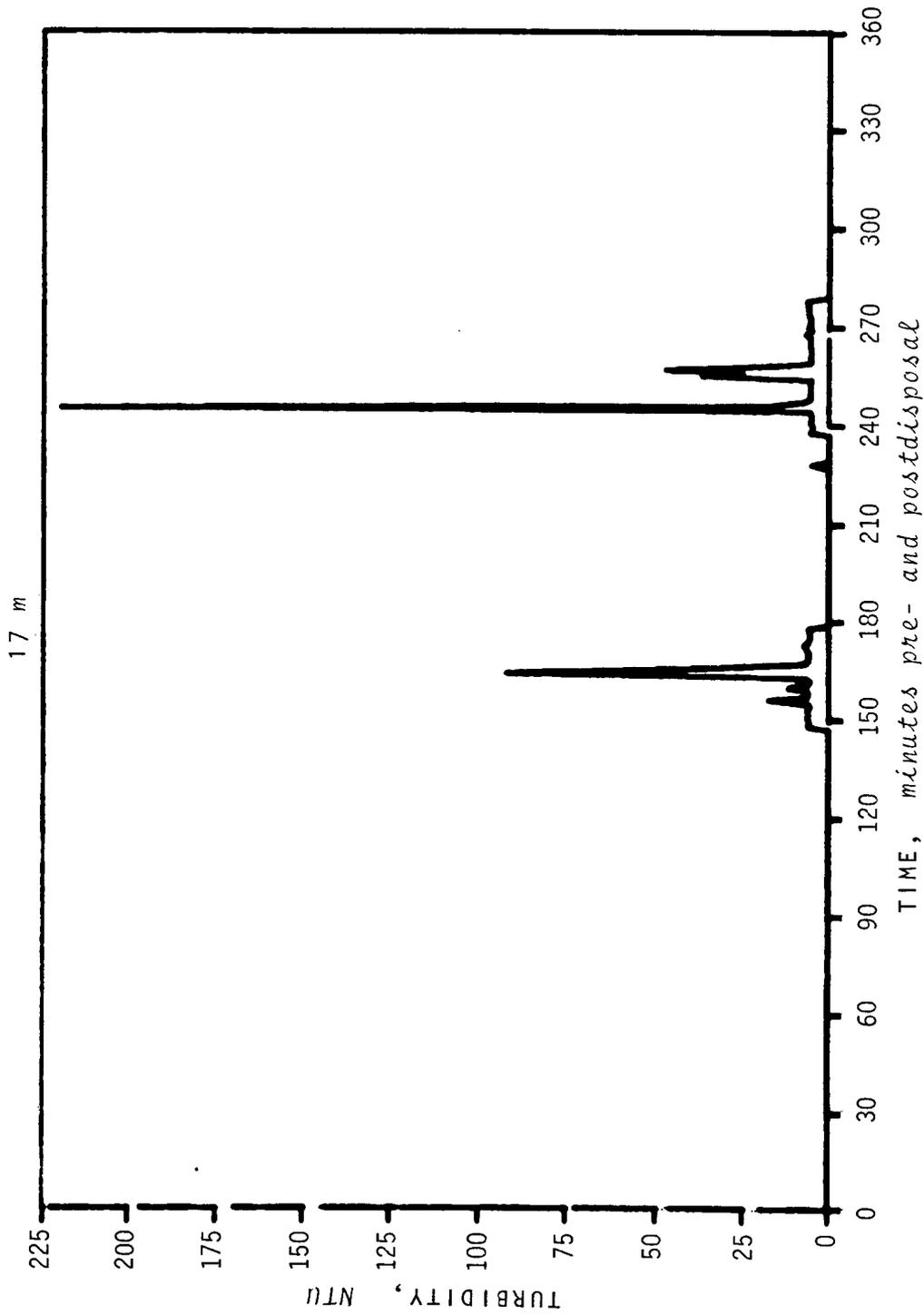


Figure 41. Turbidity concentrations (NTU's) at the 17 m depth on 25 May 1976 as measured on-site via continuous monitoring on the JCU vessel located approximately 100 m west of NDS (monitoring was only completed after disposals 3 and 4 of that day) relative to the first disposal of the day (time=0) at NDS

17 m

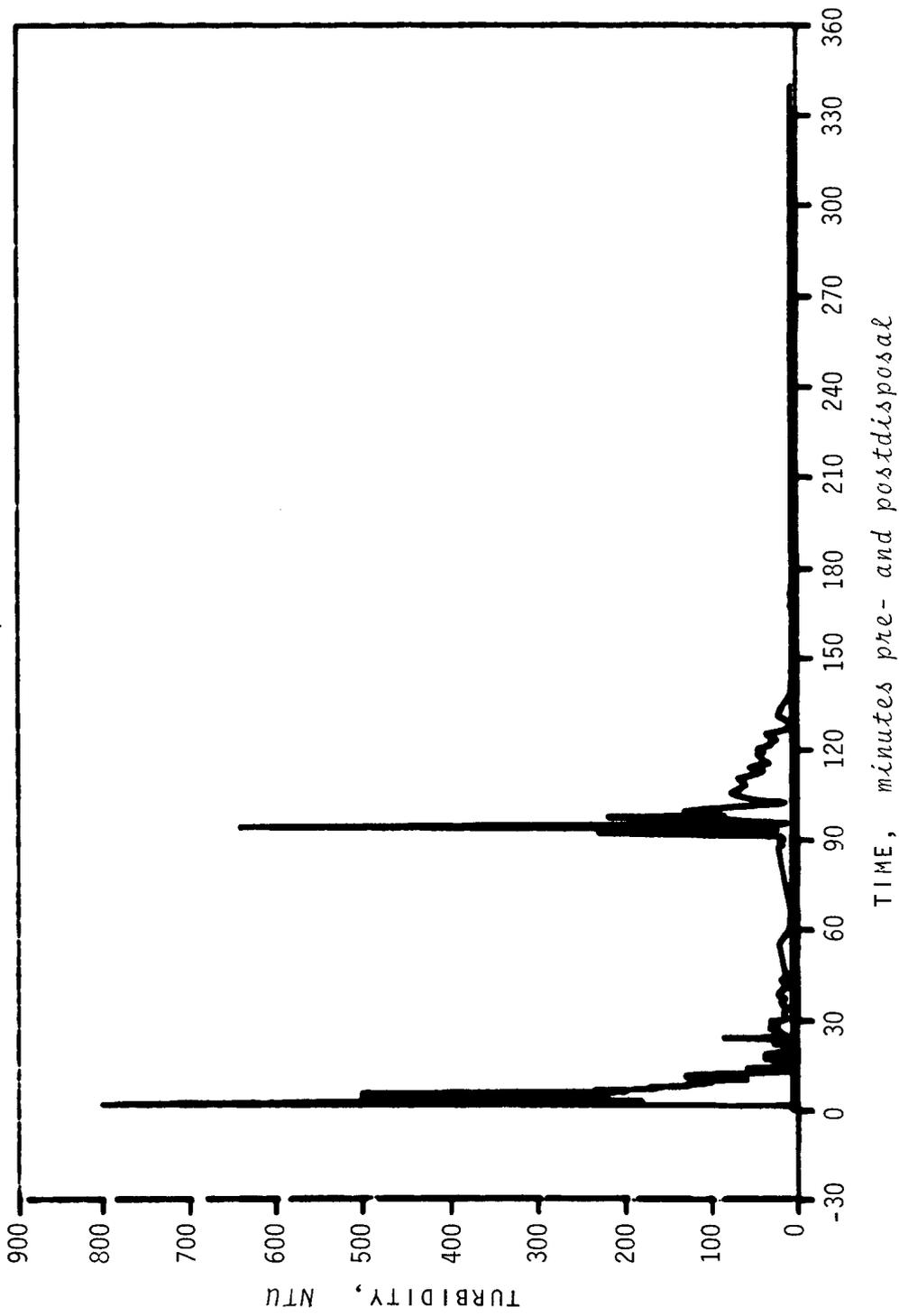


Figure 42. Turbidity concentrations (NTU's) at the 17 m depth on 26 May 1976 as measured on-site via continuous monitoring on the JCU vessel located approximately 75 m southwest of NDS for disposal 1 and approximately 150 m southwest of NDS for disposal 2 relative to the first disposal of the day (time=0) at NDS

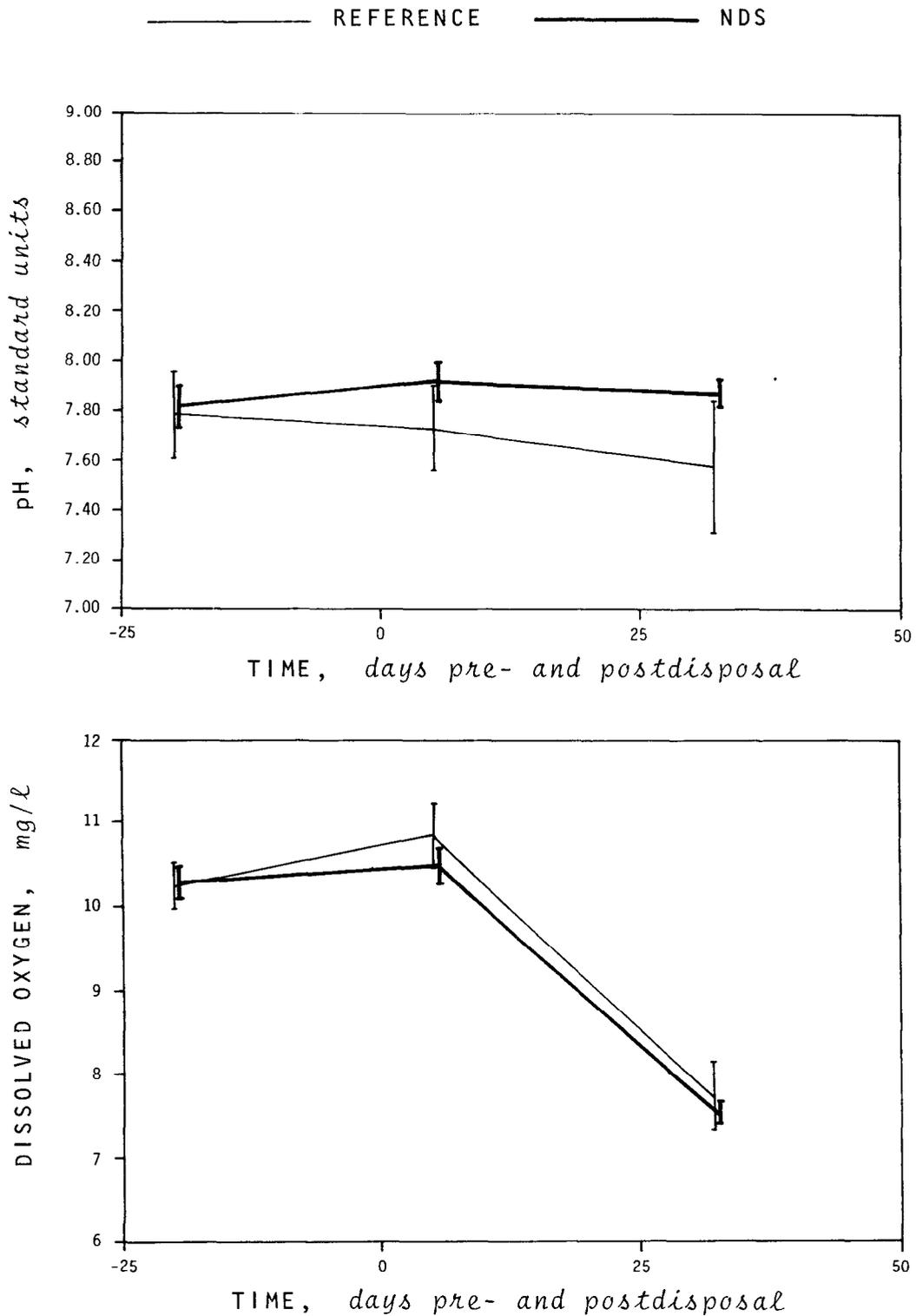


Figure 43. Mean and 95 percent confidence levels of pH (*standard units*) and dissolved oxygen (*mg/l*) concentrations of interface water from core collections at the reference site and NDS relative to time in days pre- and postdisposal 1976

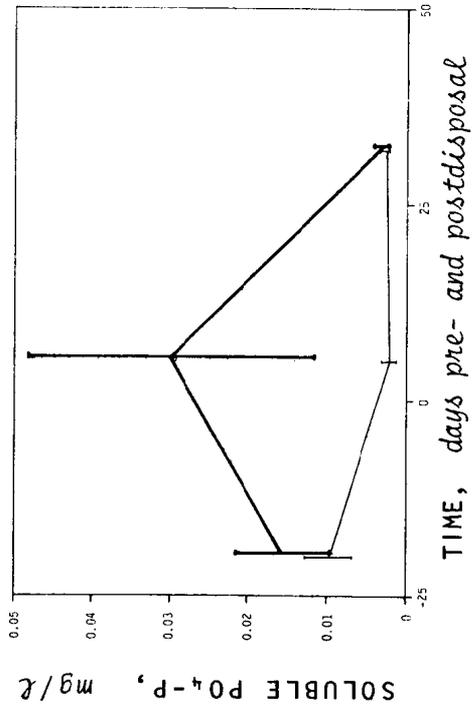
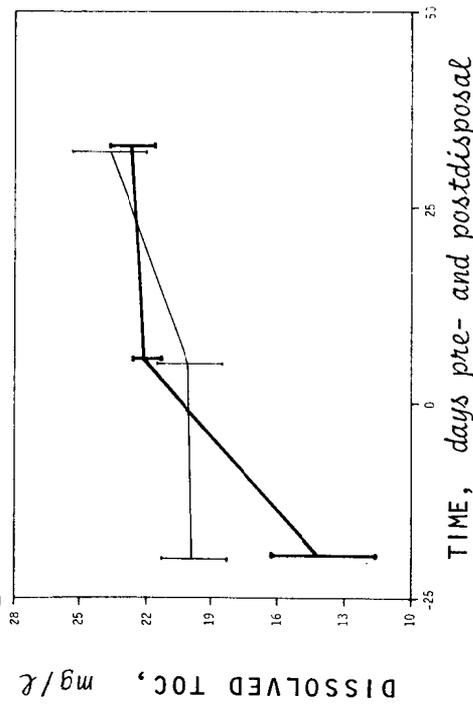
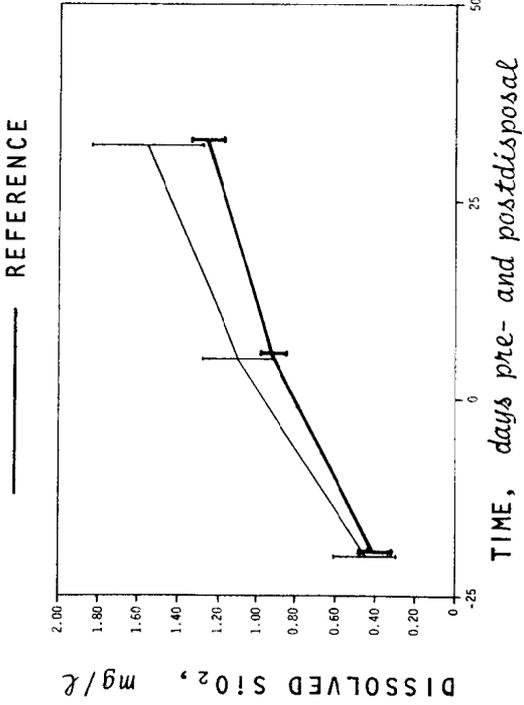
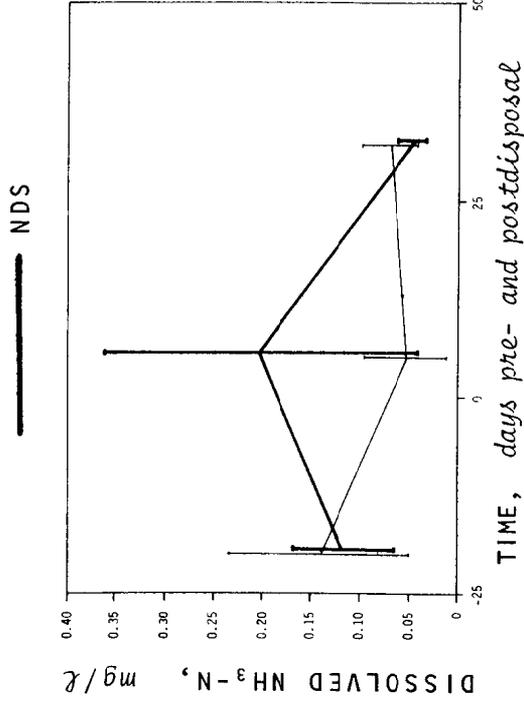


Figure 44. Mean and 95 percent confidence levels of soluble silica, ammonia, orthophosphorus and total organic carbon (mg/L) concentrations of interface water from core collections at the reference site and NDS relative to time in days pre- and postdisposal 1976

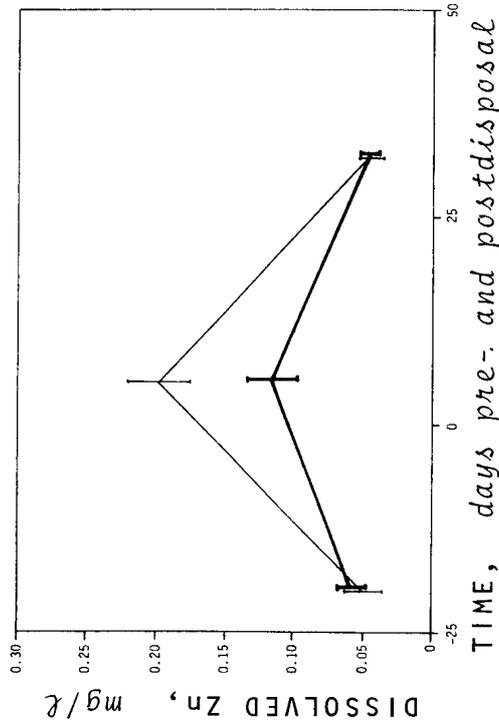
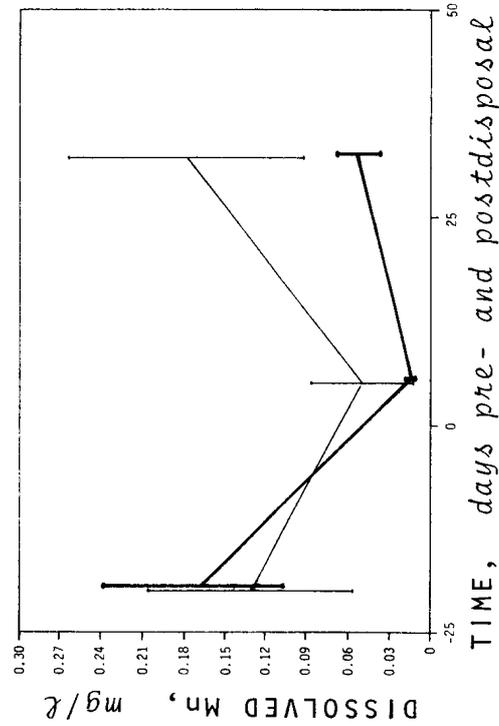
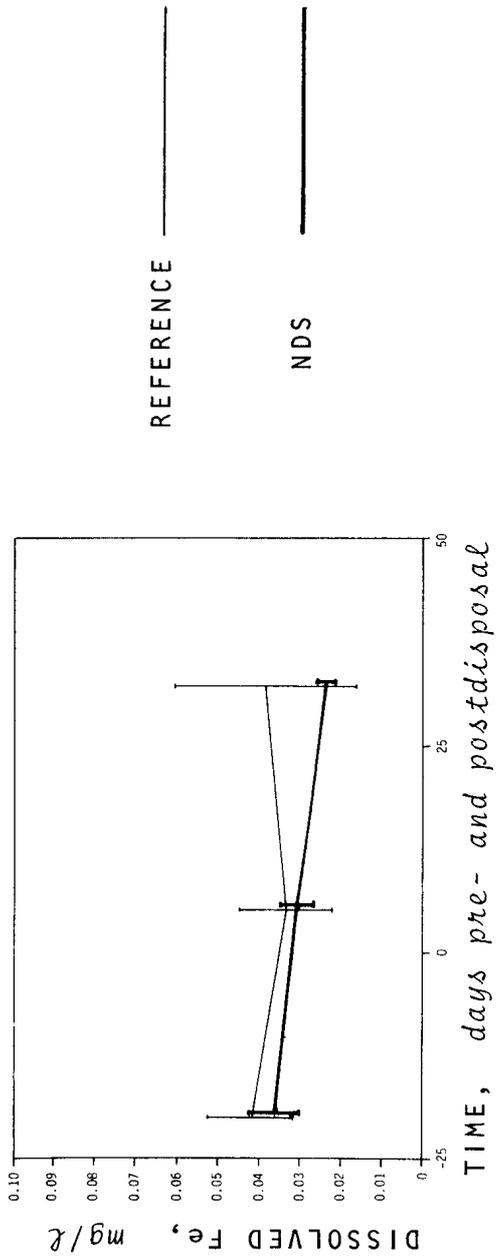


Figure 45. Mean and 95 percent confidence levels of dissolved iron, manganese and zinc concentrations (mg/l) of interface water from core collections at the reference site and NDS relative to time in days pre- and postdisposal 1976

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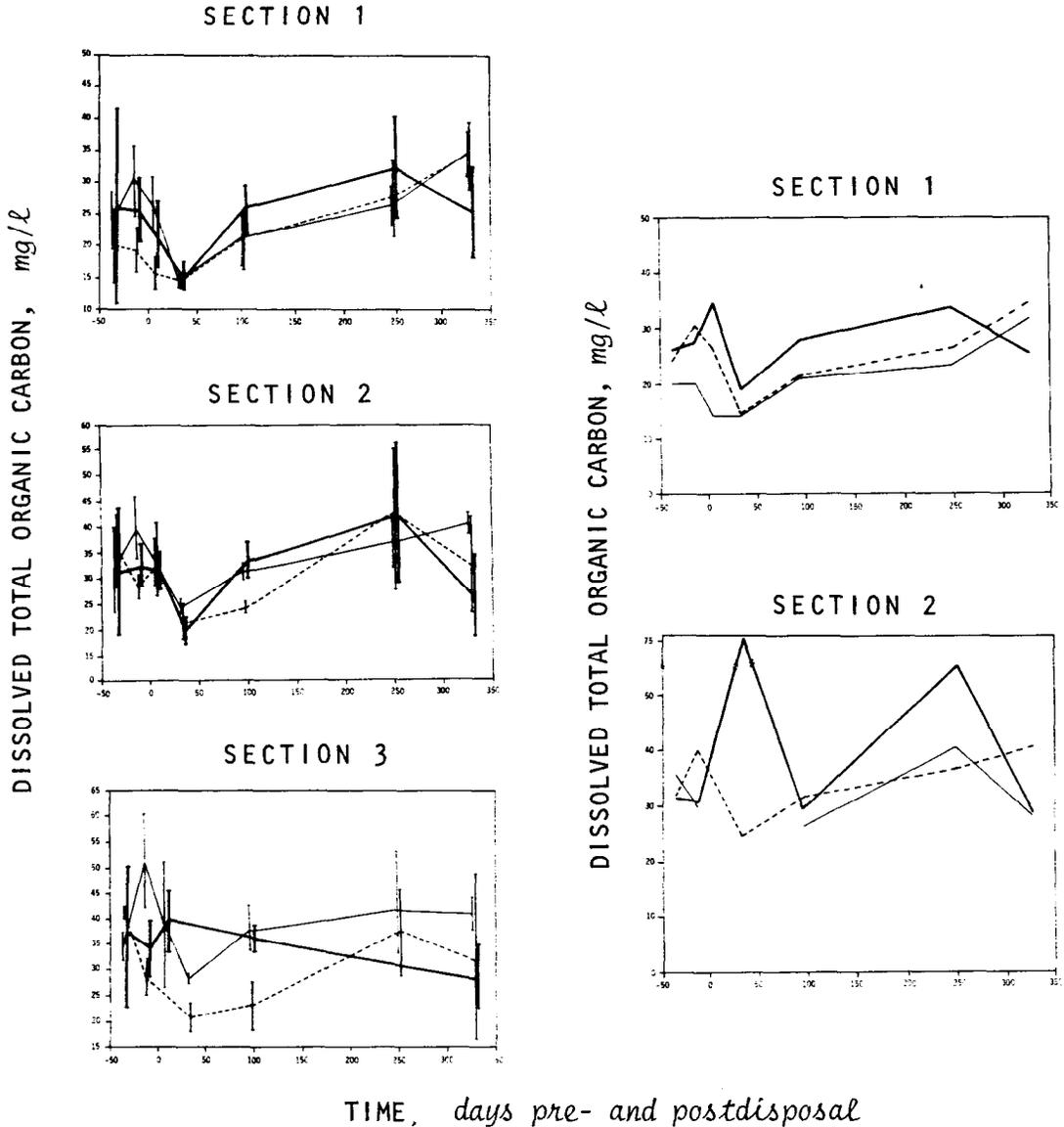


Figure 46. Mean and 95 percent confidence levels of dissolved total organic carbon concentrations (mg/l) from interstitial water extractor from reference site, harbor disposal site and river disposal site sampl in the first, second and third sections of each core and mean dissolve total organic carbon concentrations (mg/l) from the reference site, station D2, and station D8 in the first and second core sections relati to time in days pre- and postdisposal 1975

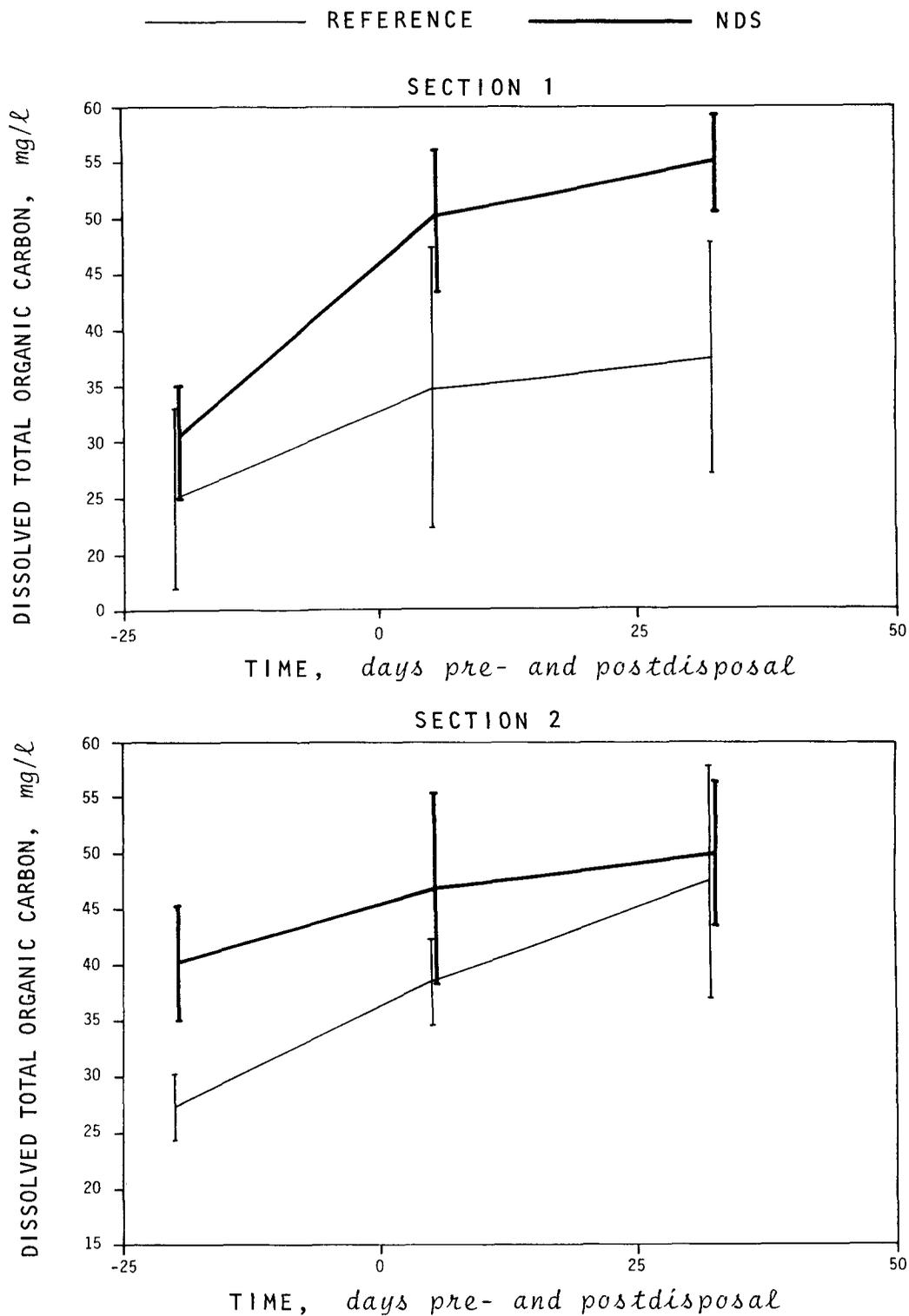


Figure 47. Mean and 95 percent confidence levels of dissolved total organic carbon concentrations (mg/l) from interstitial water extracted from reference site and NDS samples in the first and second sections of each core relative to time in days pre- and postdisposal 1976

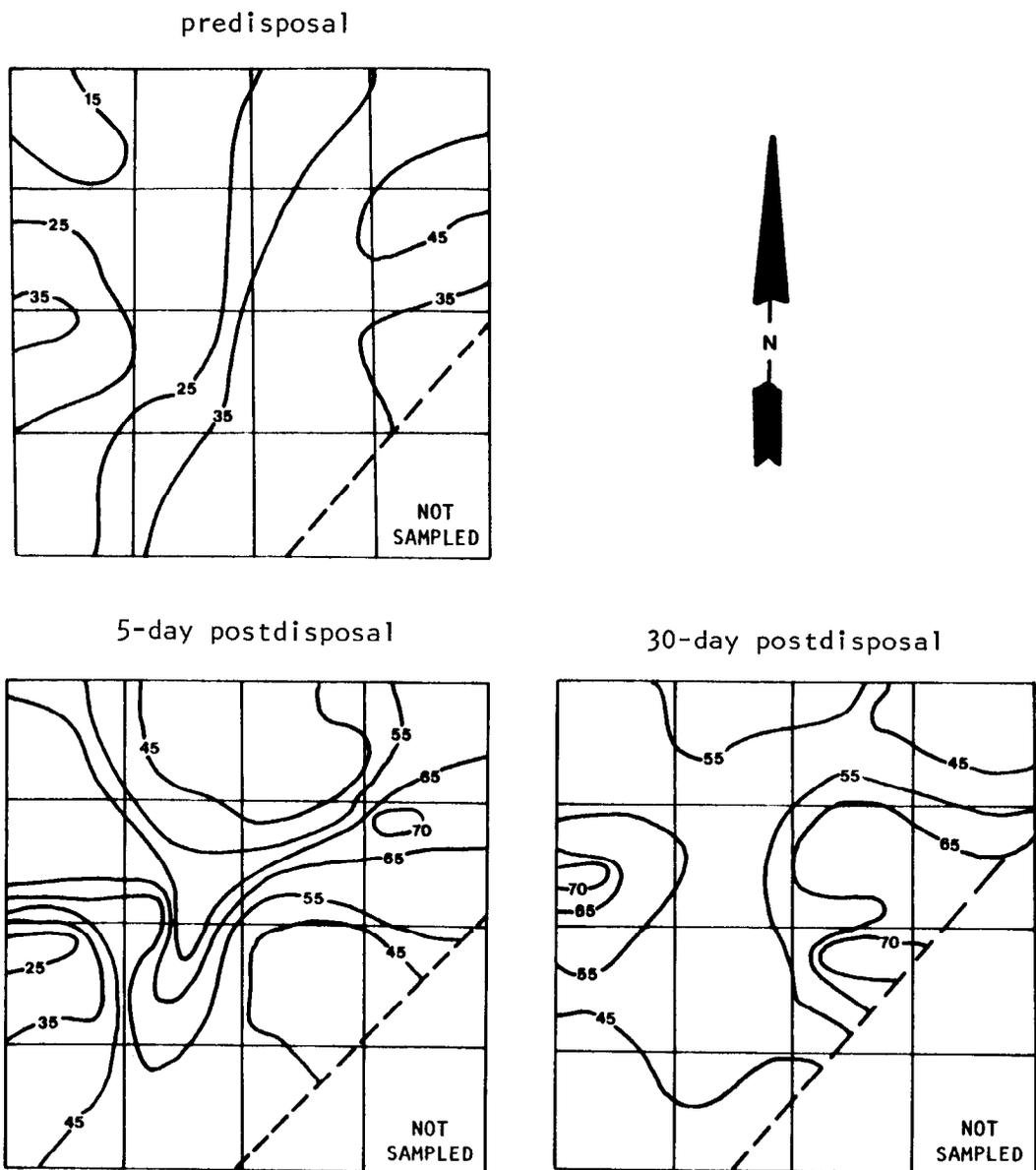


Figure 48. Dissolved total organic carbon concentration (mg/l) isopleths of first core section interstitial water over the entire NDS sampling area from the predisposal and 5- and 30-day postdisposal collections 1976

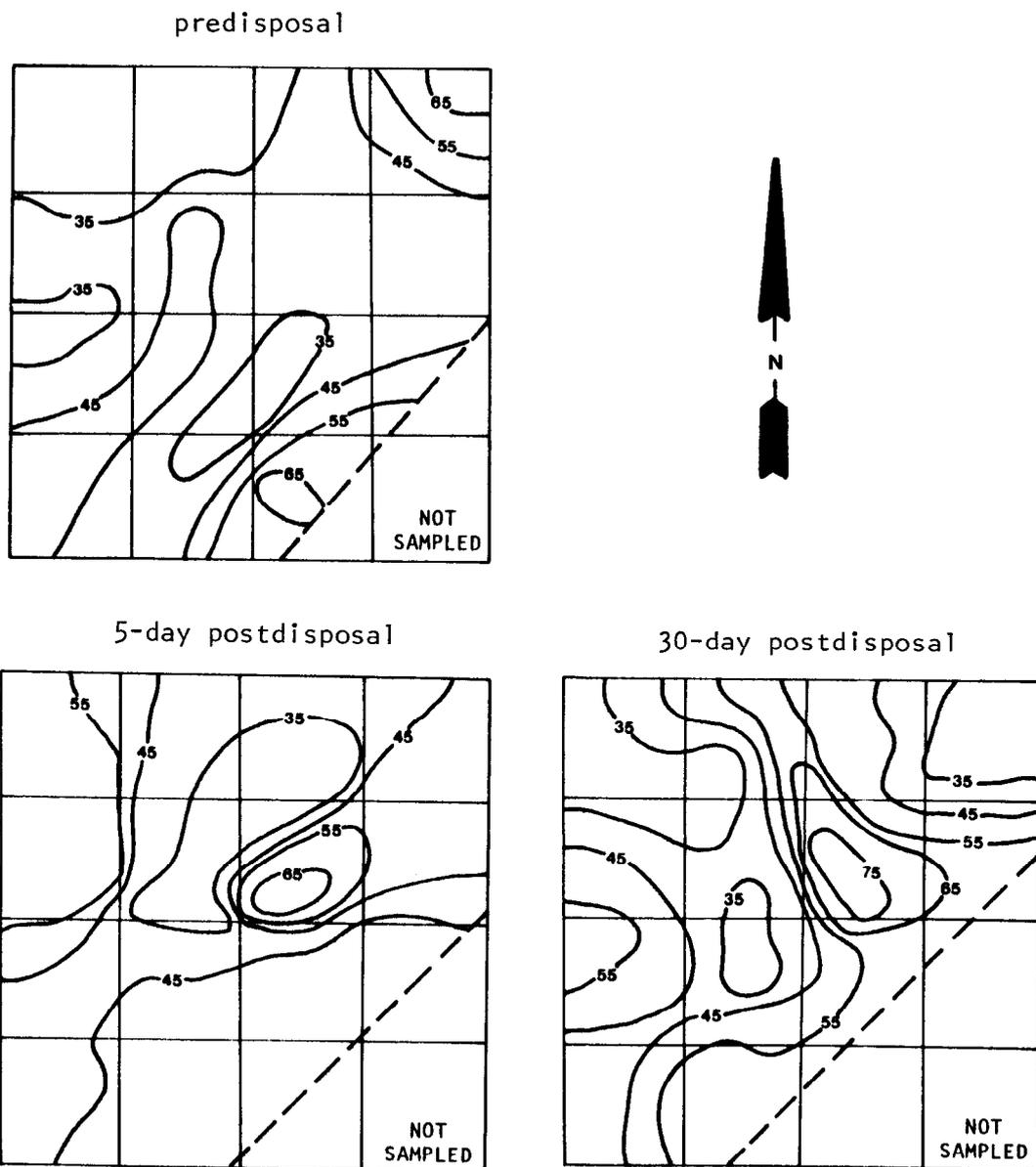


Figure 49. Dissolved total organic carbon concentration (mg/l) isopleths of second core section interstitial water over the entire NDS sampling area from the predisposal and 5- and 30-day postdisposal collections 1976

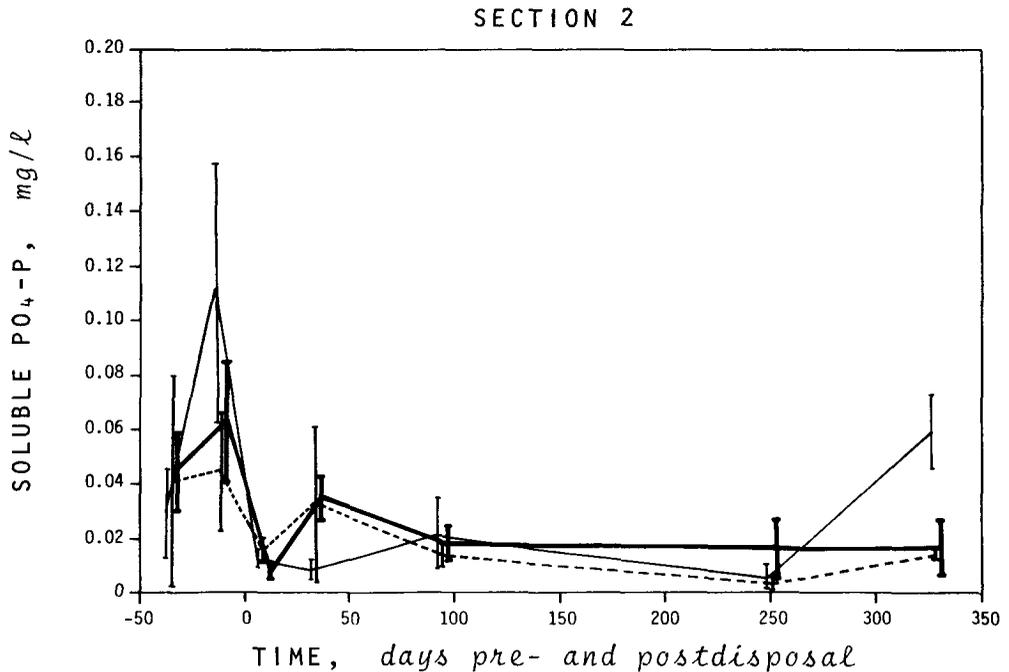
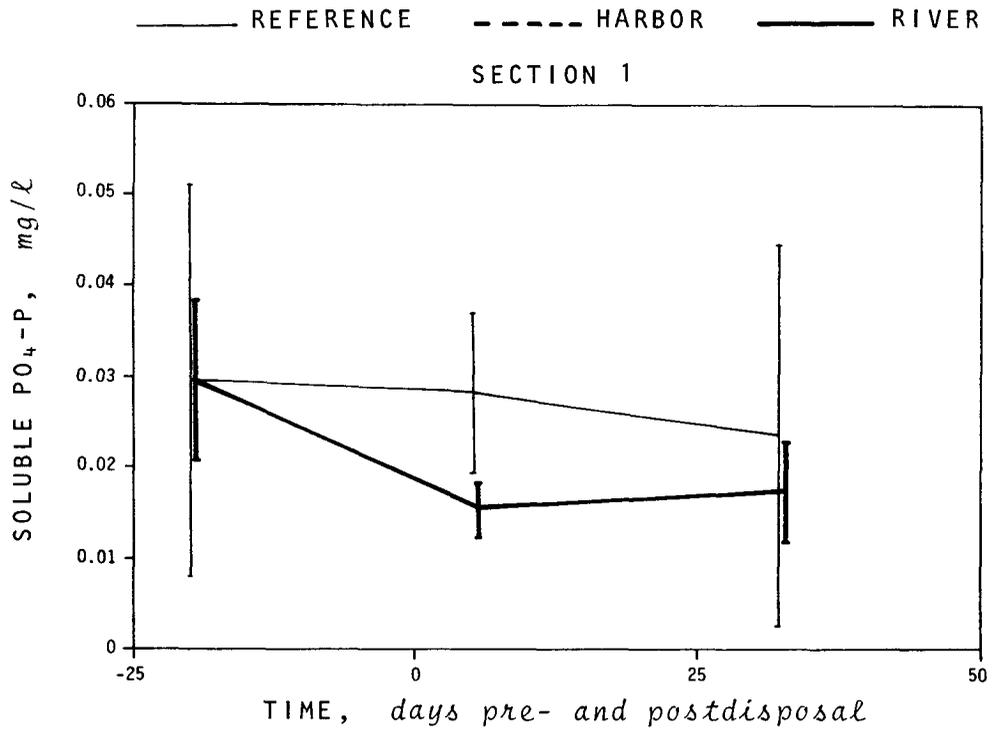


Figure 50. Mean and 95 percent confidence levels of soluble orthophosphorus concentrations (mg/l) from interstitial water extracted from second core sections of samples from the reference, harbor disposal and river disposal sites in 1975 and first core sections of samples from the reference site and NDS in 1976 relative to time in days pre- and postdisposal 1975 and 1976, respectively

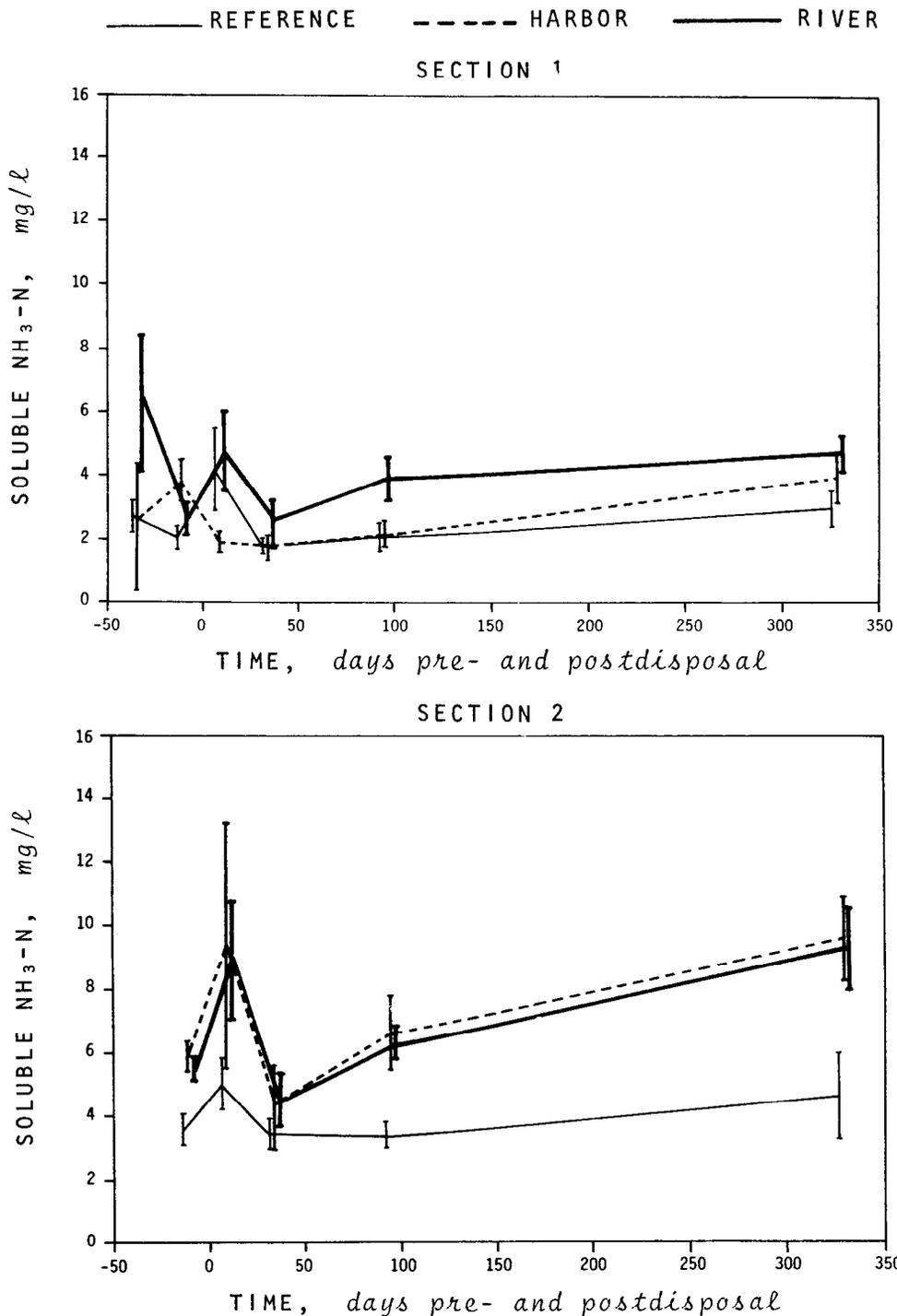


Figure 51. Mean and 95 percent confidence levels of soluble ammonium nitrogen concentrations (mg/ℓ) of interstitial water extracted from first and second sections of cores collected at the reference, harbor disposal and river disposal sites relative to time in days pre- and postdisposal 1975

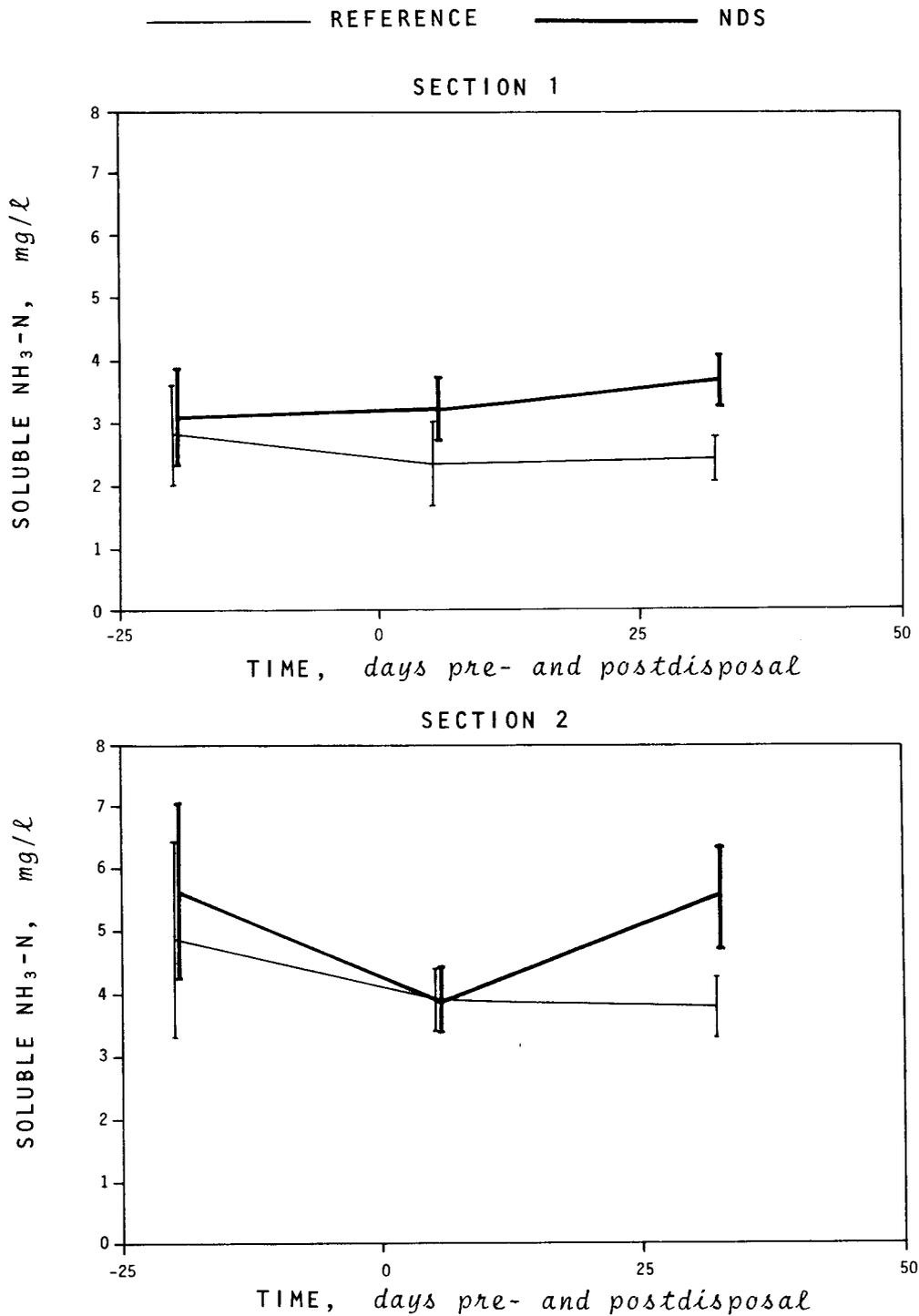


Figure 52. Mean and 95 percent confidence levels of soluble ammonium nitrogen concentrations (mg/l) of interstitial water extracted from first and second sections of cores collected at the reference site and NDS relative to time in days pre- and postdisposal 1976

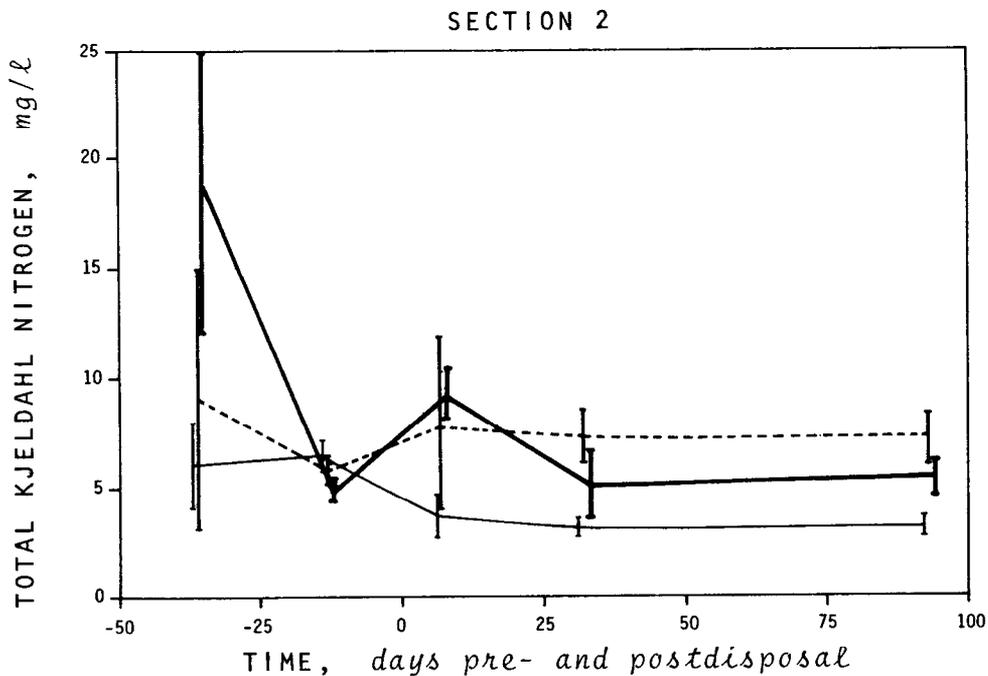
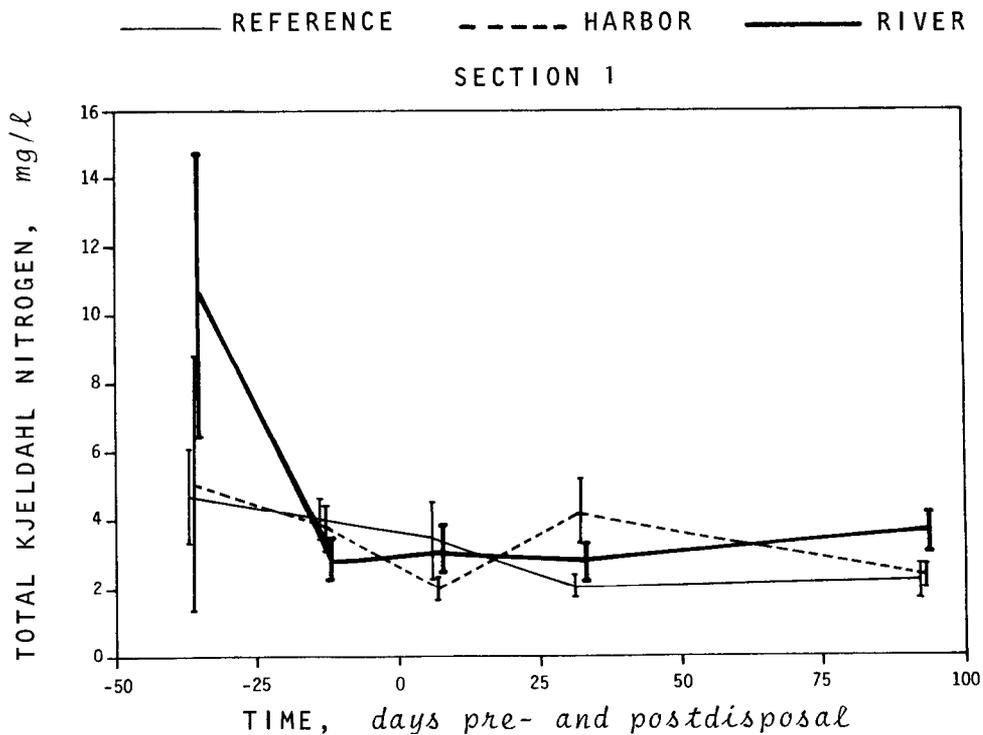


Figure 53. Mean and 95 percent confidence levels of dissolved total Kjeldahl nitrogen concentrations (mg/l) of interstitial water extracted from first and second sections of cores collected at the reference, harbor disposal and river disposal sites relative to time in days pre- and postdisposal 1975

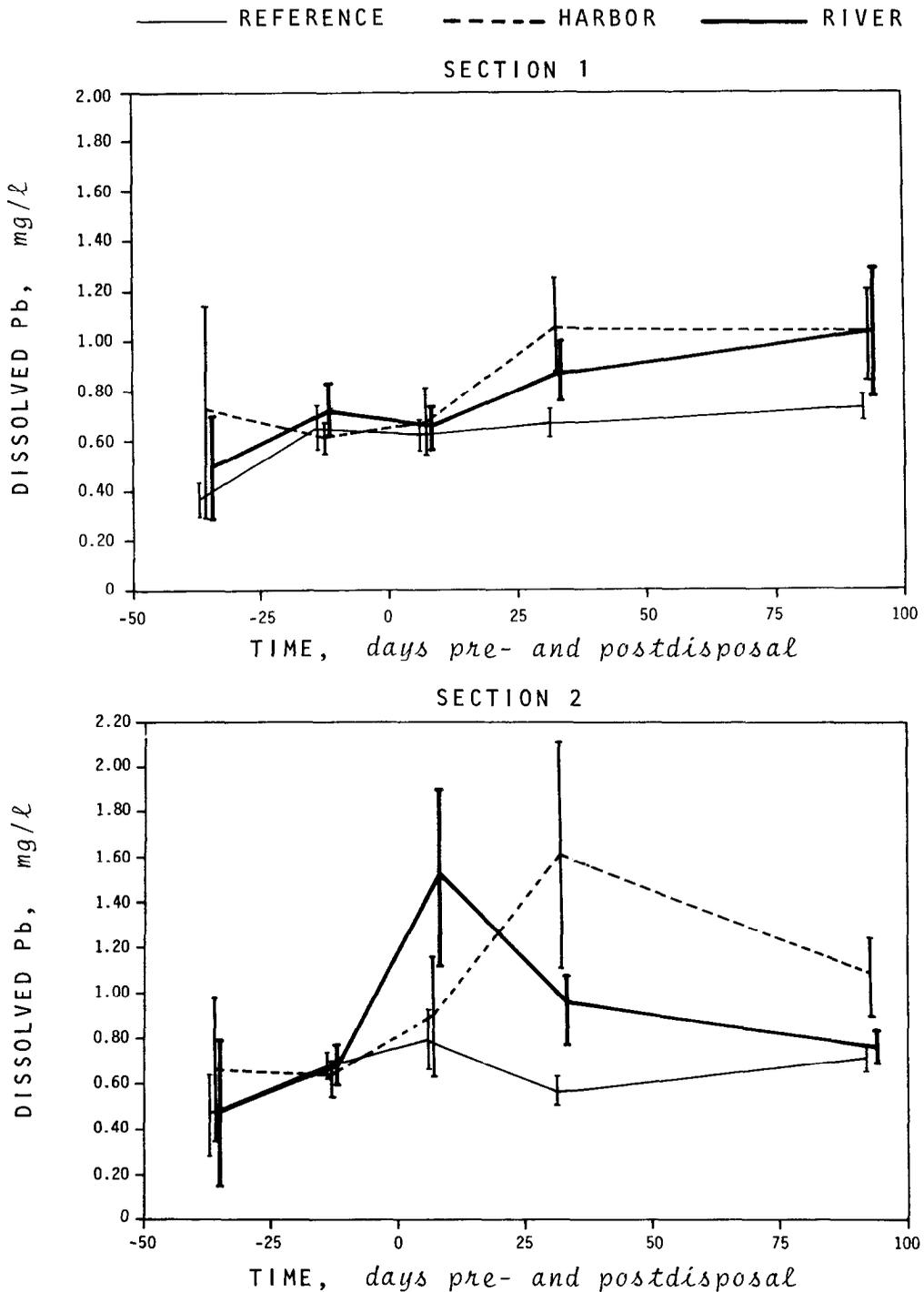


Figure 54. Mean and 95 percent confidence levels of dissolved lead concentrations (mg/l) of interstitial water extracted from the first and second sections of cores collected at the reference, harbor disposal and river disposal sites relative to time in days pre- and postdisposal 1975

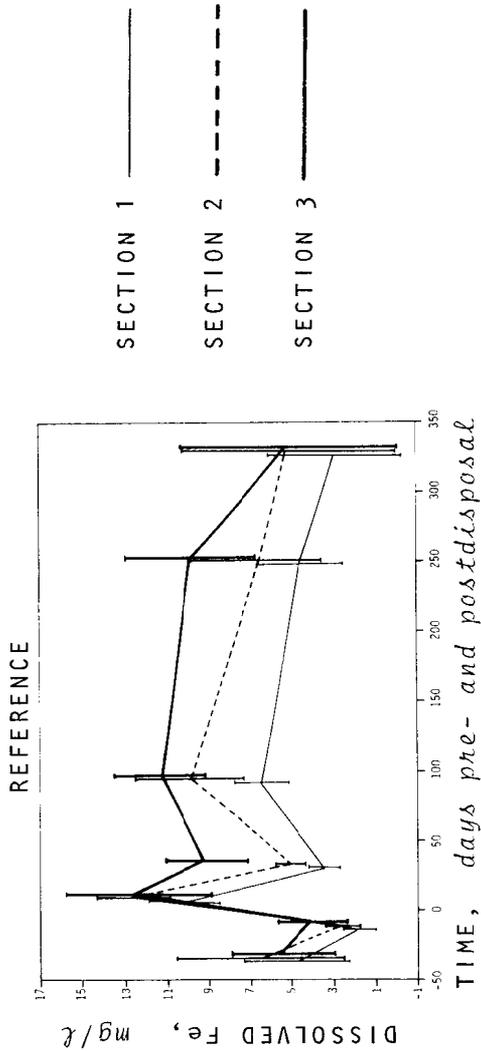
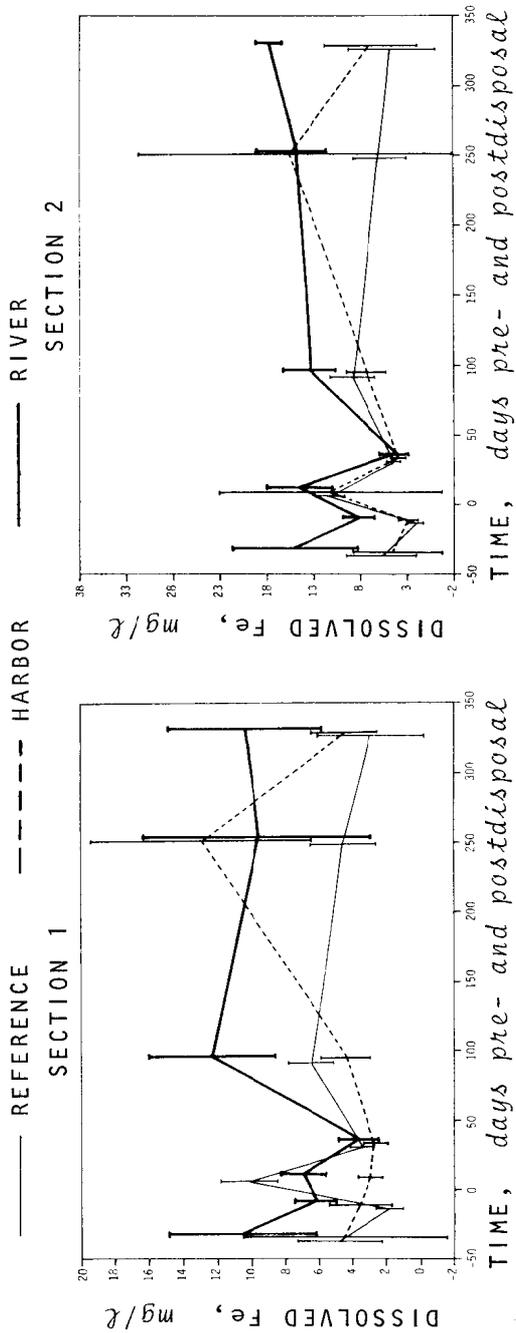


Figure 55. Mean and 95 percent confidence levels of dissolved iron concentrations (mg/L) of interstitial water extracted from first and second sections of cores collected at the reference, harbor disposal and river disposal sites and first, second and third section interstitial water dissolved iron from the reference site relative to time pre- and postdisposal 1975

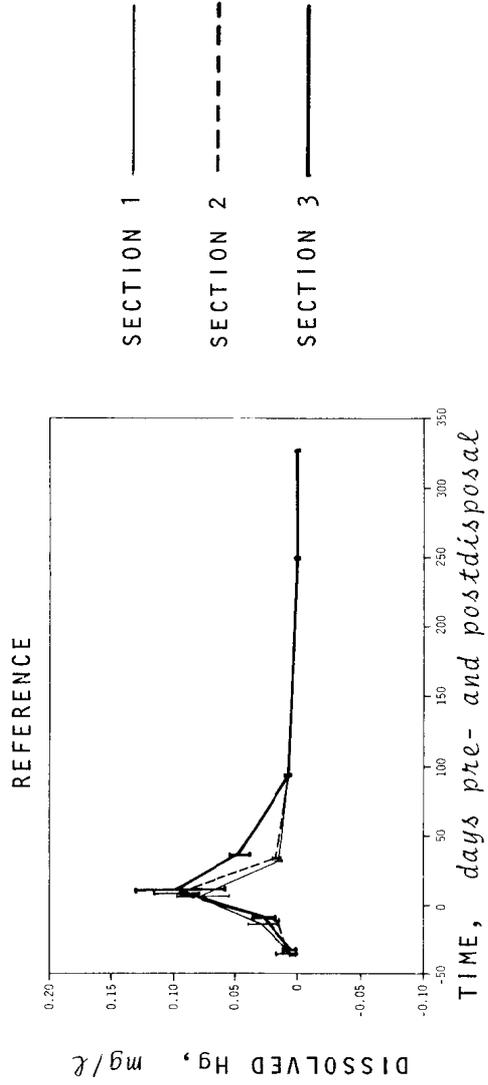
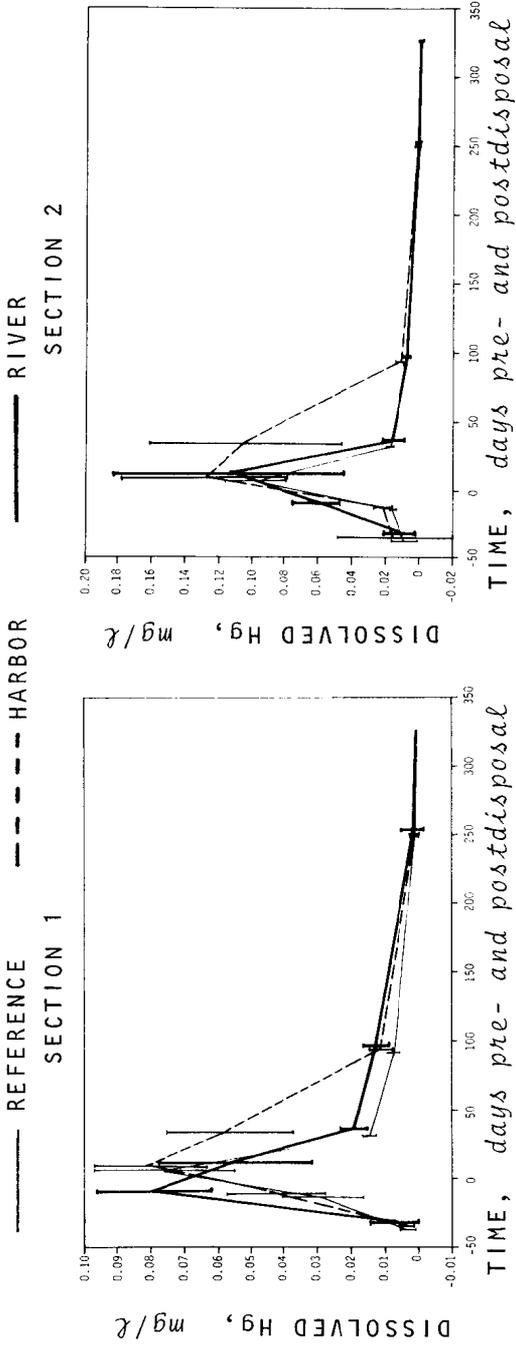
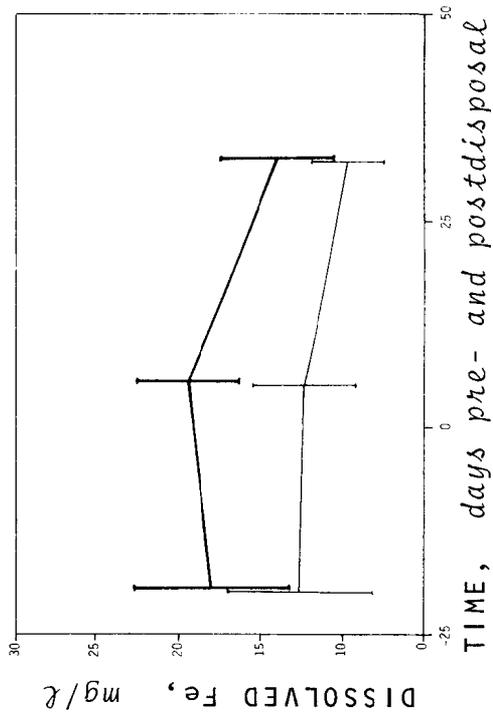


Figure 56. Mean and 95 percent confidence levels of mercury concentrations (mg/l) of interstitial water extracted from first and second sections of cores collected at the reference, harbor disposal and river disposal sites and first, second and third section interstitial water dissolved mercury from the reference site relative to time pre- and postdisposal 1975



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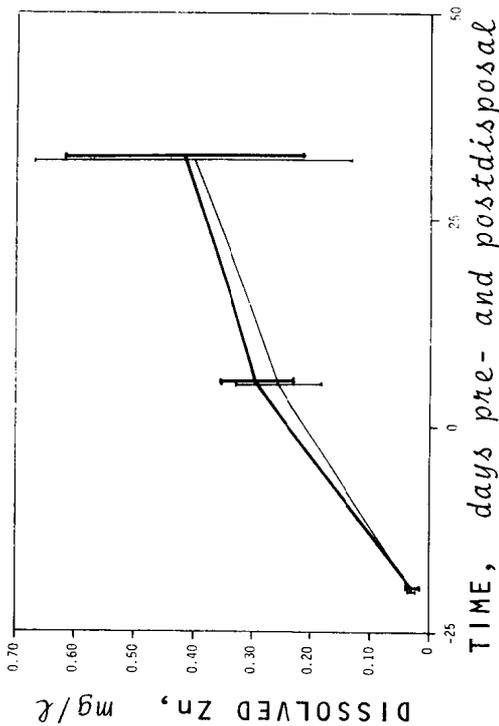
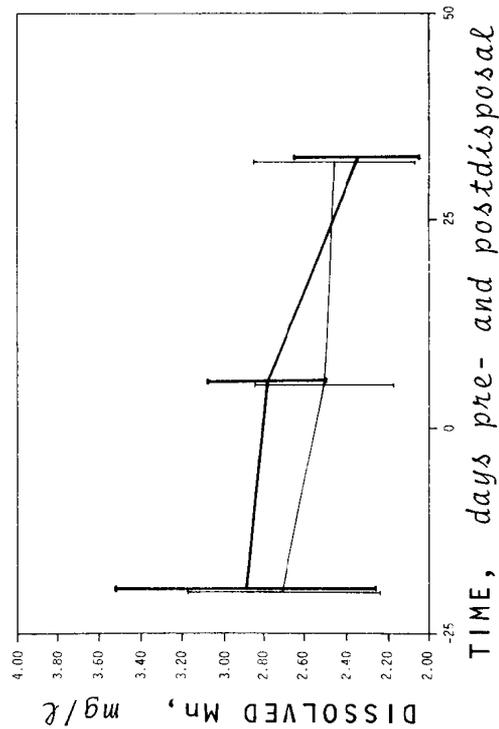


Figure 57. Mean and 95 percent confidence levels of dissolved iron, manganese and zinc concentrations (mg/l) of interstitial water extracted from first and second core sections collected at the reference site relative to time in days pre- and postdisposal 1976

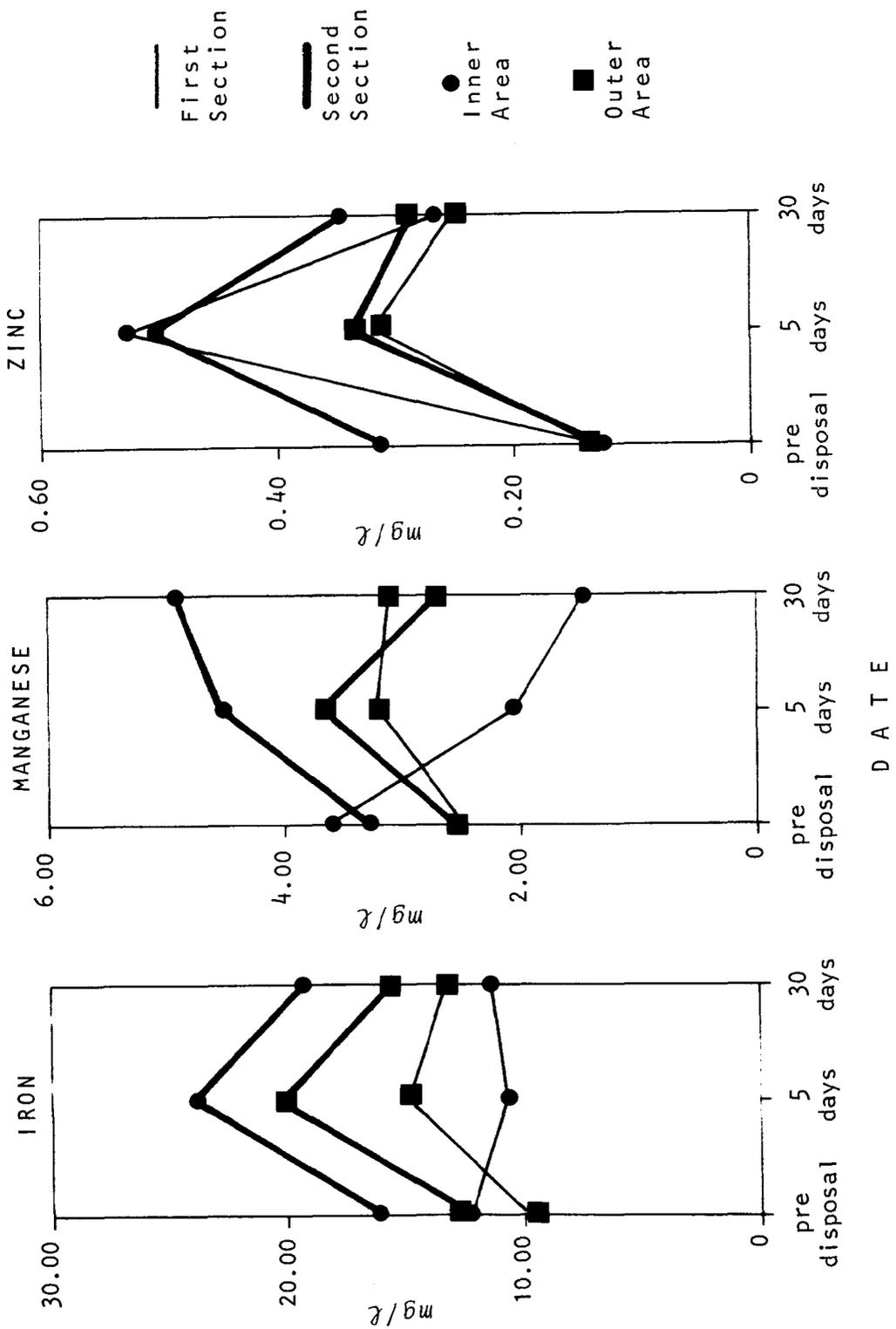


Figure 58. Comparison of mean dissolved iron, manganese and zinc concentrations (mg/L) by core section and area within the NDS site each relative to time in days pre- and postdisposal 1976

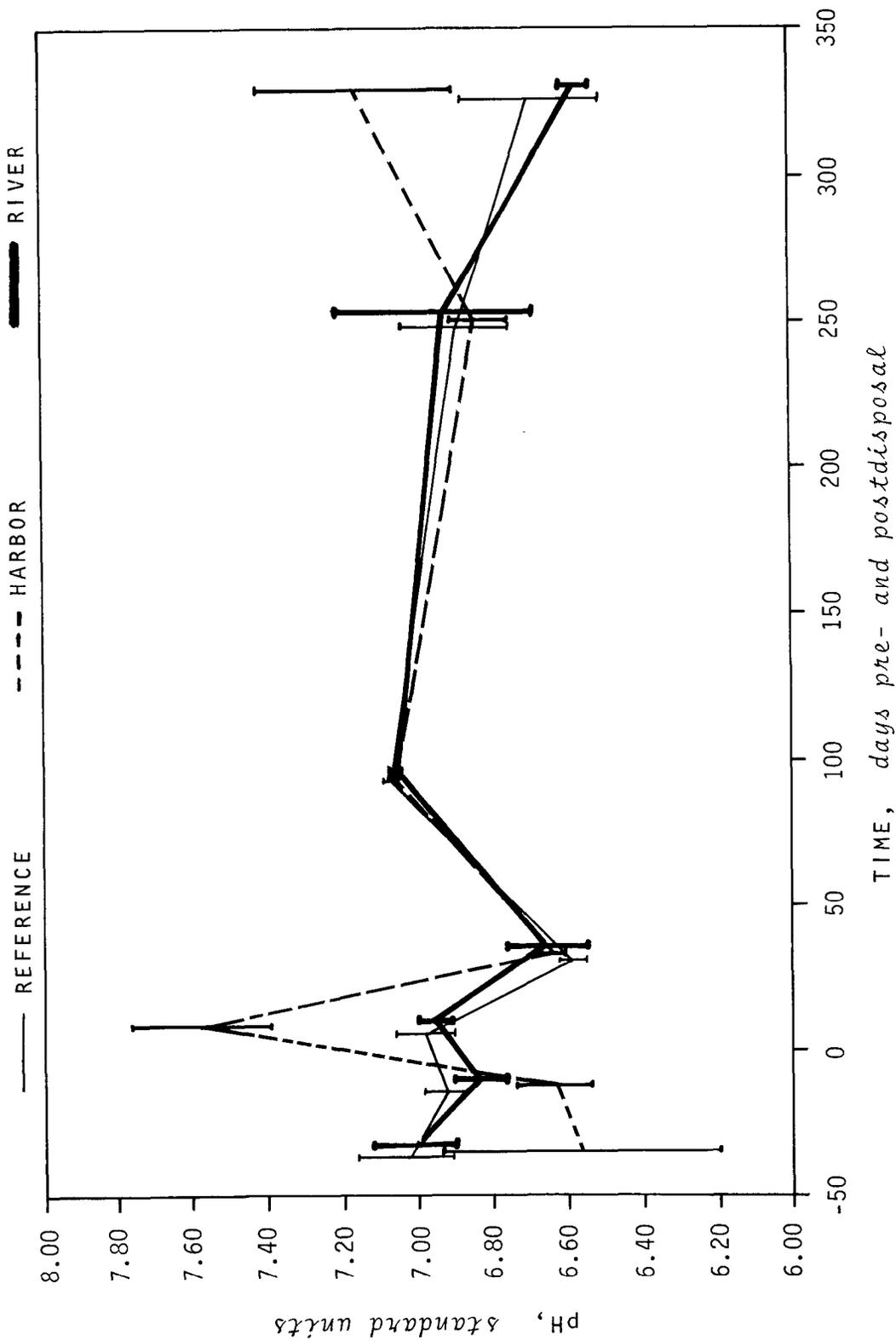


Figure 59. Mean and 95 percent confidence levels of pH (standard units) of first section sediment samples from the reference, harbor disposal and river disposal sites relative to time in days pre- and postdisposal 1975

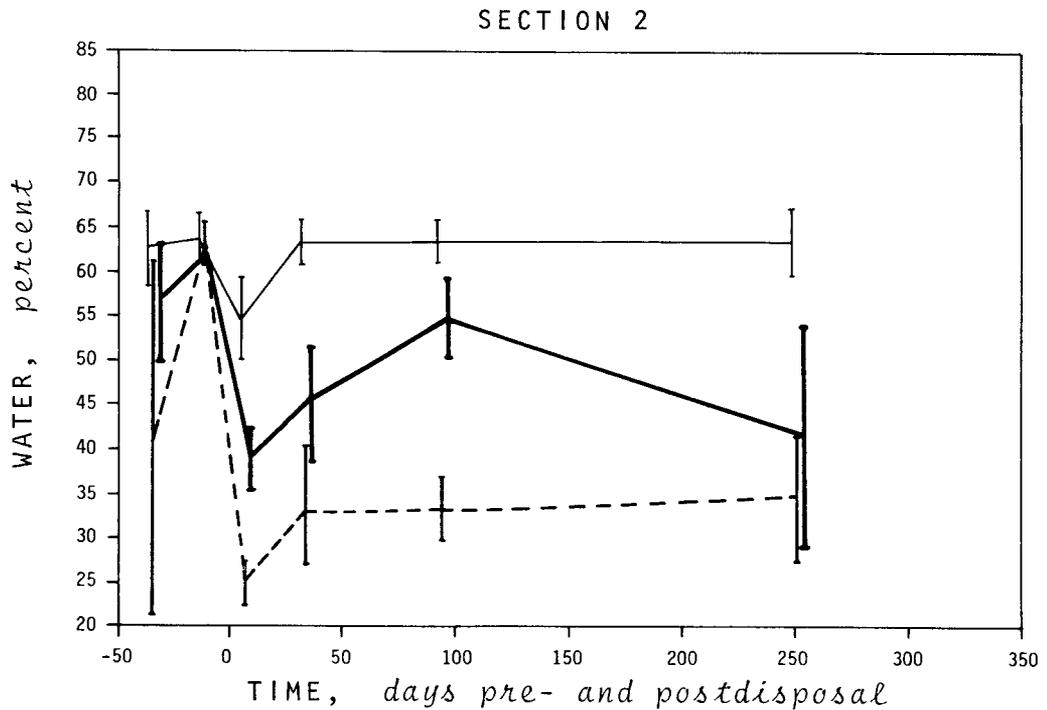
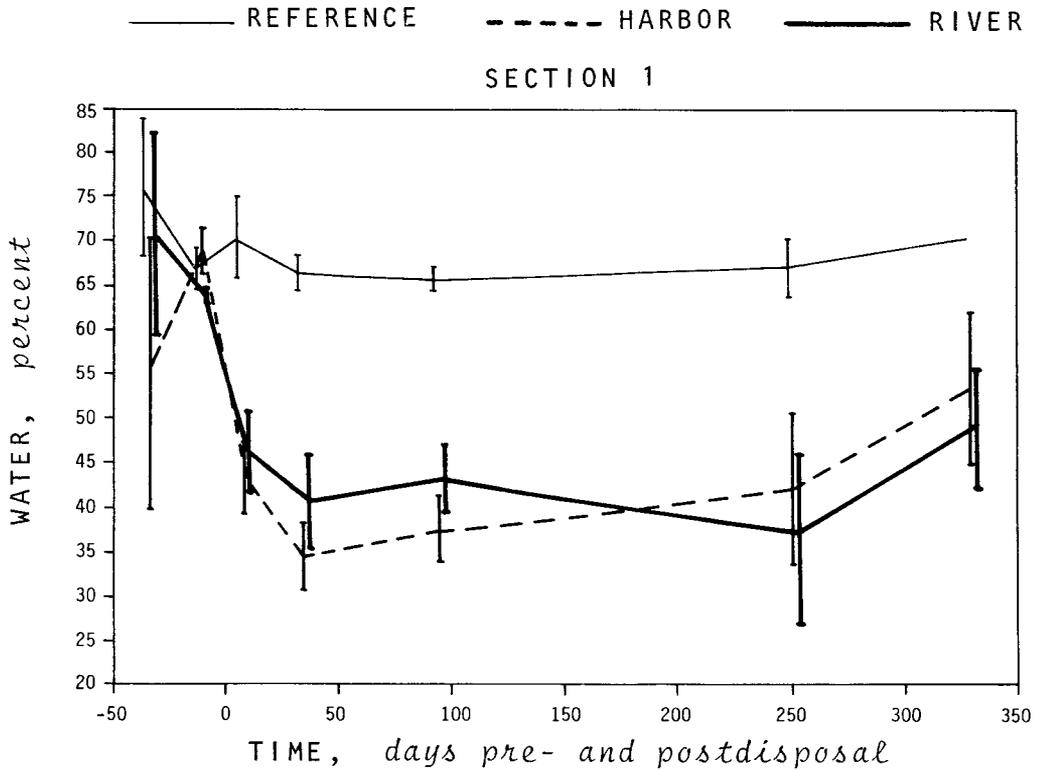


Figure 60. Mean and 95 percent confidence levels of percent water content of first and second section sediment samples from the reference, harbor disposal and river disposal sites relative to time in days pre- and postdisposal 1975

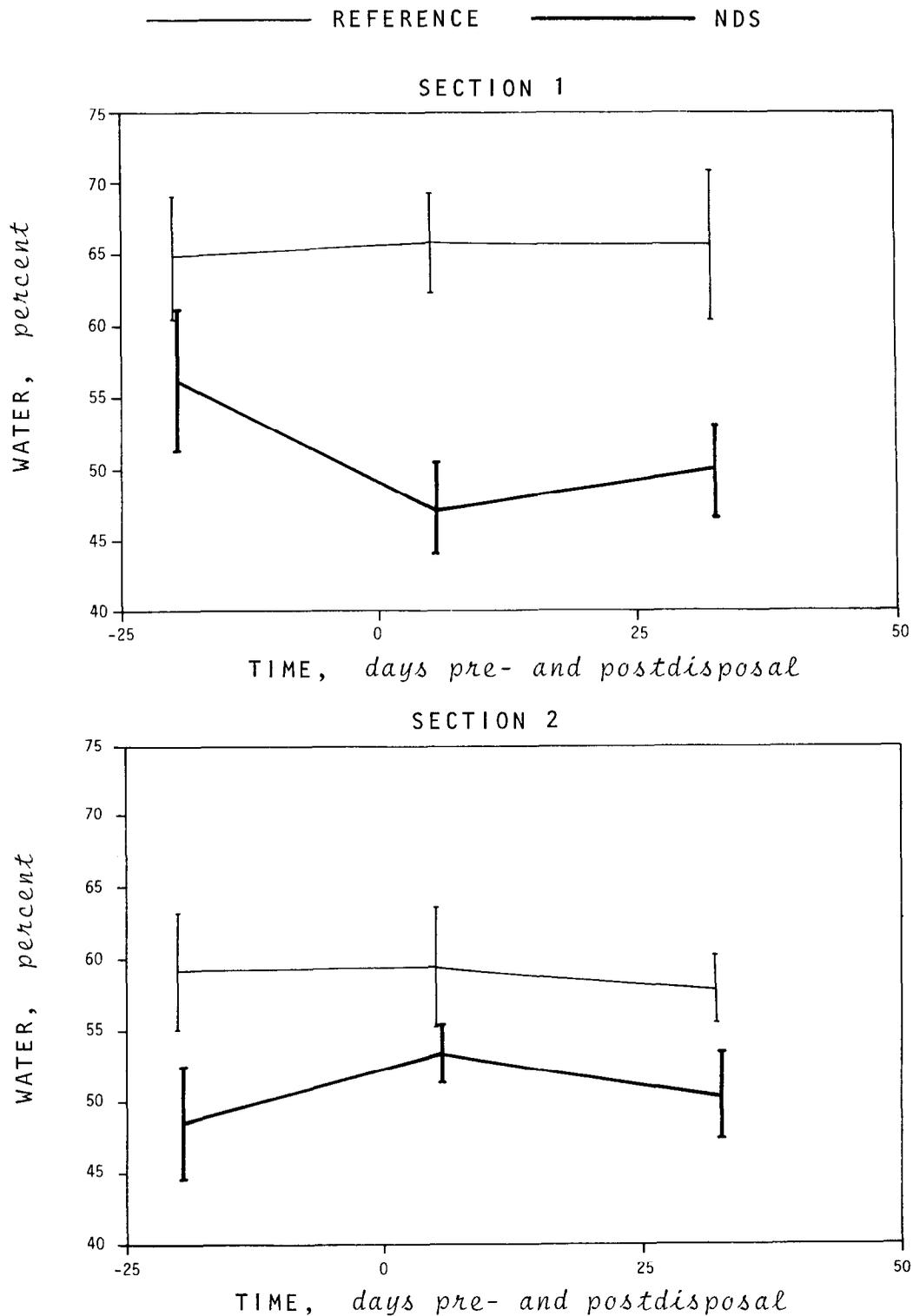


Figure 61. Mean and 95 percent confidence levels of percent water content of first and second section sediment samples from the reference site and NDS relative to time in days pre- and postdisposal 1976

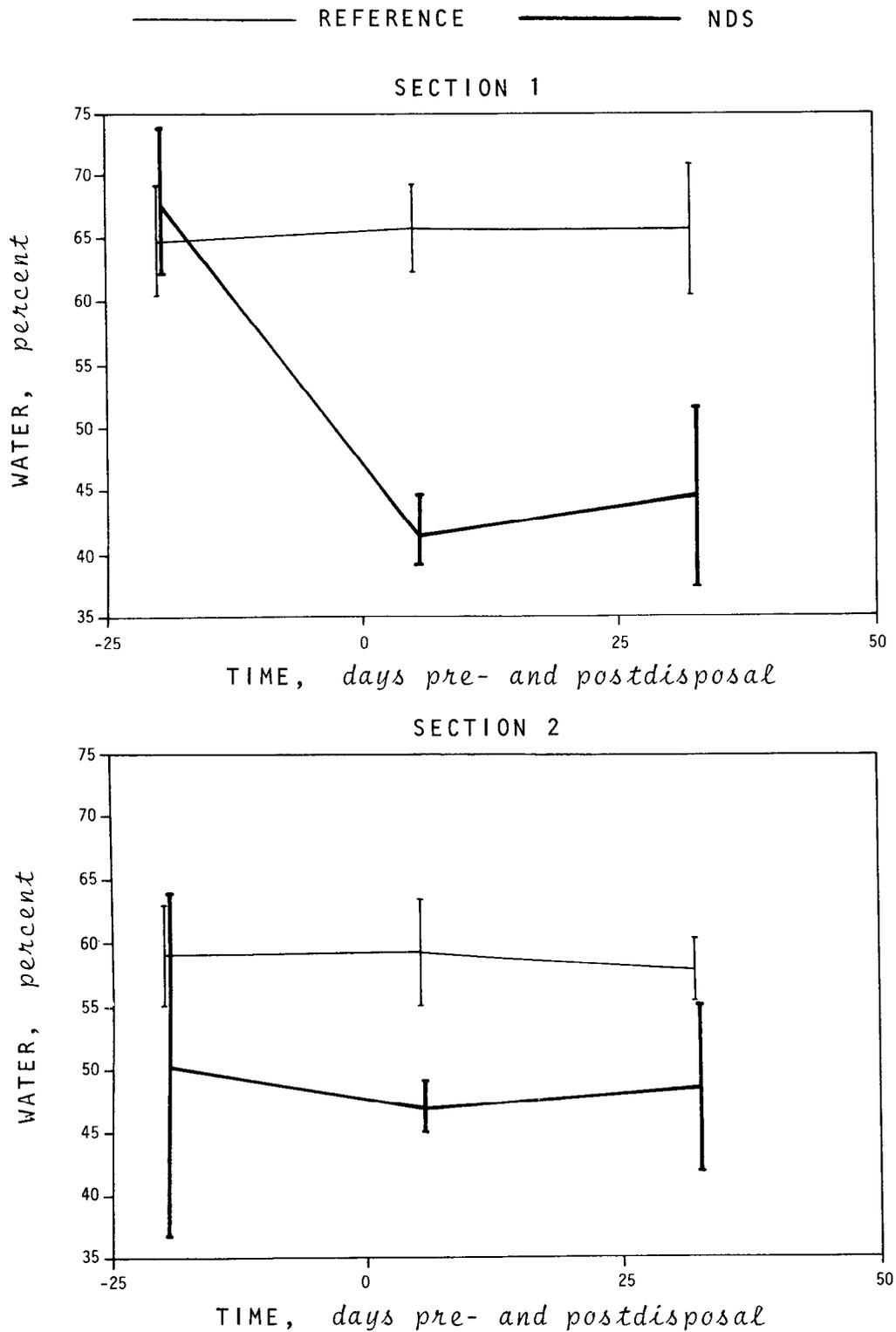


Figure 62. Mean and 95 percent confidence levels of percent water content of first and second section sediment samples from the reference site and NDS (central disposal stations only - SD6, SD7, SD10, SD11) relative to time in days pre- and postdisposal 1976

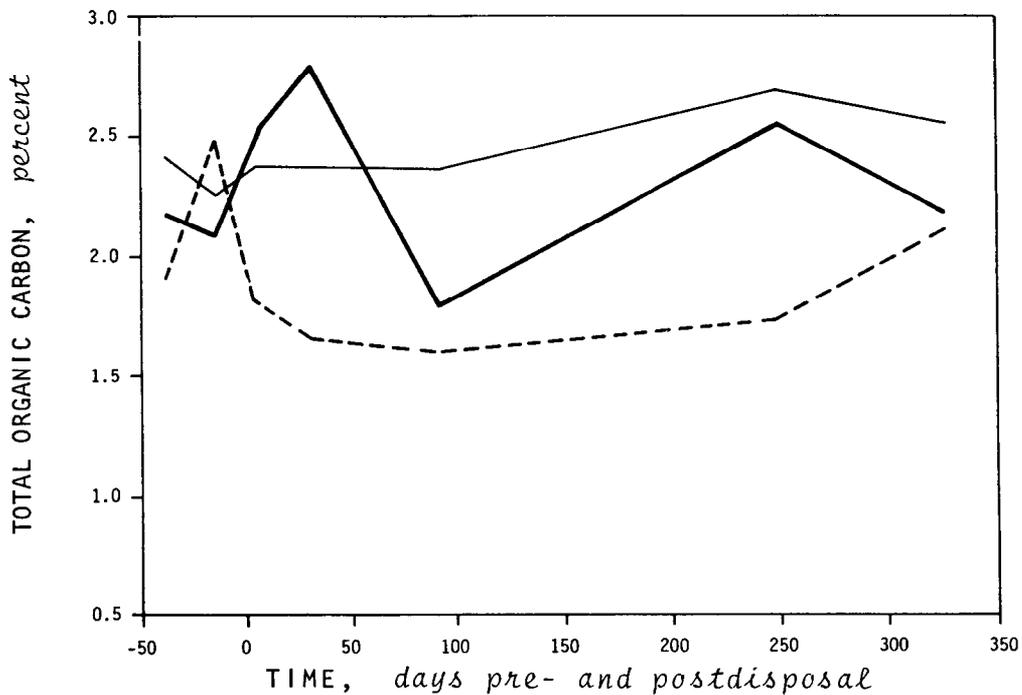
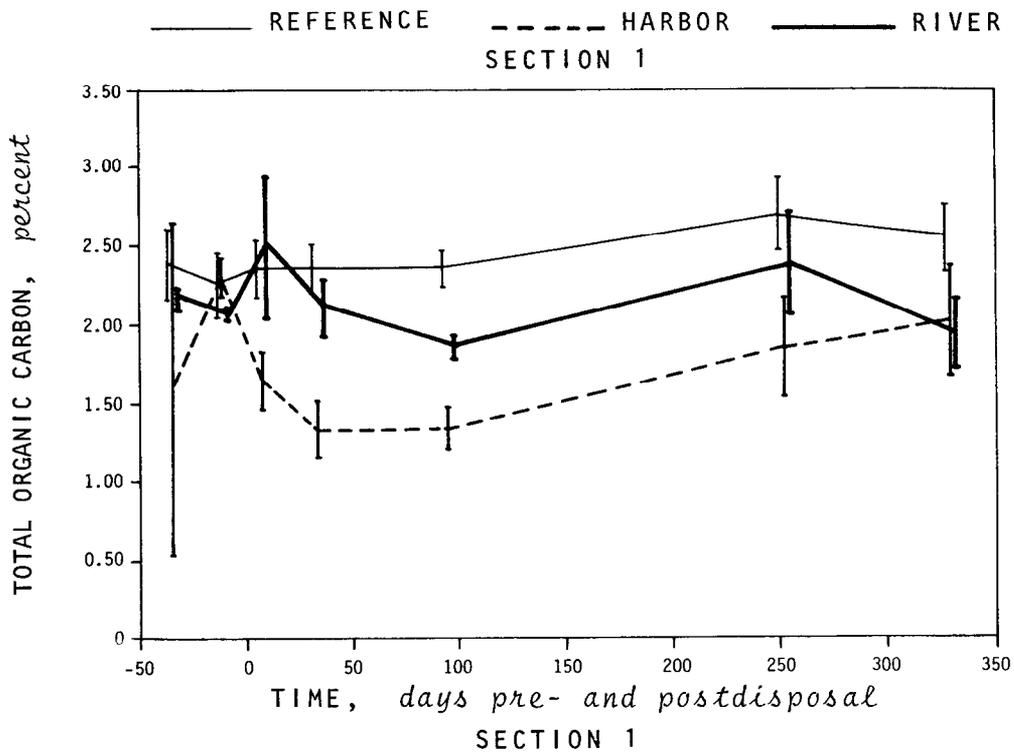


Figure 63. Mean and 95 percent confidence levels of total organic carbon content (percent) in first section sediment cores from the reference, harbor disposal and river disposal sites and mean total organic carbon content (percent) in first section sediments from the reference sites, station D2 and station D8 relative to time in days pre- and postdisposal 1975

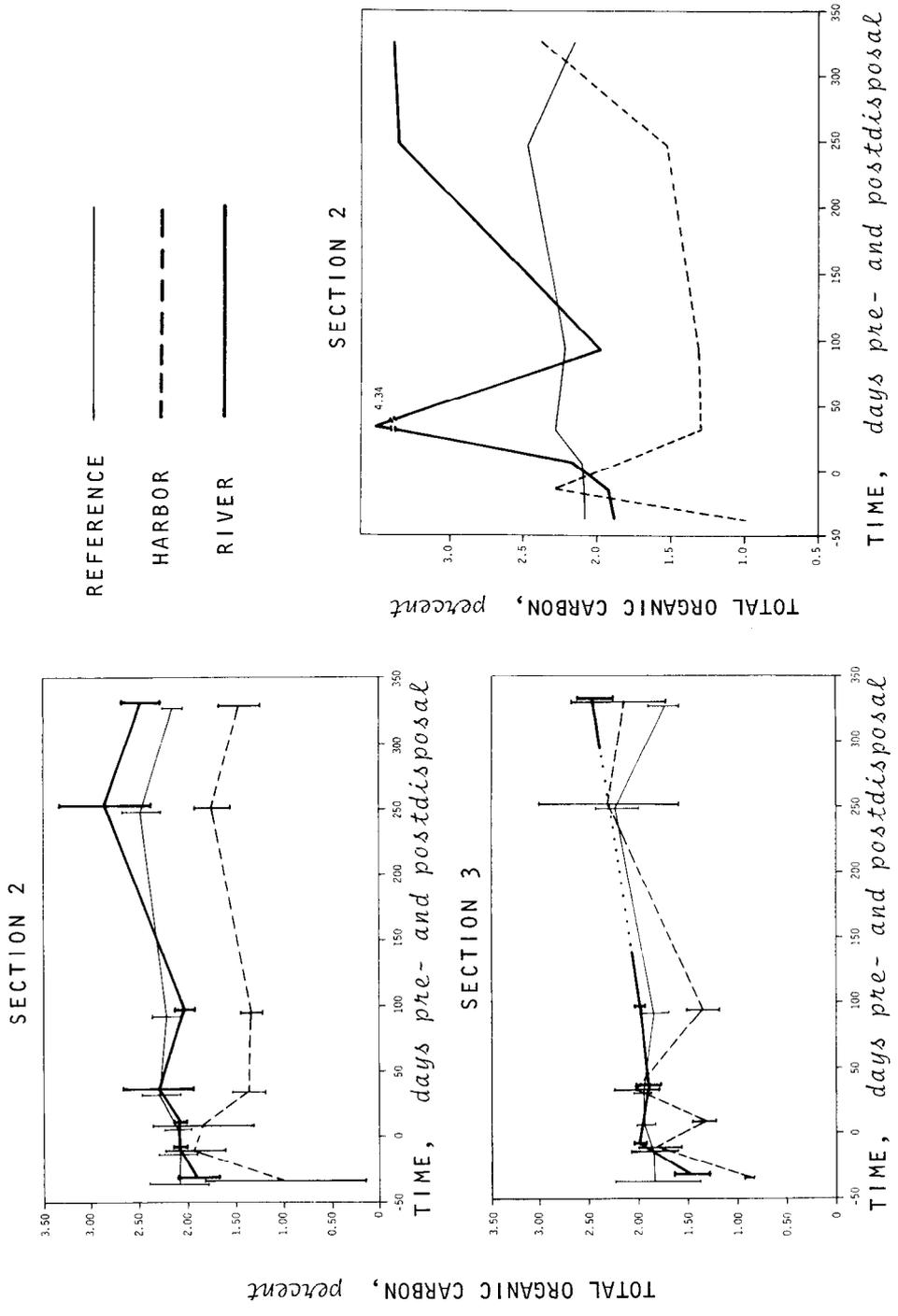
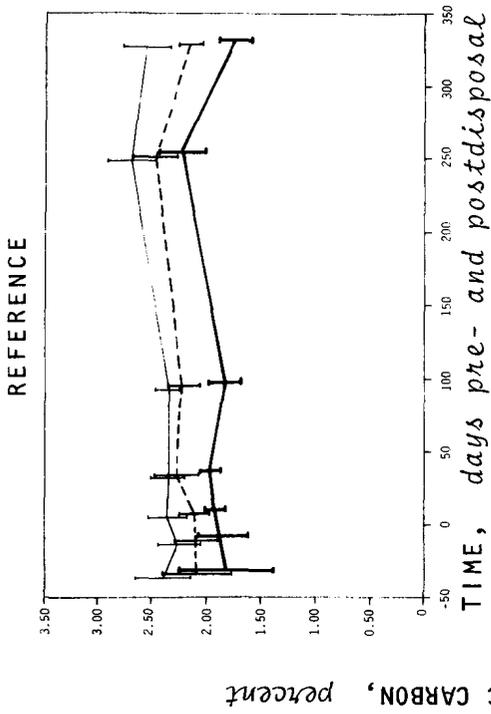


Figure 64. Mean and 95 percent confidence levels of total organic carbon (percent) content in second and third section sediment cores from the reference, harbor disposal and river disposal sites and mean total organic carbon (percent) content in second section sediment cores from the reference sites, station D2 and station D8 relative to time in days pre- and postdisposal 1975



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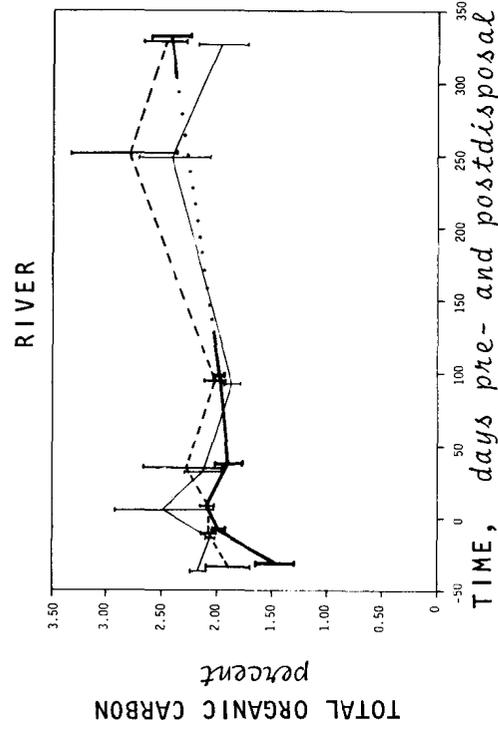
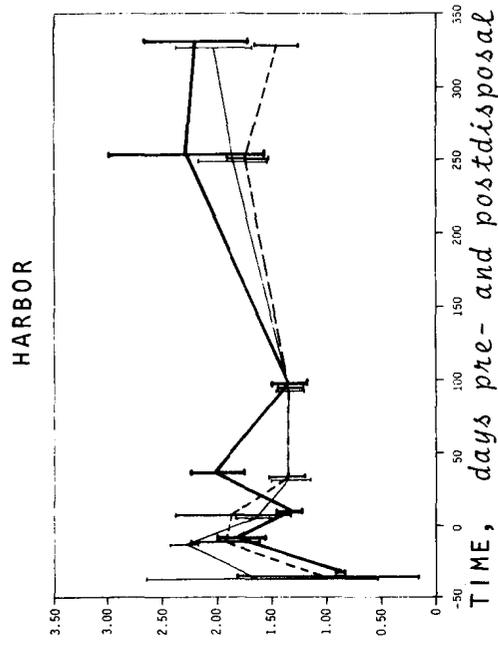


Figure 65. Mean and 95 percent confidence levels of total organic carbon content (percent) in first, second and third section sediment cores relative to time in days pre- and postdisposal 1975 for reference site, harbor disposal site and river disposal site stations

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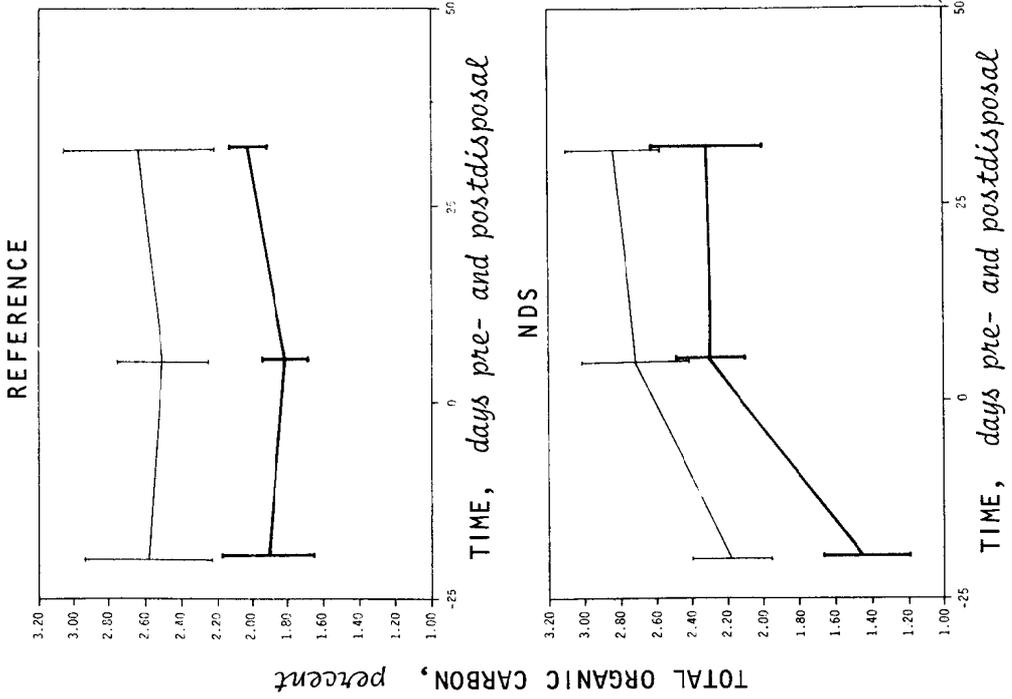


Figure 66. Mean and 95 percent confidence levels of total organic carbon (percent) from reference site and NDS sediments illustrated by core sections and collection sites relative to time in days pre- and postdisposal 1976

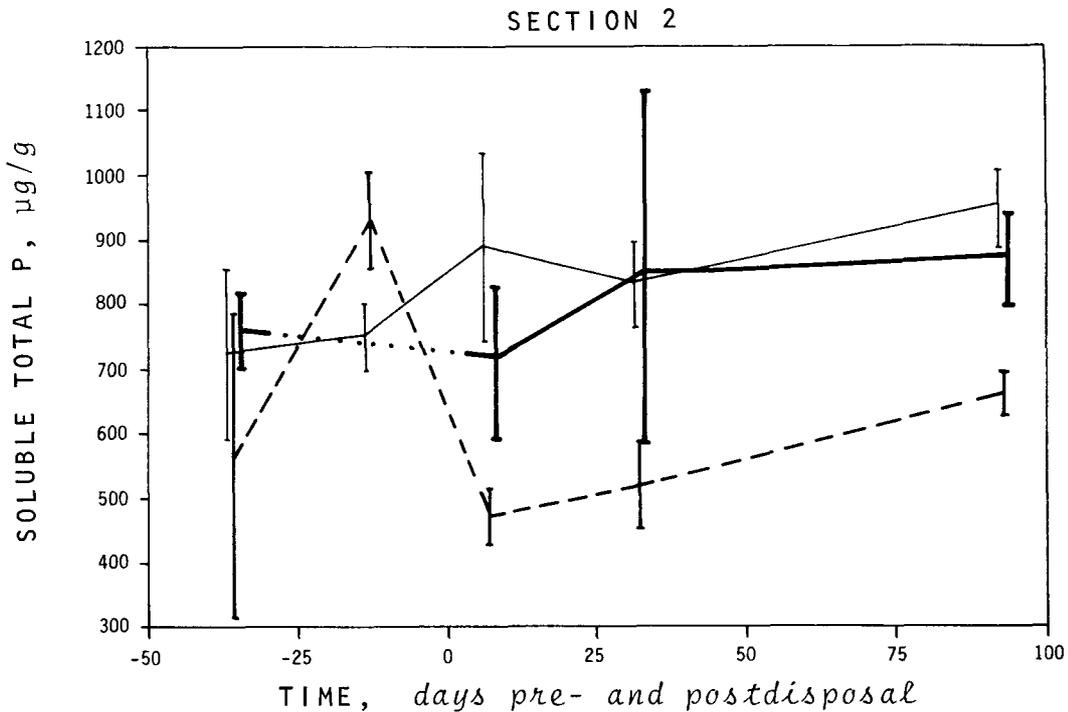
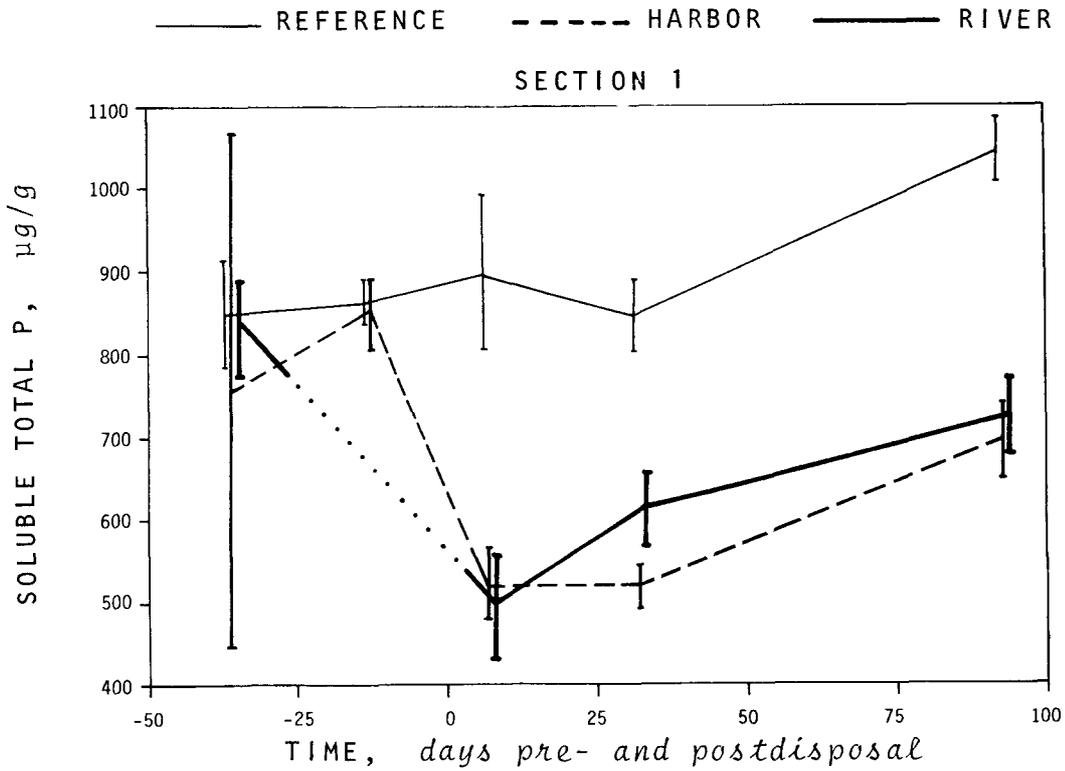


Figure 67. Mean and 95 percent confidence levels of total phosphorus concentrations ($\mu\text{g/g}$, dry weight basis) from first and second section core sediments for the reference site, harbor disposal and river disposal sites relative to time in days pre- and postdisposal 1975

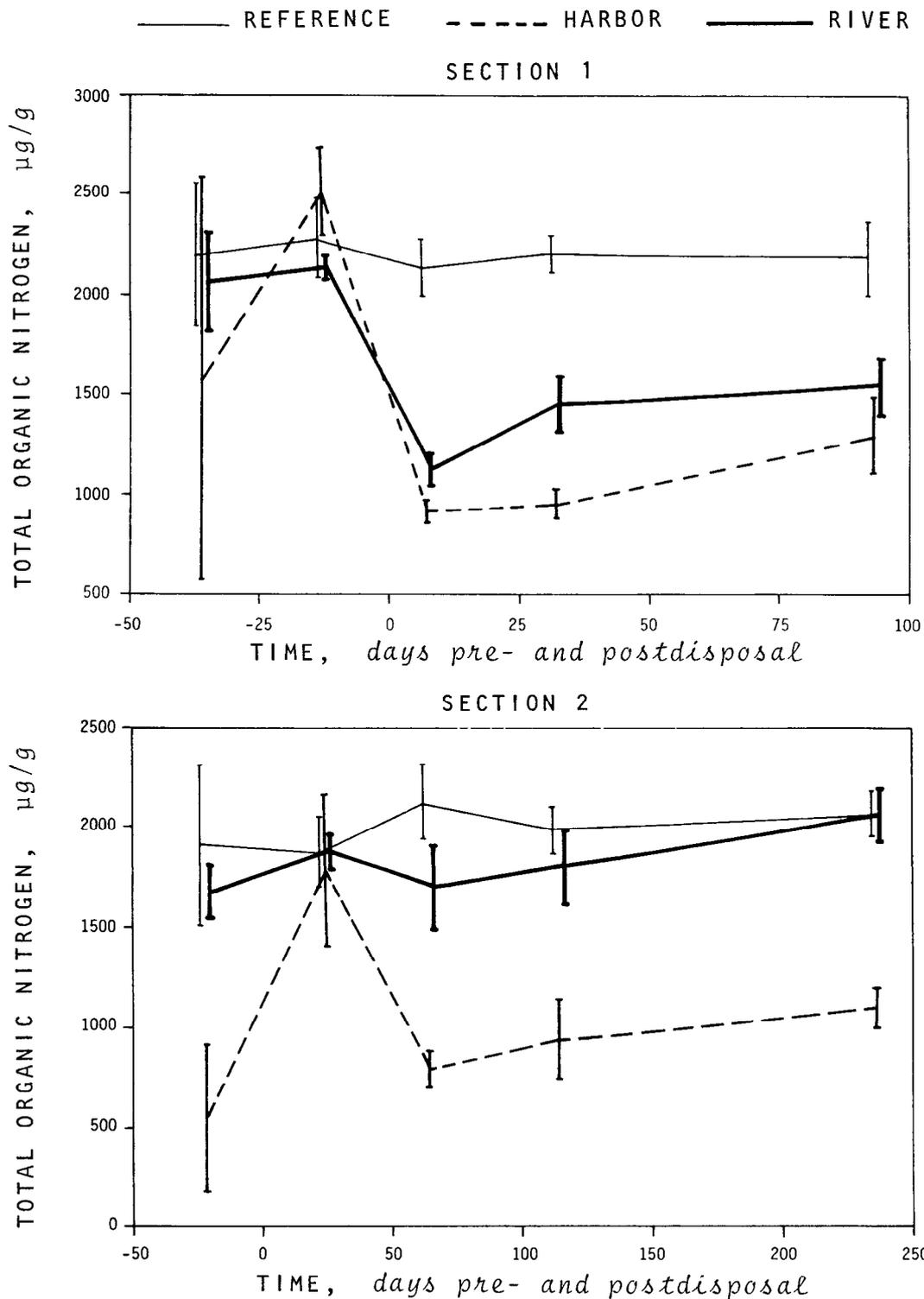


Figure 68. Mean and 95 percent confidence levels of total organic nitrogen concentrations ($\mu\text{g/g}$, dry weight basis) from first and second core sediments for the reference site, harbor disposal and river disposal sites relative to time in days pre- and postdisposal 1976

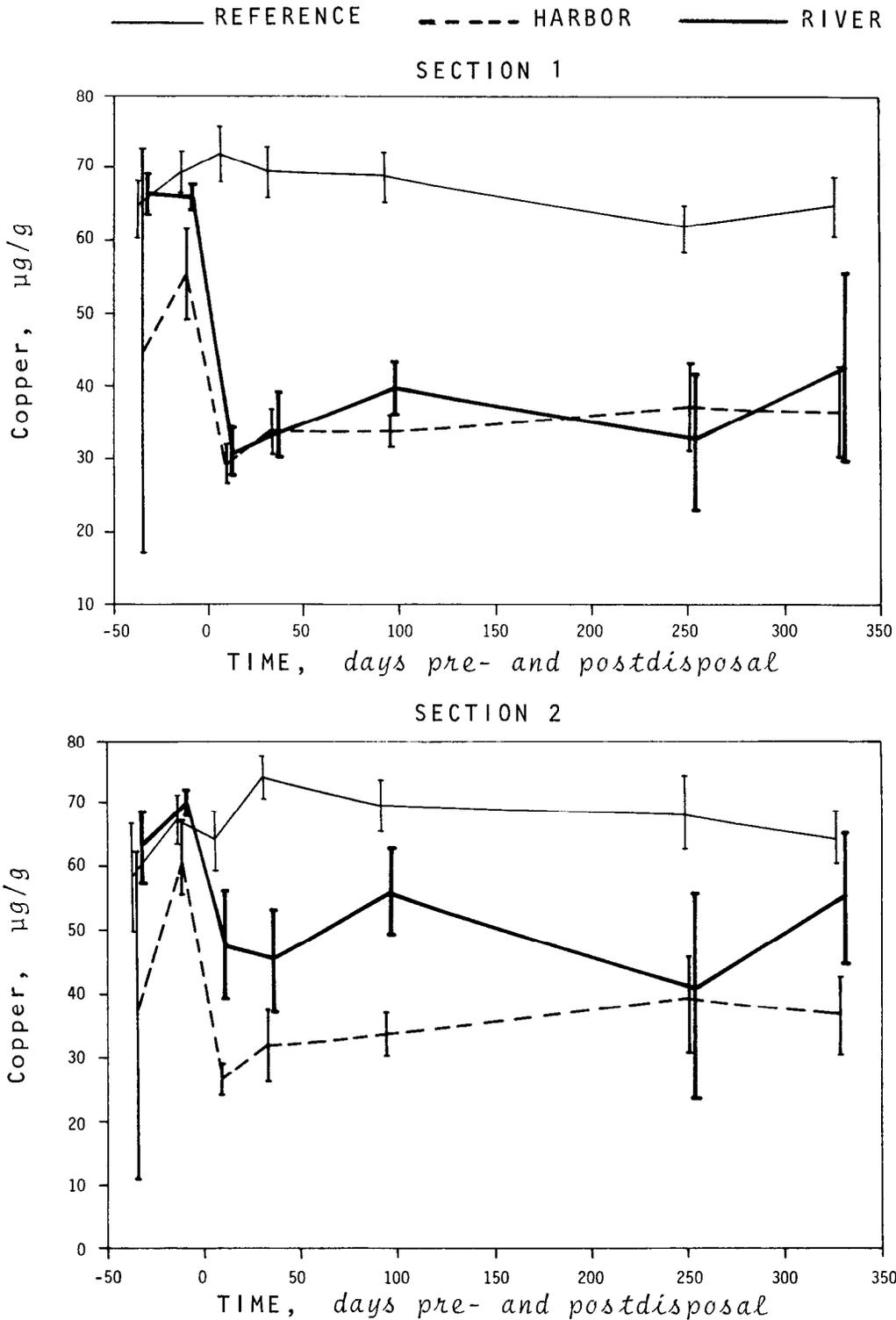
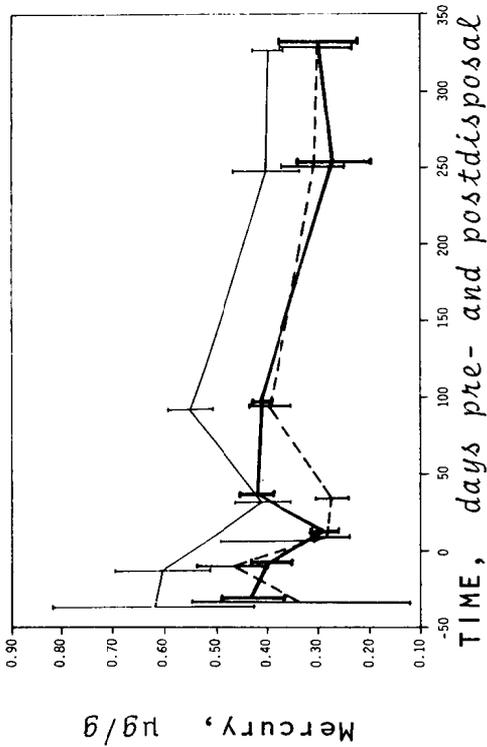
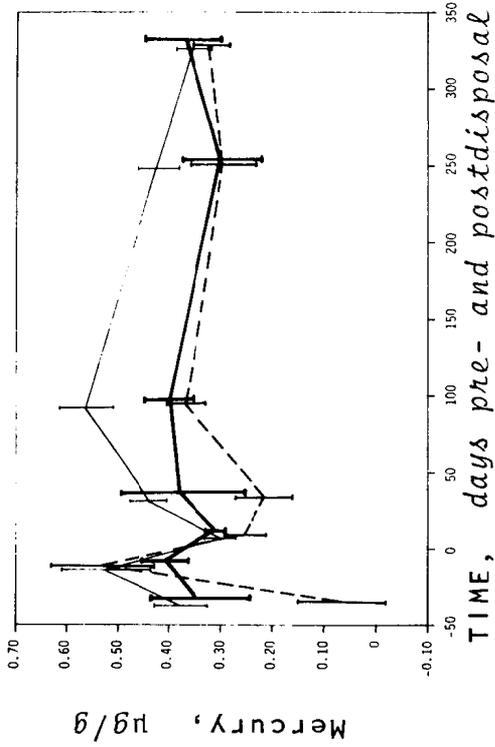


Figure 69. Mean and 95 percent confidence levels of copper concentrations ($\mu\text{g/g}$, dry weight basis) from first and second section core sediments for the reference site, harbor disposal and river disposal sites relative to time in days pre- and postdisposal 1975

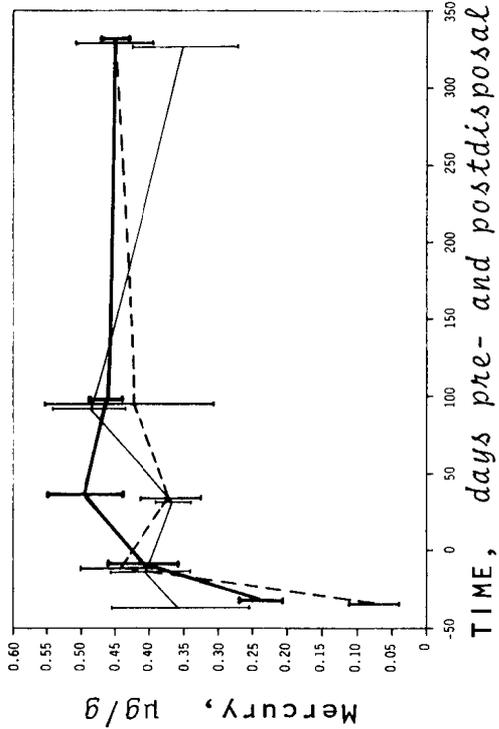
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SECTION 3

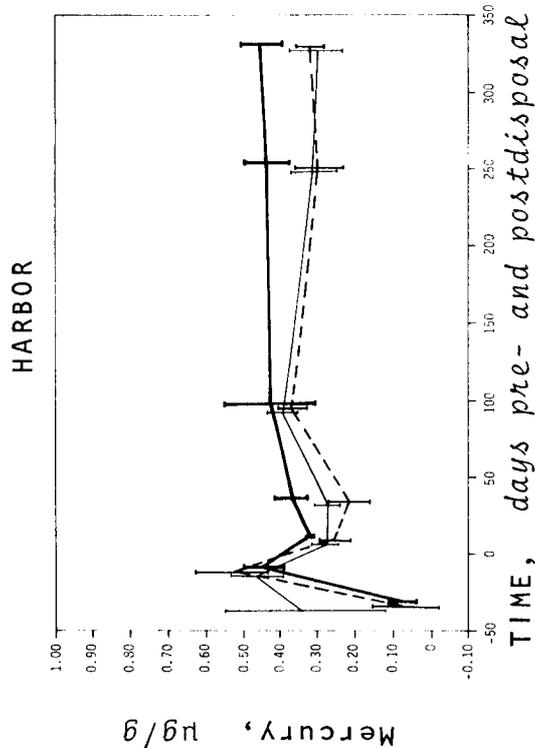
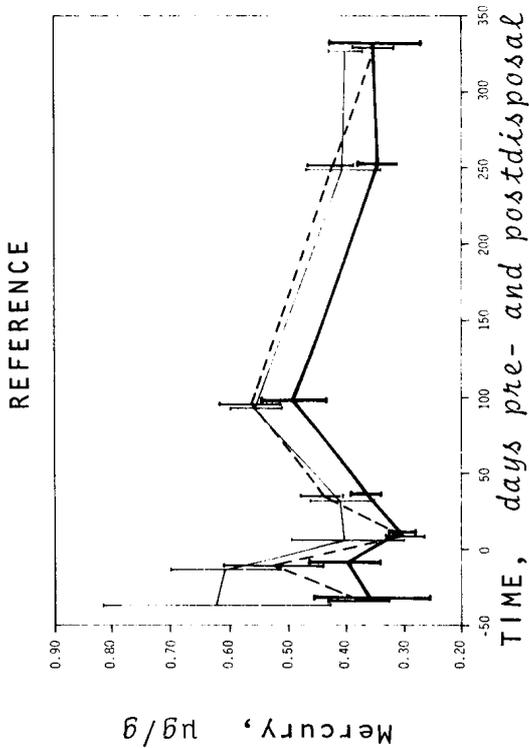


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Figure 70. Mean and 95 percent confidence levels of mercury concentrations ($\mu\text{g/g}$, dry weight basis) from first, second and third section core sediments for the reference site, harbor disposal and river disposal sites relative to time in days pre- and postdisposal 1975



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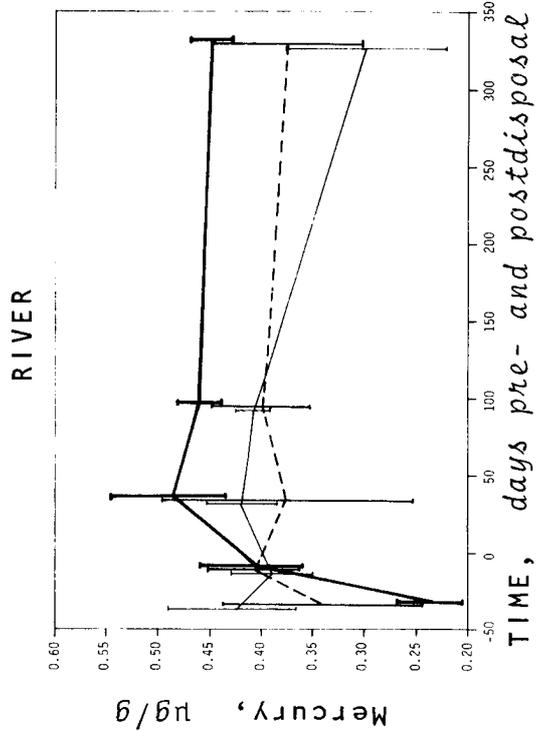


Figure 71. Mean and 95 percent confidence levels of mercury concentrations ($\mu\text{g/g}$, dry weight basis) from collections at the reference site, harbor disposal and river disposal sites from first, second and third section core sediments relative to time in days pre- and postdisposal 1975

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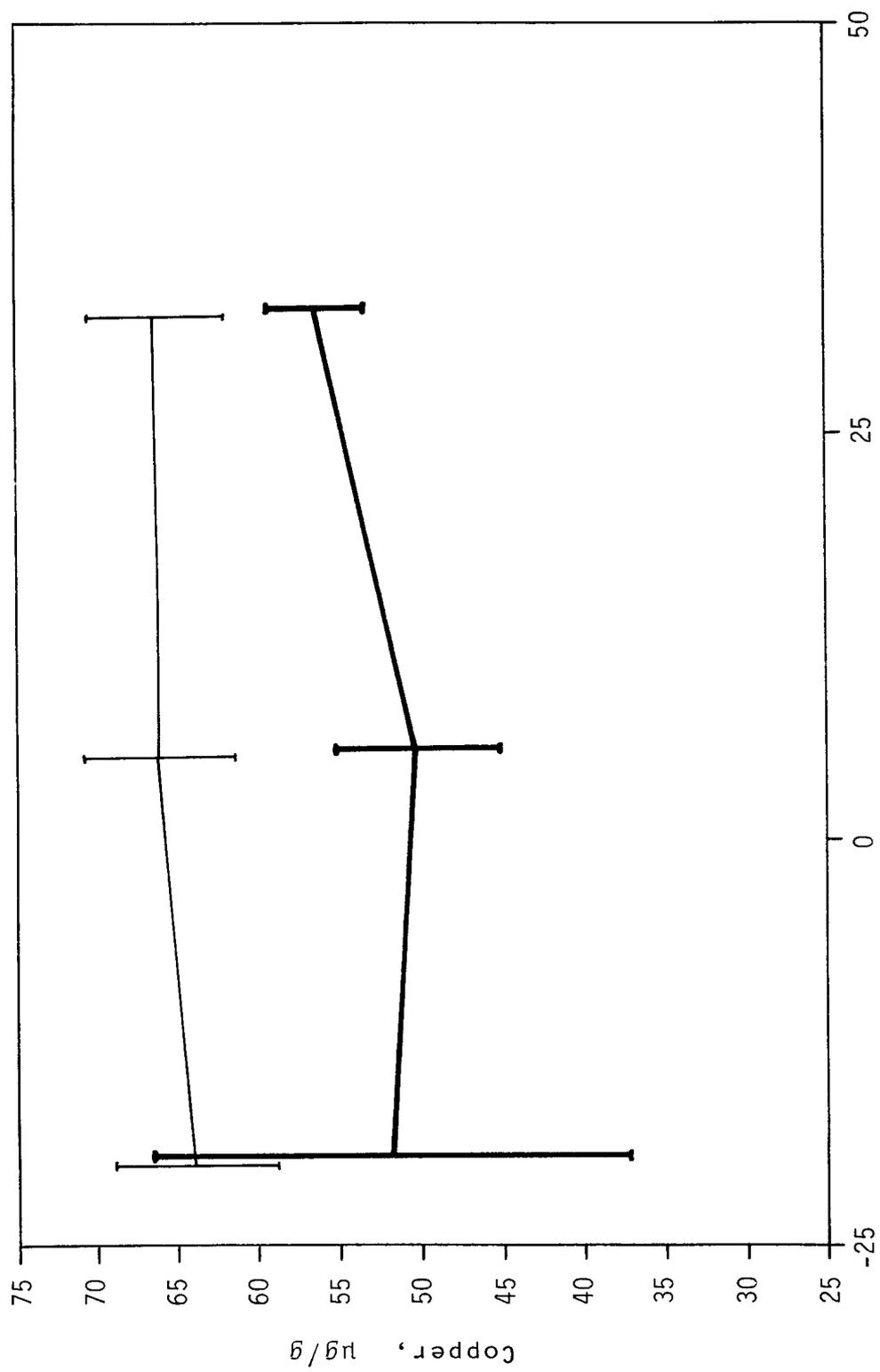


Figure 72. Mean and 95 percent confidence levels of copper concentrations ($\mu\text{g/g}$, dry weight basis) from the reference site for first and second section core sediments relative to time in days pre- and postdisposal 1976

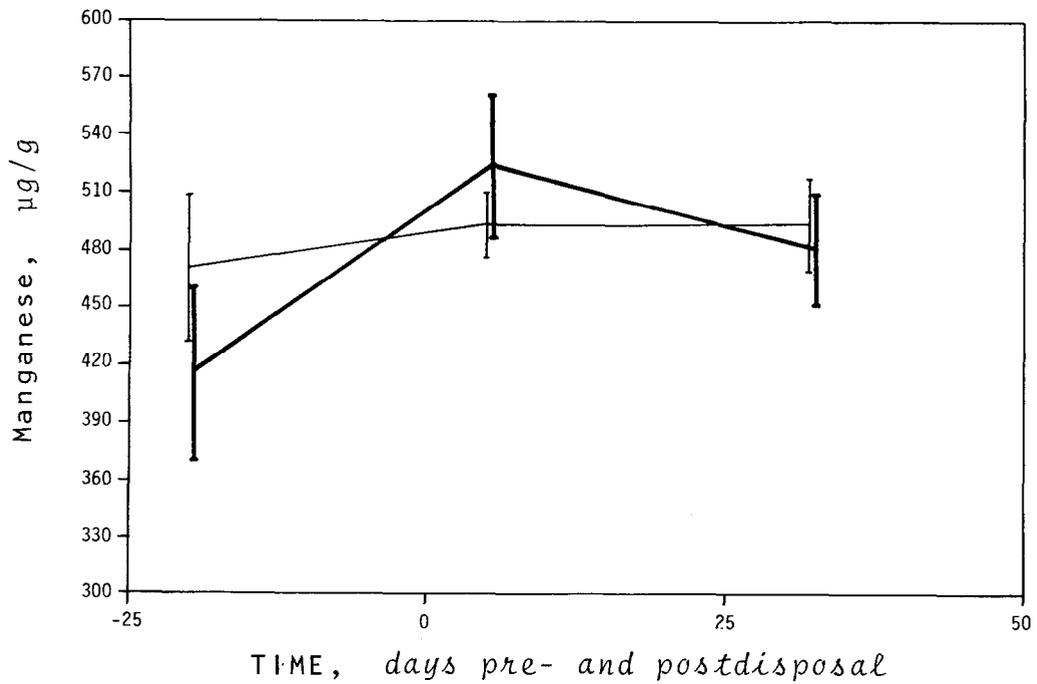
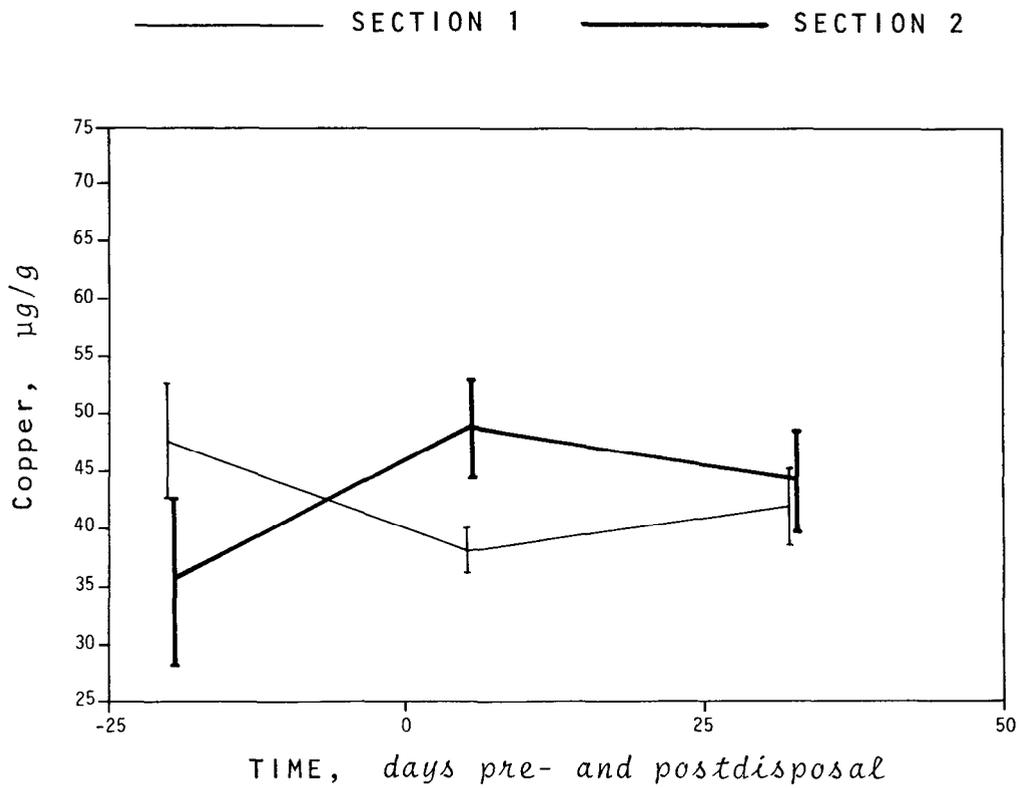
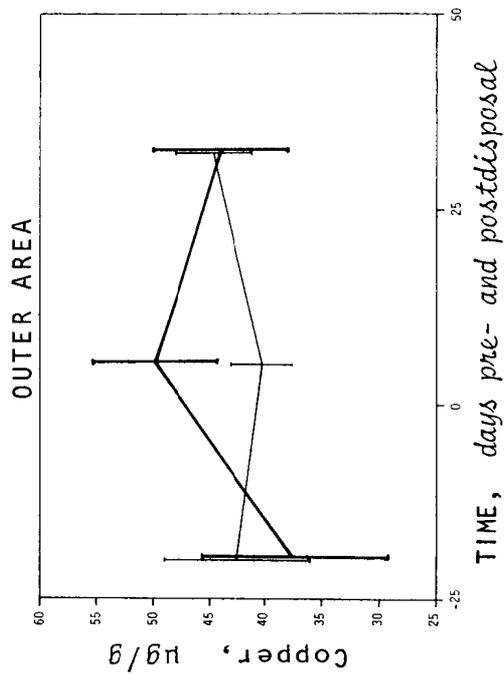
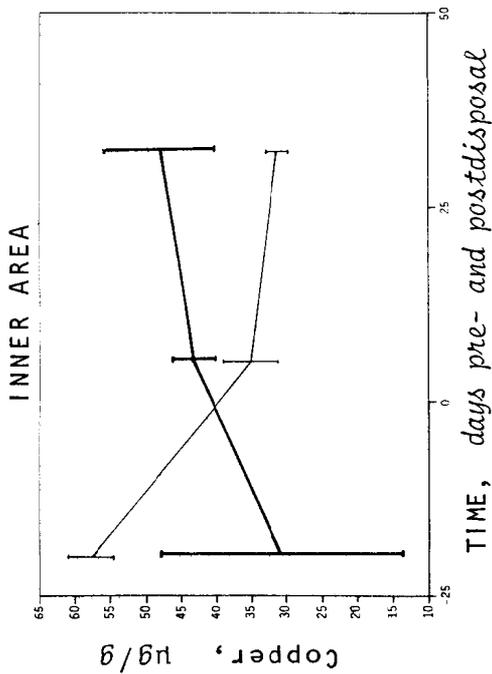


Figure 73. Mean and 95 percent confidence levels of copper concentrations ($\mu\text{g/g}$, dry weight basis) from NDS for first and second section core sediments relative to time in days pre- and postdisposal 1976

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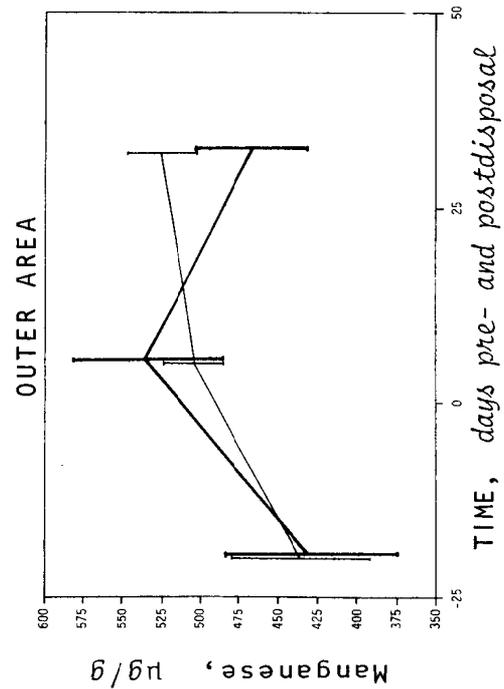
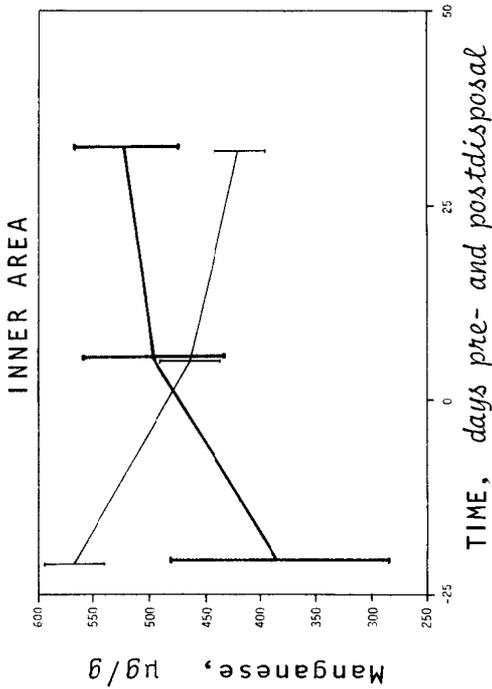


Figure 74. Mean and 95 percent confidence levels of copper and manganese concentrations ($\mu\text{g/g}$, dry weight basis) from first and second section core sediments from the inner and outer areas of the NDS site relative to time in days pre- and postdisposal 1976

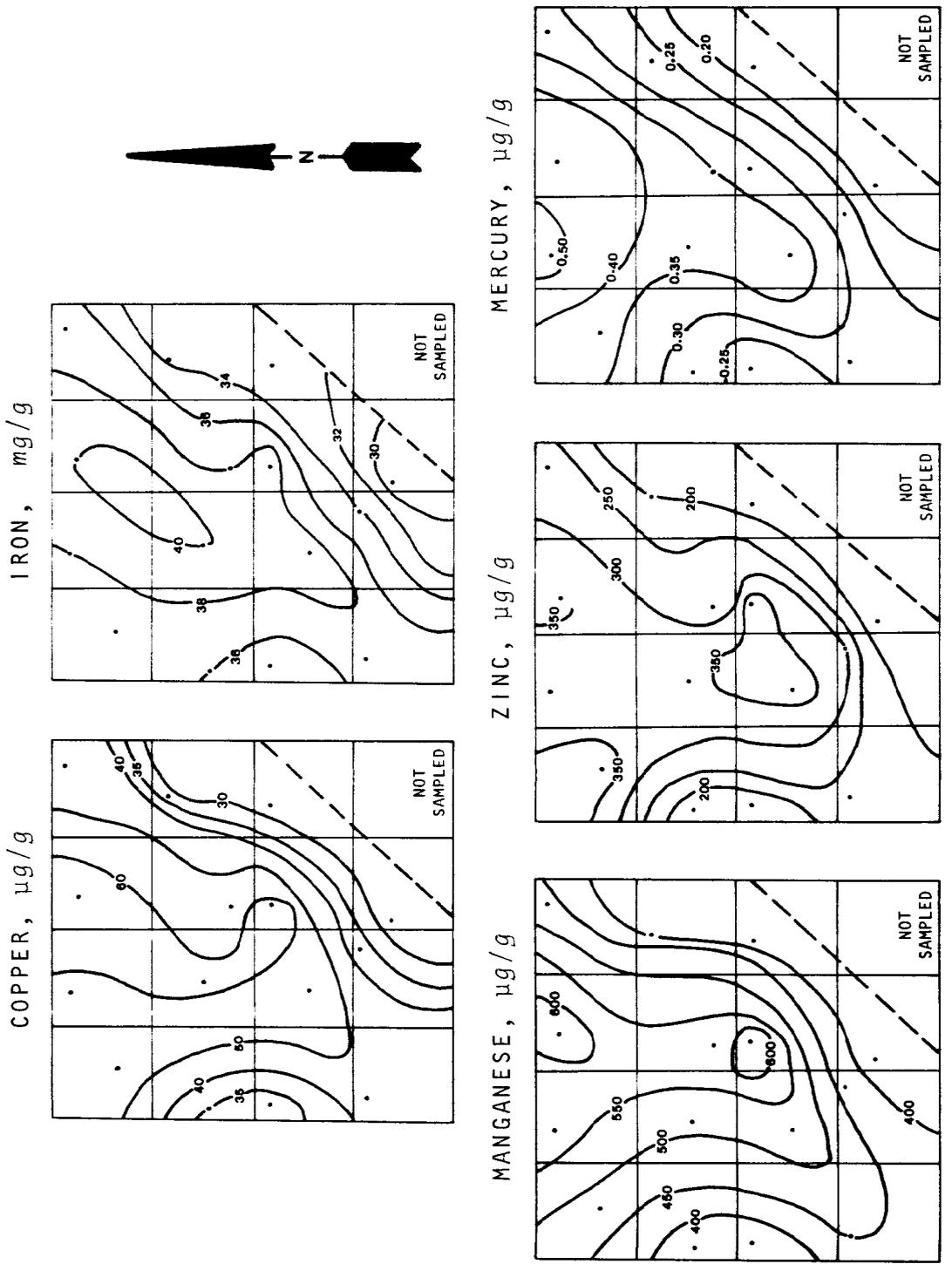


Figure 75. Copper, manganese, zinc, mercury ($\mu\text{g/g}$, dry weight basis) and iron (mg/g , dry weight basis) concentration isopleths for first section core sediments from the 1976 predisposal collections at NDS

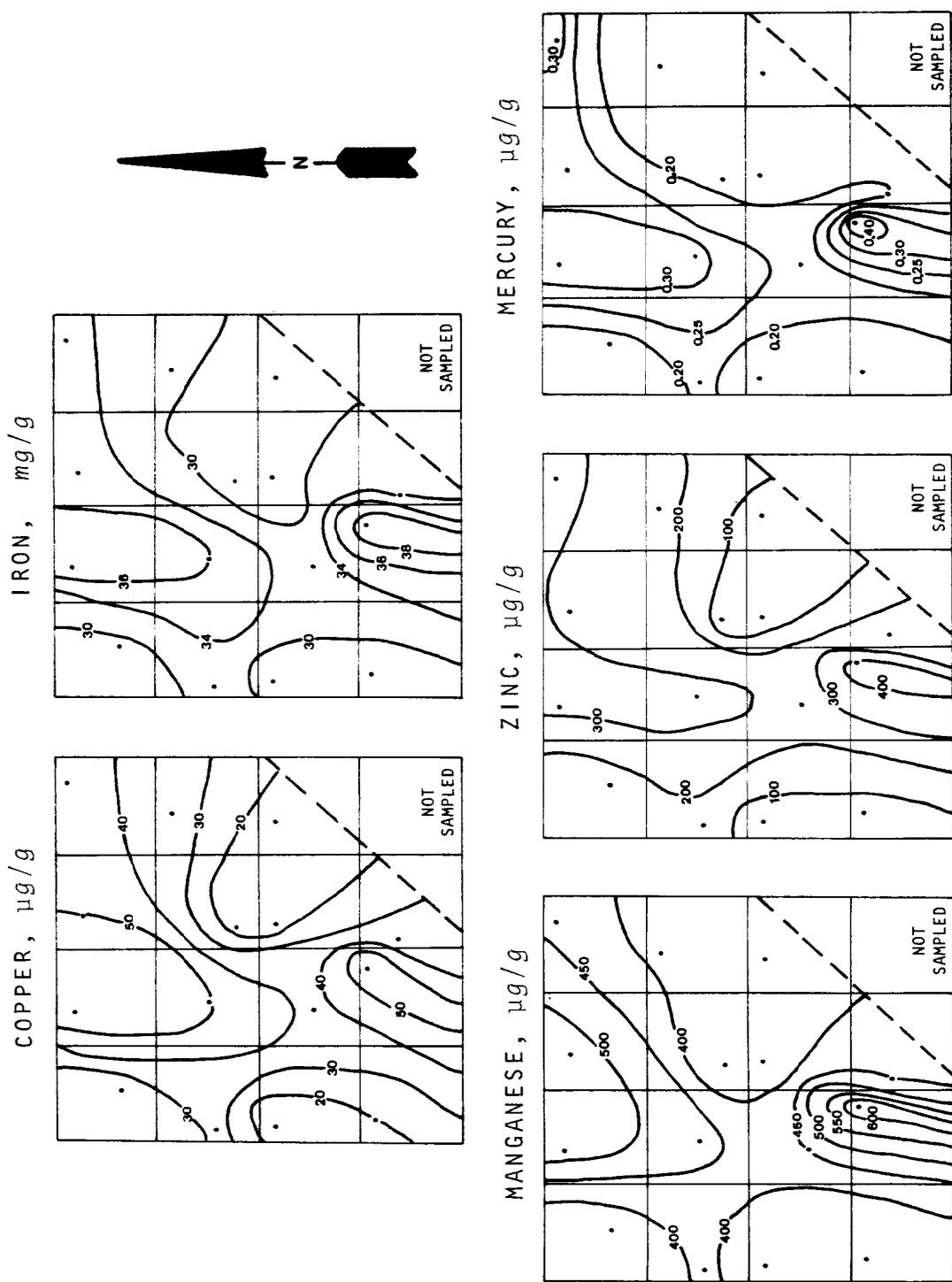


Figure 76. Copper, manganese, zinc, mercury ($\mu\text{g/g}$, dry weight basis) and iron (mg/g , dry weight basis) concentration isopleths for second section core sediments from the 1976 predisposal collections at NDS

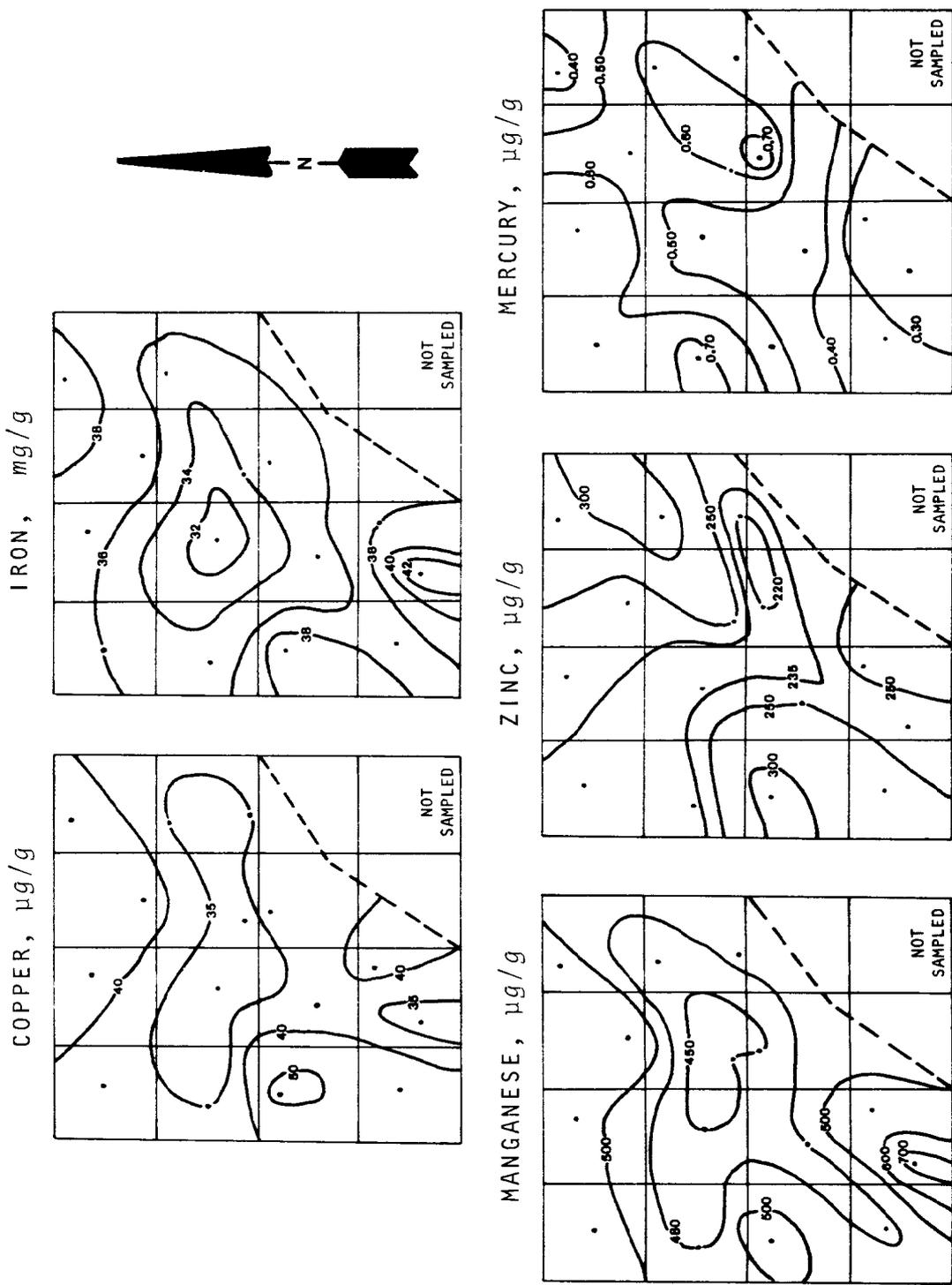


Figure 77. Copper, manganese, zinc, mercury ($\mu\text{g/g}$, dry weight basis) and iron (mg/g , dry weight basis) concentration isopleths for first section core sediments from the 1976 5-day postdisposal collections at NDS

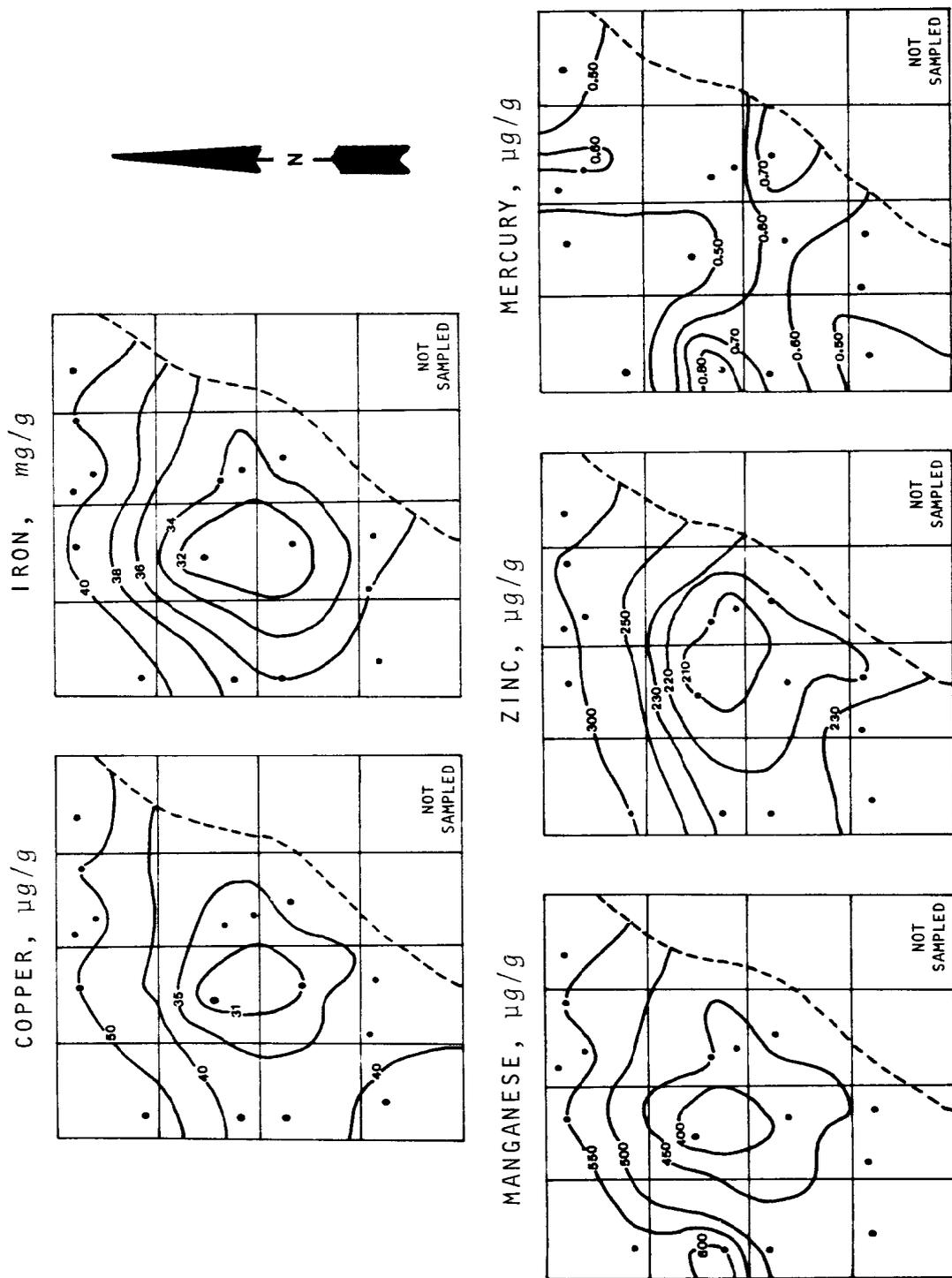


Figure 78. Copper, manganese, zinc, mercury ($\mu\text{g/g}$, dry weight basis) and iron (mg/g , dry weight basis) concentration isopleths for first section core sediments from the 1976 30-day postdisposal collections at NDS

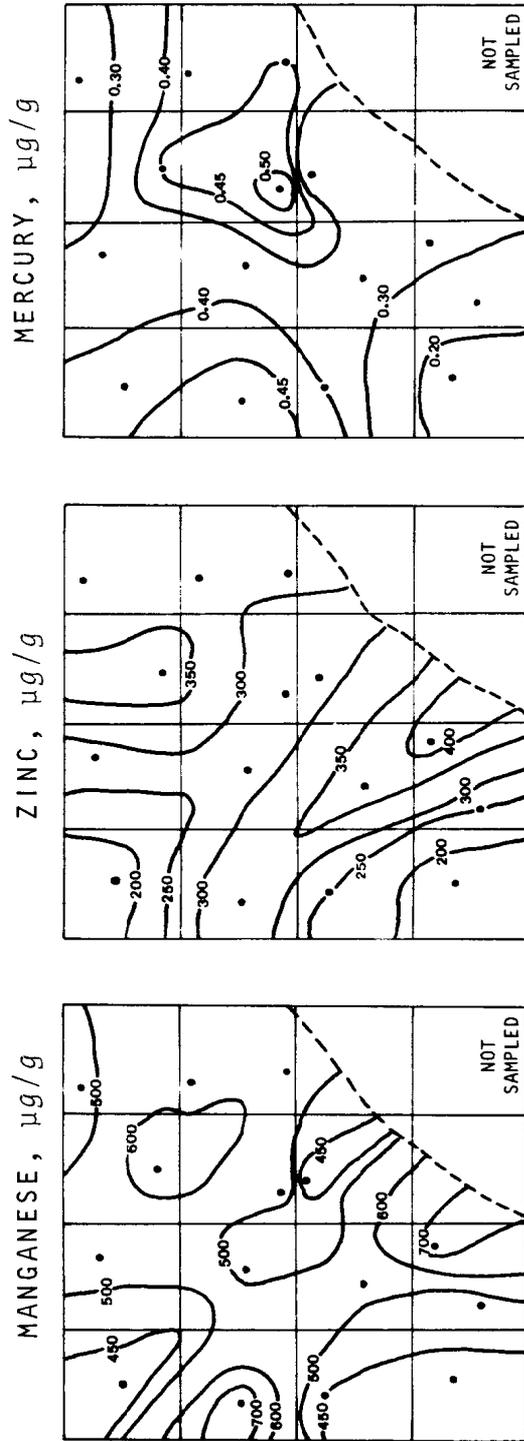
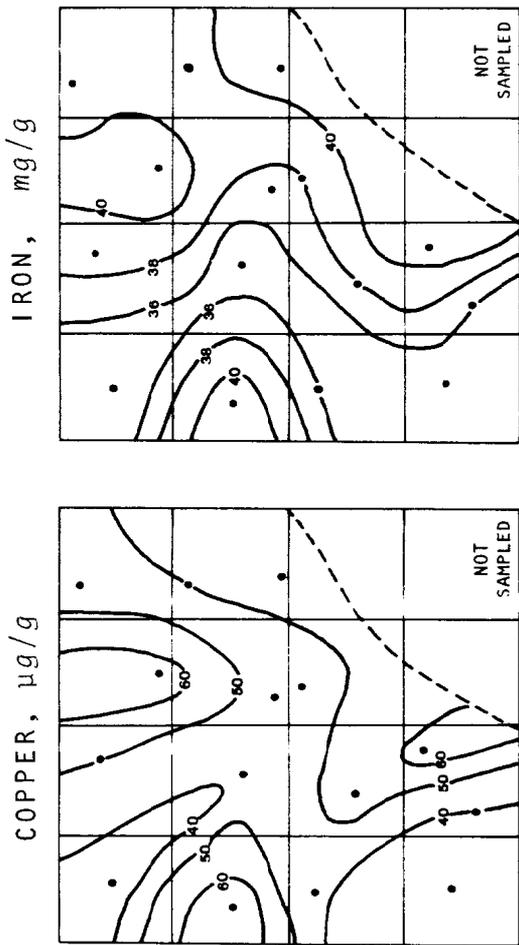


Figure 79. Copper, manganese, zinc, mercury ($\mu\text{g/g}$, dry weight basis) and iron (mg/g , dry weight basis) concentration isopleths for second section core sediments from the 1976 5-day postdisposal collections at NDS

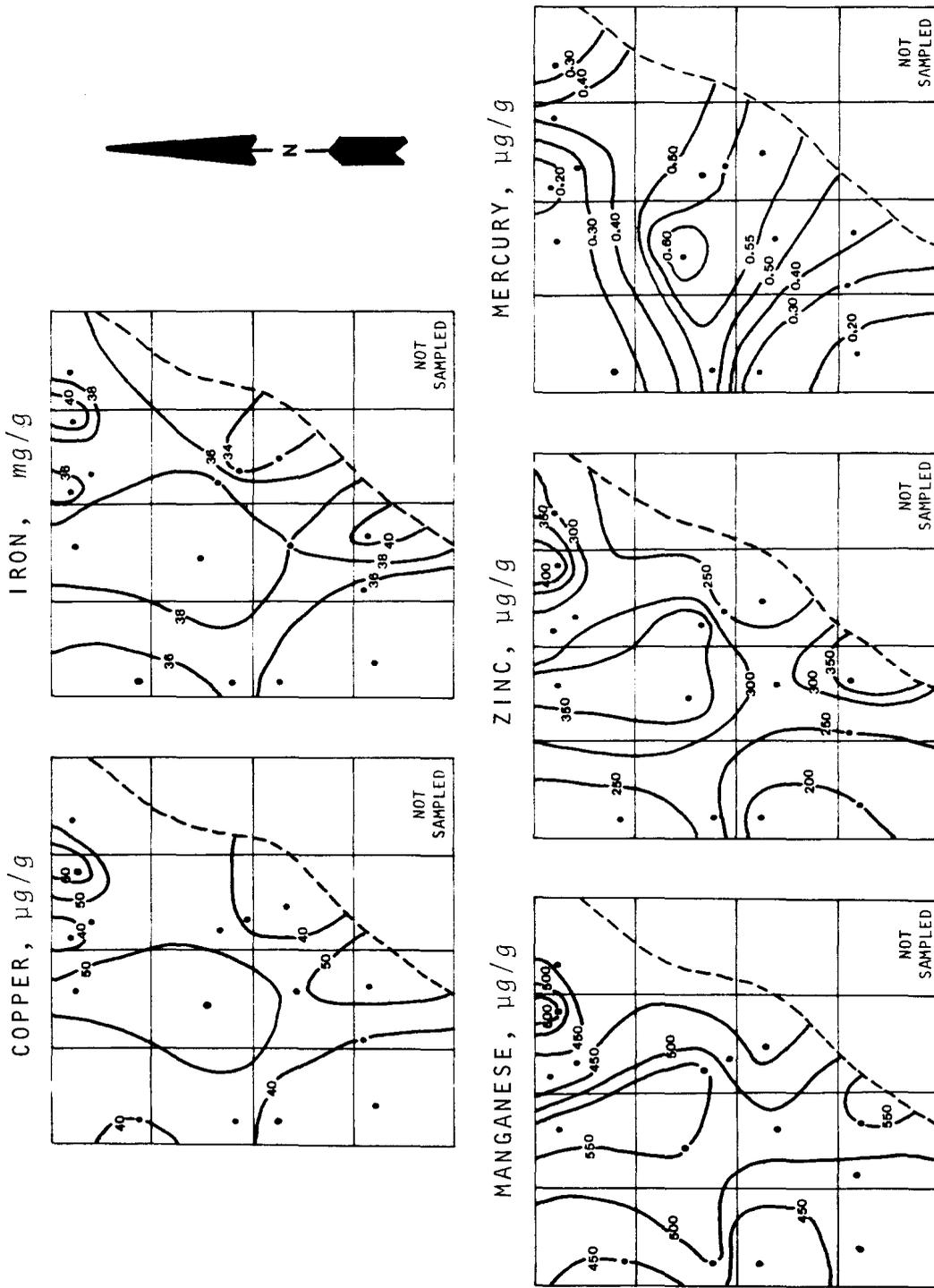


Figure 80. Copper, manganese, zinc, mercury ($\mu\text{g/g}$, dry weight basis) and iron (mg/g , dry weight basis) concentration isopleths for second section core sediments from the 1976 30-day postdisposal collections at NDS

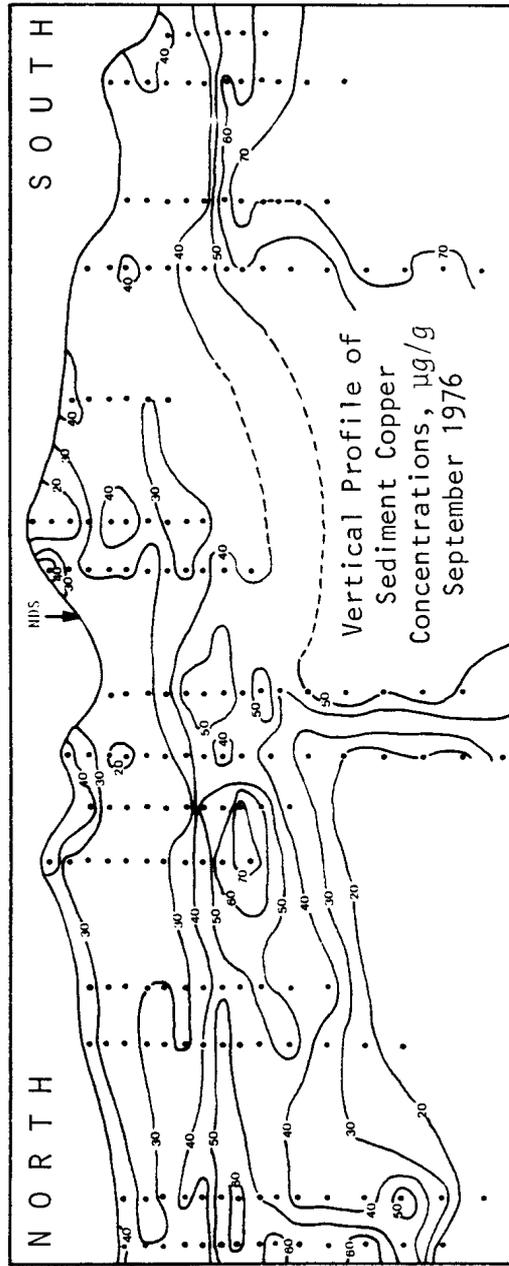
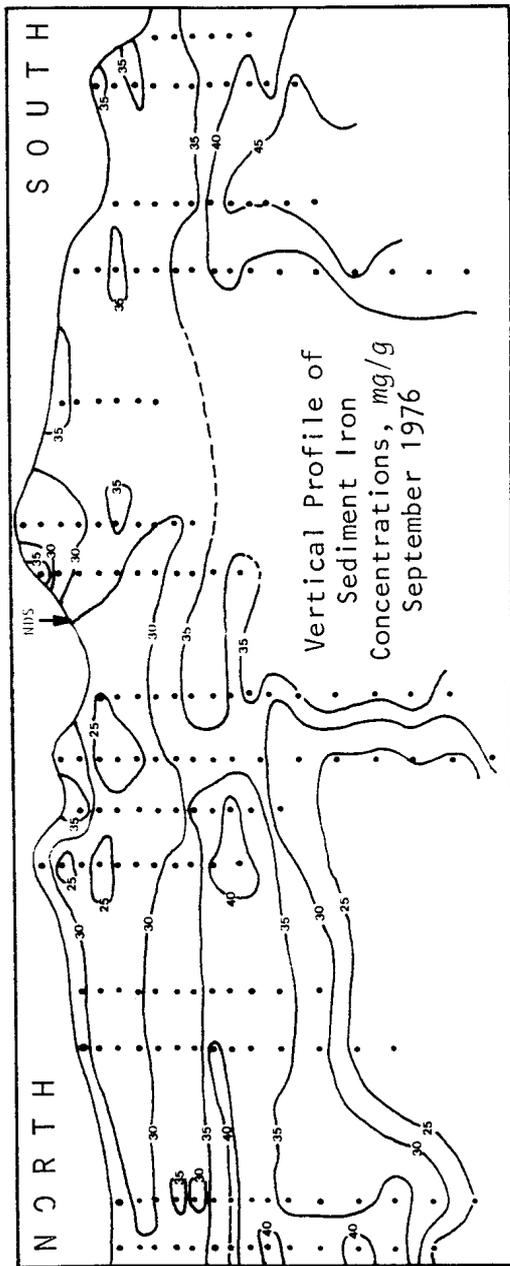


Figure 81. North-south vertical profiles of iron concentrations (mg/g, dry weight basis) and copper concentrations (µg/g, dry weight basis) in sediment core sections collected in September 1976 at NDS

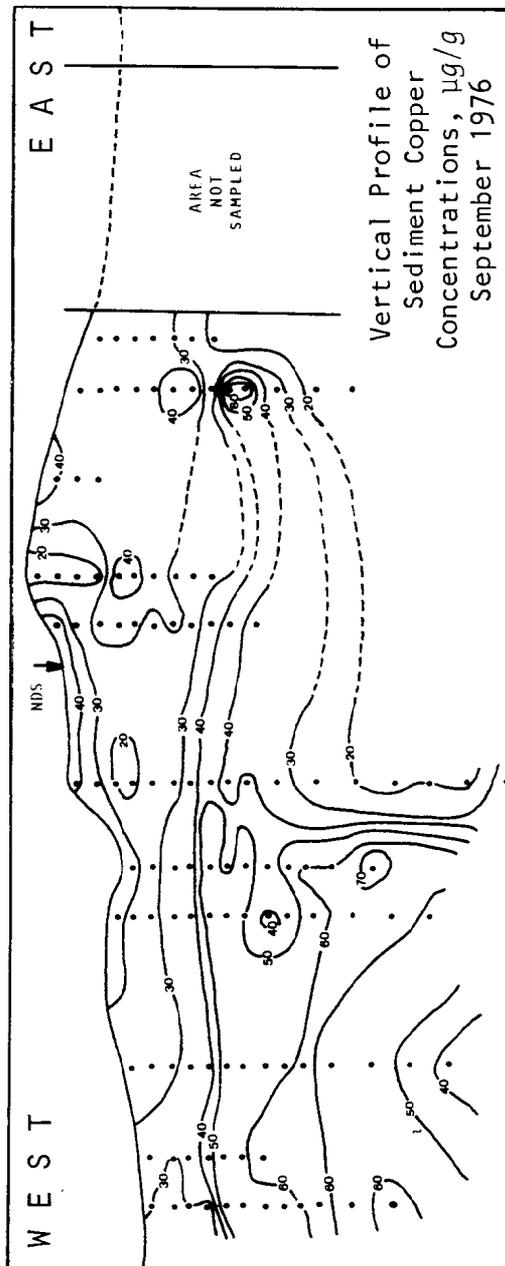
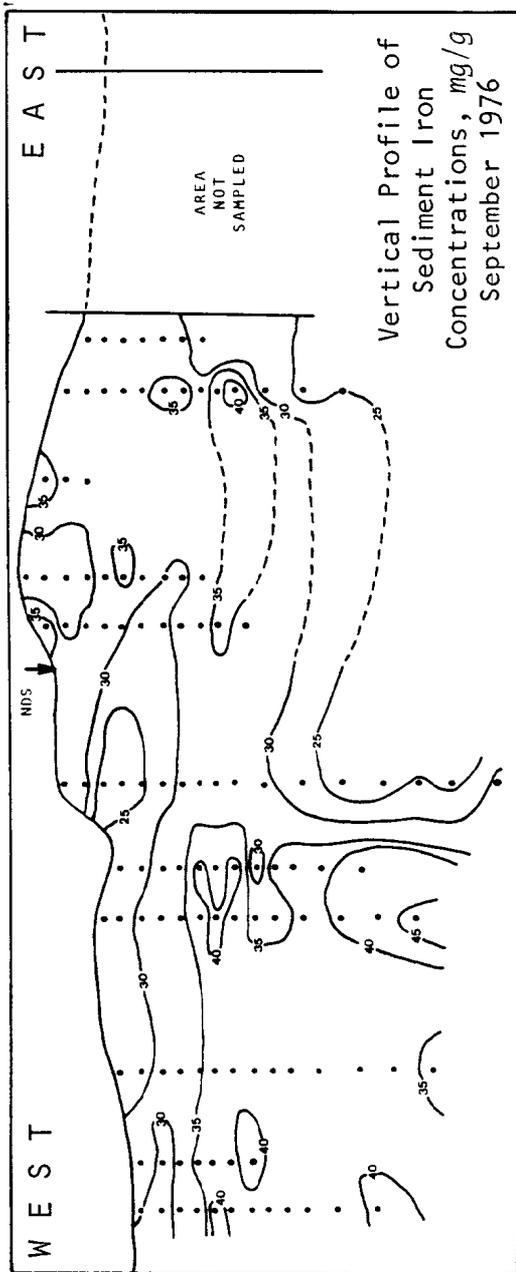


Figure 82. West-east vertical profiles of iron concentrations (mg/g, dry weight basis) and copper concentrations (µg/g, dry weight basis) in sediment core sections collected in September 1976 at NDS

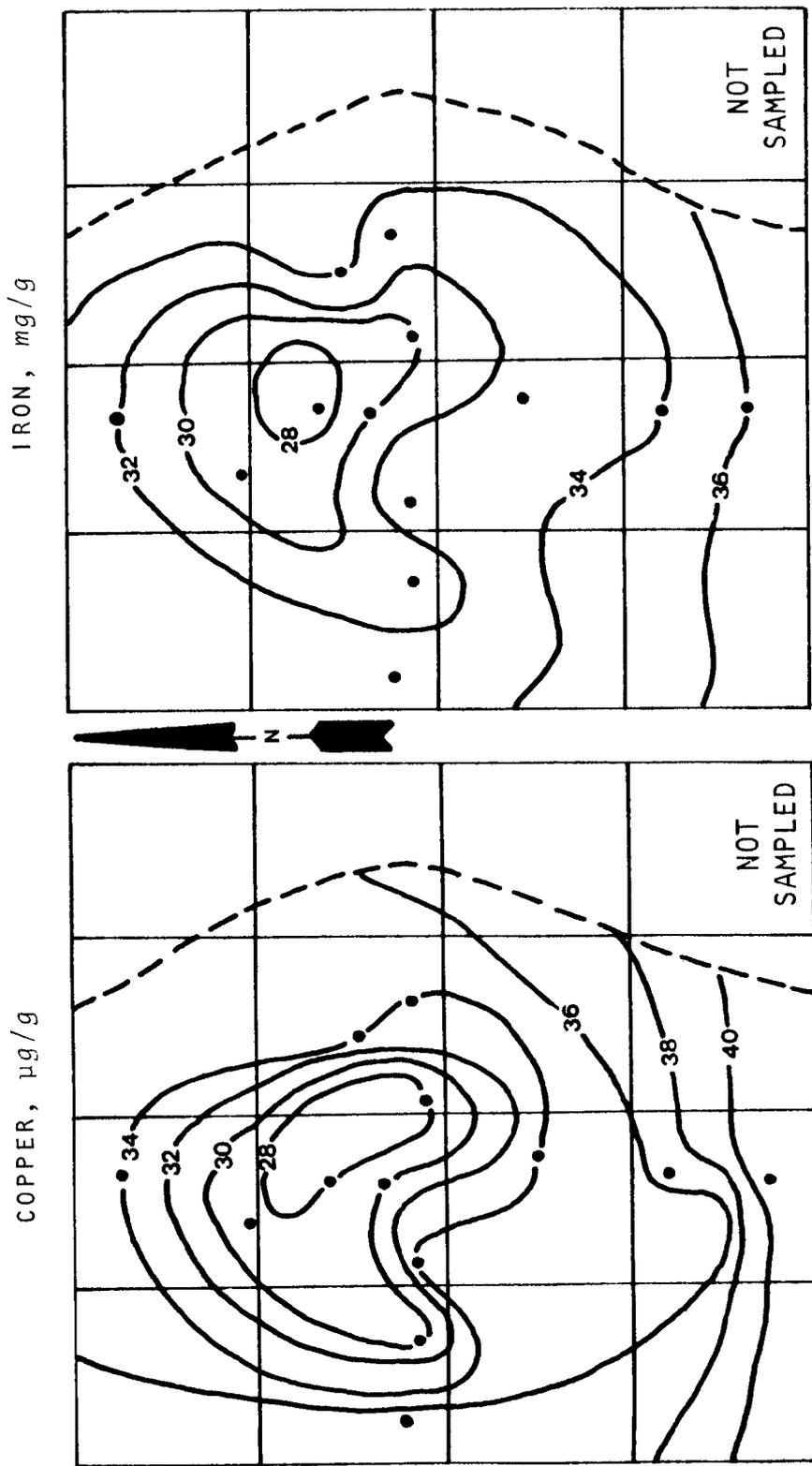


Figure 83. Copper concentration ($\mu\text{g/g}$, dry weight basis) and iron concentration (mg/g , dry weight basis) isopleths based on equivalent first section core sediments from the September 1976 collections at NDS

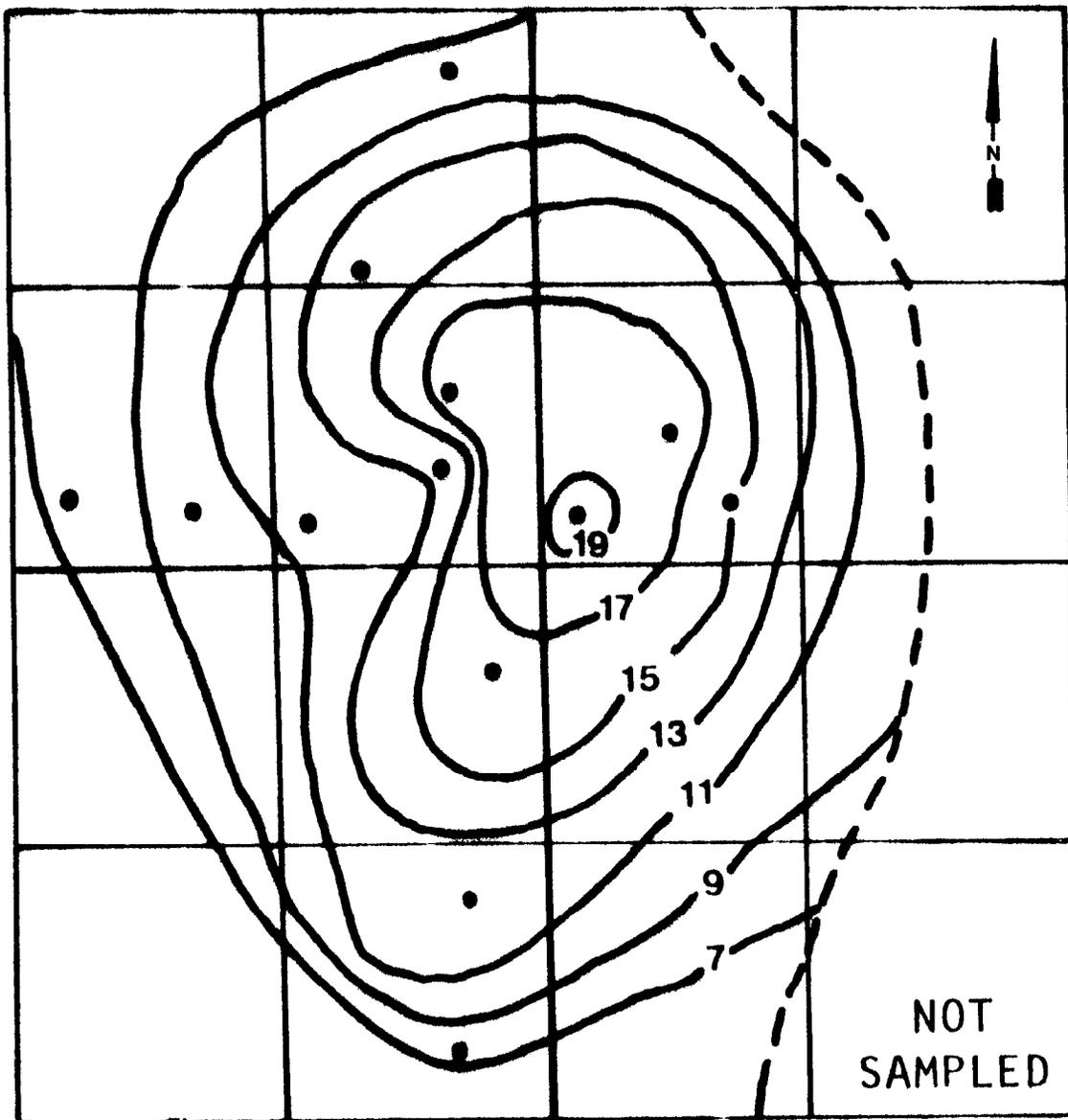


Figure 84. Contour map of the approximate depths in cm of dredged materials during the September 1976 collections at NDS

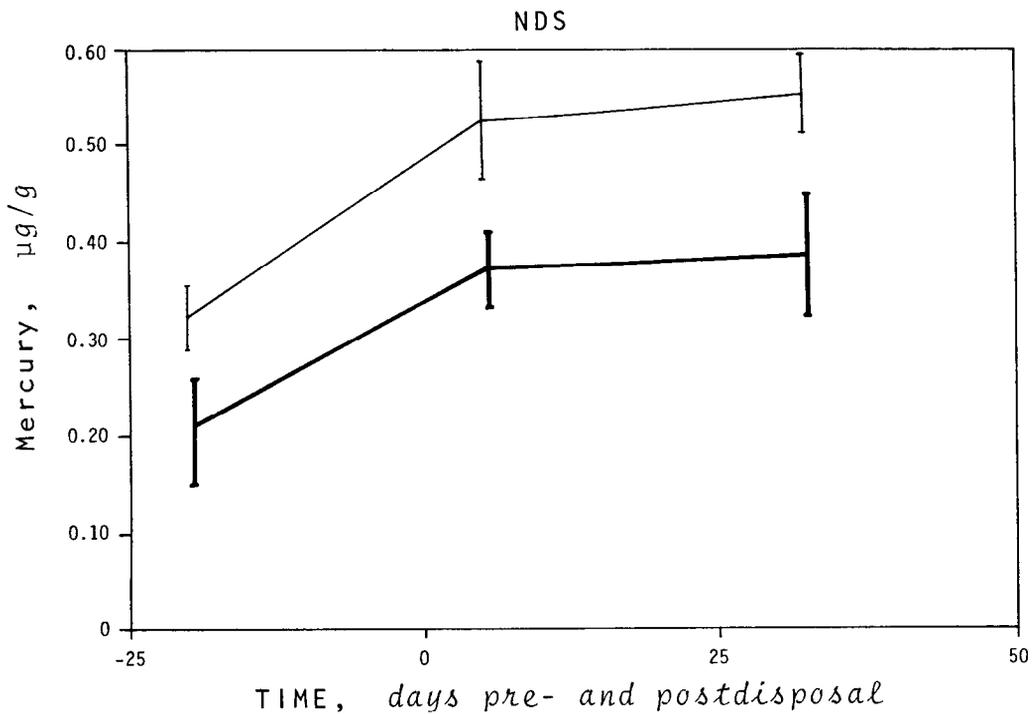
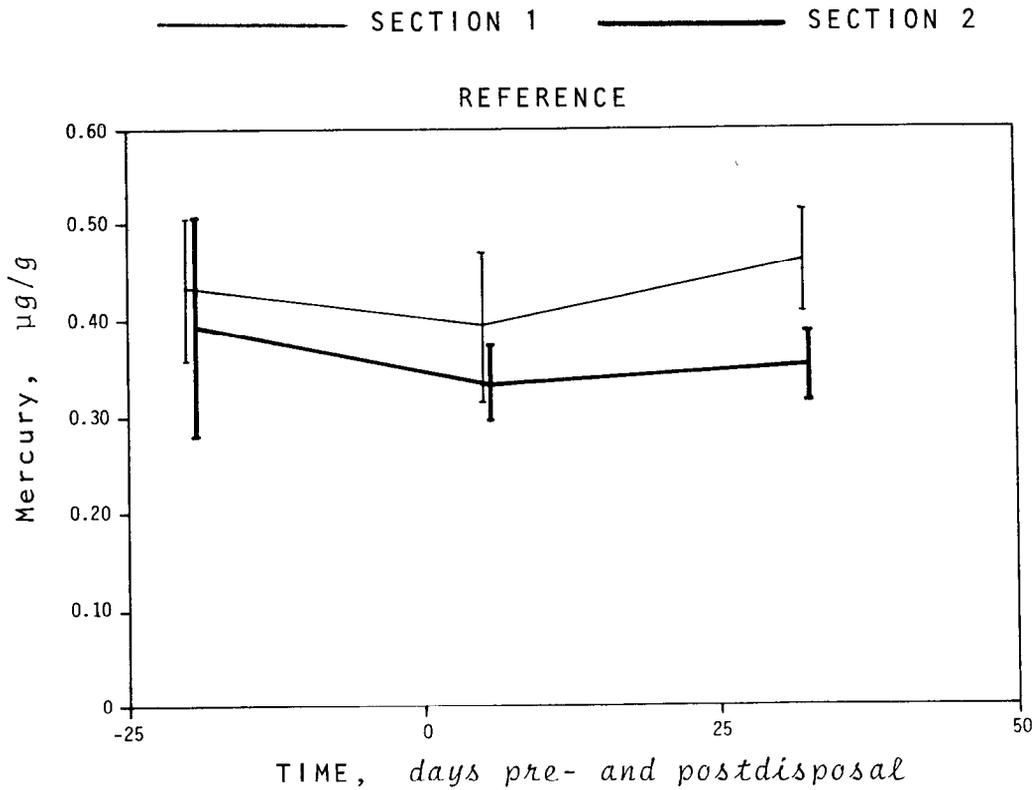


Figure 85. Mean and 95 percent confidence levels of mercury concentrations ($\mu\text{g/g}$, dry weight basis) from the reference site and NDS in first and second section core sediments relative to time in days pre- and postdisposal 1976

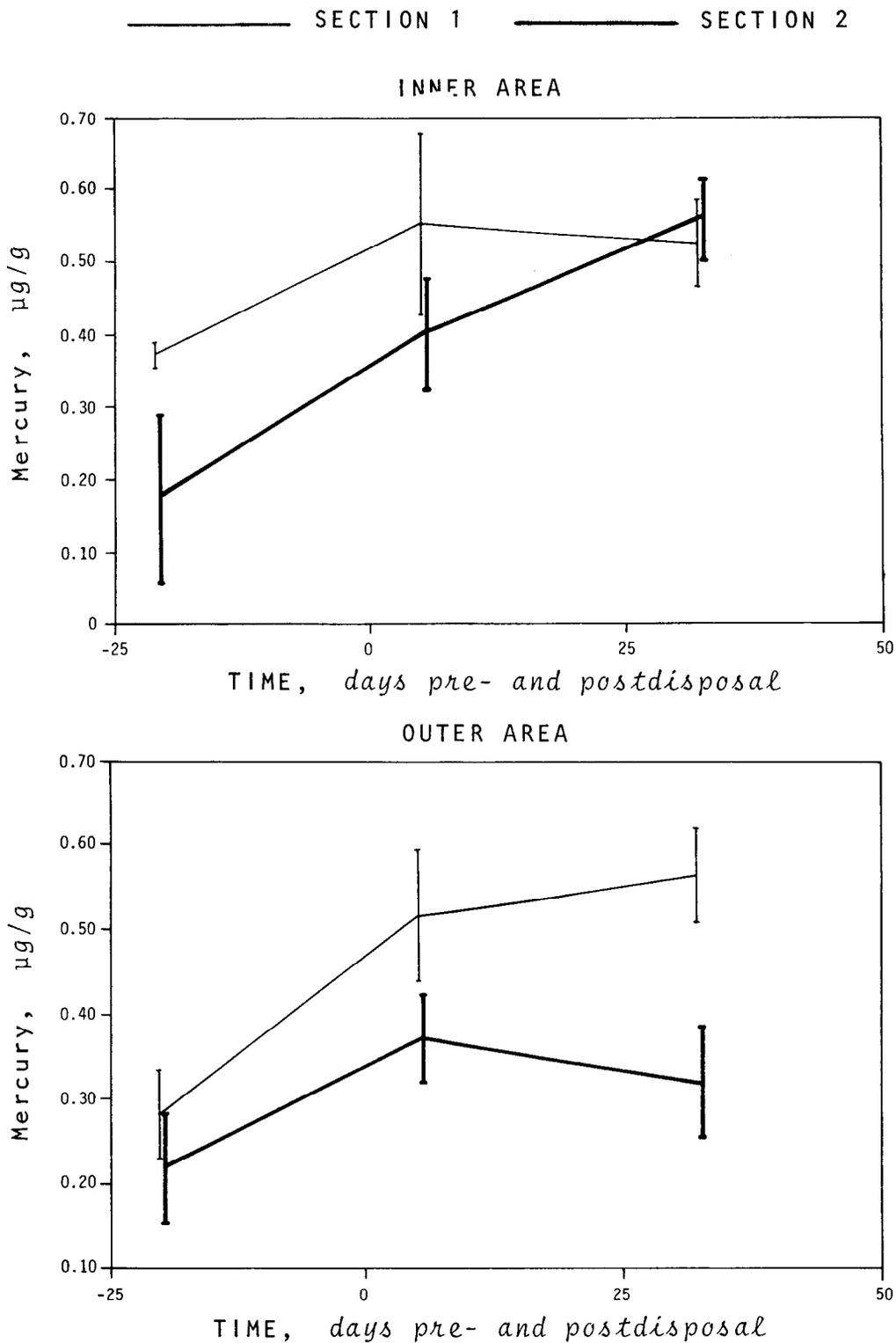


Figure 86. Mean and 95 percent confidence levels of mercury concentrations ($\mu\text{g/g}$, dry weight basis) from the inner and outer areas at NDS in first and second section core sediments relative to time in days pre- and postdisposal 1976

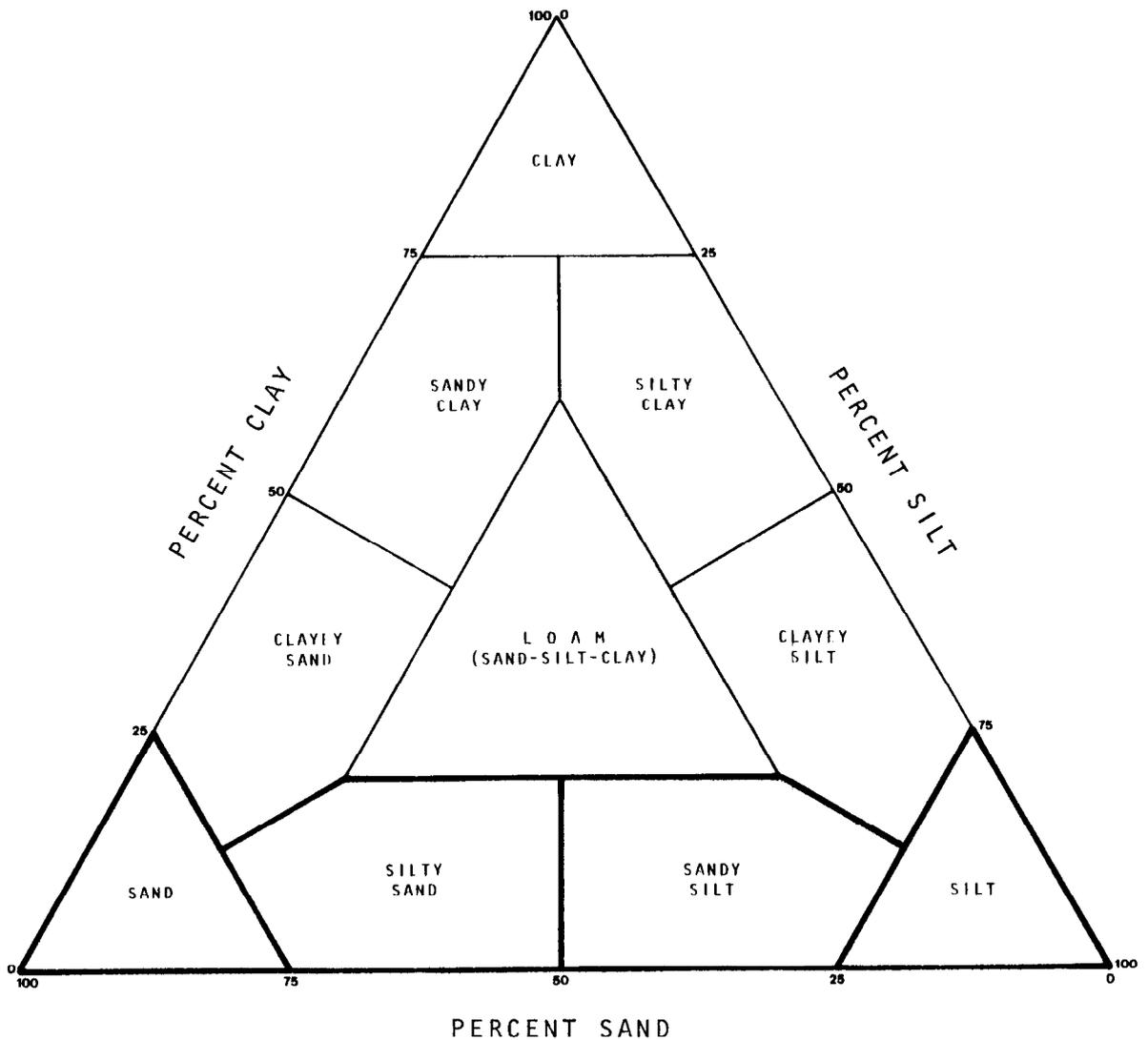


Figure 87. Basic triangular diagram used for the illustration of particle size data for sediment cores collected in both 1975 and 1976 at Ashtabula, Ohio

CODE	STATION DESIGNATION						
A	----- C1	5	----- D5	22	----- SD2	30	----- SD10
B	----- C2	7	----- D7	23	----- SD3	31	----- SD11
C	----- C3	8	----- D8	24	----- SD4	32	----- SD12
D	----- C4	9	----- D9	25	----- SD5	33	----- SD13
1	----- D1	10	----- D10	26	----- SD6	34	----- SD14
2	----- D2	11	----- D11	27	----- SD7	35	----- SD15
3	----- D3	21	----- SD1	28	----- SD8	36	----- SD16
4	----- D4			29	----- SD9		

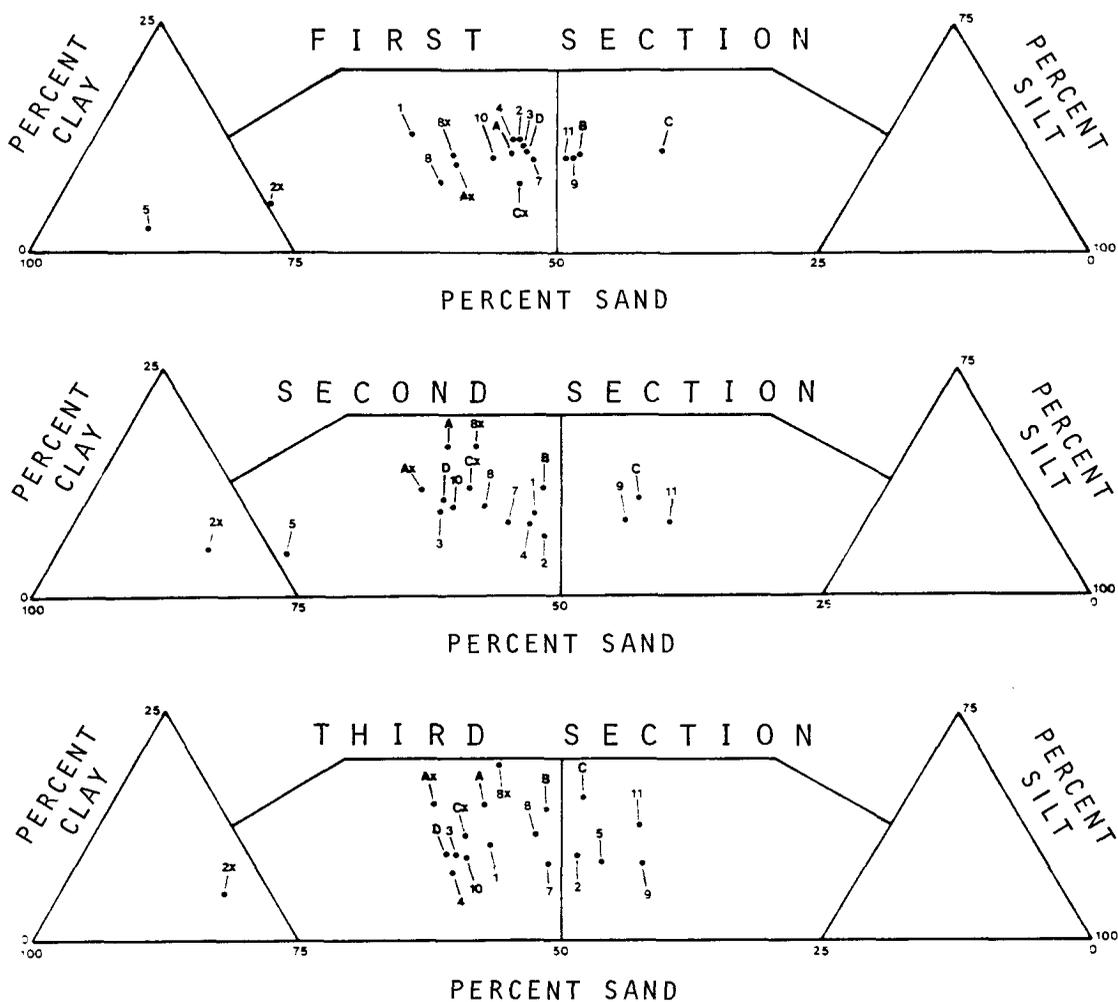


Figure 88. Particle size classification of predisposal sediments (8-10 July (x) and 30 July-1 August 1975) from the reference site, harbor disposal and river disposal sites for first, second, and third core sections

CODE	STATION DESIGNATION						
A	----- C1	5	----- D5	22	----- SD2	30	----- SD10
B	----- C2	7	----- D7	23	----- SD3	31	----- SD11
C	----- C3	8	----- D8	24	----- SD4	32	----- SD12
D	----- C4	9	----- D9	25	----- SD5	33	----- SD13
1	----- D1	10	----- D10	26	----- SD6	34	----- SD14
2	----- D2	11	----- D11	27	----- SD7	35	----- SD15
3	----- D3	21	----- SD1	28	----- SD8	36	----- SD16
4	----- D4			29	----- SD9		

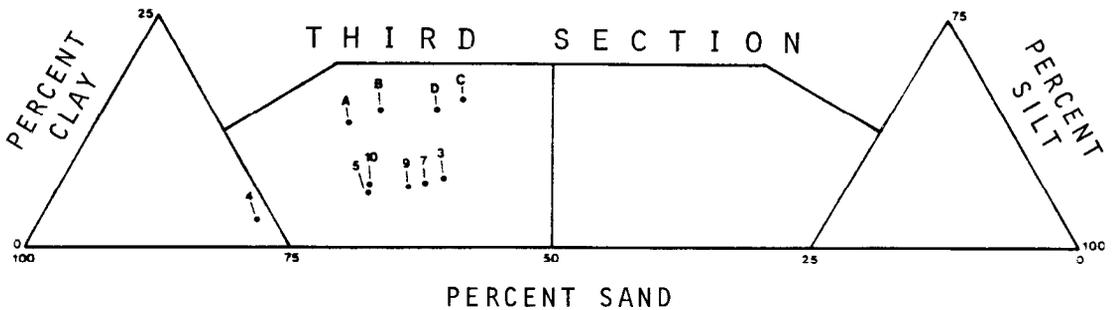
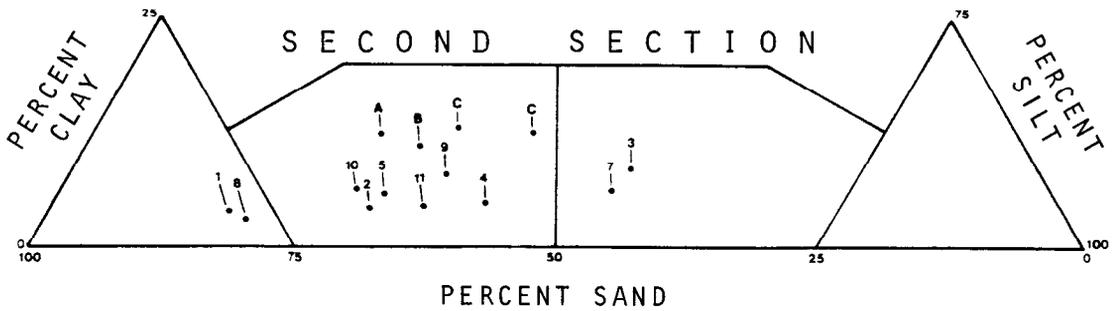
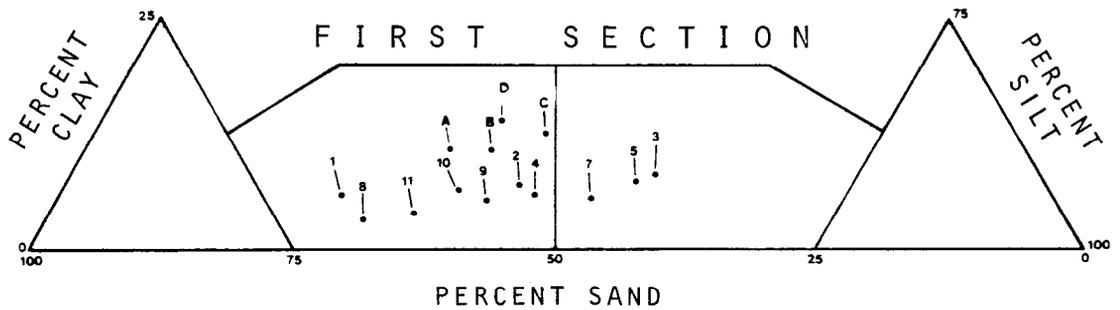


Figure 90. Particle size classification of 30-day postdisposal sediments (1975) from reference site, harbor disposal and river disposal sites for first, second, and third core sections

CODE	STATION DESIGNATION						
A	C1	5	D5	22	SD2	30	SD10
B	C2	7	D7	23	SD3	31	SD11
C	C3	8	D8	24	SD4	32	SD12
D	C4	9	D9	25	SD5	33	SD13
1	D1	10	D10	26	SD6	34	SD14
2	D2	11	D11	27	SD7	35	SD15
3	D3	21	SD1	28	SD8	36	SD16
4	D4			29	SD9		

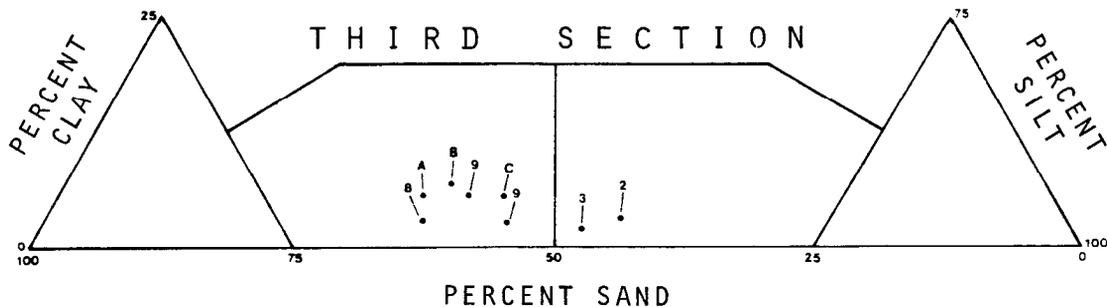
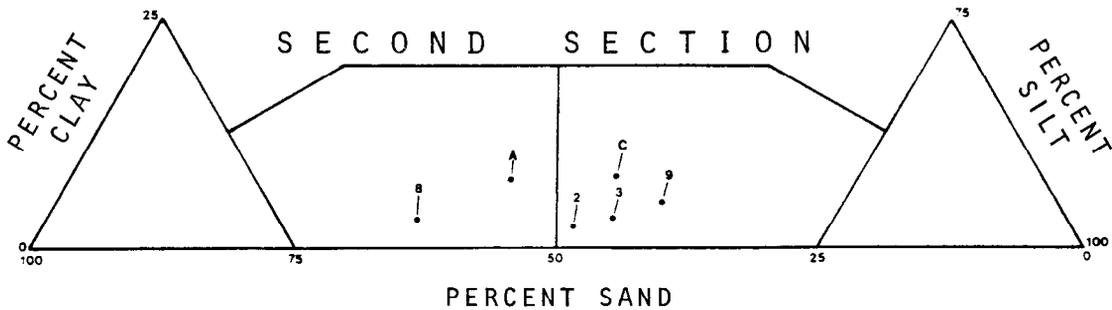
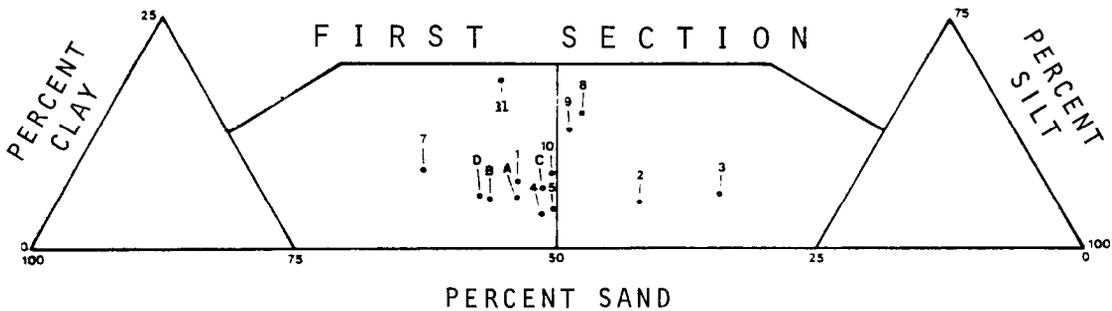


Figure 91. Particle size classification of 90-day postdisposal sediments (1975) from reference site, harbor disposal and river disposal sites for first, second, and third core sections

CODE	STATION DESIGNATION						
A	C1	5	D5	22	SD2	30	SD10
B	C2	7	D7	23	SD3	31	SD11
C	C3	8	D8	24	SD4	32	SD12
D	C4	9	D9	25	SD5	33	SD13
1	D1	10	D10	26	SD6	34	SD14
2	D2	11	D11	27	SD7	35	SD15
3	D3	21	SD1	28	SD8	36	SD16
4	D4			29	SD9		

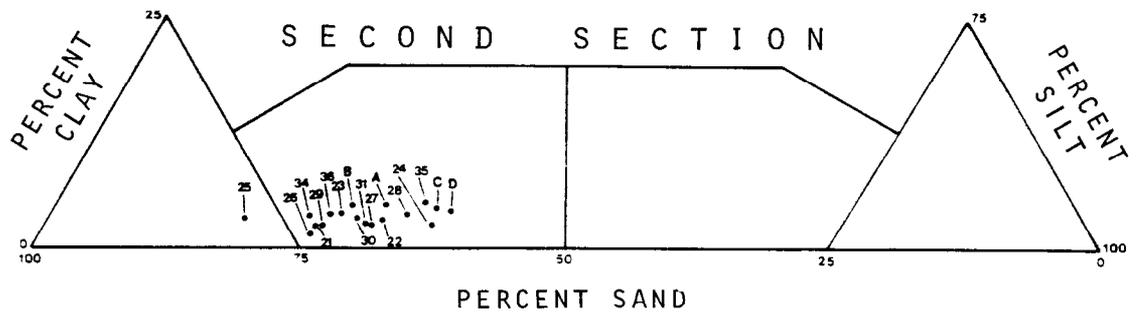
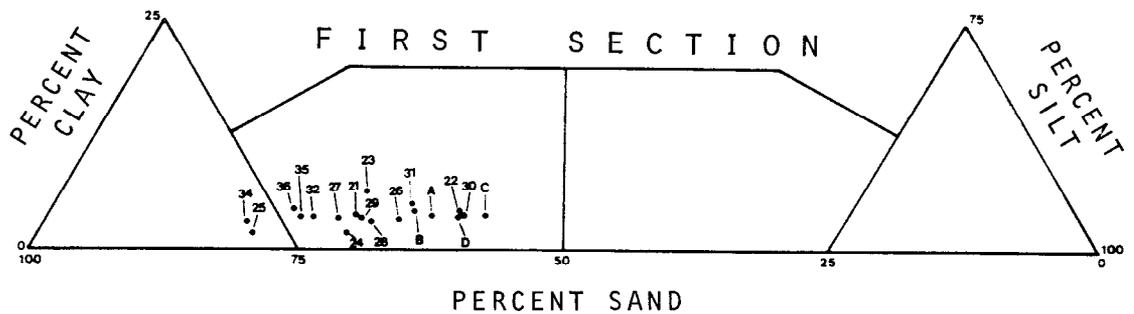


Figure 92. Particle size classification of predisposal sediments (1976) from the reference site and NDS for first and second core sections

CODE	STATION DESIGNATION						
A	----- C1	5	----- D5	22	----- SD2	30	----- SD10
B	----- C2	7	----- D7	23	----- SD3	31	----- SD11
C	----- C3	8	----- D8	24	----- SD4	32	----- SD12
D	----- C4	9	----- D9	25	----- SD5	33	----- SD13
1	----- D1	10	----- D10	26	----- SD6	34	----- SD14
2	----- D2	11	----- D11	27	----- SD7	35	----- SD15
3	----- D3	21	----- SD1	28	----- SD8	36	----- SD16
4	----- D4			29	----- SD9		

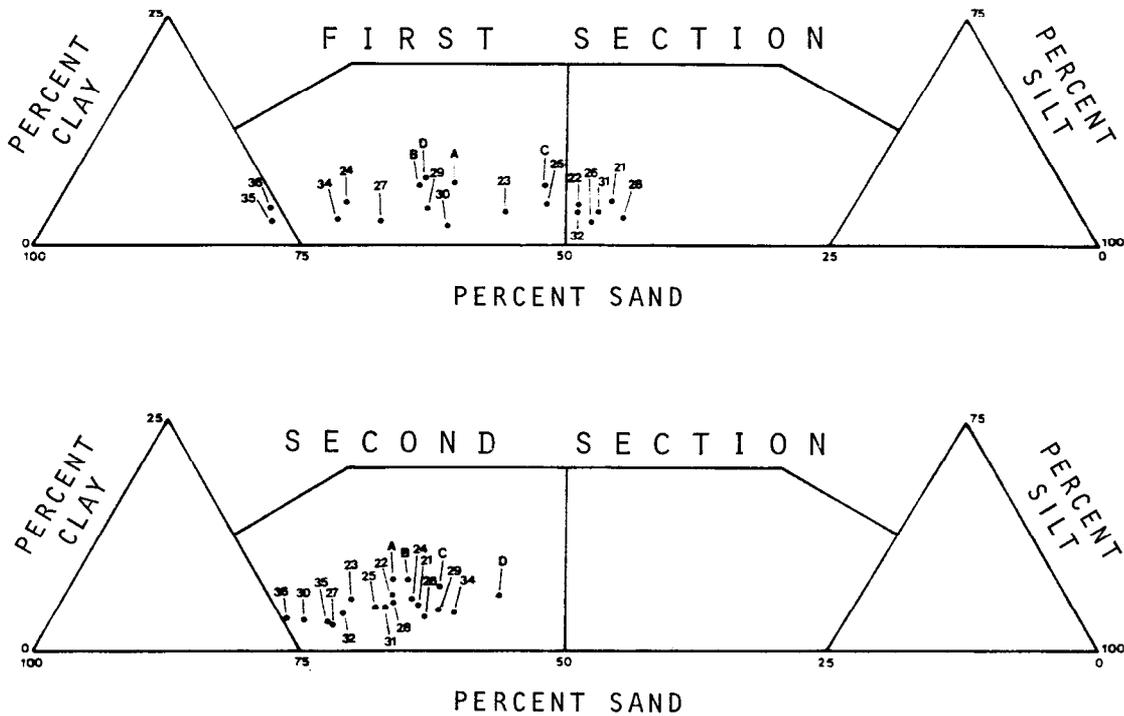


Figure 93. Particle size classification of 5-day postdisposal sediments (1976) from the reference site and NDS for first and second core sections

CODE	STATION DESIGNATION						
A	----- C 1	5	----- D 5	22	----- SD 2	30	----- SD 10
B	----- C 2	7	----- D 7	23	----- SD 3	31	----- SD 11
C	----- C 3	8	----- D 8	24	----- SD 4	32	----- SD 12
D	----- C 4	9	----- D 9	25	----- SD 5	33	----- SD 13
1	----- D 1	10	----- D 10	26	----- SD 6	34	----- SD 14
2	----- D 2	11	----- D 11	27	----- SD 7	35	----- SD 15
3	----- D 3	21	----- SD 1	28	----- SD 8	36	----- SD 16
4	----- D 4			29	----- SD 9		

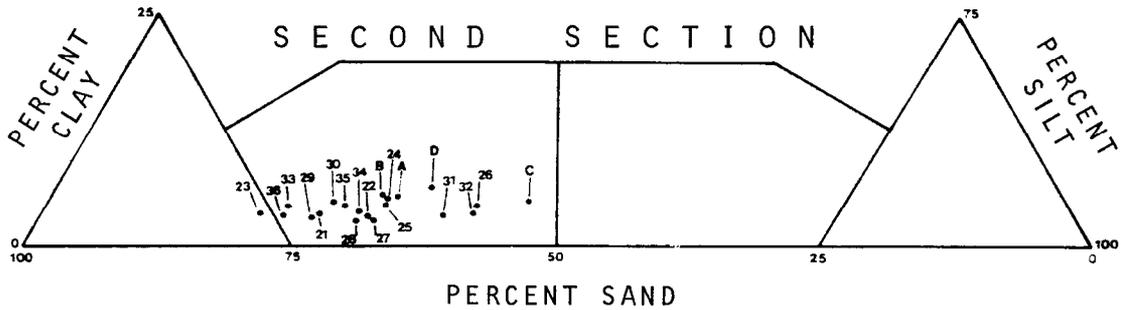
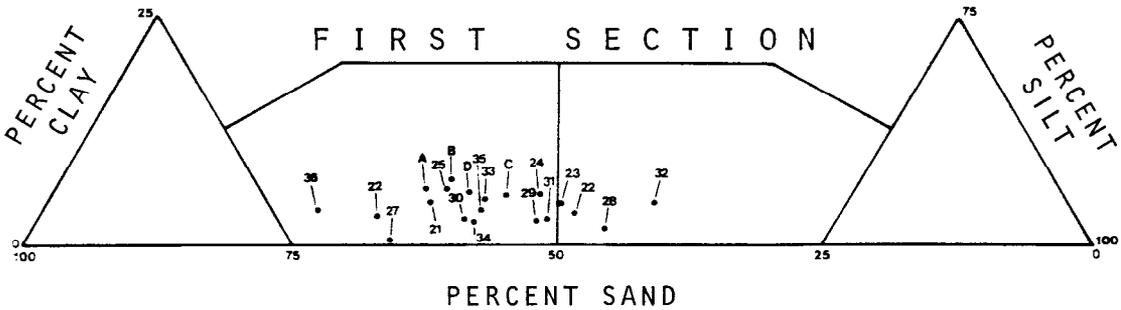
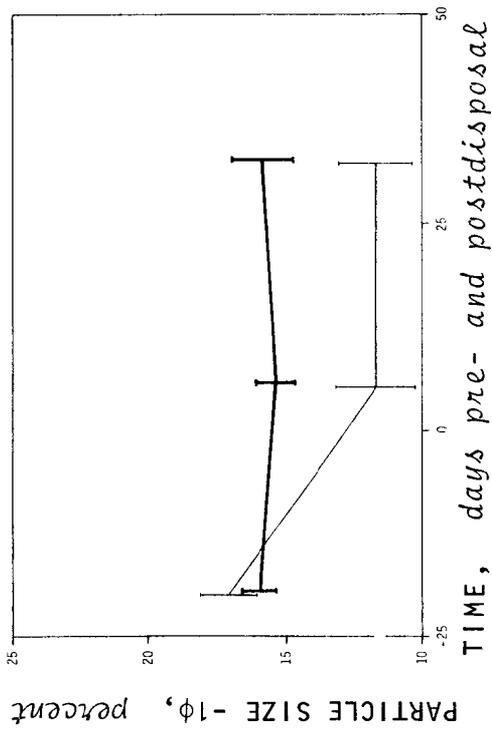


Figure 94. Particle size classification of 30-day postdisposal sediments (1976) from the reference site and NDS for first and second core sections



SECTION 1 _____

SECTION 2 _____

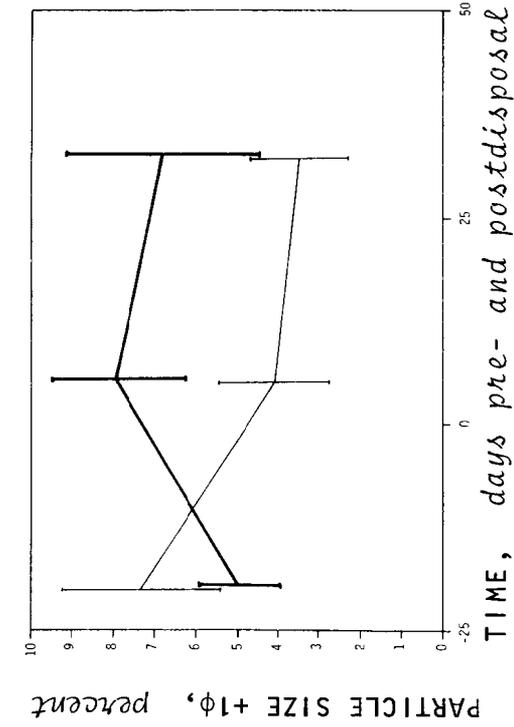
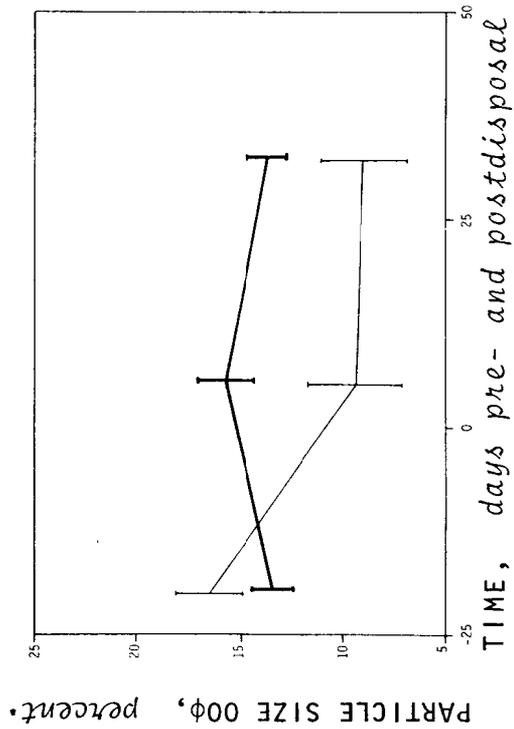
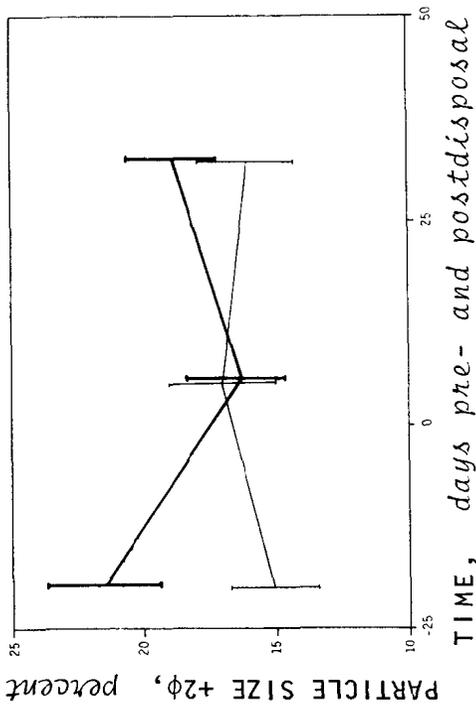


Figure 95. Mean and 95 percent confidence levels of -1ϕ , 0ϕ and $+1\phi$ particle sizes for first and second section core sediments from the NDS site relative to time in days pre- and postdisposal 1976



SECTION 1 ———
SECTION 2 - - - -

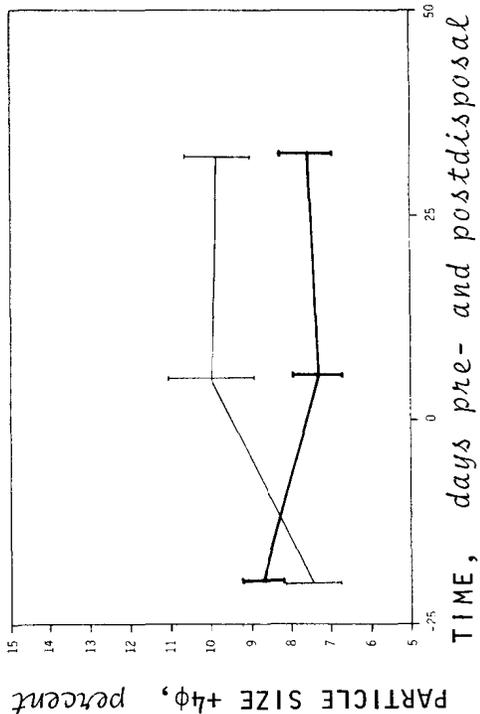
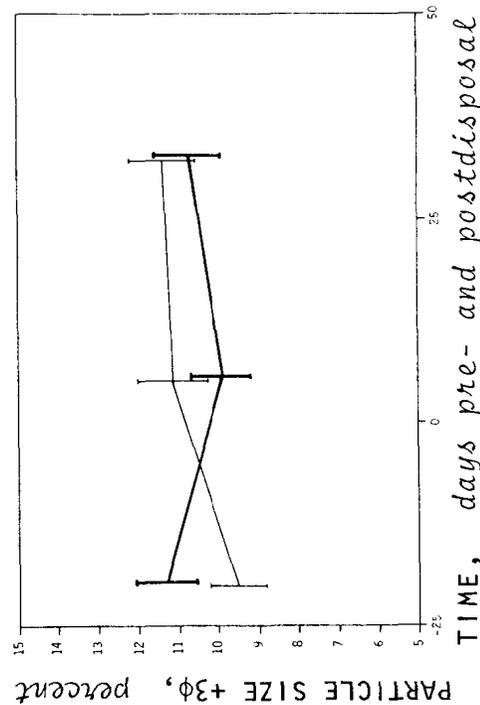
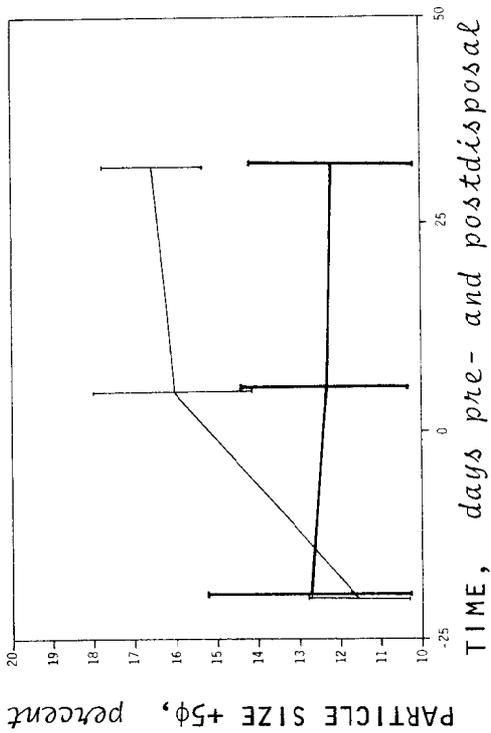


Figure 96. Mean and 95 percent confidence levels of +2φ, +3φ and +4φ particle sizes for first and second section core sediments from the NDS site relative to time in days pre- and postdisposal 1976



SECTION 1 ———

SECTION 2 ———

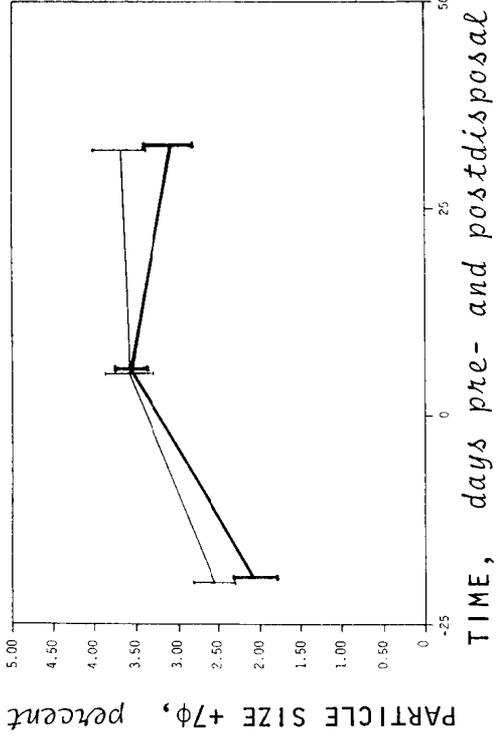
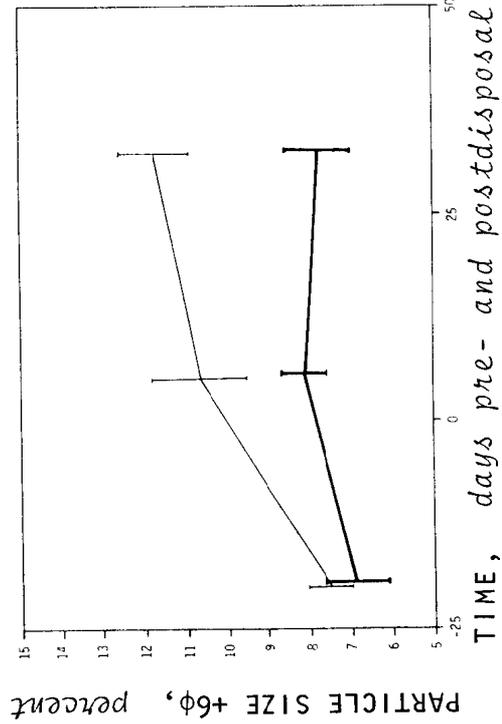


Figure 97. Mean and 95 percent confidence levels of +5φ, +6φ and +7φ particle sizes for first and second section core sediments from the NDS site relative to time in days pre- and postdisposal 1976

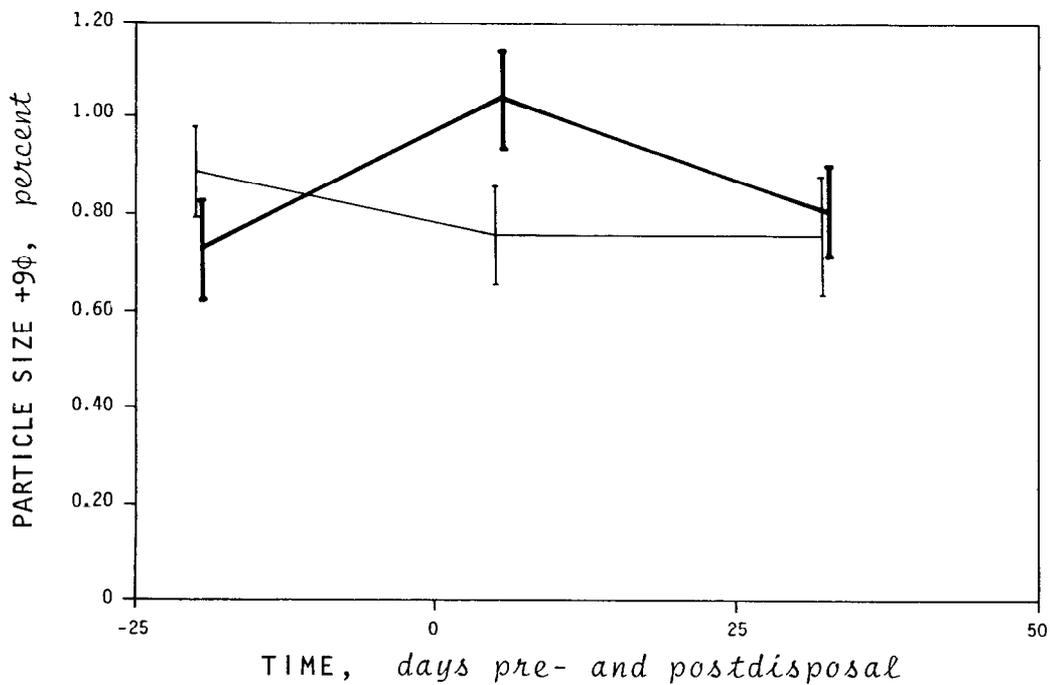
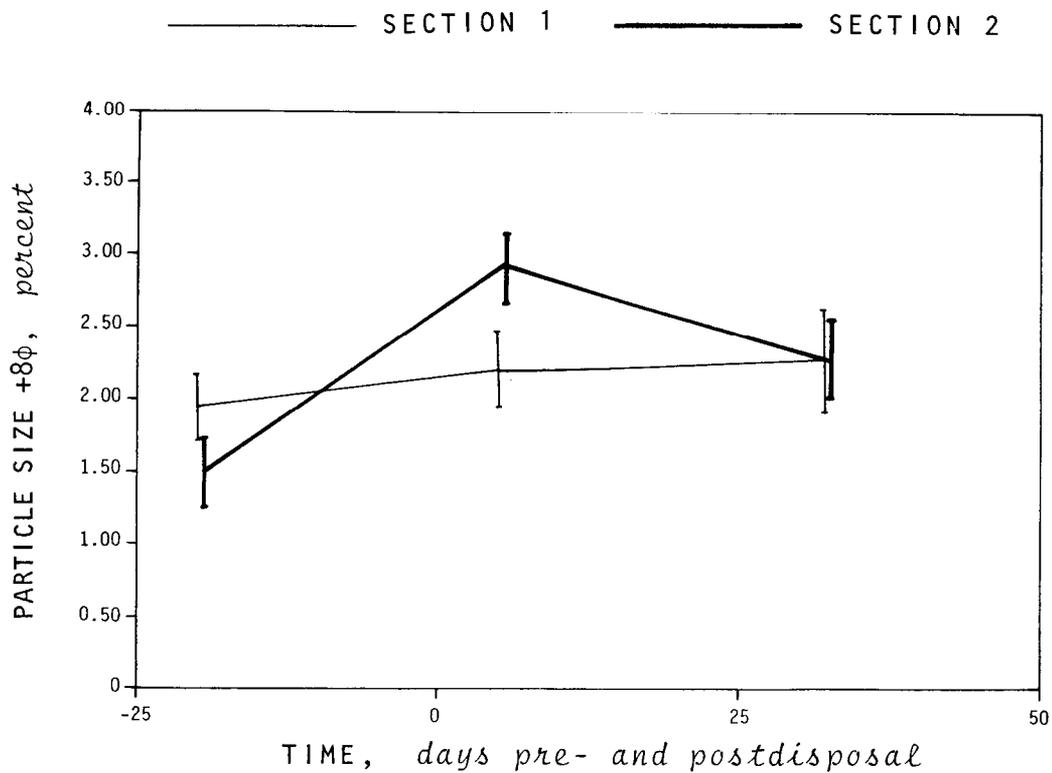


Figure 98. Mean and 95 percent confidence levels of +8φ and +9φ particle sizes for first and second section core sediments from the NDS site relative to time in days pre- and postdisposal 1976

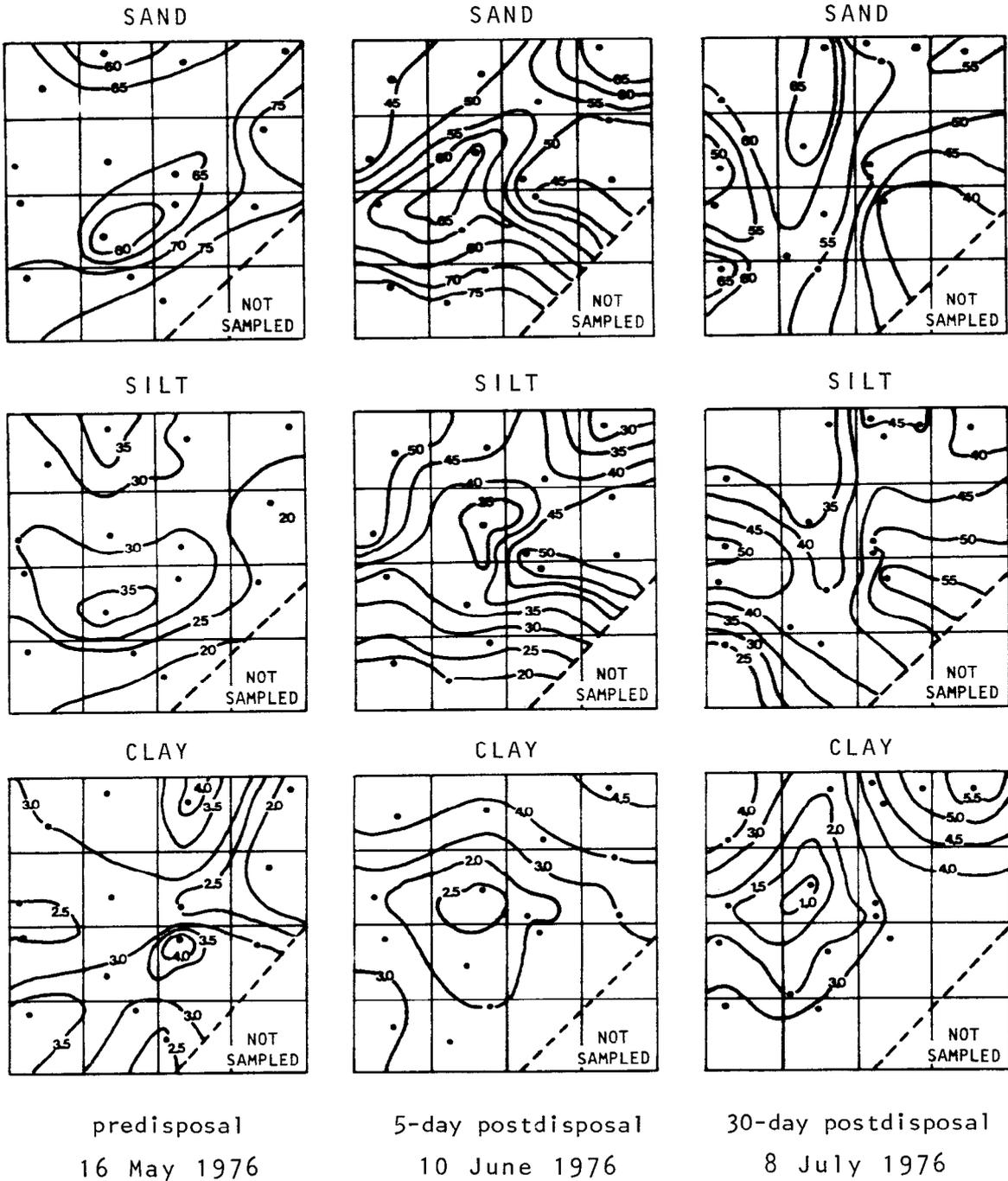


Figure 99. Contour maps of total percent sand, silt and clay content of first section core sediments at NDS from predisposal collections (16 May 1976) and 5- and 30-day postdisposal collections (10 June and 8 July 1976, respectively)

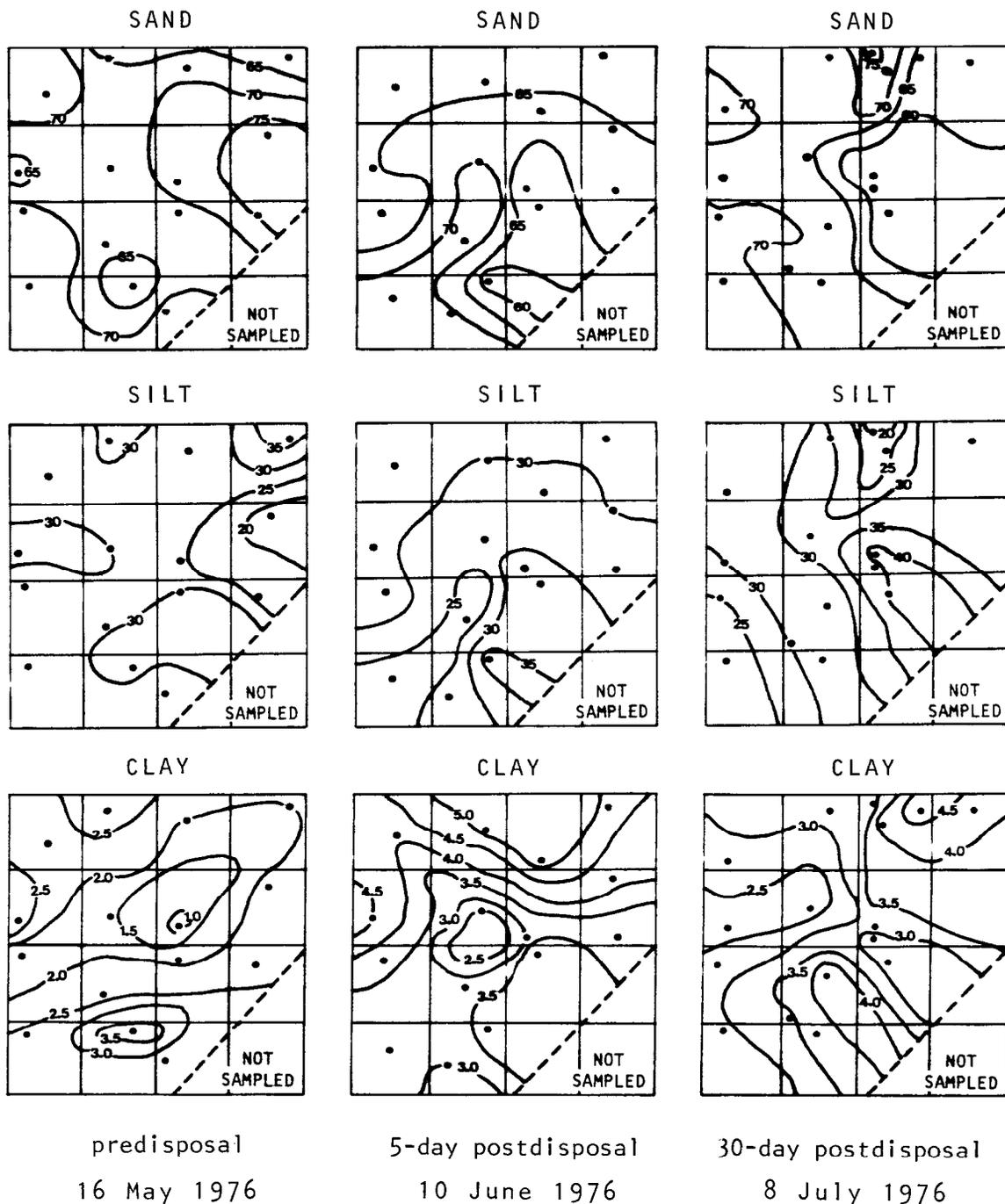


Figure 100. Contour maps of total percent sand, silt and clay content of second section core sediments at NDS from predisposal collections (16 May 1976) and 5- and 30-day postdisposal collections (10 June and 8 July 1976, respectively)

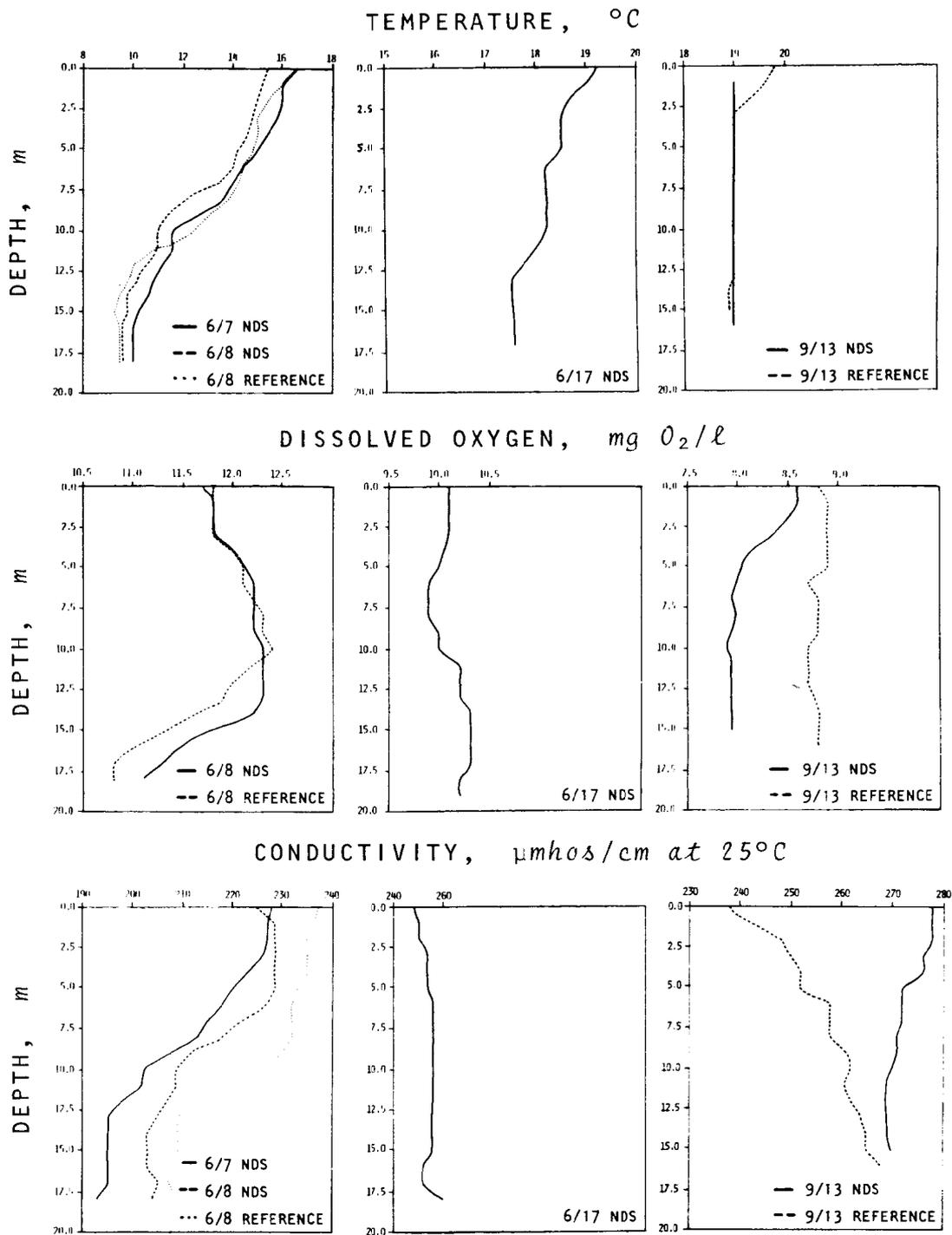


Figure 101. Temperature (°C), dissolved oxygen (mg/ℓ) and specific conductivity (µmhos/cm at 25°C) profiles at reference sites and/or NDS during the 6-7 June, 17 June and 13 September 1976 sediment oxygen demand sampling periods

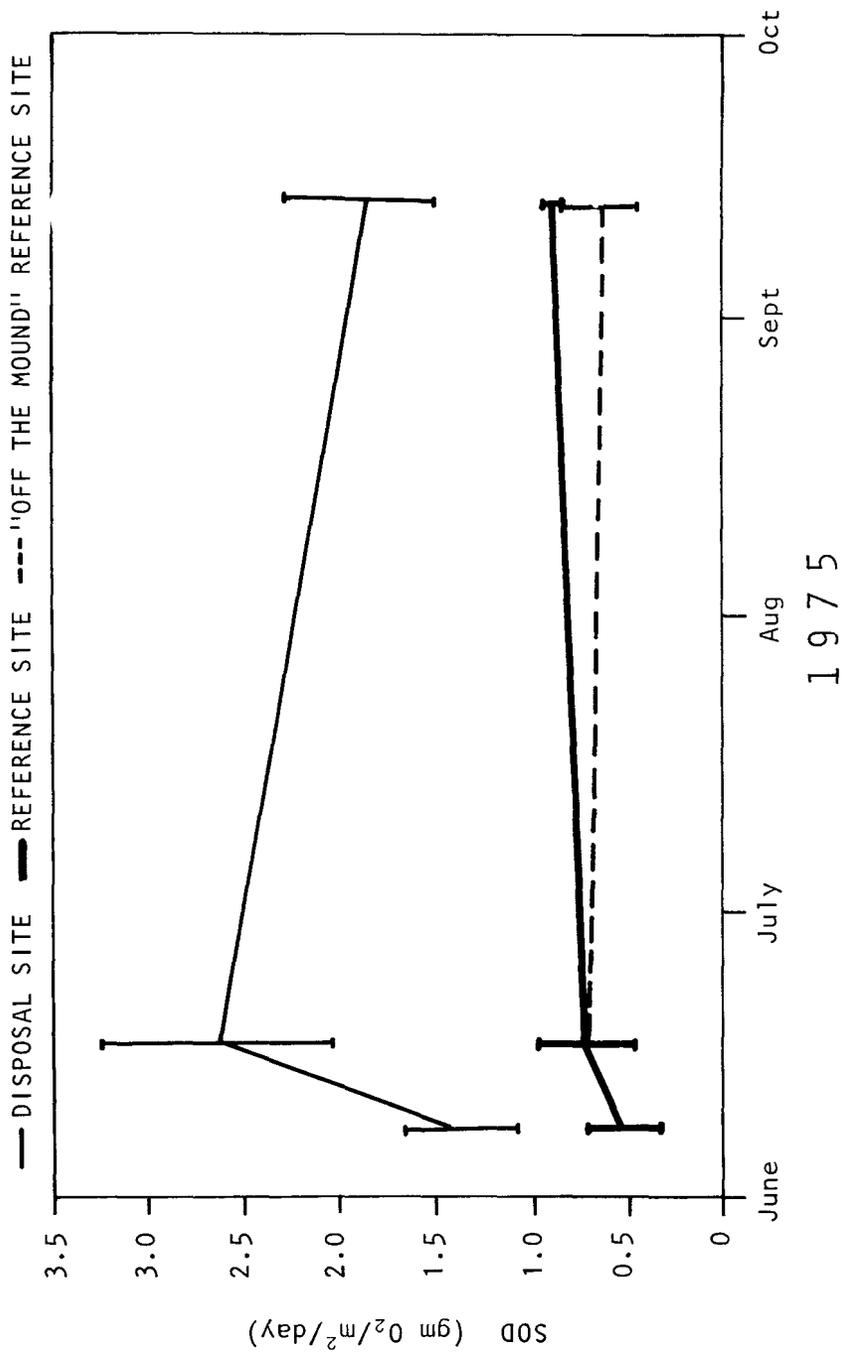


Figure 102. Mean and 95 percent confidence levels of sediment oxygen demand data (gm O₂/m²/day) between 7 June and 13 September 1976 at the reference site, disposal site and "off-the-mound" disposal site

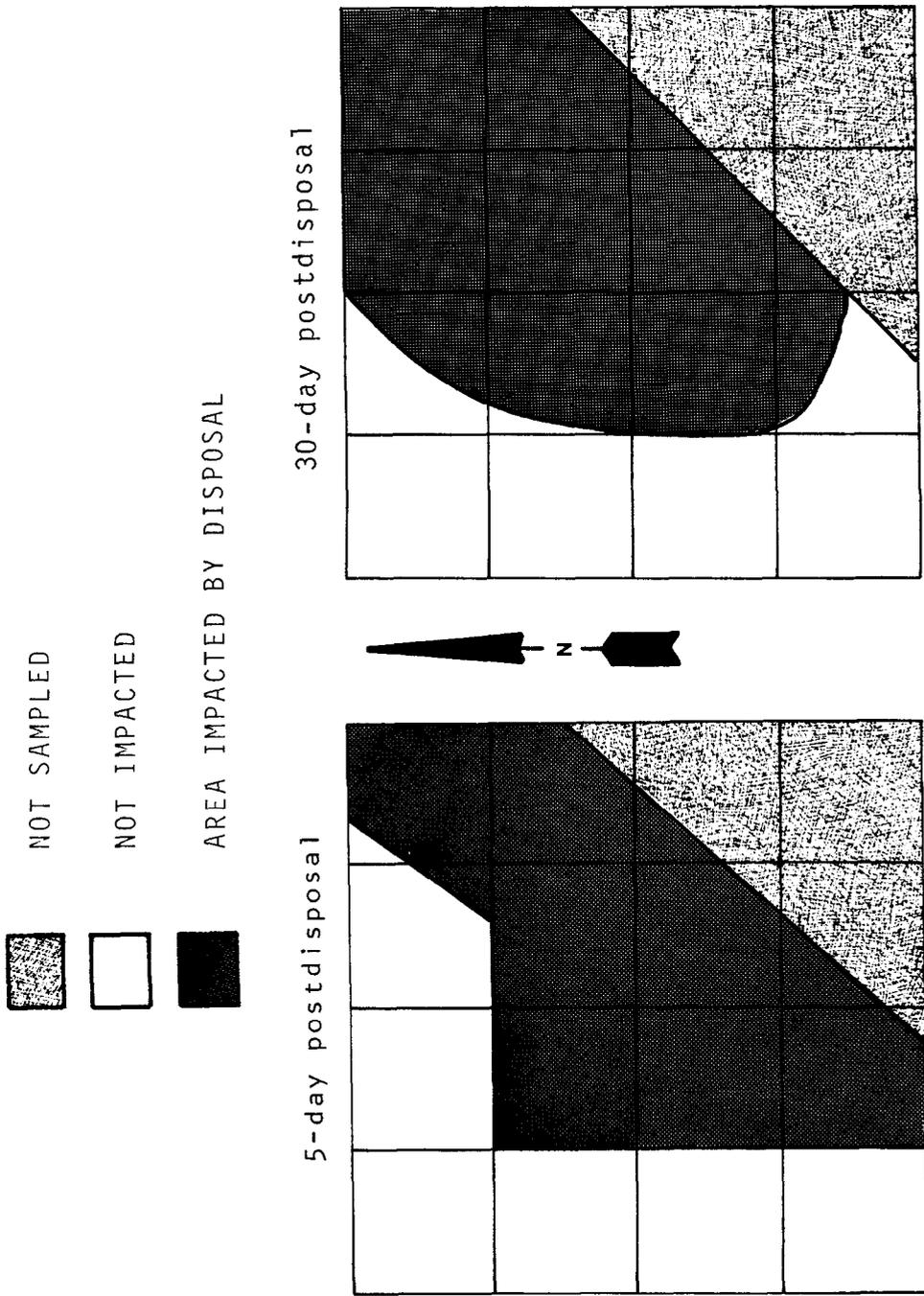


Figure 103. Graphic presentation of the results of discriminant analyses as applied to the interface water chemistry data from 5- and 30-day postdisposal collections at NDS

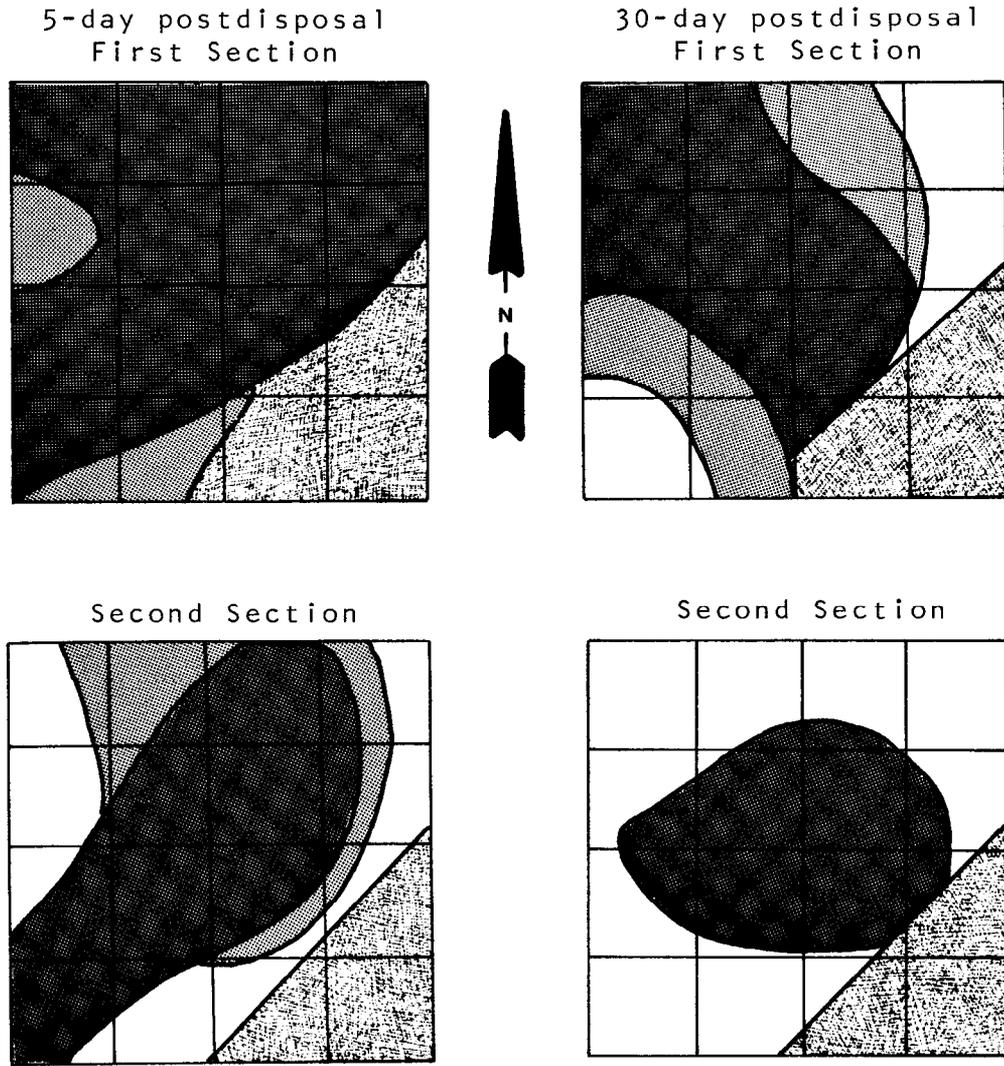
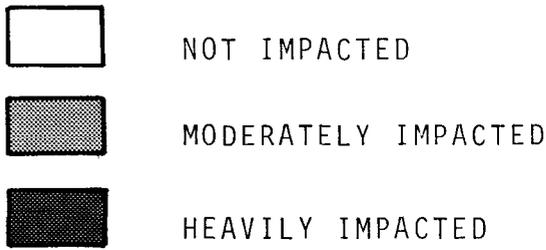
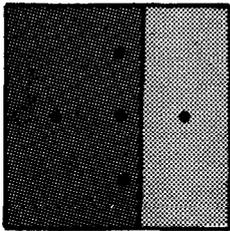


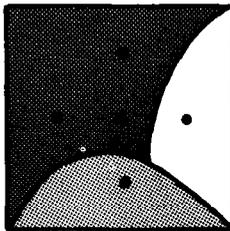
Figure 104. Graphic presentation of the results of discriminant analyses as applied to the interstitial water data from both first and second section sediment cores for the 5- and 30-day postdisposal collections at NDS



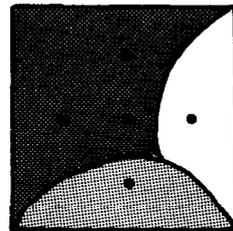
5-day
postdisposal



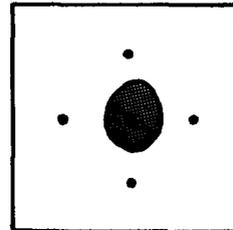
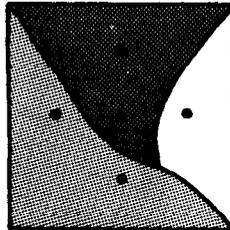
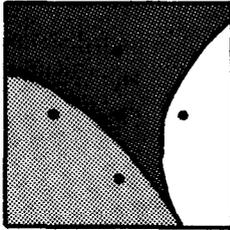
30-day postdisposal
HARBOR DISPOSAL SITE
First Section



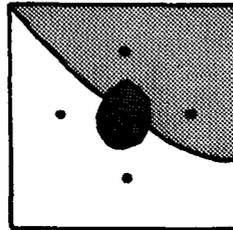
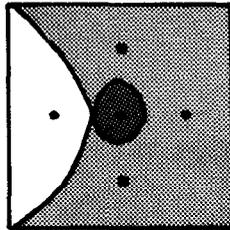
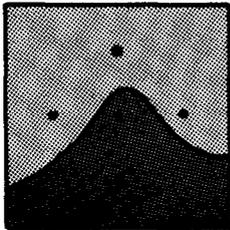
90-day
postdisposal



Second Section



RIVER DISPOSAL SITE
First Section



Second Section

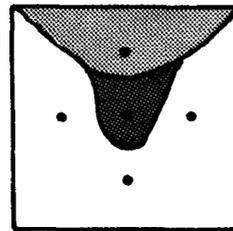
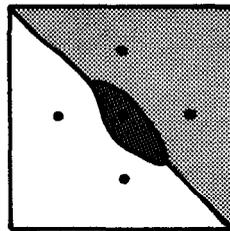
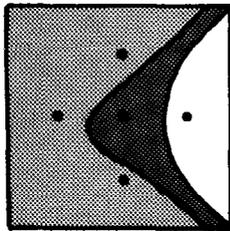


Figure 105. Graphic presentation of the results of discriminant analyses as applied to the sediment chemistry data from both first and second core sections for the 5-, 30-, and 90-day postdisposal (1975) collections at the harbor disposal site and the river disposal site

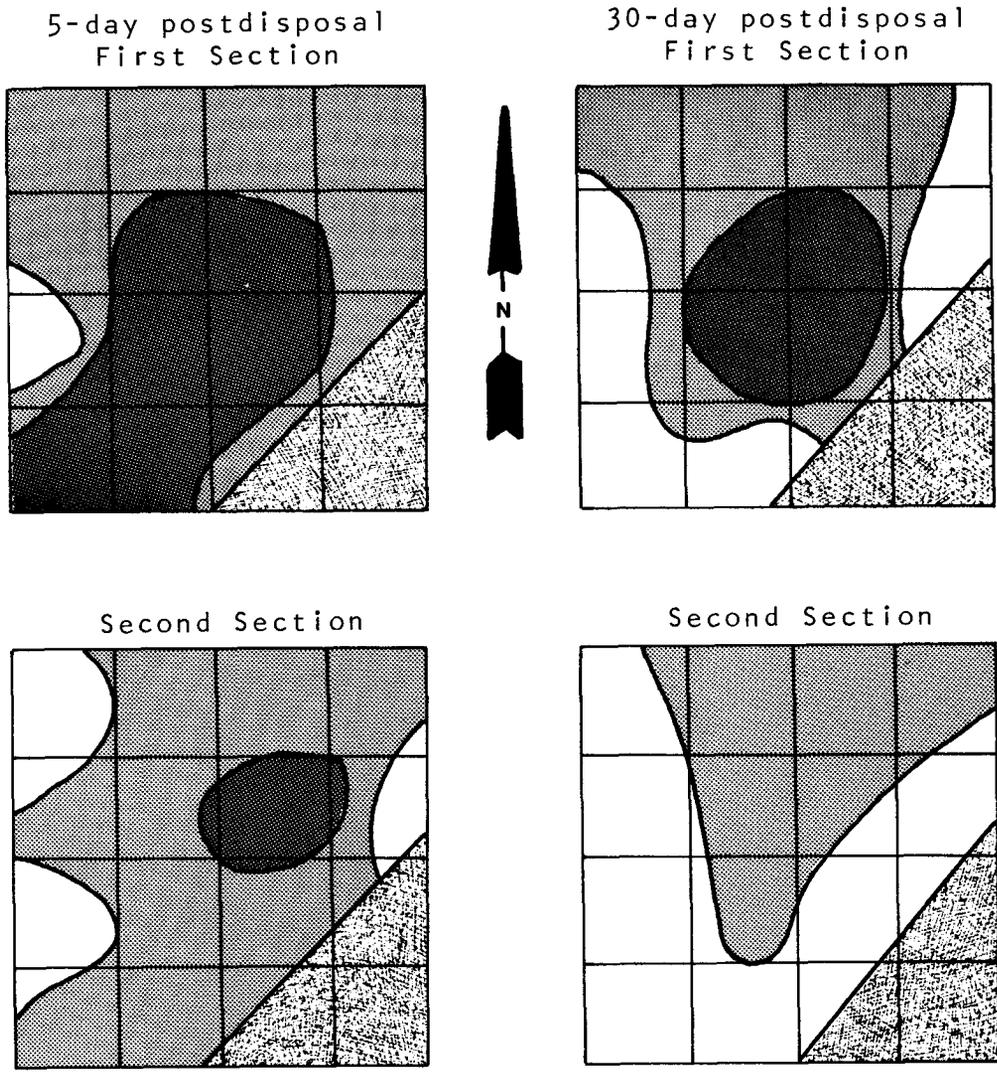


Figure 106. Graphic presentation of the results of discriminant analyses as applied to the sediment chemistry data from both the first and second core sections for the 5- and 30-day postdisposal (1976) collections at NDS

APPENDIX A': HEAVY METALS CONTENT OF BENTHIC
MACROINVERTEBRATES FROM SELECTED AREAS
IN REFERENCE AND DISPOSAL SITES IN
LAKE ERIE OFF ASHTABULA, OHIO

PART I: INTRODUCTION

1. The following study was initiated in order to ascertain background levels of iron (Fe), manganese (Mn), copper (Cu), cadmium (Cd), and zinc (Zn) in benthic macroinvertebrates and to determine whether dredged material disposal operations at Ashtabula, Ohio, had any effect on the concentration of these elements in selected bottom organisms.

PART II: METHODS

2. Five replicate box core sediment samples were taken at Lake Stations C1 (a Reference station), SD6, SD7, SD10, and SD11 during each of the three cruises (a pre-, 5- and 30-day postdisposal) in 1976 and at two River stations, E1 and E4, during the predisposal 1976 cruise. Each sample was washed through a U.S.G.S. #30 plastic sieve using Lake water. The retained organisms were stored at 4° C and returned to the Buffalo, New York labs of the Great Lakes Laboratory (GLL). The live benthos were removed using plastic-tipped forceps, sorted by major taxa, and placed in vials of distilled water to allow the animals to empty their digestive tracts. The efficiency of this process was not completely ascertainable. Station locations for sediment sampling are shown in Figure A'1.

3. Replicate collections from each station did not always have sufficient organisms of any one taxa for metals quantification. Therefore, some replicate collections were combined to form one, two, or three "replicate" subsamples based upon weight and/or number of organisms. In some cases, it was also necessary to group the organisms from several stations in order to have a biomass greater than 0.02 grams for metals analyses. Often there was a sufficient number of organisms to produce more than three replicate subsamples per station. These "extra" samples, which totaled 14, were used to measure the Hg content in Oligochaeta. One sample of chironomids also was analyzed for Hg concentration.

4. To prepare the remaining samples (138 samples = 153 total samples less 15 for Hg) for metals analysis, the organisms were removed from the distilled water and allowed to air-dry. By placing the organisms on a 64 μ mesh netting with absorbent tissue underneath, the water was drawn away. This left the biota on a dry surface from which they were easily removed by means of plastic-tipped forceps. The organisms were then placed in a pre-weighed 20 ml test tube and weighed to the nearest 0.1 mg. Five milliliters of concentrated HNO₃ were slowly added to avoid losses due to frothing. Acidified samples in a plastic-coated test tube rack were placed in a 50° C water bath for two hours. After this digestion period, any particulate residue (mostly small

amounts of sediments) was removed by macro-filtration through an acid-washed, 0.45- μ membrane filter. The volume of sample was then taken to 10.0 ml and aspirated directly to a Varian Model 1200 Atomic Absorption Spectrophotometer. The small volume of sample was sufficient for the quantification of only cadmium (Cd), copper (Cu), manganese (Mn), zinc (Zn), and iron (Fe). The concentration of the five metals was measured in $\mu\text{g}/\ell$. The calculation of metals concentration in $\mu\text{g}/\text{g}$ of wet sample was as follows:

$$\mu\text{g}/\text{g (wet weight)} = (\mu\text{g}/\ell \times 0.010) \div \text{wt. in grams of wet samples} \quad (1)$$

PART III: RESULTS AND DISCUSSION

5. A total of 153 benthic macroinvertebrates samples were analyzed for heavy metals content. The five major taxa collected were Oligochaeta, Chironomidae, Isopoda, Sphaeriidae, and Gastropoda.

6. The predisposal cruise (May) yielded 72 samples for analysis while the 5- and 30-day postdisposal collections produced 51 and 30 samples, respectively. Oligochaeta were the most abundant organisms collected. Of the 153 samples analyzed, 62 were composed of Oligochaeta. This taxon was the only major group for which collections from each station and sampling period were of sufficient number for analyses.

7. Table A'1 is a summary of the metals results (except Hg). The table compares metals concentrations in Oligochaeta by collection area and time of collection using mean and 95% confidence intervals. Concentrations in the organisms from the Disposal Site (SD6, SD7, SD10, and SD11) were grouped according to the pre-, 5-day, and 30-day postdisposal sampling dates. There were only five total samples from the Reference Site (C1) throughout the three collection periods. Therefore, those results also were pooled. Concentrations of the various metals from the two River stations (Stations E1 and E4), collected prior to dredging, comprised another group.

8. The mean metals concentrations indicated decreases in all metals concentrations in the organisms collected from the Disposal Sites from pre- to postdisposal. Note that Zn concentrations increased then decreased in going from pre- to 5- to 30-day postdisposal. There also appeared to be a slight decrease between the 5- and 30-day postdisposal results for Cu, Zn, and Fe. Comparison of confidence intervals in Figure A'2 and subsequent one-way analysis of variance indicates that for Cd, Cu, Zn, and Fe, there were significant differences in tissue concentrations over the study period. Cd concentrations were different in the Oligochaeta ($P = 0.044$) between the 5-day postdisposal and the predisposal results. Both the 5- and 30-day postdisposal organism concentrations of Cu were lower than the predisposal results ($P = 0.018$ and 0.009 , respectively). Fe and Zn results showed a significant decrease between the predisposal

and the 30-day postdisposal ($P = 0.02$ and 0.040 , respectively), but not between predisposal and the 5-day postdisposal results in the *Oligochaeta*. Except for the Zn levels in the organisms from the 5-day postdisposal collection, the metals contents during postdisposal collections were indistinguishable from the concentrations observed in the organisms from the River stations. Therefore, it appeared as though the postdisposal samplings consisted primarily of organisms displaced from the River by the dredging and disposal process.

9. The mean concentrations of Cd, Cu, Mn, and Fe in *Oligochaeta* from the Reference Site samples were slightly higher than, but statistically equivalent to those results from the predisposal collections at the Disposal Site.

10. Metal concentration results for the other four major taxa were based on the analysis of only one or two samples for an entire area. Due to the sparsity of organisms in the samples, the heavy metal content of the other major taxa could not be presented in the same fashion as the results of the *Oligochaeta* without the possibility of misinterpretation. Table A'2 illustrates the mean, standard deviation, and range of metals concentrations found for all samples of each of the major taxa regardless of area or date of sampling.

11. Before pooling of these data for Table A'2, some trends were noted. However, these were not statistically significant. As with the *Oligochaeta* collections, the Chironomidae from the River Sites contained slightly lower levels of Cu, Mn, and Fe than those organisms found at both the Reference and Disposal Sites (from predisposal collections). Due to the small numbers of this group found during postdisposal sampling, no further generalizations could be made. In a similar manner, Gastropoda showed a slight decrease in Mn and Fe concentrations with a statistically significant ($P = 0.026$) decrease in Zn content between pre- and postdisposal samplings. Since no River Site gastropods were found, no comparisons were possible with collections from that site.

12. Analyses of Sphaeriidae yielded the most variable results in terms of metal concentrations from sampling to sampling as well as from

area to area. In contrast to other taxa, Isopoda showed a small but statistically non-significant increase in Cd, Mn, and Fe concentration in the 5-day postdisposal collections.

13. Table A'3 lists the metal concentrations found for three miscellaneous samples. Collections from different stations (as shown on the table) were combined to form two separate Amphipoda samples from two different samplings. One large leech (Hirudinea) also was digested and analyzed. The metals concentrations in this organism were considerably lower than the amount found in most of the organisms of other taxa.

14. Mercury analyses were completed on 14 samples of Oligochaeta from the 5- and 30-day postdisposal collections. Due to the low numbers of organisms collected, no Hg data were acquired for the benthic macro-invertebrates from the River and Reference Sites or the predisposal collection at the Disposal Sites. The mean Hg values (Table A'4) indicate a slight decrease between the two postdisposal collection dates. This decrease was shown to be statistically insignificant. The overall mean Hg content in the organisms was 0.137 $\mu\text{g/g}$ (wet). The mean bulk Hg content of sediments from the same collection times and areas was 0.320 $\mu\text{g/g}$ (wet). One sample of Chironomidae from Station C1 of the 5-day postdisposal sampling also was analyzed for Hg content and the concentration was found to be 0.038 $\mu\text{g/g}$ (wet). This value was considerably less than the amounts in either the Oligochaeta or the Lake sediments.

15. Data are reported in $\mu\text{g/g}$ (wet) due to the low weight of the majority of the samples (i.e. not enough samples to calculate a representative percent of dry weight).

16. Table A'5 illustrates the relationship between the weight of the organisms and their total metals content. The mean weight in milligrams of the organism was calculated using the number of organisms in each sample and the weight of wet samples subjected to digestion. The relative order of weight per single organism was Gastropoda > Isopoda > Sphaeriidae > Chironomidae > Oligochaeta. The number of nanograms of metal per organism based on mean weight was calculated using the mean metals concentration for Table A'2 and the calculated mean weight. Gastropoda had the highest mean weight and also contained the largest amounts

of most metals. Samples of Oligochaeta had the smallest mean weight and contained the lowest amounts of metals. Although these results are based on a relatively small number of organisms, these data were useful in estimating the amount of metals in major taxa and the approximate amount of metals that possibly could be ingested by a predator consuming an "average" organism of each taxon.

PART IV: CONCLUSIONS

17. Oligochaeta analyzed for Fe, Mn, Zn, Cu, Cd, and Hg showed apparent decreases in metals concentrations after the disposal operations. These decreases, which were statistically significant during one and/or both of the postdisposal samplings for Cd, Cu, Zn, and Fe, were believed to be primarily a function of the transfer of organisms from the River Dredged Sites to the Disposal Sites. These organisms exhibited significantly lower concentrations of the above metals than were measured in the indigenous Lake organisms.

18. The small number of organisms available for analyses necessitated the results being expressed on a wet-weight basis. Therefore, precautions should be made when comparing these metal-benthic data to other bulk sediment data of this and/or other studies in which results are reported on a dry-weight basis.

19. These data did not reveal any accelerated uptake of metals by Oligochaeta as a consequence of disposal. This is not to say there was a similar or different impact on other benthic species since no other taxa were closely studied. Also, it could not be verified whether the lower concentrations found in the organisms from the postdisposal collections were the result of the River organisms being carried out by the dredge, indigenous Lake benthic forms that migrated through the disposal materials, and/or other Lake benthos which recolonized the Disposal Area. In each of the latter cases, the lower metal concentrations could have resulted if the heavy metals in the tissues of indigenous Lake organisms reached an equilibrium with the lower sediment metal concentrations in the deposited sediments and/or if the organisms recolonizing the area had lower concentrations of these metals.

20. The continued decrease in metals found in organisms from the 30-day postdisposal collection suggest another possible explanation. If the results observed in the previous collection were indeed a function of the transport of River organisms, the continued decreases by the second postdisposal sampling suggest a survival of the River organism and a relative decline via migration and/or cessation of the indigenous Lake benthos.

21. These data also suggest that the order of magnitude of metals content (Fe > Zn > Mn , Cu > Cd) appears to be the same for each of the different taxa of "mean" weight. The same basic order of concentration, except for an inversion of Zn and Mn, was found in the surrounding sediment (Fe > Mn > Zn > Cu > Cd). Uptake of metals by the organisms (based on the above orders) appears to be more a function of availability rather than selectivity. However, the relatively low Mn concentrations along with the proportionately lower Fe concentrations in the organisms relative to the sediment seem to indicate the presence of factors other than bioaccumulation may be involved.

22. Other information that may be of value to more fully evaluate the results of future studies are: (1) mobility of these organisms in the sedimented materials, (2) a proven method of eliminating ingested sediments from the digestive tracts of the organisms so that metals of organism plus sediments are not measured, and (3) feeding mechanisms of the major taxa.

23. It must be emphasized that site-specific problems and relationships must be considered when extrapolating conclusions about possible effects of open lake disposal from this study to other dredge disposal sites.

TABLE A'1

Comparison of Metal Concentrations in Oligochaeta by Area
(all values $\mu\text{g/g}$ wet)

Metal	Reference Site All Cruises	Mean $\pm 95\%$ Confidence Interval				Disposal Sites July (30-days post)
		Disposal Sites May (predisposal)	River Sites May (predredging)	Disposal Sites June (5-days post)	Disposal Sites July (30-days post)	
Cd	0.72	0.29	0.03	0.13	0.13	
	± 0.61	± 0.09	-	± 0.07	± 0.12	
Cu	11.0	11.6	3.0	3.7	2.7	
	± 9.0	± 4.7	± 2.0	± 0.6	± 0.7	
Mn	18.9	11.1	7.9	7.5	9.1	
	± 14.7	± 3.7	± 5.3	± 2.7	± 2.0	
Zn	152	54.6	21.0	57.2	27.4	
	± 80.8	± 15.5	± 5.2	± 16.8	± 3.0	
Fe	1385	952	450	696	587	
	± 671	± 271	± 341	± 204	± 91	

TABLE A'2

Overall Statistics for Metal Concentrations in Benthos (all values $\mu\text{g/g}$ wet)						
<u>Statistic</u>	<u>Metal</u>	<u>Oligochaeta</u>	<u>Chironomidae</u>	<u>Isopoda</u>	<u>Sphaeriidae</u>	<u>Gastropoda</u>
Mean	Cd	0.24	1.45	0.43	1.88	2.86
Standard Deviation		0.27	1.51	0.33	1.09	0.91
Range		0.02 - 1.16	0.10 - 5.76	0.08 - 1.06	0.03 - 4.55	0.90 - 4.00
	Cu	6.6 6.0	5.0 2.3	36.2 19.1	13.5 7.2	37.6 7.7
		0.4 - 26.7	1.8 - 10.9	10.4 - 95.1	1.2 - 32.7	26.6 - 50.9
	Mn	10.5 6.5	4.8 3.9	24.1 25.1	76.7 59.7	31.7 20.9
		3.3 - 36.9	1.2 - 18.7	2.8 - 83.8	6.2 - 208.0	9.8 - 84.2
	Zn	59.5 47.1	70.8 76.6	271 351	192 222	260 203
		15.8 - 233	10.4 - 259	8.4 - 1360	15.1 - 766	56.4 - 721
	Fe	808 398	237 163	630 341	5,480 5,990	424 128
		214 - 2160	44 - 675	228 - 1280	520 - 23,500	170 - 600

TABLE A'3

Metal Concentration of Minor Taxa
(all values $\mu\text{g/g}$ wet)

<u>Taxa</u>	<u>Amphipoda</u>	<u>Amphipoda</u>	<u>Hirudinea</u>
<u>Stations</u>	SD6, E4	C1, SD7, SD10	E4
<u>Date</u>	Predisposal May 1976	5-Day Postdisposal June 1976	Predisposal May 1976
<u># of Organisms</u>	4	13	1
<u>Cd</u>	0.35	0.59	0.03
<u>Cu</u>	3.5	6.0	1.0
<u>Mn</u>	2.4	6.7	1.5
<u>Zn</u>	278	21.0	30.0
<u>Fe</u>	170	149	33.0

TABLE A'4

Mercury Concentrations in Oligochaeta (all values $\mu\text{g/g}$ wet)					
<u>Date</u>	<u>Station</u>	<u>Value</u>	<u>Date</u>	<u>Station</u>	<u>Value</u>
5-Day Postdisposal June 1976	SD7	0.141	30-Day Postdisposal July 1976	SD6	0.096
		0.125		SD7	0.163
		0.125			0.104
		0.193		SD10	0.125
	SD10	0.194			0.104
		0.110		SD11	0.124
	SD11	0.198			0.120
			<u>Mean</u>		0.119
			<u>Standard Deviation</u>		0.022
			<u>Range</u>		0.096 - 0.163

TABLE A'5

Total Metal Content in Relation to Weight of Benthic Organisms

<u>Weight</u> <u>(milligrams per organism)</u>	<u>Oligochaeta</u>	<u>Chironomidae</u>	<u>Isopoda</u>	<u>Sphaeriidae</u>	<u>Gastropoda</u>
Mean	1.30	5.89	8.35	4.49	33.1
Standard Deviation	0.49	3.21	3.65	2.49	25.2
Range	0.44 - 2.52	1.72 - 12.4	0.60 - 15.5	1.24 - 12.0	5.55 - 81.6
<u>Nanograms</u> <u>of metal</u> <u>per organism</u> <u>of mean weight</u>					
<u>Cd</u>	0.31	10.10	3.59	8.44	94.7
<u>Cu</u>	8.6	29.5	302	60.6	1,240
<u>Mn</u>	13.7	28.3	201	344	1,050
<u>Zn</u>	77.4	417	2,260	862	8,610
<u>Fe</u>	1,050	1,400	5,260	24,600	14,000
<u>Hg</u>	0.178	-	-	-	-

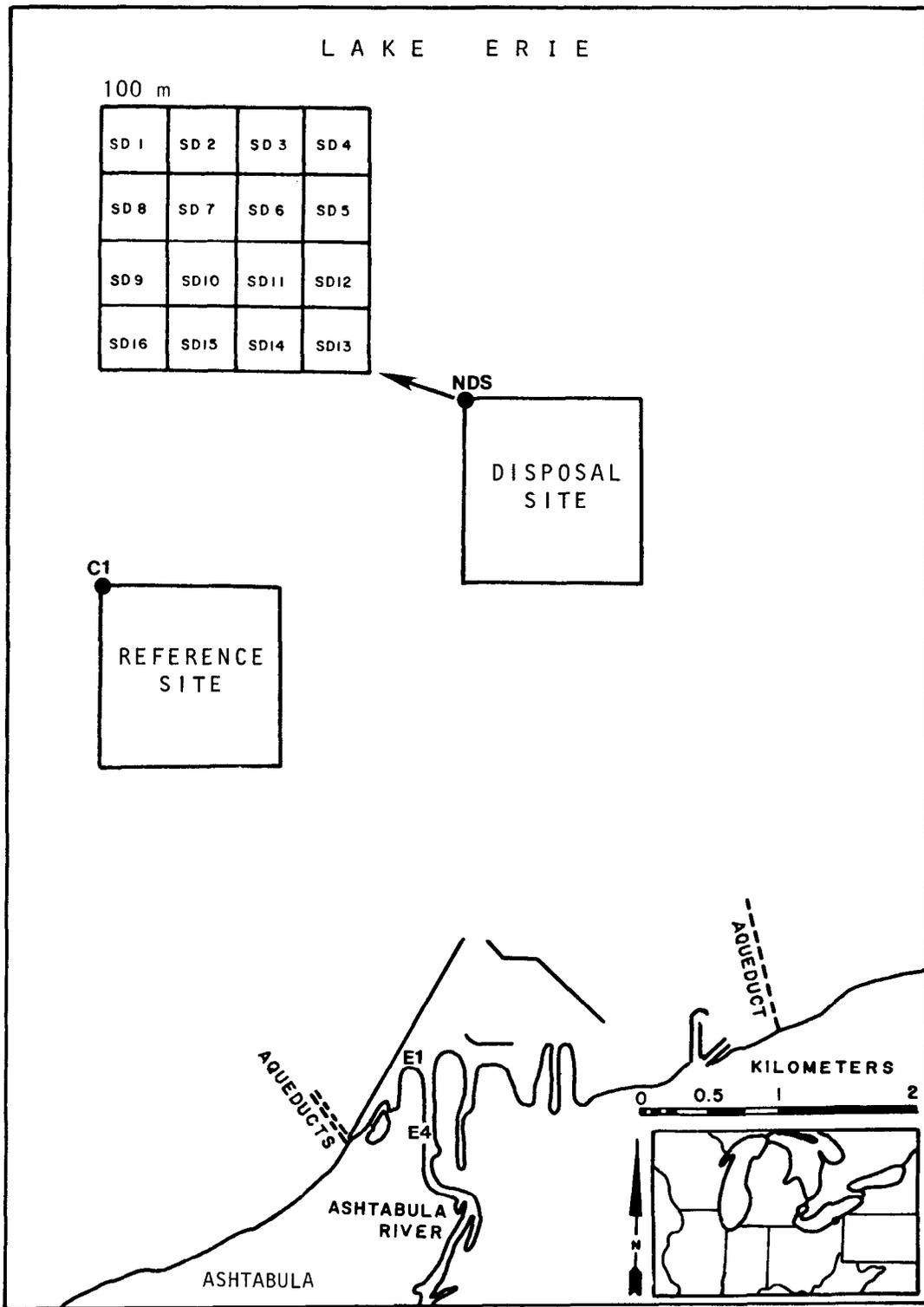
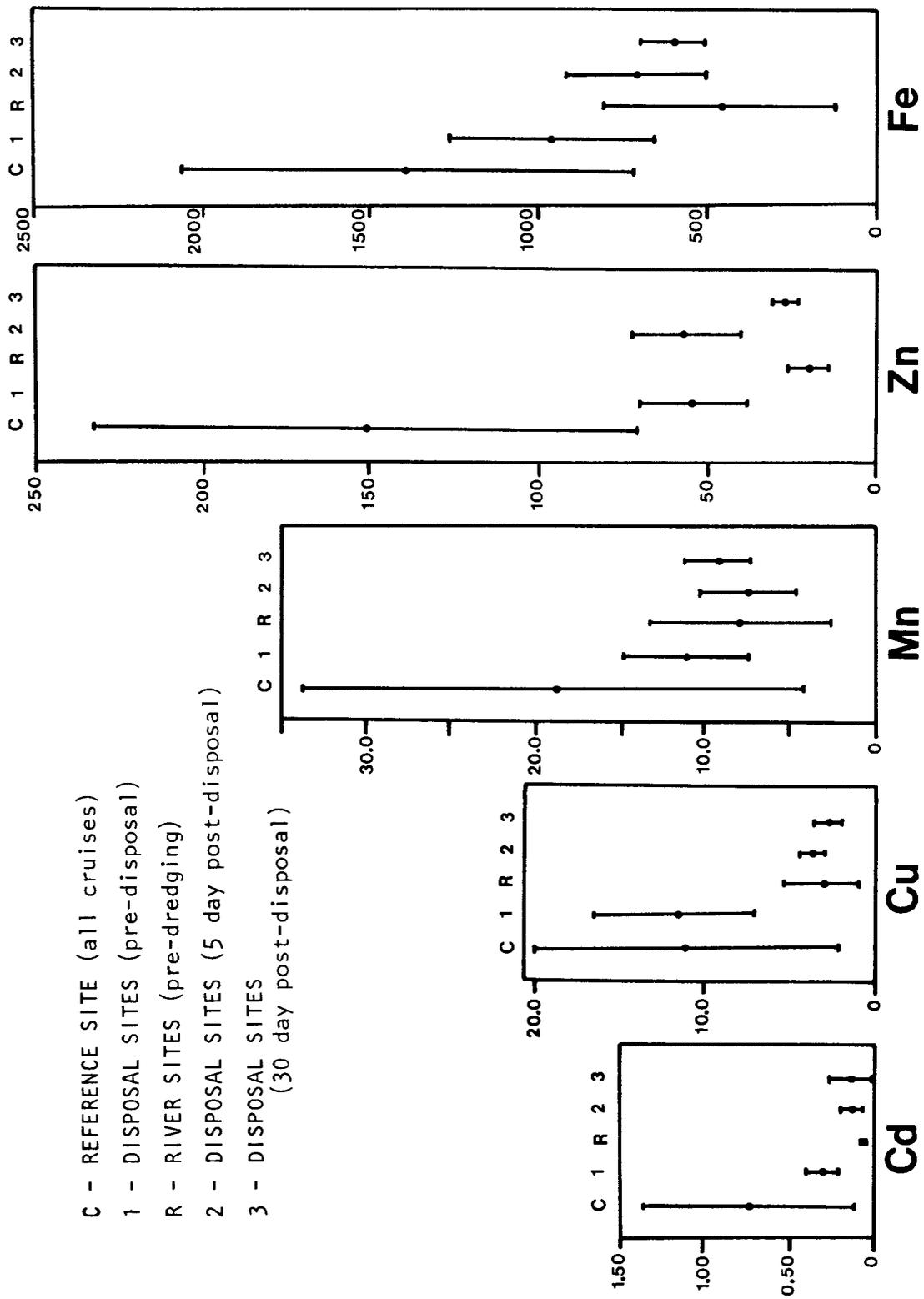


FIGURE A'1. Station locations for sediment sampling at Ashtabula, Ohio



- C - REFERENCE SITE (all cruises)
- 1 - DISPOSAL SITES (pre-disposal)
- R - RIVER SITES (pre-dredging)
- 2 - DISPOSAL SITES (5 day post-disposal)
- 3 - DISPOSAL SITES (30 day post-disposal)

FIGURE A'2. Mean and 95% confidence intervals of metal concentrations in Oligochaeta by area (all values $\mu\text{g/g wet}$)

APPENDIX B': HEAVY METAL CONTENT OF FISH FROM
SELECTED AREAS IN REFERENCE AND DISPOSAL
SITES IN LAKE ERIE OFF ASHTABULA, OHIO

PART I: INTRODUCTION

1. The concern that fish may concentrate trace elements from their external environment and that such pollutants may impact those organisms, including man, that feed directly on fish, prompted the following study to determine concentration levels of mercury (Hg), iron (Fe), lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), and manganese (Mn) in fish prior to and after the disposal of dredged materials. The species were gathered in Lake Erie off Ashtabula, Ohio. This investigation was one phase of an effort to evaluate the impact of disposal on biological aspects of an aquatic environment.

PART II: METHODS

2. A total of 163 fish of 14 species were collected at 6 sites (NDS, D8, D2, F-11, F-18, and 1 mile north of CEI) 10 days before and 5 and 30 days after the 1975 and 1976 dredged material disposal operations. The fish were captured via gill nets by Dr. Andrew White and his associates from the Cleveland Environmental Research Group. The fish were removed from the nets, counted, and classified according to species. The specimens were frozen quickly with dry ice. The fish were transported to the Great Lakes Laboratory (GLL), Buffalo, New York, where the samples were stored at 0° C. Fish collection stations are shown in Figure B'1.

3. In May 1977, the fish were transported to the United States Fish and Wildlife Service Great Lakes Fisheries Laboratory (USFWS) in Ann Arbor, Michigan for sample preparation and measurement of total length and weight of each fish by GLL personnel. Fish were taken to Ann Arbor because the Great Lakes Laboratory did not have the equipment necessary for initial

preparation of the fish. Also, since the USFWS was conducting a Great Lakes Basin-wide survey of contaminants in fish, it was believed that if the GLL used similar techniques and instrumentation, the GLL and USFWS results could be more readily compared. The larger fish (60 in total) were ground using a small Hobart grinder (Model A-210, 1/4 hp, 1725 rpm). Once ground, each sample was homogenized in the grinder collection container, subsampled randomly, and placed in an acid-washed 8-oz glass bottle until the bottles were full or no sample remained in the collection container. All equipment was rinsed and cleaned between each sample with deionized water to prevent contamination among samples. The smaller fish were cut up and placed in separate 8-oz bottles. All samples were immediately stored at 4 °C to minimize deterioration. The sample containers were then brought back to the Great Lakes Laboratory for further sample preparation and analysis.

4. At the Great Lakes Laboratory, the smaller fish were removed from the bottles and individually blended using a Waring Commercial Blender (Model 91-263) until a homogeneous mixture was observed. Each sample was then placed back in the 8-oz bottle in which it had been stored. The larger fish samples were sufficiently homogenized and, therefore, not blended.

5. The following digestion procedure was used to prepare each of the samples for direct aspiration into an atomic absorption spectrophotometer. Approximately 10 g of each wet sample were dried at 70 °C for a 24-hr period. The percent water content was determined for mercury (Hg) analysis. Then 0.50 g of these samples were weighed into 125-ml Erlenmeyer flasks. Ten ml of 30% H₂O₂ were added to each flask to promote the digestion of the organic matter. A slow heating followed to remove excess H₂O₂ to a level where only the bottom of the flask was covered. When the flasks cooled, 10.0 ml of HCl was added and the mixture was slowly heated for a period of 15-30 min. At this point, 20.0 ml of HNO₃ was added and vigorous heating was initiated. These samples were heated until complete digestion of each sample was obtained, which occurred in 1-2 hr. After cooling, the samples were poured on to a 0.45-μ membrane filter and the filtrate was brought up to a 50-ml volume. Analyses of the samples for the previously mentioned

heavy metals, except Hg, were performed using a Model 1200 Varian Techtron Atomic Absorption Spectrophotometer.

6. For Hg analysis, about 1 g of wet sample was used and processed via H_2SO_4 , HNO_3 , $KMnO_4$, and steam autoclave (15 psi for 15 min) digestion procedure. Hg analysis was completed using a Perkin-Elmer Mercury Analyzer System (Coleman Model 50) reading the percent absorbance scale.

7. Prior to their implementation, both digestion procedures were reviewed and approved by Dr. James Seelye, formerly of the U. S. Army Engineer Waterways Experiment Station (WES).

8. Statistical analyses on the data was performed using Pearson Correlation and one-way analyses of variance.

PART III: RESULTS AND DISCUSSION

9. Due to the number and variety of species involved [consisting of 119 perch (Perca flavescens), 4 trout-perch (Percopsis amiscoyus), 12 freshwater drum (Aplodinotus grunniens), 10 smelt (Osmerus mordax), 2 walleye (Stizostedion vitreum vitreum), 1 auger (Stizostedion candense), 2 alewife (Alosa pseudoharengus), 1 carp goldfish hybrid, 1 white bass (Morone chrysops), 3 white suckers (Catostomus commersoni), 1 redhorse (Moxostoma m. macrolepidotum), 2 Eastern quillback carpsucker (Carpionodes c. cyprinus), 4 stone cat (mad tom) (Noturus flavus), and 1 channel cat (Ictalurus punctatus)], these fish were grouped as follows for statistical purposes. The Lake stations were grouped as Reference Area (F-18 site), Disposal Area (NDS, F-11, D2, D8), and 1 mile north of the CEI Area (CEI) for 1975 and 1976 pre- and postdisposal operations. Statistical analysis was run on all fish, then all perch, drum, and smelt were run separately because there was sufficient numbers of each of these species to do so statistically. One-way analysis of variance was run between pre- and postdisposal parameters on the fish from the Reference and Disposal Sites. Means, standard deviations, and ranges were evaluated for each group for each period with the results in Table B'1. Table B'2 is similar to Table B'1, but only with respect to perch. Metal concentrations, weight, and total length of each fish species are given in Table B'3-20. Blanks in these tables indicate lack of sufficient sample for chemical analyses.

10. Comparison of pre- and postdisposal Reference Area fish showed a statistically significant difference in Pb for the 1975 disposal. The mean value for Pb during Predisposal 1975 was 9.3 $\mu\text{g/g}$, with a range of 6 fish samples from 3.0 to 23.0 $\mu\text{g/g}$. The mean value was significantly lower for Pb during Post-dredging 1975 with a value of 1.7 $\mu\text{g/g}$ with a range of 11 samples from < 1.0 to 9.0 $\mu\text{g/g}$. It might also be mentioned that there was a significant difference between pre-

and postdisposal 1975 with respect to Fe ($P = 0.0127$), with a decrease in mean concentration from 171 $\mu\text{g/g}$ to 46 $\mu\text{g/g}$, respectively. The other metals analyzed showed no significant difference. However, all decreased in mean concentration with respect to postdisposal 1975. Reference Area perch showed a significant difference with respect to Pb ($P = 0.0413$) for the 1975 disposal season.

11. Most fish captured in the disposal areas for 1975 showed a statistically significant increase with respect to Fe, Cd, Ni, and Mn after the dredged material disposal operation ($P = 0.0421$, 0.018, 0.028, and 0.0286, respectively). Mean concentrations for Hg, Cd, and Ni doubled after Disposal 1975. For Hg, the mean concentration went from 0.18 $\mu\text{g/g}$ to 0.38 $\mu\text{g/g}$. Cd and Ni followed similar patterns with a 0.7 $\mu\text{g/g}$ to 1.7 $\mu\text{g/g}$ and 1.6 $\mu\text{g/g}$ to 3.8 $\mu\text{g/g}$ increase, respectively. Pb, Cr, and Cu also increased after disposal. It should be mentioned that the mean weights of fish caught at the Reference Area decreased after disposal from 165.7 g to 55.0 g. However, the fish collected in the Disposal Areas exhibited an increase in mean weight after disposal (80.3 g to 153.8 g).

12. Perch showed a significant difference with respect to Hg ($P = 0.0368$), Fe ($P = 0.0472$), Pb ($P = 0.0413$), Cd ($P = 0.0001$), Ni ($P = 0.0019$), and Mn ($P = 0.0058$). All mean metal concentrations in perch increased after the disposal operation. It should be noted that the mean weight of perch increased from 80.2 g to 104.1 g for the 1975 Disposal Area.

13. For the 1976 phase of the study, no fish were collected in the Reference Area prior to the disposal operation. Therefore, samples collected during the postdisposal of 1976 at the Reference Area were compared to predisposal 1975 Reference data. This comparison showed no significant differences between metals.

14. The Disposal Area was sufficiently sampled to show a significant difference from pre- to postdisposal conditions in 1976 with respect to Fe ($P = 0.001$). Fe mean concentrations in fish increased also for Cd, Cr, Cu, and Mn. However, these were not statistically significant. Mean weight decreased from 150.7 g to 115.3 g. Hg and Pb followed similar patterns in decreasing, while Ni mean concentration (3.8 $\mu\text{g/g}$) did not change.

15. Perch, again, showed a significant difference with respect to Hg ($P = 0.0084$) with this mean concentration decreasing from $0.33 \mu\text{g/g}$ to $0.20 \mu\text{g/g}$. Perch mean weight also decreased from 147.3 g to 115.9 g.

16. Drum showed no statistical differences or correlations with respect to metals, weight, or sites during both the 1975 and 1976 disposal years. Smelt showed a positive correlation with respect to Ni and Cu with weight ($P = 0.009$ and 0.017 , respectively) at the Reference Area after Disposal 1975. However, there were no statistical differences during the 1976 disposal year.

17. The CEI Area was sampled after and prior to the 1976 Disposal operations with eight and four fish caught, respectively. The only significant difference was with respect to weight. Postdisposal 1975 collections had a mean weight of 270.0 g with a decrease in Pre-disposal 1976 samples to a mean of 86.8 g.

18. Grouping the fish with respect to the different areas was seen to be the most practical way to handle these data to show any significant differences with respect to heavy metal concentrations as a function of the disposal of dredged materials in Lake Erie. Due to the small number of samples, further breakdown of the data by species, site, and collection period made it impossible to do an ecologically logical vigorous statistical analyses of the data.

PART IV: CONCLUSIONS

19. Generally, the disposal operation for 1975 had an apparently greater impact with respect to the increase in heavy metal concentration than did the 1976 disposal year. All the mean metal concentrations, during the 1975 season, of Hg, Fe, Pb, Cd, Cr, Ni, Cu, and Mn increased with the Fe, Cd, Ni, and Mn data being statistically significant. If fish are concentrators of trace elements from their external environment, then perhaps the disposal operation had an influence on such accumulations. This is provided that the dredged disposal material consisting of possible fish food sources contained higher concentrations of trace elements than originally found in the Disposal Area. However, since the average weight of the captured fish was higher after disposal, this may account for the apparent increase with respect to trace element concentrations. Heavier fish concentrate a larger quantity of trace elements in their body tissue. Since fish have been known to migrate considerable distances, perhaps the fish caught in the Disposal Area were not originally from that region. The fish may have just entered the area on the day they were caught. Other factors influencing heavy metal content are the eating habits of these fish. The disposal operation could have caused the fish originally in the area to feed elsewhere.

20. For 1976 samplings, the only statistically significant increase was with respect to Fe. In 1976, Hg in the fish decreased as compared to an increase in the 1975 season.

21. From these data it was noted that the magnitude of metal concentrations of fish show a resemblance to the concentrations found in the sediments of the study area; that is, $Fe > Mn > Cu > Cd$. The heavy metals in the benthic macroinvertebrates from these areas followed a similar pattern. It should be noted that the heavy metal concentrations in the dredged material was lower than those in the "natural" Lake sediment. Likewise, the heavy metals in the macroinvertebrates from the dredged areas were lower than those in Lake Erie off Ashtabula.

22. Several of the Hg concentrations were above the maximum permissible level of 0.5 mg/kg established by the U. S. Food and Drug Administration (U. S. FDA). This warrants further studies of heavy metal

contamination of edible game fish. Dredged material should be included in such an investigation.

23. To say that the disposal of dredged material in Lake Erie caused the significant increase or decrease in the concentration of trace elements in the fish was impossible. Other external factors such as the trace elements valence, nature, and concentration of the element in the surrounding volume of water, the form of the element in water or food source (e.g. soluble chelate), pH, time of exposure to the element, temperature, dissolved oxygen, condition of the fish species, water currents, and eating habits can influence the uptake of trace elements by fish.

TABLE B'1

Overall Statistics for Weight and Metal Concentrations in Fish Groups

	1975		Reference Area Pre-75 6 Samples	Disposal Area Pre-75 19 Samples	Reference Area Post-75 11 Samples	Disposal Area Post-75 44 Samples	1 mi N CEI Area Post-75 8 Samples
	Mean	Standard Deviation Range					
Wt (g)	165.7	167.7 29.0-402.0	0.51	80.3 54.1 26.0-279.0	55.0 37.0 16.0-140.0	153.8 244.0 12.2-1429.0	270.0 275.6 35.0-773.0
Hg ($\mu\text{g/g}$ dry)	0.44	0.03-1.05	0.11 0.01-0.46	0.18	0.25	0.38	0.31
Fe ($\mu\text{g/g}$ dry)	171	137 58-440	9.3	110 149 7-680	46 25 19-110	197 129 35-605	181 245 53-781
Pb ($\mu\text{g/g}$ dry)	7.6	3.0-23.0	5.9	2.5 3.4 <1.0-15.0	1.7 2.4 <1.0-9.0	5.3 6.0 <1.0-23.0	5.5 4.6 <1.0-13.0
Cd ($\mu\text{g/g}$ dry)	0.6	<0.1-29.3	0.6	0.7 0.7 <0.1-3.3	0.6 0.7 <0.1-2.2	1.7 1.2 <0.1-7.0	0.9 0.5 0.2-1.6
Cr ($\mu\text{g/g}$ dry)	1.2	<0.1-3.0	0.6	0.3 0.4 <0.1-1.5	1.1 2.4 <0.1-8.2	1.1 2.3 <0.1-9.2	0.8 1.4 <0.1-4.0

(CONTINUED)

TABLE B'1 (CONTINUED)

1975 (concluded)	Reference Area Pre-75 6 Samples	Disposal Area Pre-75 19 Samples	Reference Area Post-75 11 Samples	Disposal Area Post-75 44 Samples	1 mi N CEI Area Post-75 8 Samples
Mean	4.2	1.6	2.5	3.8	3.8
Standard Deviation	1.7	0.9	2.3	2.5	3.8
Range	2.0-7.0	<1.0-4.0	<1.0-9.0	<1.0-11.0	<1.0-10.0
Mean	3.6	4.0	3.2	5.8	3.5
Standard Deviation	1.0	4.8	0.9	4.0	1.2
Range	2.4-5.0	2.2-23.8	1.8-4.6	0.8-23.4	2.2-5.2
Mean	15.1	11.6	10.2	17.8	10.5
Standard Deviation	4.8	7.1	4.2	10.0	2.5
Range	7.5-20.4	5.6-37.8	5.9-17.9	1.9-50.4	7.8-12.9

(CONTINUED)

TABLE B'1 (CONTINUED)

	1976	Disposal Area Pre-76 26 Samples	1 mi N CEI Area Pre-76 4 Samples	Reference Area Post-76 9 Samples	Disposal Area Post-76 36 Samples
Wt (g)		150.7	86.8	150.2	115.3
Mean Standard Deviation Range		120.2 17.0-457.0	130.8 20.0-283.0	149.2 19.0-494.0	126.2 21.0-500.0
Hg (µg/g dry)		0.49	0.50	0.32	0.20
Mean Standard Deviation Range		0.39 0.08-1.58	0.18 0.31-0.74	0.17 0.15-0.63	0.12 0.1-0.5
Fe (µg/g dry)		172	161	102	252
Mean Standard Deviation Range		98 47-405	121 48-325	65 43-236	205 53-891
Pb (µg/g dry)		4.4	7.0	3.9	4.3
Mean Standard Deviation Range		6.4 <1.0-23.0	4.3 <1.0-11.0	6.6 <1.0-21.0	5.2 <1.0-19.0
Cd (µg/g dry)		1.0	2.2	1.2	3.5
Mean Standard Deviation Range		0.6 <0.1-2.1	1.3 1.2-4.1	0.8 0.1-2.5	10.2 0.2-62.0
Cr (µg/g dry)		0.2	0.1	0.3	0.6
Mean Standard Deviation Range		0.3 <0.1-1.0	0 <0.1	0.6 <0.1-2.0	1.5 <0.1-8.8

(CONTINUED)

TABLE B'1 (CONCLUDED)

1976 (concluded)	Disposal Area Pre-76 26 Samples	1 mi N CEI Area Pre-76 4 Samples	Reference Area Post-76 9 Samples	Disposal Area Post-76 36 Samples
Ni (µg/g dry)	Mean	4.8	4.0	3.8
	Standard Deviation	7.5	4.7	2.7
	Range	<1.0-16.0	<1.0-15.0	<1.0-11.0
Cu (µg/g dry)	Mean	10.5	4.1	5.6
	Standard Deviation	6.7	1.9	2.7
	Range	4.8-20.2	1.4-7.6	0.8-11.4
Mn (µg/g dry)	Mean	17.8	13.9	15.8
	Standard Deviation	10.2	9.1	9.0
	Range	4.9-29.8	6.3-34.6	<0.1-47.0

TABLE B'2
Overall Statistics for Weight and Metal
Concentrations in Perch Groups

		Reference Area Pre-75 <u>3 Samples</u>	Disposal Area Pre-75 <u>19 Samples</u>	Reference Area Post-75 <u>6 Samples</u>	Disposal Area Post-75 <u>36 Samples</u>
Wt. (g)	Mean	33.3	80.2	77.7	104.1
	Standard Deviation	3.8	54.1	34.6	116.1
	Range	29.0-36.0	26.0-279.0	41.0-140.0	29.0-597.0
Hg (µg/g dry)	Mean	0.13	0.18	0.20	0.26
	Standard Deviation	0.11	0.11	0.13	0.15
	Range	0.03-0.24	0.01-0.46	0.07-0.39	0.07-0.74
Fe (µg/g dry)	Mean	92	110	48	189
	Standard Deviation	31	149	34	128
	Range	58-119	7-680	19-110	37-605
Pb (µg/g dry)	Mean	13.0	2.5	1.0	5.4
	Standard Deviation	9.2	3.4	-	5.5
	Range	5.0-23.0	<1.0-15.0	<1.0-1.0	<1.0-19.0
Cd (µg/g dry)	Mean	10.5	0.7	1.0	1.6
	Standard Deviation	16.3	0.7	0.7	0.8
	Range	<0.1-29.3	<0.1-3.3	0.2-2.2	0.1-2.9
Cr (µg/g dry)	Mean	1.1	0.3	1.5	1.0
	Standard Deviation	1.7	0.4	3.3	2.3
	Range	<0.1-3.0	<0.1-1.5	<0.1-8.2	<0.1-9.2
Mn (µg/g dry)	Mean	4.0	1.6	3.5	4.3
	Standard Deviation	1.0	0.9	2.8	3.4
	Range	3.0-5.0	<1.0-4.0	<1.0-9.0	<1.0-18.0
Cu (µg/g dry)	Mean	4.4	4.0	3.5	6.4
	Standard Deviation	0.5	4.8	1.2	4.0
	Range	4.0-5.0	2.2-23.8	1.8-4.6	2.4-23.4
Mn (µg/g dry)	Mean	16.7	11.6	10.8	18.9
	Standard Deviation	4.8	7.1	5.1	9.4
	Range	11.3-20.4	5.6-37.8	5.9-17.9	4.6-50.4

(CONTINUED)

TABLE B'2 (CONCLUDED)

		Disposal Area Pre-76 <u>12 Samples</u>	Reference Area Post-76 <u>8 Samples</u>	Disposal Area Post-76 <u>31 Samples</u>
Wt (g)	Mean	147.3	143.0	115.9
	Standard Deviation	142.1	157.8	124.4
	Range	33.0-457.0	19.0-494.0	23.0-500.0
Hg ($\mu\text{g/g}$ dry)	Mean	0.33	0.32	0.20
	Standard Deviation	0.16	0.18	0.12
	Range	0.10-0.75	0.15-0.63	<0.01-0.50
Fe ($\mu\text{g/g}$ dry)	Mean	152	93	263
	Standard Deviation	104	64	212
	Range	47-405	43-236	53-891
Pb ($\mu\text{g/g}$ dry)	Mean	3.5	4.3	4.6
	Standard Deviation	5.5	6.9	5.4
	Range	<1.0-17.0	<1.0-21.0	<1.0-19.0
Cd ($\mu\text{g/g}$ dry)	Mean	1.0	1.4	3.9
	Standard Deviation	0.6	0.7	10.9
	Range	<0.1-2.1	0.6-2.5	0.8-62.0
Cr ($\mu\text{g/g}$ dry)	Mean	0.3	0.3	0.7
	Standard Deviation	0.3	0.7	1.7
	Range	<0.1-1.0	<0.1-2.0	<0.1-8.8
Ni ($\mu\text{g/g}$ dry)	Mean	3.0	4.4	4.1
	Standard Deviation	2.2	4.9	2.7
	Range	<1.0-8.0	<1.0-15.0	<1.0-11.0
Cu ($\mu\text{g/g}$ dry)	Mean	5.3	4.5	5.9
	Standard Deviation	2.4	1.8	2.6
	Range	2.2-10.4	1.6-7.6	2.2-11.4
Mn ($\mu\text{g/g}$ dry)	Mean	11.7	14.6	16.3
	Standard Deviation	5.3	9.4	9.5
	Range	4.2-20.4	6.3-34.6	<0.1-47.0

TABLE B'3

<u>Metal Concentrations, Weight and Total Length of Perch Caught at Station F18 on 31 July 1975</u>									
<u>Wt (g)</u>	<u>Length (cm)</u>	<u>Hg ($\mu\text{g/g dry}$)</u>	<u>Fe ($\mu\text{g/g dry}$)</u>	<u>Pb ($\mu\text{g/g dry}$)</u>	<u>Cd ($\mu\text{g/g dry}$)</u>	<u>Cr ($\mu\text{g/g dry}$)</u>	<u>Ni ($\mu\text{g/g dry}$)</u>	<u>Cu ($\mu\text{g/g dry}$)</u>	<u>Mn ($\mu\text{g/g dry}$)</u>
36.0	14.4	0.03	98	11.0	2.0	<0.1	3.0	4.0	18.3
35.0	14.2	0.11	58	5.0	<0.1	<0.1	4.0	4.2	11.3
29.0	13.3	0.24	119	23.0	29.3	3.0	5.0	5.0	20.4

TABLE B'4

<u>Metal Concentrations, Weight and Total Length of Perch Caught at Station F18 on 19-20 August 1975</u>									
<u>Wt (g)</u>	<u>Length (cm)</u>	<u>Hg ($\mu\text{g/g dry}$)</u>	<u>Fe ($\mu\text{g/g dry}$)</u>	<u>Pb ($\mu\text{g/g dry}$)</u>	<u>19 August 1975</u>		<u>Ni ($\mu\text{g/g dry}$)</u>	<u>Cu ($\mu\text{g/g dry}$)</u>	<u>Mn ($\mu\text{g/g dry}$)</u>
					<u>Cd ($\mu\text{g/g dry}$)</u>	<u>Cr ($\mu\text{g/g dry}$)</u>			
80.0	18.2	0.15	39	<1.0	0.7	0.2	3.0	4.0	9.0
78.0	18.1	0.29	110	<1.0	1.0	0.5	2.0	4.0	16.4
41.0	14.5	0.07	65	1.0	2.2	8.2	9.0	4.6	17.9
<u>20 August 1975</u>									
140.0	22.2	0.39	30	<1.0	1.0	<0.1	3.0	4.2	7.8
77.0	17.4	0.08	25	<1.0	1.1	<0.1	3.0	2.2	7.6
50.0	15.7	0.22	19	<1.0	0.2	<0.1	<1.0	1.8	5.9

TABLE B'5

Metal Concentrations, Weight and Total Length of Perch Caught at Station F11 on 31 July 1975										
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)	
279.0	27.2	0.31	69	5.0	1.2	<0.1	2.0	2.6	9.5	
123.0	20.4	0.46	162	5.0	<0.1	0.5	<1.0	2.8	5.6	
112.0	20.0	0.30	182	<1.0	0.7	<0.1	1.0	3.6	12.5	
100.0	19.5	0.22	66	1.0	0.9	<0.1	1.0	4.8	6.5	
79.0	18.5	0.13	22	<1.0	0.4	<0.1	<1.0	2.4	8.5	
78.0	18.7	0.11	63	5.0	0.5	0.5	3.0	23.8	8.3	
77.0	18.2	0.11	156	<1.0	0.1	<0.1	<1.0	3.2	8.9	
75.0	18.0	0.23	155	<1.0	<0.1	<0.1	<1.0	2.4	16.8	
73.5	17.6	0.06	71	15.0	1.0	1.5	<1.0	2.8	37.8	
73.0	17.6	0.14	157	<1.0	<0.1	0.2	<1.0	3.0	14.1	
66.0	16.7	0.25	20	<1.0	0.4	<0.1	2.0	2.2	8.8	
65.0	16.7	0.28	52	<1.0	0.4	<0.1	4.0	3.0	10.6	
63.0	16.7	0.01	86	<1.0	0.8	1.0	<1.0	2.8	7.9	
62.0	16.8	0.12	7	<1.0	<0.1	<0.1	2.0	3.2	11.3	
57.0	15.5	0.11	41	<1.0	<0.1	<0.1	<1.0	2.2	10.4	
45.0	15.2	0.12	27	<1.0	1.2	<0.1	<1.0	2.6	10.5	
43.0	15.1	0.13	30	<1.0	3.3	<0.1	3.0	2.4	8.6	
29.0	13.3	0.15	50	3.0	0.6	<0.1	1.0	2.6	13.0	
26.0	12.9	0.12	680	<1.0	0.6	<0.1		3.8		

TABLE B'6

Metal Concentrations, Weight and Total Length of Perch Caught at Station D8 on 19 August 1975										
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)	
113	19.9	0.23	245	7.0	1.0	<0.1	18.0	10.6	14.1	
81.0	18.5	0.18	59	<1.0	0.4	<0.1	3.0	10.0	12.5	
80.0	18.1	0.19	56	1.0	0.6	<0.1	<1.0	8.0	16.9	
72.0	18.2	0.19	37	11.0	1.0	<0.1	2.0	3.0	6.2	

TABLE B'7

<u>Metal Concentrations, Weight and Total Length of Perch Caught at Station D8 on 18 September 1975</u>										
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)	
110.0	21.2	0.41	128	<1.0	1.5	0.2	3.0	2.4	10.2	
83.0	19.5	0.20	78	<1.0	0.8	<0.1	2.0	3.8	15.0	
32.0	14.5	0.21	79	<1.0	1.0	<0.1	11.0	3.2	13.6	
31.0	14.4	0.26	204	17.0	2.5	1.0	5.0	6.8	23.6	

TABLE B'8

<u>Metal Concentrations, Weight and Total Length of Perch Caught at Station CEI on 18 September 1975</u>										
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)	
75.0	19.0	0.37	166	<1.0	0.7	4.0	9.0	5.2	12.1	
68.0	19.0	0.13	53	<1.0	1.1	<0.1	1.0	5.0	11.9	
48.0	16.3	0.18	72	7.0	1.5	<0.1	<1.0	2.8	11.9	
35.0	15.0	0.26	72	13.0	1.6	<0.1	1.0	3.0	12.2	

TABLE B'9

Metal Concentrations, Weight, and Total Length of Perch Caught at Station F11 on 24 May 1976										
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)	
457.0	30.5	0.75	405	1.0	2.1	<0.1	3.0	3.8	9.2	
358.0	28.8	0.27	146	17.0	1.7	<0.1	4.0	5.6	17.9	
278.0	26.7	0.50	57	<1.0	0.2	0.5	8.0	10.4	4.2	
169.0	23.5	0.32	47	<1.0	1.4	<0.1	3.0	4.4	8.3	
137.0	21.8	0.10	74	13.0	1.3	<0.1	<1.0	2.2	11.7	
78.0	18.0	0.19	191	<1.0	0.1	<0.1	<1.0	4.0	6.8	
57.0	16.8	0.30	49	<1.0	0.1	0.2	1.0	2.8	4.6	
57.0	16.5	0.23	167	<1.0	0.6	1.0	5.0	4.2	11.6	
56.0	15.8	0.26	98	3.0	0.6	<0.1	2.0	5.6	18.0	
55.0	15.4	0.31	134	1.0	1.0	0.5	<1.0	4.4	14.1	
33.0	13.8	0.35	249	<1.0	1.3	0.5	2.0	7.0	13.7	
33.0	14.0	0.32	210	<1.0	1.0	<0.1	5.0	8.8	20.4	

TABLE B'10

Metal Concentrations, Weight, and Total Length of Perch Caught at Station NDS on 14 June 1976										
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)	
500.0	30.3	0.50	223	11.0	2.0	<0.1	<1.0	4.0	10.2	
415.0	29.0	0.26	145	<1.0	1.7	<0.1	3.0	4.2	5.2	
330.0	27.2	0.37	123	<1.0	1.9	<0.1	5.0	3.4	14.5	
307.0	25.7	0.37	141	<1.0	2.4	<0.1	2.0	3.4	16.1	
142.0	20.2	0.37	305	1.0	2.6	<0.1	4.0	8.6	15.5	
87.0	19.1	0.31	138	<1.0	1.6	<0.1	3.0	3.8	<0.1	
65.0	17.8	0.29	293	14.0	2.0	<0.1	10.0	7.8	10.0	
64.0	16.9	0.10	180	<1.0	1.0	<0.1	2.0	4.6	8.1	
57.0	16.3		169	3.0	62.0	8.8	5.0	6.8	16.8	
54.0	16.2	0.08	588	<1.0	0.9	<0.1	4.0	2.2	8.7	
45.0	15.6	0.11	100	3.0	1.3	<0.1	8.0	5.0	18.0	
39.0	15.3	0.06	891	1.0	1.8	<0.1	6.0	6.2	38.7	

(CONTINUED)

TABLE B'10 (CONCLUDED)

Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)
37.0	14.5	0.27	689	<1.0	1.4	<0.1	3.0	5.0	21.6
36.0	13.9		215	5.0	1.5	0.8	1.0	4.2	21.6
34.0	14.0	0.13	326	15.0	2.2	<0.1	8.0	7.8	19.7
33.0	14.4	<0.01	170	5.0	2.5	<0.1	7.0	9.6	28.9
23.0	12.2	0.04	163	<1.0	0.9	2.8	3.0	6.4	47.0

TABLE B'11

<u>Metal Concentrations, Weight, and Total Length of Perch Caught at Station D8 on 13 June 1976</u>									
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)
597.0	33.2	0.67	59	<1.0	0.1	<0.1	<1.0	2.4	8.6
143.0	21.7	0.25	145	<1.0	0.2	<0.1	6.0	5.6	14.1
91.0	19.5	0.27	97	3.0	1.3	<0.1	4.0	4.4	18.1
86.0	19.6	0.74	307	19.0	2.4	8.0	8.0	13.2	25.8
75.0	18.1	0.29	241	<1.0	1.2	<0.1	6.0	5.8	22.7
62.0	16.5	0.13	92	5.0	0.6	<0.1	<1.0	4.0	8.7
53.0	16.2	0.15	154	<1.0	0.7	<0.1	<1.0	3.6	4.6
42.0	14.4	0.17	75	9.0	1.2	<0.1	1.0	4.0	11.6
35.0	14.5	0.16	96	7.0	1.5	<0.1	1.0	3.6	19.8
29.0	13.8	0.24	164	11.0	1.9	<0.1	8.0	4.4	19.4

TABLE B'12

Metal Concentrations, Weight, and Total Length of Perch
Caught at Station D2 on 14 June 1976

Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)
404.0	30.4	0.64	183	<1.0	1.7	0.2	5.0	3.6	8.0
374.0	28.5	0.46	206	5.0	1.7	6.5	5.0	3.6	7.2
147.0	22.4	0.27	307	13.0	1.5	<0.1	5.0	8.0	14.1
115.0	20.6	0.40	232	<1.0	2.7	<0.1	5.0	11.6	18.8
115.0	19.8	0.13	297	<1.0	1.8	9.2	3.0	10.0	18.1
106.0	20.6	0.32	291	<1.0	2.3	1.5	3.0	7.0	14.5
68.0	16.6	0.13	213	13.0	2.7	<0.1	7.0	5.4	29.2
66.0	16.5	0.16	168	1.0	2.8	<0.1	5.0	4.4	50.4
63.0	16.1	0.21	88	15.0	2.2	<0.1	1.0	8.2	28.4
63.0	16.0	0.24	155	7.0	2.0	<0.1	4.0	4.8	30.4
62.0	16.2	0.19	351	<1.0	1.6	<0.1	1.0	5.6	23.0
61.0	16.8	0.17	92	1.0	2.8	4.5	6.0	5.0	17.7
61.0	15.0	0.07	287	3.0	1.8	<0.1	4.0	23.4	26.2
59.0	17.4	0.37							
51.0	15.9	0.15	164	7.0	2.6	0.8	4.0	4.4	20.8
49.0	15.5	0.22	605	<1.0	2.8	<0.1	1.0	7.0	28.8
35.0	15.0	0.16	536	5.0	2.9	<0.1	3.0	6.6	33.7
32.0	14.2	0.20	123	15.0	2.1	<0.1	5.0	5.6	26.6

TABLE B'13

Metal Concentrations, Weight, and Total Length of Perch Caught at Station F18 on 9 July 1976									
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)
494.0	31.0	0.63	46	<1.0	0.6	<0.1	<1.0	1.6	6.3
238.0	24.8	0.36	45	5.0	2.5	<0.1	4.0	4.8	15.2
125.0	20.2	0.25	71	3.0	1.1	<0.1	5.0	5.8	9.7
103.0	21.2	0.55	236	21.0	2.2	2.0	7.0	7.6	11.7
77.0	18.2	0.19	43	<1.0	1.1	<0.1	<1.0	4.6	11.7
64.0	17.3	0.24	91	<1.0	0.7	<0.1	<1.0	3.8	6.6
24.0	12.6	0.17	93	<1.0	0.9	<0.1	15.0	3.6	21.2
19.0	11.8	0.15	122	1.0	1.8	<0.1	1.0	3.8	34.6

TABLE B'14

Metal Concentrations, Weight, and Total Length of Perch Caught at Station NDS on 9 July 1976									
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)
346.0	28.9	0.21	78	5.0	0.8	<0.1	2.0	2.6	6.9
123.0	20.9	0.16	117	<1.0	1.0	1.5	<1.0	10.0	11.3
120.0	19.2	0.17	86	1.0	2.2	1.5	3.0	6.2	13.5
108.0	19.3	0.29	252	<1.0	1.5	<0.1	2.0	10.4	17.1
101.0	20.3	0.32	301	13.0	1.5		5.0	10.6	18.2
80.0	18.2	0.21	215	11.0	1.5	<0.1	4.0	4.2	13.0
77.0	17.8	0.09	92	<1.0	10.3	<0.1	5.0	3.2	7.2
68.0	16.7	0.05	59	<1.0	1.0	1.2	1.0	8.2	23.4
64.5	16.4	0.08	53	<1.0	0.8	0.8	3.0	3.8	10.0
64.5	17.3	0.10	234	<1.0	3.0	1.0	1.0	3.4	7.7
57.0	15.7	0.18	250	13.0	1.7	<0.1	11.0	5.6	21.8
52.0	15.6	0.13	810	7.0	1.3	<0.1	<1.0	2.8	15.1
39.0	14.4	0.20	320	<1.0	1.6	<0.1	8.0	7.2	17.3
26.0	12.5	0.23	415	19.0	2.4	<0.1	5.0	11.4	21.2

TABLE B'15

<u>Metal Concentrations, Weight and Total Length of Trout Perch Caught at Station CEI on 24 May 1976 and Station NDS on 14 June 1976</u>											
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)		
<u>24 May 1976</u>											
22.0	13.0	0.50	325	11.0	4.1	<0.1	16.0	20.2	29.8		
22.0	13.1	0.46	99	<1.0	1.5	<0.1	<1.0	4.8	18.5		
20.0	12.8	0.31	172	7.0	1.8	<0.1	1.0	8.0	17.8		
<u>14 June 1976</u>											
30.0	14.1	0.37	459	9.0	2.2	<0.1	2.0	5.8	14.9		

TABLE B'16

<u>Metal Concentrations, Weight and Total Length of Drum Caught at Station F18 on 31 July 1975 and 9 July 1976</u>											
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)		
<u>31 July 1975</u>											
402.0	34.2	0.95	171	11.0	2.4	<0.1	7.0	3.2	16.9		
344.0	30.2	1.05	141	3.0	0.6	<0.1	2.0	2.8	7.5		
148.0	25.7	0.66	440	3.0	0.3	<0.1	4.0	2.4	15.9		
<u>9 July 1976</u>											
208.0	25.2	0.32	169	<1.0	0.1	<0.1	<1.0	1.4	7.9		

TABLE B'17

<u>Metal Concentrations, Weight and Total Length of Drum Caught at Station F11 on 24 May 1976</u>									
<u>Wt (g)</u>	<u>Length (cm)</u>	<u>Hg ($\mu\text{g/g dry}$)</u>	<u>Fe ($\mu\text{g/g dry}$)</u>	<u>Pb ($\mu\text{g/g dry}$)</u>	<u>Cd ($\mu\text{g/g dry}$)</u>	<u>Cr ($\mu\text{g/g dry}$)</u>	<u>Ni ($\mu\text{g/g dry}$)</u>	<u>Cu ($\mu\text{g/g dry}$)</u>	<u>Mn ($\mu\text{g/g dry}$)</u>
					<u>24 May 1976</u>				
324.0	30.6	0.93	195	1.0	1.4	<0.1	6.0	3.4	18.5
168.0	24.3	0.08	185	<1.0	1.5		9.0	11.4	12.9
164.0	23.6	0.12	118	9.0	0.6		9.0	9.2	14.6
100.0	21.1	0.13	199	5.0	1.8	<0.1	5.0	10.4	23.1
19.0	12.5	0.30	142	<1.0	0.8	<0.1	1.0	4.6	31.5

TABLE B'18

<u>Metal Concentrations, Weight and Total Length of Drum Caught at Station D8 on 18 September 1975 and Station NDS on 9 July 1976</u>									
<u>Wt (g)</u>	<u>Length (cm)</u>	<u>Hg ($\mu\text{g/g dry}$)</u>	<u>Fe ($\mu\text{g/g dry}$)</u>	<u>Pb ($\mu\text{g/g dry}$)</u>	<u>Cd ($\mu\text{g/g dry}$)</u>	<u>Cr ($\mu\text{g/g dry}$)</u>	<u>Ni ($\mu\text{g/g dry}$)</u>	<u>Cu ($\mu\text{g/g dry}$)</u>	<u>Mn ($\mu\text{g/g dry}$)</u>
					<u>18 September 1975</u>				
202.0	26.5		259	3.0	2.7	4.2	5.0	4.8	20.1
91.5	33.7	1.99	215	5.0	7.0	3.2	4.0	7.0	14.5
					<u>9 July 1976</u>				
38.0	15.2	0.17	129	<1.0	0.8	<0.1	2.0	5.2	15.0

TABLE B'19

Metal Concentrations, Weight and Total Length of Smelt Caught at Stations F18, NDS, and F11 on Various Dates										
Wt (g)	Length (cm)	Hg ($\mu\text{g/g dry}$)	Fe ($\mu\text{g/g dry}$)	Pb ($\mu\text{g/g dry}$)	Cd ($\mu\text{g/g dry}$)	Cr ($\mu\text{g/g dry}$)	Ni ($\mu\text{g/g dry}$)	Cu ($\mu\text{g/g dry}$)	Mn ($\mu\text{g/g dry}$)	
<u>Station F18 on 19-20 August 1975</u>										
36.0	18.5	0.54	47	<1.0	0.4	<0.1	3.0	3.8	7.3	
19.0	15.7		41	9.0	<0.1	<0.1	<1.0	3.0	13.9	
17.0	14.5		47	<1.0	0.2	2.2	<1.0	2.8	6.4	
16.0	15.2		27	<1.0	<0.1	<0.1	<1.0	2.6	7.8	
<u>Station NDS on 20 August 1975</u>										
13.0	15.0	0.32	73	<1.0	0.6	1.2	<1.0	8.4	26.4	
12.2	14.5	2.13	191	23.0	2.2	1.2	7.0	11.2	9.1	
<u>Station NDS on 9 July 1976</u>										
21.0	16.7	0.23	84	<1.0	0.4	<0.1	<1.0	2.8	9.5	
<u>Station F11 on 24 May 1976</u>										
67.0	21.5	0.44	68	<1.0	<0.1	<0.1	1.0	2.6	9.3	
45.0	20.0	0.58	91	<1.0	1.7	<0.1	6.0	5.8	24.2	
17.0	15.9		110	<1.0	1.0	0.5	2.0	4.0	16.4	

TABLE B-20

Metal Concentrations, Weight and Total Length
of Various Species Caught during the 1975-1976 Disposal Season

Species	Station	Date	Year	Weight (g)	Length (cm)	------(µg/g dry)-----									
						Hg	Fe	Pb	Cd	Cr	Ni	Cu	Mn		
Walleye D-8	CEI	Sept 18	1975	325.0	32.2	0.77	475	<1.0	<0.1	<0.1	3.0	1.4	5.2		
		Sept 18	1975	255.0	30.9	0.46	781	9.0	0.9	<0.1	10.0	4.4	5.1		
Sauger D-2		Sept 5	1975	409.0	34.4	0.61	35	<1.0	<0.1	<0.1	<1.0	0.8	1.9		
		Aug 19	1975	51.0	17.8	0.22	52	1.0	<0.1	<0.1	<1.0	2.6	12.7		
Alewife F-18	NDS	July 9	1976	88.0	17.0	0.20	113	<1.0	0.4	<0.1	2.0	3.4	17.4		
		Carp/Goldfish Hybrid													
D-8		Sept 18	1975	1429.0	43.8	0.13	133	<1.0	<0.1	<0.1	<1.0	1.8	4.0		
White Bass CEI		May 24	1976	283.0	28.0	0.74	48	9.0	1.2	<0.1	1.0	9.0	4.9		
		May 24	1976	354.0	29.9	0.40	165	<1.0	0.3	<0.1	7.0	4.0	8.1		
White Sucker F-11	NDS	May 24	1976	244.0	28.3	0.47	310	<1.0	<0.1	0.8	2.0	4.6	7.2		
		July 9	1976	380.0	31.6	0.20	146	<1.0	0.2	<0.1	3.0	0.8	7.7		
Golden Red Horse (Sucker) CEI		Sept 18	1975	773.0	39.0	0.54	105	9.0	0.4	1.5	5.0	2.4	12.9		
		Sept 18	1975	572.0	30.5	0.34	119	3.0	0.2	<0.1	2.0	2.6	7.8		
Eastern Quillback Carpsucker CEI	CEI	Sept 18	1975	334.0	28.1	0.21	82	<1.0	0.6	<0.1	<1.0	2.2	9.0		
		May 24	1976	187.0	25.2	1.04	338	19.0	1.5	<0.1	3.0	4.6	8.3		
Stonecat Madtom F-11	F-11	May 24	1976	173.0	24.2	1.58	355	23.0	0.8	<0.1	4.0	5.4	9.3		
		May 24	1976	160.0	24.0	1.20	248	<1.0	0.5	<0.1	4.0	3.4	10.6		
Channel Cat D-8		May 24	1976	128.0	23.1	1.01	123	7.0	1.1	<0.1	5.0	4.0	6.6		
		Sept 18	1975	269.0	31.8	0.31	78	1.0	0.5	<0.1	<1.0	1.2	3.8		

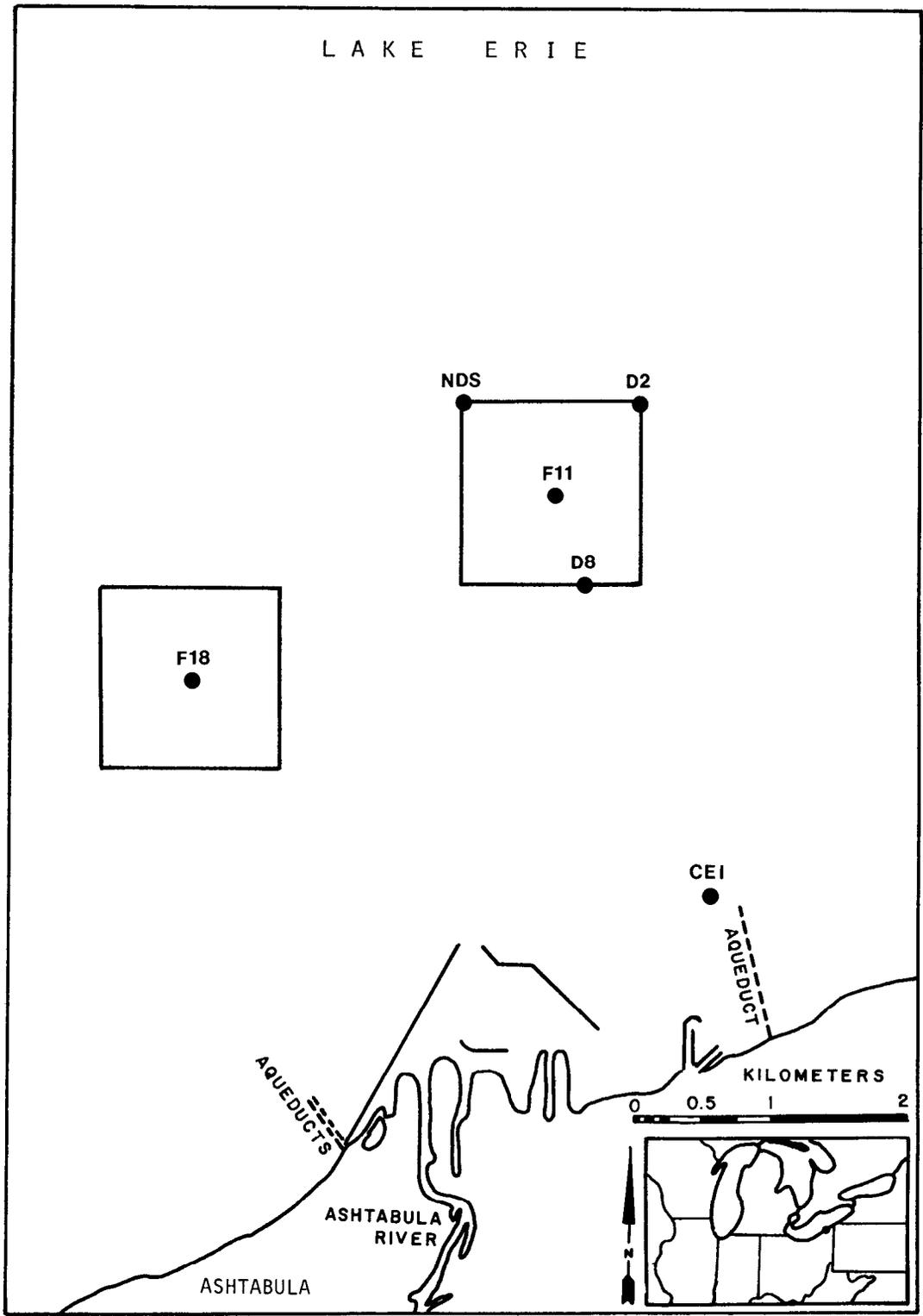


FIGURE B'1. FISH COLLECTION STATIONS

APPENDIX C': TIME DEPENDENCY OF
STANDARD ELUTRIATE TEST PREPARATIONS

PART I: INTRODUCTION

1. The Standard Elutriate Test was developed in order to assist decision makers to ascertain potential impacts of placing dredged and/or fill material in aquatic environments. Initially, certain Standard Elutriate Test criteria were established that had to be met before open-water disposal of the dredged and/or fill material could be considered acceptable (Keeley and Engler 1974). This criteria was based on the ratio of concentrations in the Standard Elutriate and the Disposal Site water. The most recent guidance for performing the Elutriate Test specifies that the results shall be used to indicate those contaminants that may be released to the water column during disposal and the mixing zone area required to assimilate the discharge (Anon. 1976). This study was conducted to clarify one aspect of the Standard Elutriate Test, namely the dependency of the results on the time of preparation. This was accomplished by comparing the results of analyses from on-site versus in-lab preparations of elutriates.

PART II: METHODS

2. Five replicate Ashtabula River sediment and water samples were collected on 14 September 1976 from one location (Figure G'1). Five replicate Disposal Site waters were also collected from a single station located in the northwest corner of the Disposal Area in Lake Erie near Ashtabula, Ohio (Figure C'1). A separate elutriate was prepared from each collection. To minimize any time lapse between collection and preparation, each sample was gathered only after the previous elutriate was prepared. The sediment samples were homogenized and subsamples were prepared for the elutriate using the method of Keeley and Engler (1974) while on-site. Dissolved oxygen measurements were made to insure oxic conditions through-

out the preparation. An unfiltered subsample of Dredge Site water was used in making up the on-site elutriates. Another subsample of Dredge and Disposal Site water was filtered for chemical analysis. The remaining unfiltered Dredge and Disposal Site water was stored at 4° C for future analysis. The sediment was stored at 4° C under a nitrogen atmosphere. All on-site prepared samples were brought back to the Great Lakes Laboratory facilities in Buffalo, New York for immediate chemical analysis. This initial analysis period was referred to as "Time zero" or "T₀". The lab preparation of the elutriate waters made six days after the field preparation was termed "Time six" or "T₆". This was followed by a 77-day post-field, in-lab preparation. This latter time period was designated "Time 77" or "T₇₇". At T₆ and T₇₇ a subsample of the unfiltered, stored Dredge and Disposal Site waters were filtered and analyzed along with the newly prepared elutriates. All samples were immediately analyzed at the completion of the elutriate preparations. Sediment and water samples were stored in 3.78-ℓ wide-mouth, polyethylene jars. The caps were poly-seal, which combine a bakelite shell with a cone-shaped polyethylene liner. Figure C'2 is a schematic flow diagram of the elutriate time preparations. The variables measured were chloride, total organic carbon, ammonia, soluble reactive phosphorus, iron, cadmium, manganese, copper, zinc, nickel, mercury, and chromium. All analysis followed methods described by the Great Lakes Laboratory (Wyeth and Sweeney 1978).

3. The statistical methods involved finding the mean of each variable per time period for each type of sample (i.e. elutriate, Dredge, and Disposal Site waters). The means were then displayed graphically with a 95% confidence interval (Figures C'3-C'11). The horizontal line represents the means while the vertical bar indicates the confidence interval for each group and time. A one-way analysis of variance from the SPSS computer package (Nie et al. 1970) was run to determine if there were any significant differences with time and the Bartlett's test was used to check for non-homogeneity of data (Table C'1). A separate variance estimate t-test was calculated to determine which time periods were significantly different (Tables C'2-C'4). This is a robust test which does not require the assumption

of homogeneity of variance. Statistical significance was considered at an alpha level of 0.050 for all comparisons discussed in this Appendix.

PART III: RESULTS AND DISCUSSION

4. Chloride. The mean Elutriate water chloride concentration increased from T_0 to T_{77} (Figure C'3). Although the increase was not statistically significant, the elongation of the confidence interval suggests a possible reproducibility problem with time. The statistically significant decrease in chloride concentrations of the Dredge Site water between T_0 and T_6 could not be readily explained. The non-homogeneity of the data as suggested by the Bartlett's Test, coupled with the relatively small f-ratio of 5.269 (Table C'1) makes the significance of the decrease suspect. Note also that no difference existed between T_0 and T_{77} for the Dredge Site waters suggesting a possible anomolous fluctuation. The Disposal Site water chloride levels were approximately 2.5 times lower than the Elutriate and Dredge Site waters' chloride concentrations and were not time dependent.

5. Total organic carbon. Figure G4 illustrates the changes in the total organic carbon concentration with time. The Bartlett's test (Table C'1) revealed the elutriate total organic carbon data was non-homogeneous, putting suspicion on the significance of the changes. However, the Dredge and Disposal Site water did change significantly with respect to total organic carbon, suggesting the changes in the elutriate levels were real. The separate variance estimate t-test performed on the elutriate data implied the significance was due to the changes between T_0 to T_{77} and T_6 to T_{77} (Table C'2). Although the total organic carbon Dredge Site water values were lower than the elutriate water values, a similarity in the pattern of changes occurred. This indicated that the changes in elutriate total organic carbon concentrations were a function of the changes in the Dredge Site water, which was used in the elutriate preparations, and not due to an increase in the release of total organic carbon from the sediments with time. The higher elutriate total organic carbon levels as compared to the Dredge Site water values indicated a release of organic carbon from the sediments. The Disposal Site water total organic carbon values increased throughout the study. The increases noted for dissolved total organic carbon in all the

types of samples were attributed to the decomposition of particulate organic matter.

6. Ammonia. A drastic and statistically significant decrease in elutriate ammonia levels was observed with time (Figure C'5). Even though non-homogeneity was suggested by the Bartlett's Test, the f-ratio of 32.940 (Table C'1) was considered sufficient to support a claim of significance. Figure C'5 and the separate variance estimate t-test reveals the largest decrease in ammonia concentrations came between T_6 and T_{77} . This trend in the elutriate ammonia data was not necessarily expected since the sediment was kept anoxic under nitrogen gas. The mean ammonia elutriate values were greater than the Dredge Site water levels, indicating ammonia release from the sediments. Two unanticipated results were the lack of any change in ammonia levels in Dredge Site water and the statistically significant increase in ammonia for Disposal Site waters. This was graphically revealed by Figure C'6, which presents mean ammonia results for the Dredge and Disposal Site waters. The increasing ammonia results for the Disposal Site waters were unexpected due to the unstable nature of ammonia. A possible explanation could have been the gradual reduction of oxygen in the storage carboys causing eventual anoxia. Anoxic conditions along with the decomposition of organic matter (as suggested by the total organic carbon results) are favorable to the accumulation of ammonia. The ratio of the ammonia concentrations in the Standard Elutriate to the Disposal Site water decreased from 160 at T_0 to 95.8 at T_6 to 2.56 at T_{77} (Table C'5). The significance of this change is the effect it could have on evaluating a proposed disposal operation. In each case, ammonia is released. However, the estimated mixing zone required to assimilate the proposed discharge would be 60% smaller if T_6 results were used rather than T_0 results. The use of T_{77} elutriate results would suggest an even smaller mixing zone would be necessary. Thus, the use of aged samples would suggest a smaller mixing zone than may actually be necessary to assimilate the discharge.

7. Soluble reactive phosphorus. No difference was observed between time periods for soluble reactive phosphorus concentrations in the Elutriate and Disposal Site water samples (Figure C'7). The Dredge Site waters showed a statistically significant change. The separate variance estimate t-test

(Table C'3) indicated the change was between T_0 to T_{77} and T_6 to T_{77} . The soluble reactive phosphorus means indicated a slight decrease from T_0 to T_6 which possibly was due to particulate sorption. The mean increases (non-significant for Elutriate and Disposal Site waters) from T_6 to T_{77} could be attributed to particulate phase breakdown releasing phosphorus to the dissolved state. (See total organic carbon and ammonia discussions.) Since no difference between mean Elutriate, Dredge, and Disposal Site water soluble reactive phosphorus concentrations existed, sediment release was not observed.

8. Cadmium, chromium, mercury, and nickel. These heavy metals were grouped together since their Elutriate, Dredge, and Disposal Site water concentrations revealed the lack of any time dependency. Also, the confidence intervals for these metals in Standard Elutriate and Dredge Site water overlapped, indicating the lack of any significant release from the sediments. The only exception occurred for chromium on T_{77} . The Elutriate to Disposal Site concentration ratio for mercury increased from 1.0 to 14.7 on T_{77} (Table C'5). However, this difference was not statistically significant at an alpha level of 0.050 due to the increased confidence interval for the mercury analyses of the elutriate during T_{77} .

9. Copper. The one-way analyses of variance for the Elutriate, Dredge, and Disposal Site water copper concentrations indicated statistically significant changes with time. The data for the Elutriate and Disposal Site waters were determined to be non-homogeneous. The combination of the high f-ratio for the one-way analysis of variance calculation and the statistically significant differences found between T_0 to T_{77} and T_6 to T_{77} with the separate variance estimate t-test strongly suggested that the elutriate copper concentrations did, indeed, change with time. The Disposal Site water copper concentration changes were a little more suspect since the f-ratio was only 4.843 ($\alpha = 0.0287$). However, the separate variance estimate t-test did show significance between T_0 to T_6 . Figure C'8 illustrates the gradual increase in copper concentrations that was observed over the 77-day period. This trend followed the same pattern observed in the total organic carbon changes (Figure C'4). The Dredge Site and Elutriate water copper levels followed the same pattern and were

not statistically different. This leads to the supposition that the elutriate copper concentration changes noted were not a consequence of sediment release but desorption from the particulates in the Dredge Site water. The elongation of the confidence intervals with time again reflects a time dependent reproducibility problem.

10. Iron. The Elutriate and Dredge Site water iron concentrations were not time dependent (Figure C'9). The Disposal Site water samples revealed a significant change between T₆ and T₇₇ based on a separate variance estimate t-test (Table C'4). The lack of a difference between T₀ and T₇₇ in iron concentrations complicates any explanation as to the reason for the previously mentioned change. Since the samples were not preserved with acid, sorption onto container walls and particles may have been involved in the soluble iron level decreases. Oxidation and precipitation of iron may also have caused the soluble phase concentration losses. The confidence interval separations between the Elutriate and Dredge Site iron values indicated the release of iron from the sediments.

11. Manganese. Manganese concentrations did not vary significantly according to the one-way analyses of variance for either the Elutriate or Disposal Site waters (Figure C'10). On the other hand, Dredge Site water manganese levels were time dependent. The decrease in manganese Dredge Site values were determined to be significant between T₀ to T₆ and T₀ to T₇₇ by the separate variance estimate t-test (Table C'3). Possible explanations for the soluble manganese changes included sorption onto container walls and particles and/or oxidation and precipitation of the metal. Dredge Site water manganese levels were lower than the elutriate concentrations indicating sediment release.

12. Zinc. Elutriate and Dredge Site water zinc concentrations did not change with time. The increase in zinc levels in the Disposal Site waters was statistically significant. Although the homogeneity test was violated, the alpha value of 0.0036 was considered low enough to suggest significance. The separate variance estimate t-test revealed a significant increase between T₀ to T₇₇ for the Disposal Site water zinc

concentrations (Table C'4). The increase was attributed to either the degradation of the organic particulate phase resolubilizing zinc complexes (see total organic carbon discussion) or the desorption of zinc from the polyethylene bottles. The use of zinc as a catalyst in the formation of polyethylene gives substance to the latter reason for the zinc time-dependency given above. Figure C'11 shows that zinc was released by the River sediments. The importance of immediate sample preparation and analysis is illustrated by the Elutriate to Disposal Site water concentration ratios, which decreased from 14.3 at T₀ to 6.56 at T₆ and 6.58 at T₇₇ (Table C'5).

PART IV: CONCLUSIONS

13. The elongation of the confidence intervals for chloride, copper, and mercury elutriate concentrations indicated a possible reproducibility problem with time. It appeared that the changes in the Elutriate, Dredge, and Disposal Site water levels for total organic carbon, ammonia, soluble reactive phosphorus, copper, and zinc were affected by the decomposition of particulate organic matter. The present guidance permits elutriate preparation one week after collection (Keeley and Engler 1974). However, the Elutriate-to-Disposal Site concentration ratios emerged as time dependent between T₀ and T₆. Noticeable changes were observed for ammonia, total organic carbon, soluble reactive phosphorus, copper, and zinc (Table C'5). The above changes and problems exemplify the time dependency of the Standard Elutriate Test. Therefore, the following recommendations are made to improve the validity of the Standard Elutriate Test:

- a. Prepare the elutriates in the field immediately after collection.
- b. The Disposal Site waters should be filtered and preserved according to EPA (1974) in the field immediately after collection.
- c. The chemical analysis should be performed as soon as possible. It is suggested that the analysis be completed within 24 hr.
- d. It is recommended that at least five replicate samples be taken at each sampling point and analyzed independently to determine if elutriate variable concentrations are statistically significantly different from the Disposal Site water variable concentrations.

PART V: LITERATURE CITED

Anon. 1976. Ecological Evaluation of Proposed Discharge of Dredged or Fill Material into Navigable Waters. Miscellaneous Paper D-76-17. U.S. Army Engineer Waterways Experiment Station. Vicksburg, Miss.

Environmental Protection Agency. 1974. Methods for Chemical Analyses of Water and Wastes. Environmental Monitoring Series E.P.A. 625/6-74-003. EPA National Environmental Research Center, Analytical Quality Control Laboratory. Cincinnati, Ohio.

Keeley, J.W. and R.M. Engler. 1974. Discussions of Regulatory Criteria for Ocean Disposal of Dredged Material: Elutriate Test Rationale and Implementation Guidelines. Miscellaneous Paper D-74-14. U.S. Army Engineer Waterways Experiment Station. Vicksburg, Miss.

Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bendi. 1970. Statistical Package for Social Sciences (SPSS). McGraw-Hill, Inc. New York, N.Y. 675 pp.

Wyeth, R.K. and R.A. Sweeney. 1978. Aquatic Disposal Field Investigations Ashtabula River Disposal Site, Ohio. Appendix B: Water Quality and Sediment Parameters. Dredged Material Research Program. U.S. Army Engineer Waterways Experiment Station. Vicksburg, Miss. 258 pp.

TABLE C'1

One-Way Analysis of Variance and Bartlett's Test Summary

Variables	Elutriate		Dredge Site Water		Disposal Site Water				
	f-ratio	Probability α	f-ratio	Probability α	f-ratio	Probability α			
Chloride	3.254	.0743	x	5.269	.0228	x	.924	.4233	x
Total Organic Carbon	4.348	.0380	x	27.110	.0000		43.783	.0000	
Ammonia	32.940	.0000	x	3.611	.0592		67.321	.0000	
Soluble Reactive-P	.365	.7018		9.135	.0039		2.117	.1632	x
Cadmium	1.200	.3349		2.205	.1529		.500	.6186	x
Chromium	.038	.9631		1.200	.3349		2.667	.1101	
Mercury	2.718	.1063	x	1.000	.3966		N.R.	N.R.	N.R.
Nickel	.315	.7356		1.302	.3077		1.911	.1903	
Copper	17.723	.0003	x	25.842	.0000		4.843	.0287	x
Iron	.327	.7274	x	3.664	.0573	x	7.467	.0078	
Manganese	.955	.4121		7.763	.0069		1.167	.3444	
Zinc	2.641	.1121		.606	.5615		9.324	.0036	x

N.R. = Not Run, all data the same.

x = Non-homogeneous data.

TABLE C'2

Elutriate
Separate Variance Estimate t-Test Summary

Variables	T ₀ to T ₆		T ₀ to T ₇₇		T ₆ to T ₇₇	
	t-value	Probability α	t-value	Probability α	t-value	Probability α
Chloride	-2.267	.058	-2.152	.084	-1.197	.285
Total Organic Carbon	1.099	.333	-2.910	.027	-2.448	.050
Ammonia	2.043	.087	7.219	.002	10.067	.001
Soluble Reactive-P	.835	.442	.082	.937	-.831	.444
Cadmium	.784	.455	-.730	.486	-1.633	.141
Chromium	.224	.829	0	1.000	-.224	.829
Mercury	N.R.	N.R.	-1.649	.175	-1.649	.175
Nickel	.250	.809	.745	.478	.572	.583
Copper	-2.313	.054	-4.723	.009	-3.838	.012
Iron	-.711	.516	-.029	.978	.571	.586
Manganese	-1.405	.198	-1.001	.346	.333	.748
Zinc	-.661	.527	-2.066	.073	-1.609	.152

N.R. = Not Run, all data the same.

TABLE C'3
Dredge Site Water
Separate Variance Estimate t-Test Summary

Variables	T ₀ to T ₆		T ₀ to T ₇₇		T ₆ to T ₇₇	
	t-value	Probability α	t-value	Probability α	t-value	Probability α
Chloride	3.528	.024	2.669	.056	-.743	.479
Total Organic Carbon	3.134	.014	-4.129	.003	-7.223	.000
Ammonia	.164	.874	2.197	.070	2.031	.089
Soluble Reactive-P	.111	.914	-3.864	.012	-4.323	.005
Cadmium	.302	.773	-1.809	.120	-1.698	.128
Chromium	.632	.545	1.633	.178	1.000	.374
Mercury	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
Nickel	1.697	.150	.447	.667	-1.234	.272
Copper	0	1.000	-5.183	.001	-7.046	.001
Iron	1.946	.124	2.037	.097	.490	.642
Manganese	3.223	.023	2.859	.029	-.239	.818
Zinc	1.021	.354	.183	.860	-1.125	.311

N.R. = Not Run; all data the same.

TABLE C'4
 Disposal Site Water
 Separate Variance Estimate t-test Summary

Variables	T ₀ to T ₆		T ₀ to T ₇₇		T ₆ to T ₇₇	
	t-value	Probability α	t-value	Probability α	t-value	Probability α
Chloride	.057	.957	1.912	.128	.937	.380
Total Organic Carbon	-4.229	.004	-9.004	.000	-5.544	.001
Ammonia	-1.126	.303	-10.476	.000	-8.119	.000
Soluble Reactive-P	.834	.428	-1.335	.253	-1.616	.181
Cadmium	-1.000	.374	-1.000	.374	0	1.00
Chromium	-1.633	.178	N.R.	N.R.	1.633	.178
Mercury	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
Nickel	1.000	.374	-1.265	.275	-1.510	.206
Copper	-4.000	.016	-2.551	.063	-1.664	.172
Iron	-2.066	.084	2.138	.099	3.539	.024
Manganese	.447	.670	2.121	.067	.894	.406
Zinc	-1.886	.132	-5.658	.005	-2.032	.077

N.R. - Not Run, all the same.

TABLE C'5

Elutriate to Disposal Site Concentration Ratio

<u>Variable</u>	<u>T₀</u>	<u>T₆</u>	<u>T₇₇</u>
Chloride	2.27	2.65	3.18
Total Organic Carbon	3.18	1.96	1.69
Ammonia	160.	95.8	2.56
Soluble Reactive-P	1.29	1.13	0.99
Cadmium	2.40	1.67	2.33
Chromium	1.70	1.33	1.70
Mercury	1.00	1.00	14.7
Nickel	2.05	2.10	1.06
Copper	4.00	2.85	4.14
Iron	44.2	35.7	62.4
Manganese	252	329	423
Zinc	14.3	6.56	6.58

L A K E E R I E

- 1 - Disposal site water collection station
- 2 - Dredge site water and sediment collection station

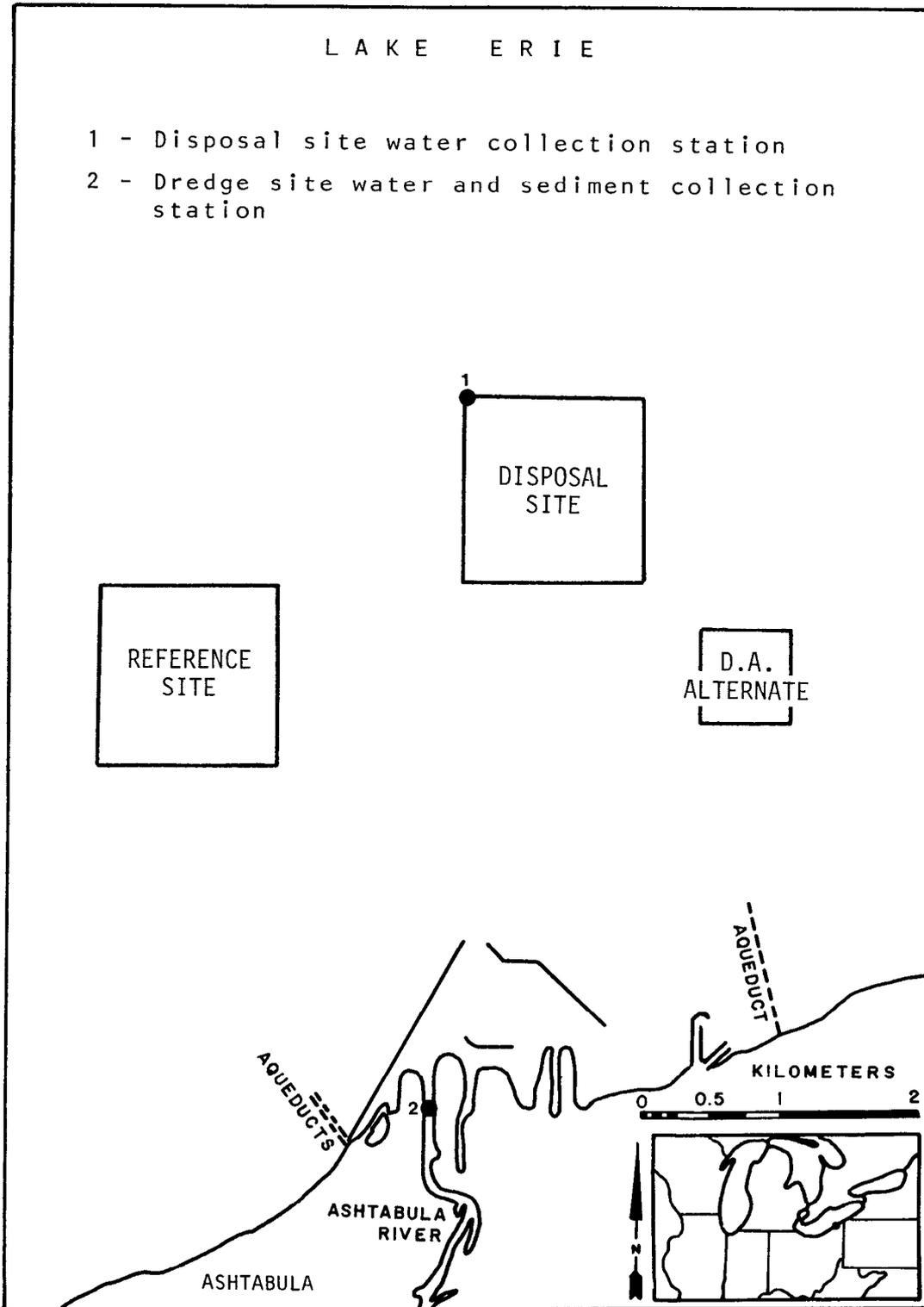


Figure C'1. Location of sampling sites

F - FILTERED U - UNFILTERED

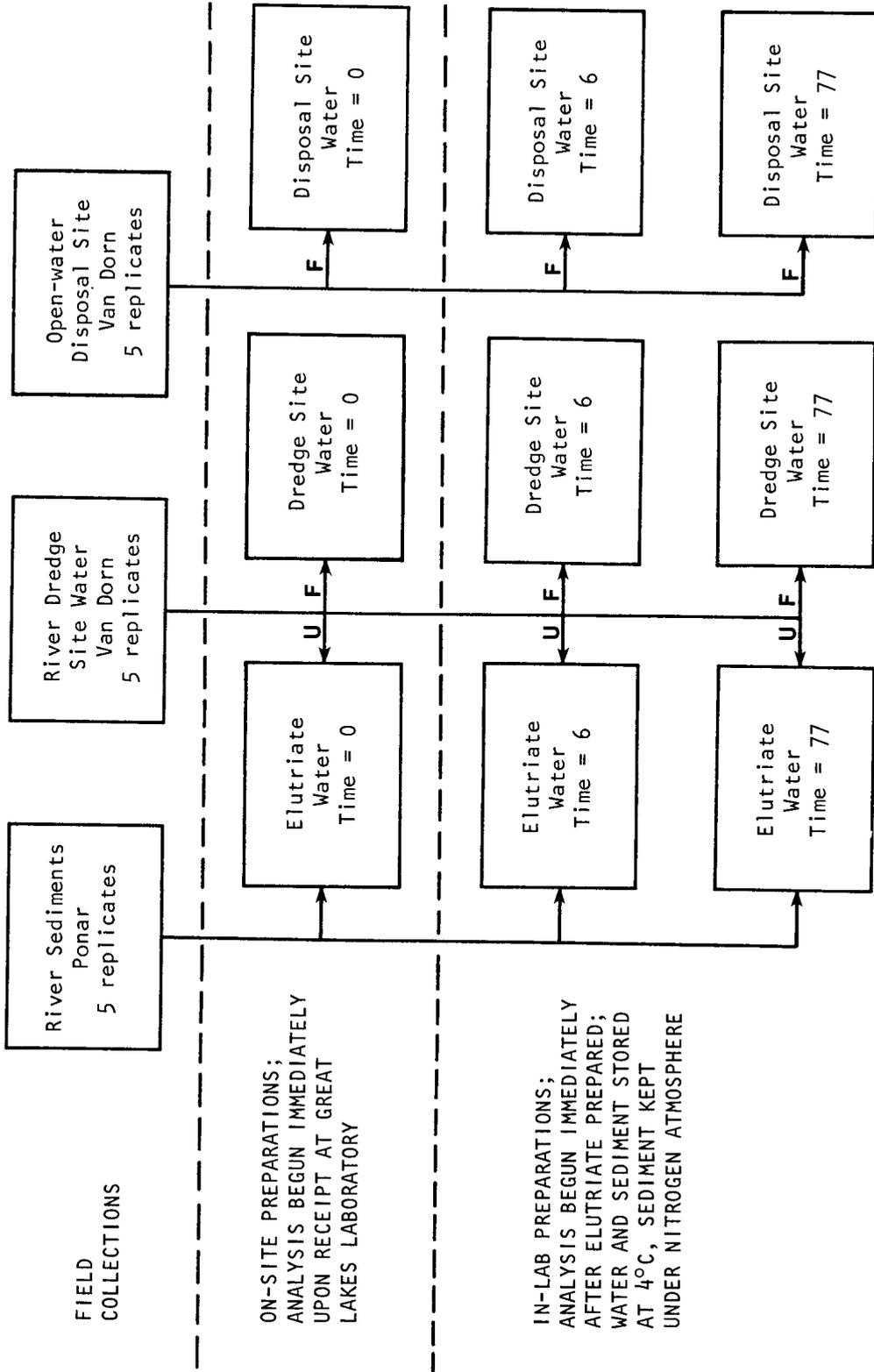


Figure C'2. Schematic flow diagram of elutriate test preparations

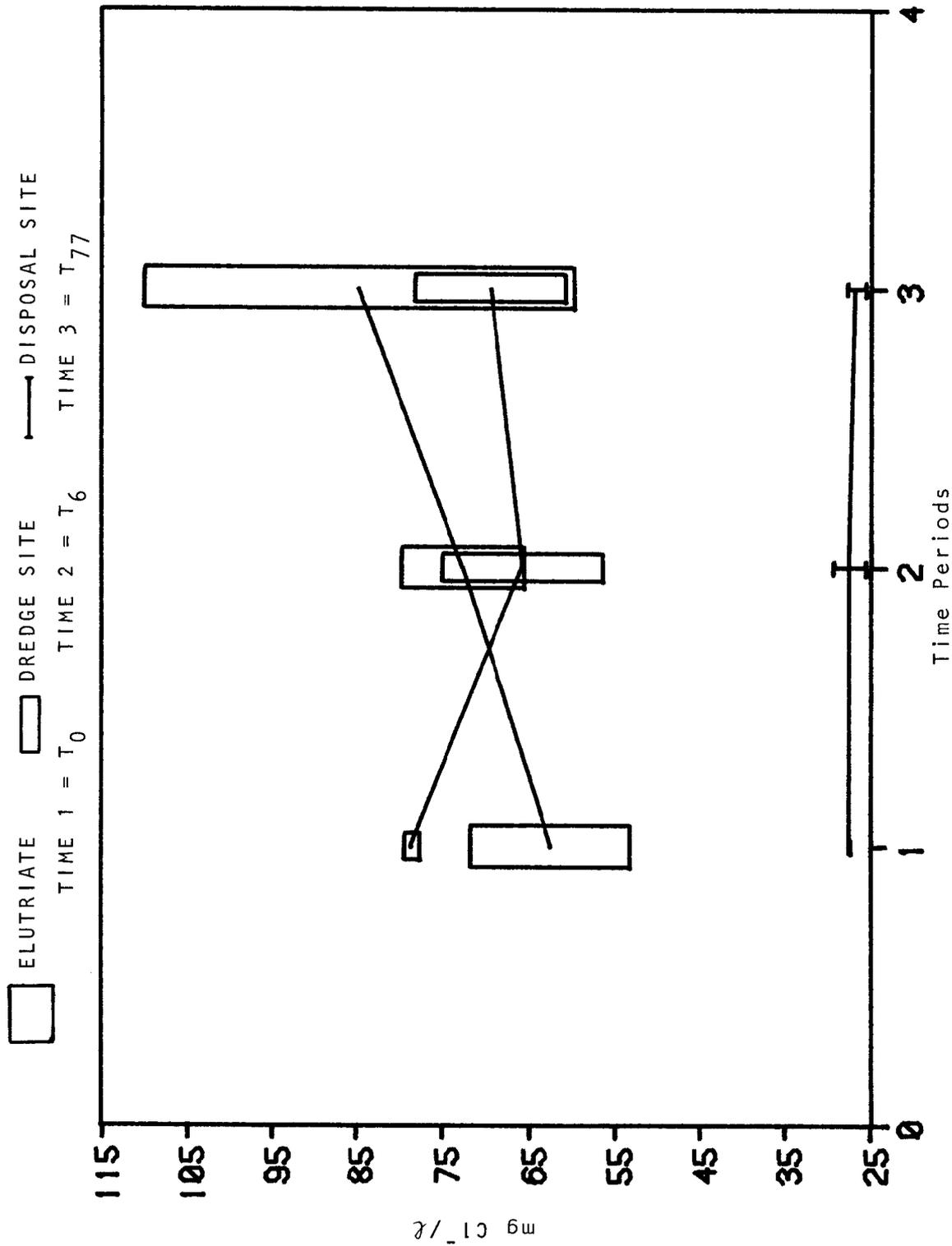


Figure C'3. Means and confidence intervals of chloride concentrations as a function of time

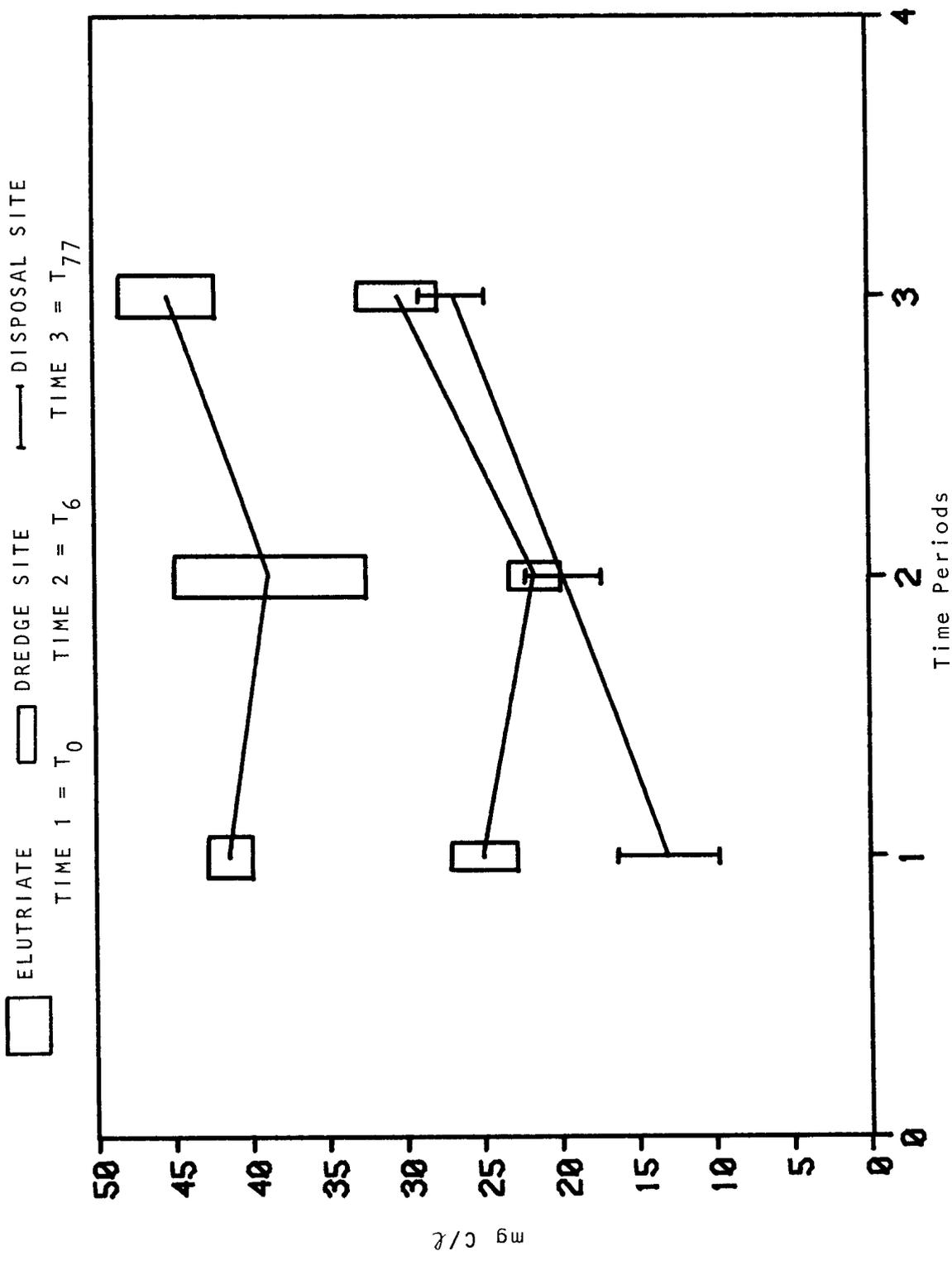


Figure C'4. Means and confidence intervals of total organic carbon concentrations as a function of time

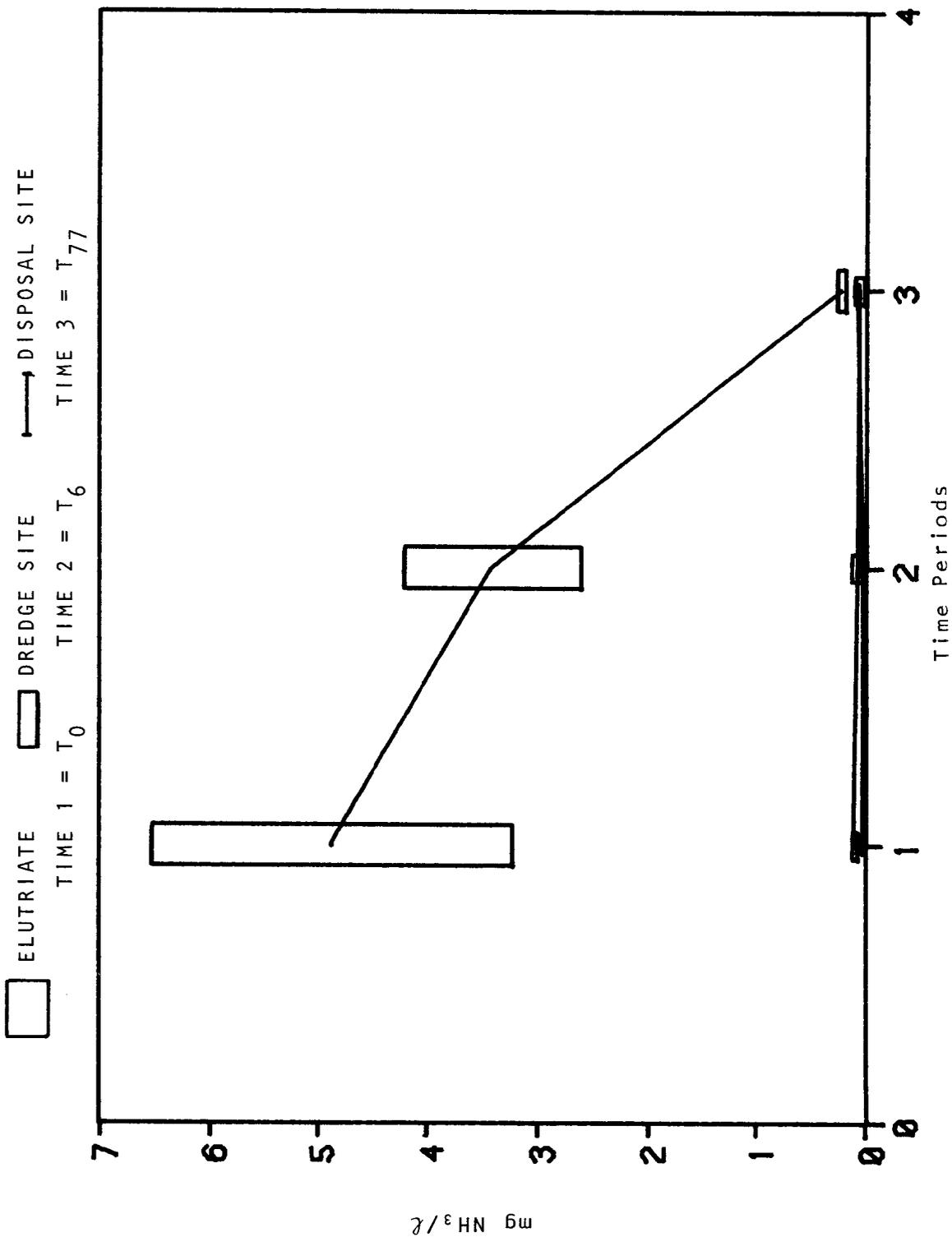


Figure C'5. Means and confidence intervals of ammonia concentrations as a function of time

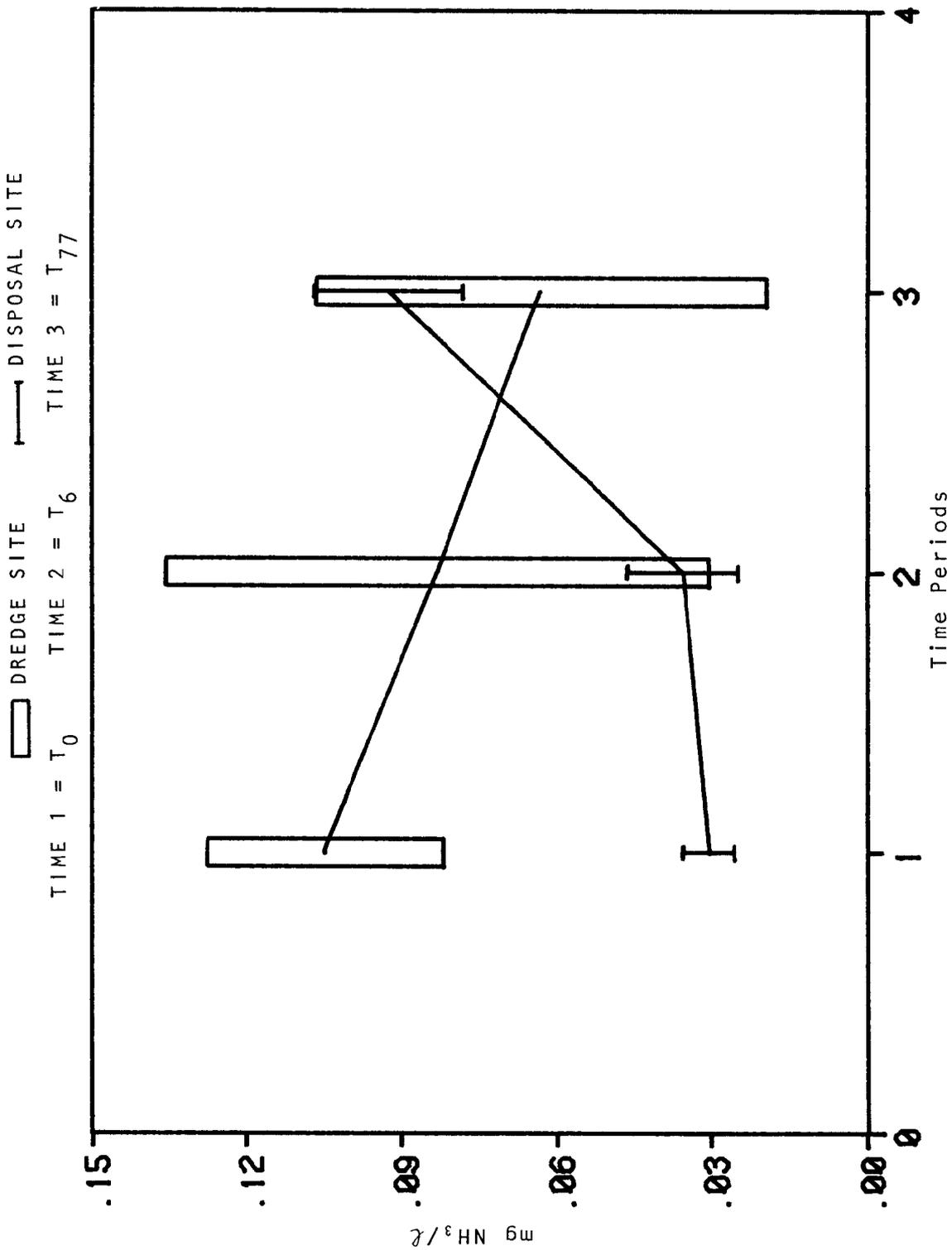


Figure C'6. Means and confidence intervals of ammonia concentrations without elutriates as a function of time

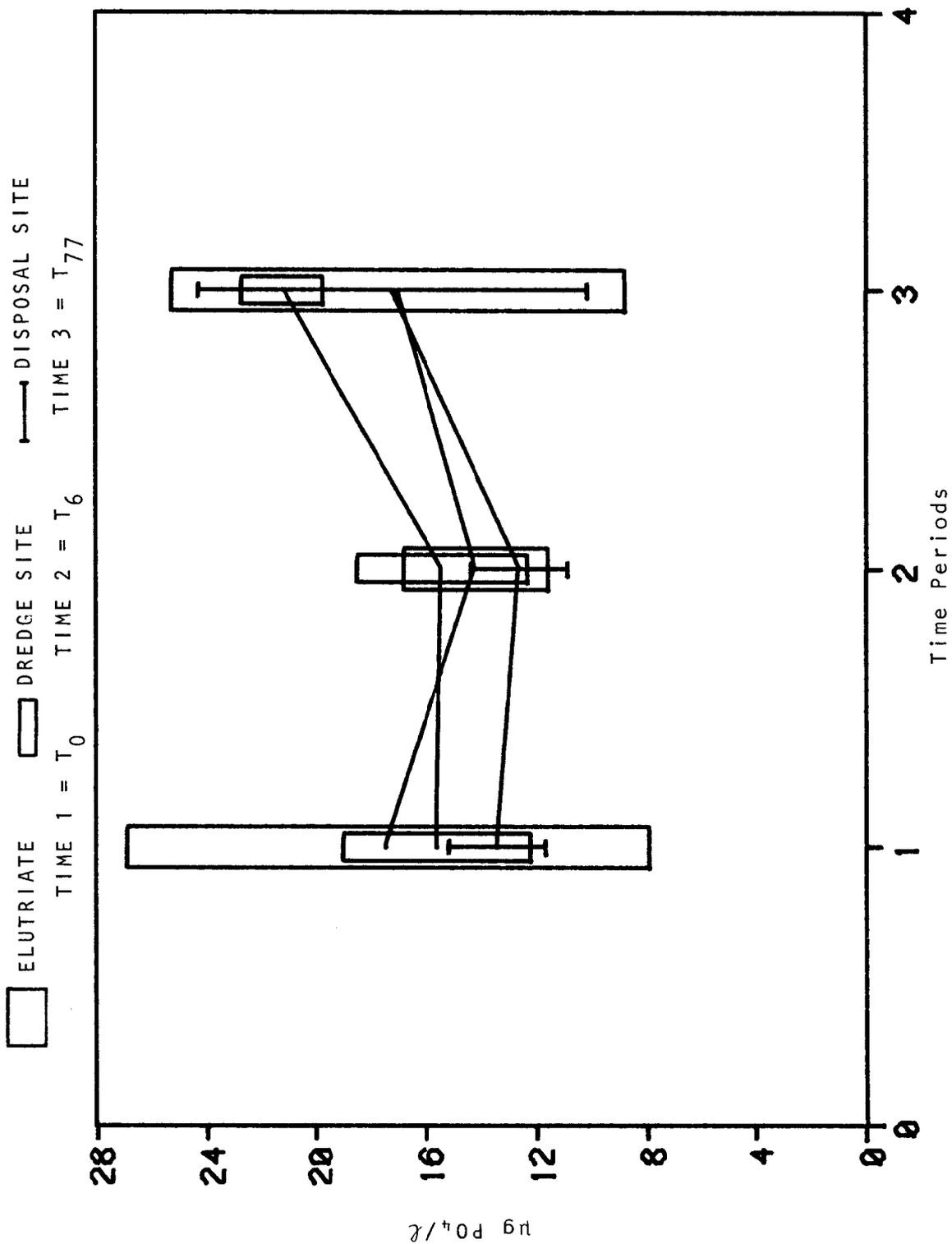


Figure C'7. Means and confidence intervals of soluble reactive phosphorus concentrations as a function of time

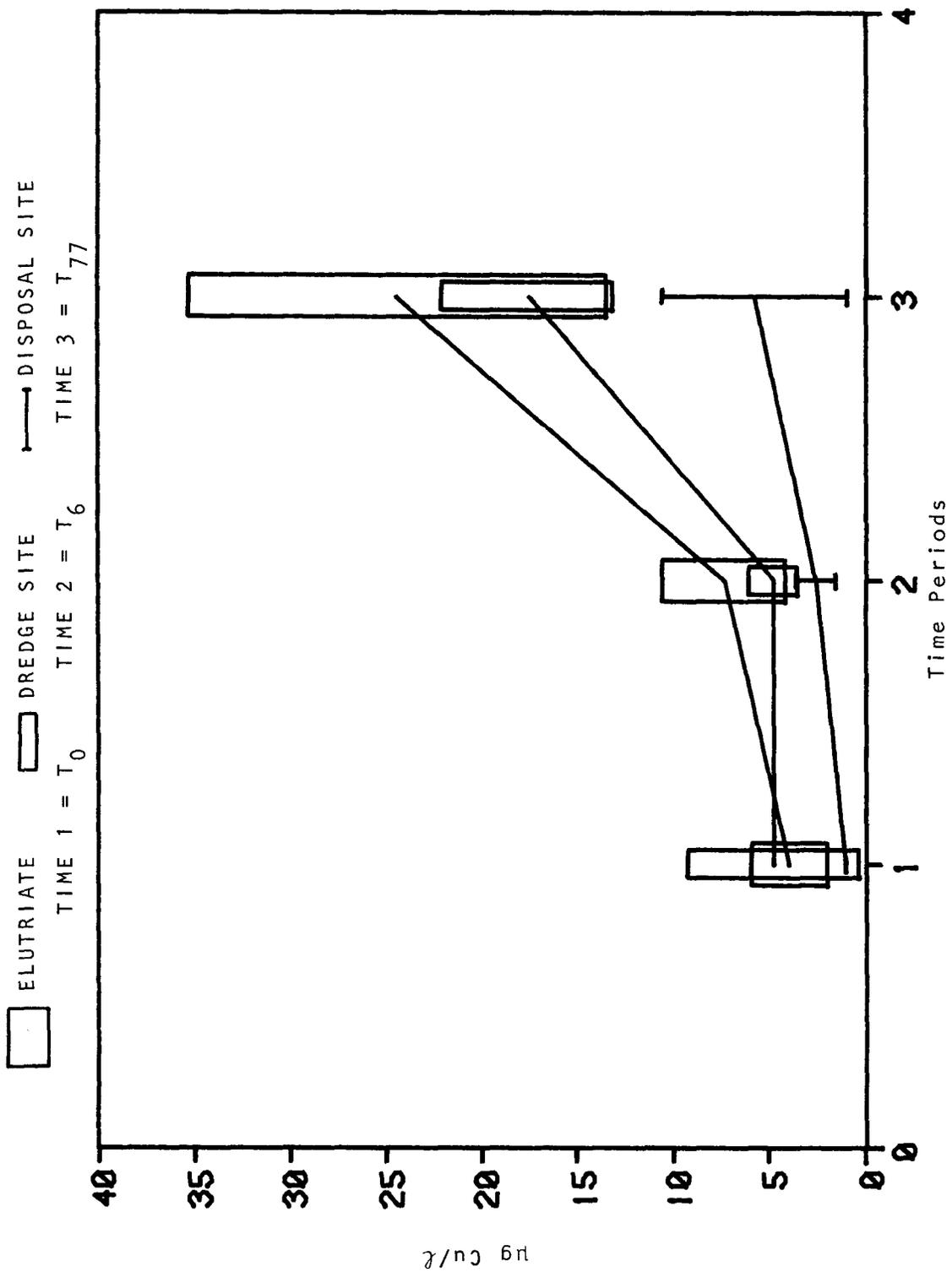


Figure C'8. Means and confidence intervals of copper concentrations as a function of time

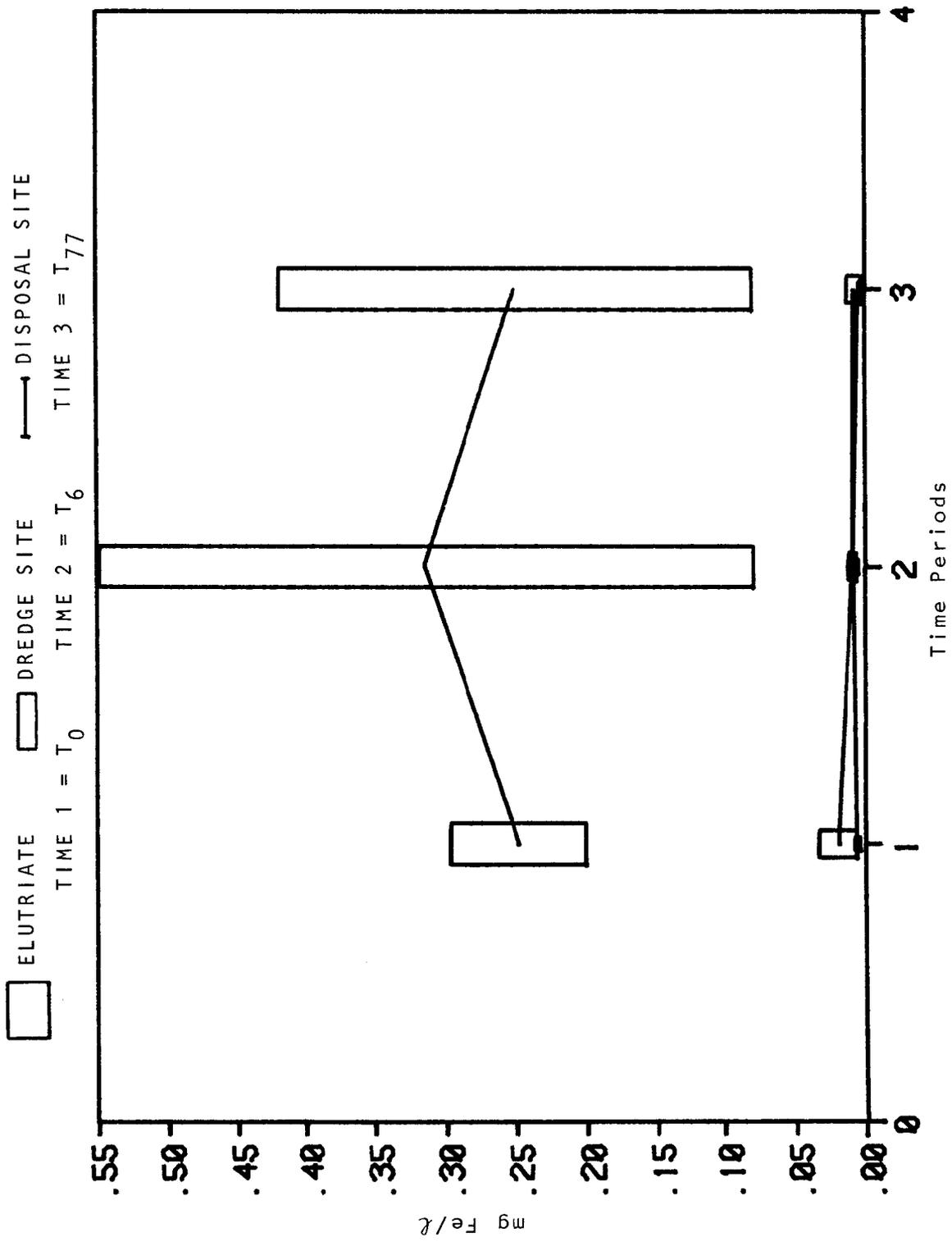


Figure C'9. Means and confidence intervals of iron concentrations as a function of time

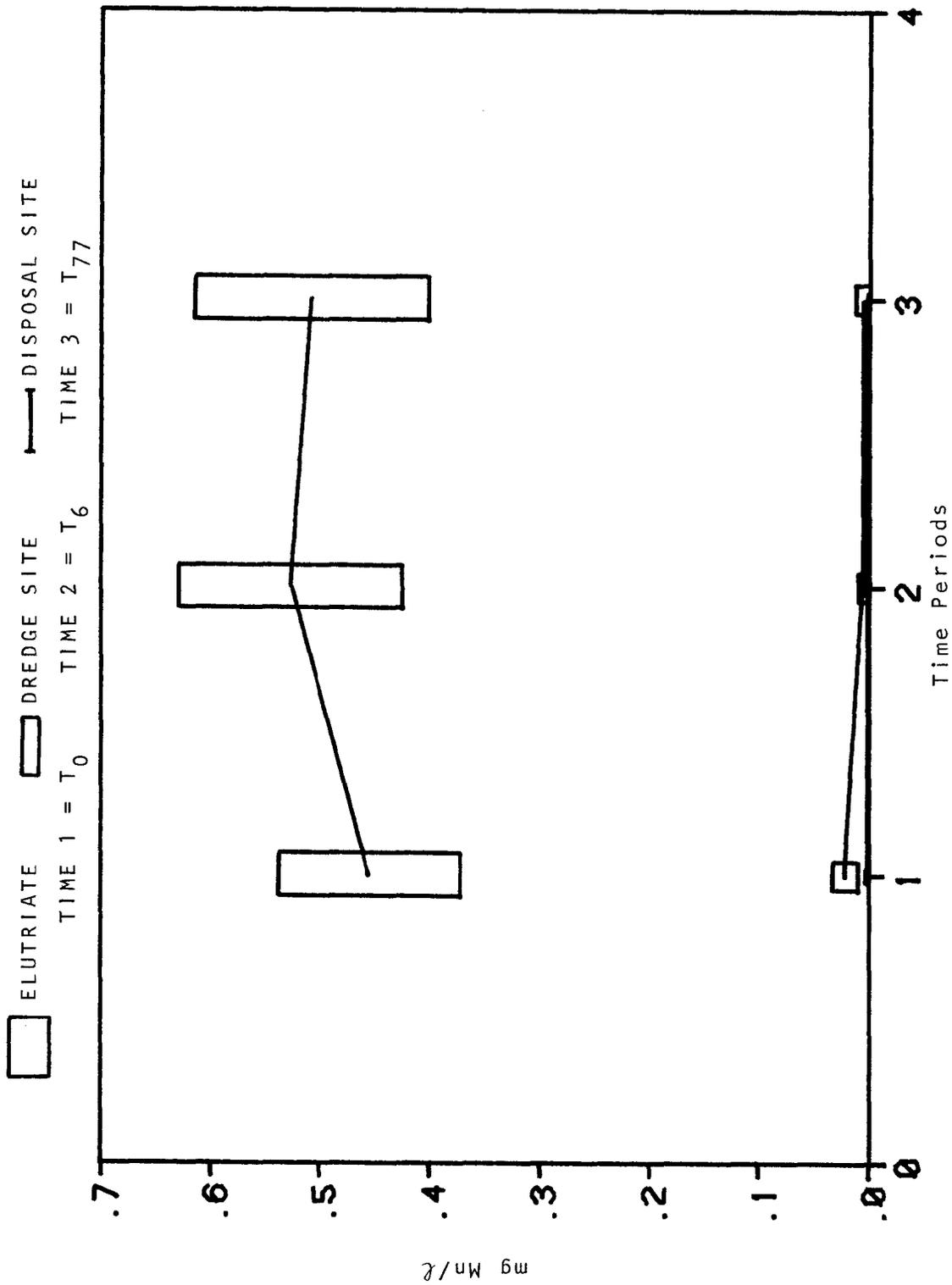


Figure C'10. Means and confidence intervals of manganese concentrations as a function of time

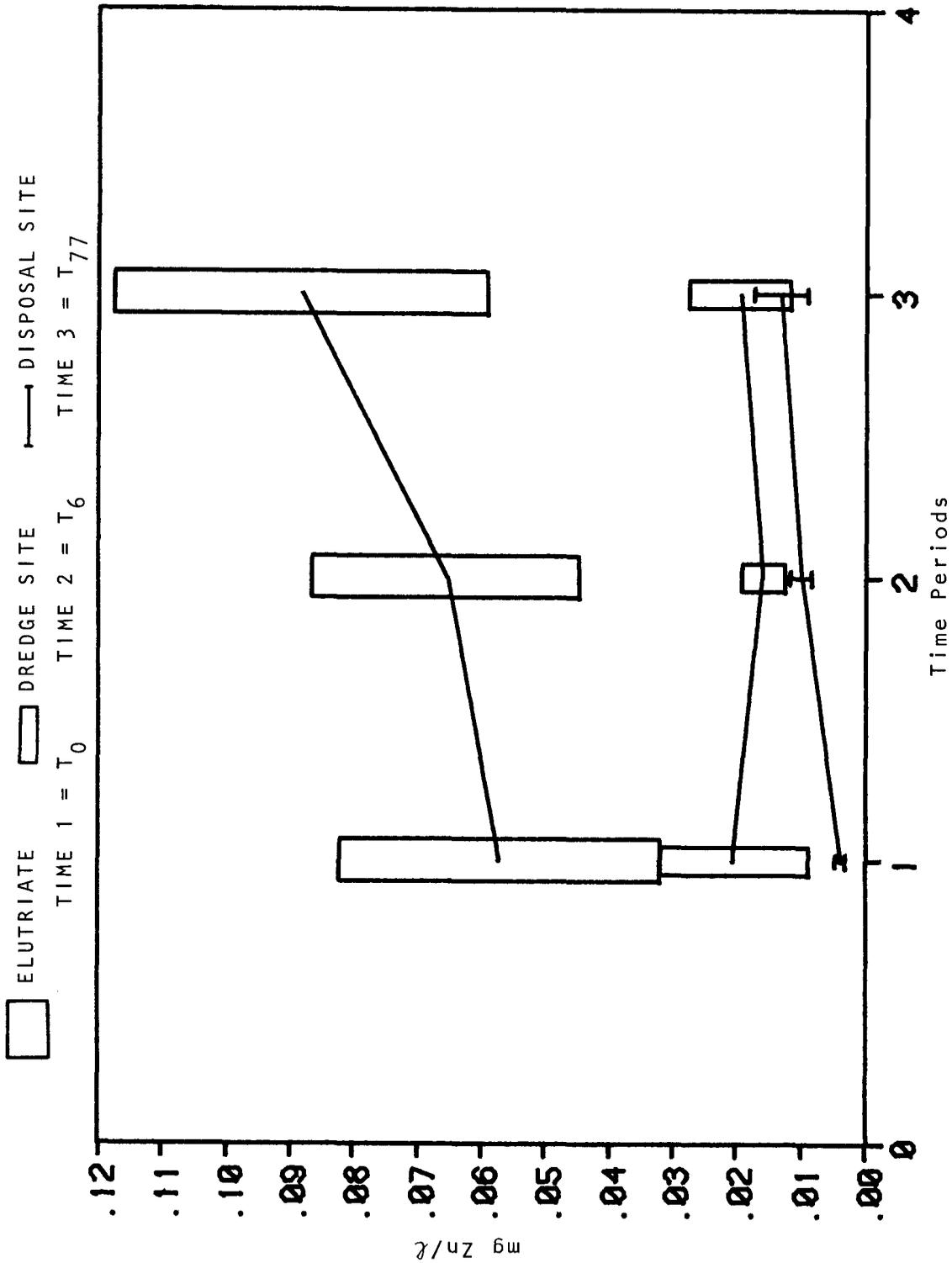


Figure C'11. Means and confidence intervals of zinc concentrations as a function of time

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Wyeth, Robert K

Aquatic disposal field investigations, Ashtabula River disposal site, Ohio; Appendix C: Investigation of water-quality and sediment parameters / by Robert K. Wyeth and Robert A. Sweeney, Great Lakes Laboratory, State University College at Buffalo, Buffalo, New York. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

xx, 325 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-42, Appendix C)

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Literature cited: p. 131-133.

1. Aquatic environment. 2. Ashtabula River. 3. Benthos. 4. Dredged material. 5. Dredged material disposal. 6. Field investigations. 7. Lake Erie. 8. Sediment. 9. Water quality.

I. Sweeney, Robert A., joint author. II. Great Lakes Laboratory. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-42, Appendix C.

TA7.W34 no.D-77-42 Appendix C