

DREDGED MATERIAL RESEARCH PROGRAM



TECHNICAL REPORT D-77-24

AQUATIC DISPOSAL FIELD INVESTIGATIONS DUWAMISH WATERWAY DISPOSAL SITE PUGET SOUND, WASHINGTON

APPENDIX D: CHEMICAL AND PHYSICAL ANALYSES OF WATER AND SEDIMENT IN RELATION TO DISPOSAL OF DREDGED MATERIAL IN ELLIOTT BAY

Volume II: September-December 1976

by

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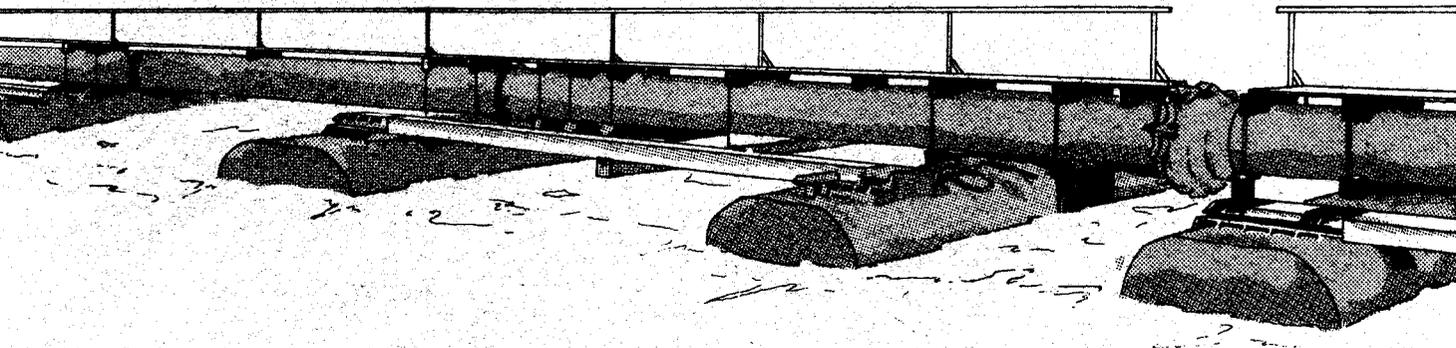
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Monitored by Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

**AQUATIC DISPOSAL FIELD INVESTIGATIONS
DUWAMISH WATERWAY DISPOSAL SITE
PUGET SOUND, WASHINGTON**

- Appendix A: Effects of Dredged Material Disposal on Demersal Fish and Shellfish in Elliott Bay, Seattle, Washington**
- Appendix B: Role of Disposal of PCB-Contaminated Sediment in the Accumulation of PCB's by Marine Animals**
- Appendix C: Effects of Dredged Material Disposal on the Concentration of Mercury and Chromium in Several Species of Marine Animals**
- Appendix D: Chemical and Physical Analyses of Water and Sediment in Relation to Disposal of Dredged Material in Elliott Bay**
- Appendix E: Release and Distribution of Polychlorinated Biphenyls Induced by Open-Water Dredge Disposal Activities**
- Appendix F: Recolonization of Benthic Macrofauna over a Deep-Water Disposal Site**
- Appendix G: Benthic Community Structural Changes Resulting from Dredged Material Disposal, Elliott Bay Disposal Site**

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31 July 1978

SUBJECT: Transmittal of Technical Report D-77-24 (Appendix D, Volume II)

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) and 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 that such sites are recolonized by benthic flora and fauna. The study reported on herein was an integral part of a series of research contracts jointly developed to achieve the general objective at the Duwamish Waterway Disposal Site, one of five study 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 the other related reports for this site.
2. This report, Appendix D: Chemical and Physical Analyses of Water and Sediment in Relation to Disposal of Dredged Material in Elliott Bay, Volume I February-June 1976 and Volume II September-December 1976, is one of seven contractor-prepared appendices published as Waterways Experiment Station Technical Report D-77-24 entitled: Aquatic Disposal Field Investigations, Duwamish Waterway Disposal Site, Puget Sound, Washington. The titles of all contractor-prepared appendices to this series are listed on the inside front cover of this report. The main report, the Evaluative Summary, will provide additional results, interpretations, and conclusions not found in the additional appendices and will provide a comprehensive summary and synthesis overview of the entire study.
3. The purpose of these two investigations, conducted as Work Units 1A10C (Volume I) and 1A10D (Volume II), was to monitor selected physical and chemical parameters in water-column and sediment samples obtained before, during, and after disposal of contaminated dredged material at

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an Elliott Bay disposal site. Appendix D is divided into two volumes since two separate research groups were involved. Volume I discusses the results of analyses of samples collected before, during, and 1 week, 1 month, and 3 months after the disposal operation while Volume II reports on samples collected 6 and 9 months after the operation.

4. The Duwamish River sediments were found to be highly heterogeneous. However, the concentrations of several significant parameters such as ammonia, alkaline-soluble sulfide, and total mercury were in general several times higher than the Elliott Bay disposal site sediments. Standard elutriate tests conducted with the river sediments indicated that ammonia and manganese would probably be released to the water column following each disposal event. Analyses of samples collected during the disposal operation revealed elevated levels of manganese, suspended solids, and ammonia in the water column for a few minutes following each dump. Interstitial water concentrations of manganese, ammonia, and sulfides remained above ambient at the disposal site through the 3 months of postdisposal monitoring discussed in Volume I. One week after the disposal operation, there were no chemical differences found between water-column samples taken at the disposal and reference sites.

5. At 6 and 9 months after the disposal operation, the levels of manganese, ammonia, and inorganic phosphate in the interstitial waters were found to be higher than at both reference sites. There were no detectable chemical differences in water-column samples from the disposal and reference sites at 1, 3, 6, and 9 months after disposal.

6. 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 dump site or for its retention within the confines of the site, whichever is preferred for maximum environmental protection at a given site.



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) This report presents results obtained in a study conducted to evaluate the extent and duration of changes in chemical characteristics of Elliott Bay, Washington, six and nine months after disposal of dredged materials from the Duwamish River. The seawater, sediment, and interstitial water were analyzed for the following chemical parameters: <p style="text-align: right;">(Continued)</p> | | |

20. ABSTRACT (Continued).

- a. Seawater. Suspended solids, arsenic, manganese, mercury, reactive silicate, inorganic phosphate, nitrate, and ammonia.
- b. Sediment. Free and total (acid soluble) sulfide, manganese, chromium, arsenic, mercury, and particle size.
- c. Interstitial water. Arsenic, manganese, reactive silicate, ammonia, and inorganic phosphate.

Temporal, depth, and spatial changes in concentrations of chemical variables were evaluated at disposal and reference sites. The results of analyses showed only minimal changes in trace metal concentrations in the water column above the disposal site, but lower Eh and pH values in the sediments than at the reference site. The manganese, inorganic phosphate, and ammonia concentration values were greater in interstitial waters at the disposal site than at the reference site.

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SUMMARY

This study is part of a comprehensive program to measure the effects on the biota, sediment, and water quality that result from open-water disposal of dredged material at the Duwamish Waterway site, Elliott Bay, Puget Sound, Washington. Specifically, this work examined the extent and duration of changes in the chemical characteristics of the water and sediment at the disposal site in Elliott Bay six and nine months after disposal. Measurements before, during, and at three months after disposal were made by the Environmental Protection Agency (EPA) laboratory in Corvallis, Oregon.

Disposal of dredged materials from the Duwamish River into Elliott Bay has resulted in minimal long-term changes in the concentrations of trace metals in water above the disposal site. The only significant changes observed were decreases in the concentration of suspended solids and arsenic in the water column above the disposal area between September and December 1976 with no comparable change in concentrations at the reference sites.

Alteration in several chemical parameters of sediments at the disposal site was significant six and nine months after disposal when compared to one or both reference stations. In September and December 1976, the sediments at the disposal site had pH and Eh values significantly lower than those determined at the west reference station. At the disposal site, concentrations of manganese, inorganic phosphate, and ammonia in the interstitial waters were higher than at both reference sites, while the chromium concentration was higher in sediments at the west reference site than at the disposal site.

The significant changes between September and December 1976 in the chemical characteristics of the sediments at the disposal site were a decrease in values for pH, Eh, and inorganic phosphate and an increase in mercury and manganese concentrations. At the reference stations only Eh was significantly different in December than in September and in December the sediments became more reducing in nature.

PREFACE

The study described in this report was performed under Contract DACW39-76-C-0167, entitled "Elliott Bay Dredge Disposal Project--Trace Metals Project," between the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, and the University of Washington, Seattle, Washington. The research was sponsored by the Office, Chief of Engineers (DAEN-CWO-M), under the Civil Works Dredged Material Research Program (DMRP), Work Unit 1A10D. The work was initiated in September 1976 and the chemical analyses of all environmental samples collected during the project were completed in July 1977. This study includes data from collections made six and nine months after disposal and thus the evaluation of changes was restricted to that time period. The measurements on samples collected at the disposal site before, during, and three months after disposal have been made by the EPA laboratory in Corvallis, Oregon.

The work was conducted by the Laboratory of Radiation Ecology, College of Fisheries, University of Washington, whose personnel included Dr. W. R. Schell (Principal Investigator), Dr. A. Nevissi, S. Sugai, S. Olsen, D. Huntamer, and M. Brown. The project officer for this contract was Mr. J. H. Johnson of the WES Environmental Laboratory under the supervision of Dr. R. M. Engler, Manager of the Environmental Impacts and Criteria Development Project at WES.

Director of WES during the period of the contract and the preparation of the report was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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AQUATIC DISPOSAL FIELD INVESTIGATIONS, DUWAMISH WATERWAY
DISPOSAL SITE, PUGET SOUND, WASHINGTON

APPENDIX D: CHEMICAL AND PHYSICAL ANALYSES OF WATER AND SEDIMENT
IN RELATION TO DISPOSAL OF DREDGED MATERIAL IN ELLIOTT BAY

VOLUME II: SEPTEMBER-DECEMBER 1976

PART I: INTRODUCTION

Objective

1. This study is part of a comprehensive program to measure effects on the biota, sediment, and water quality resulting from open-water disposal of dredged material at the Duwamish Waterway site, Elliott Bay, Puget Sound, Washington. Specifically, this work examined the extent and duration of changes in the chemical characteristics of the water and sediment at the disposal site in Elliott Bay six and nine months after disposal.

Description of Study Area

2. Elliott Bay is located on the east side of central Puget Sound and is bounded by Duwamish Head to the southwest and Magnolia Bluff to the northwest (Figure 1).

3. The Duwamish River drains an area of 1251 km², mostly industrial, and provides fresh water to Elliott Bay at an average annual rate of about 1300 cfs.¹ The river discharges into the southeast corner of Elliott Bay, around Harbor Island, through two channels--the East and West Waterways.

4. Approximately 114,250 m³ of dredged material from a 1.88-km stretch of the upper Duwamish Estuary (Figure 1) was deposited near the center of a disposal site marked by a Coast Guard lighted buoy (47°35' 42"N; 122°21'42"W) during the period 16 February 1976 to 6 March 1976. The locations of the 16 stations (1-16) at the experimental disposal

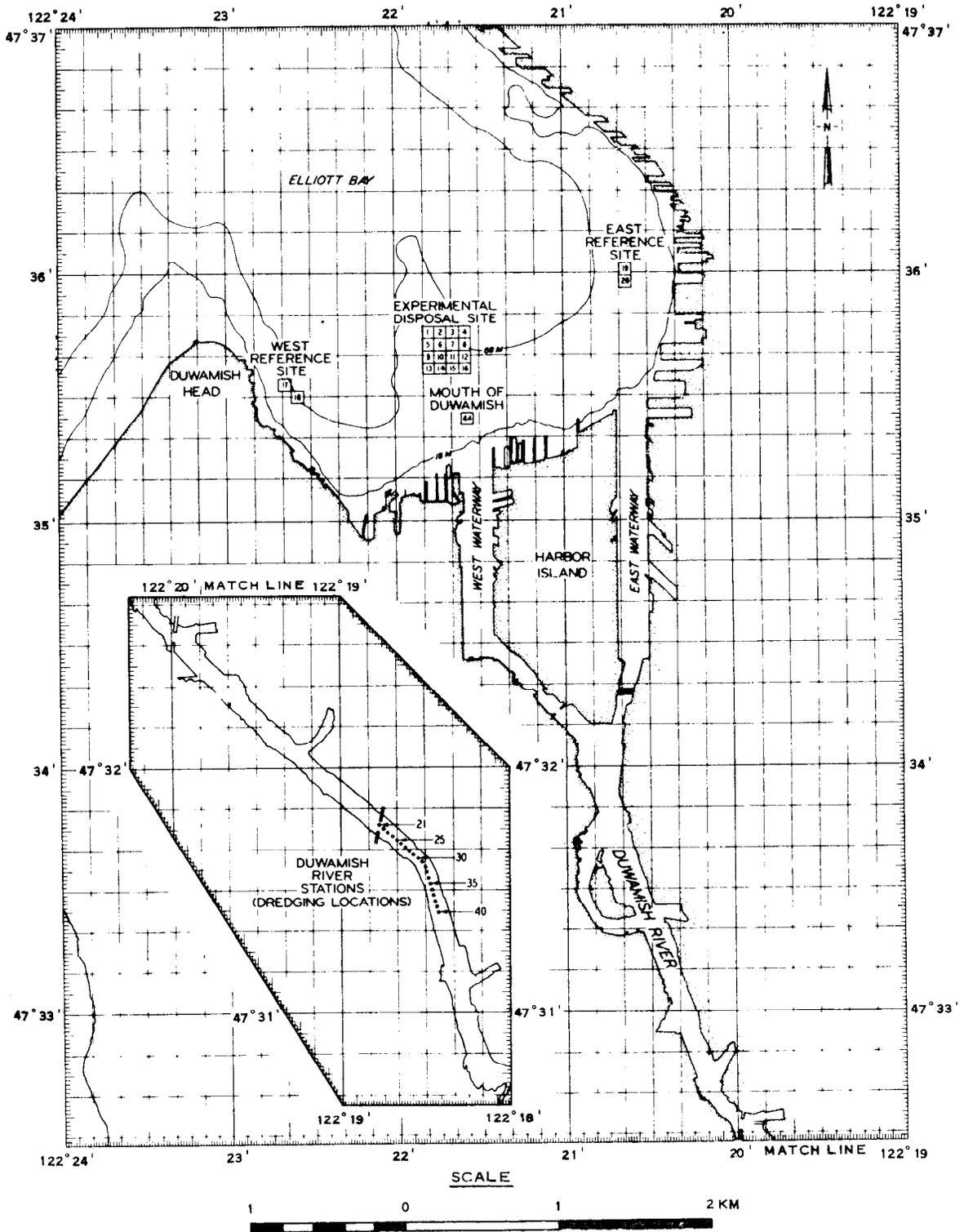


Figure 1. Locations of dredging, disposal, and reference sites

site, located due north of the mouth of the West Waterway, were selected by use of a 4 by 4 grid with the grid lines 76.2 m apart. The two reference sites were located along the east and west shores of Elliott Bay and consisted of two stations each (Figure 1). Historically the west reference site (stations 17, 18) has received the least impact from the municipal, commercial, and industrial activities of the Seattle area. Water flow over this location originates primarily from the main basin of Puget Sound rather than from the interior of Elliott Bay. The east reference site (stations 19, 20) has received effluents from the Duwamish River, shipping, and nearby shore-based activities, as well as from storm sewage overflow along the Seattle waterfront.

PART II: EXPERIMENTAL PROCEDURES

Sampling Design

5. Seawater and sediment samples for chemical analyses were collected during September and December 1976 following sampling and field procedures used during earlier portions of the disposal study.

Seawater samples

6. Water samples were collected at five stations: two stations near the center of the disposal site (station 6, north of buoy; station 10, south of buoy), two reference stations (station 17, west reference site; station 19, east reference site), and at the mouth of Duwamish River (station 44).

7. Water samples were collected at depths of 1 and 10 m above the bottom and 2 m below the surface. Two samples were taken at each station using a peristaltic pump attached to 1/2-in.-ID polyethylene tubing that had been lowered to depth on the hydrowire and then flushed thoroughly before sample collection.

Sediment samples

8. Sediment samples were taken using a double-barreled gravity cover with 67-mm-ID lucite liners at 20 sampling stations in the experimental disposal site (stations 1-20) and at two reference sites (one on the west side of the bay, stations 17 and 18; one on the east side, stations 19 and 20).

Shipboard Procedures

Seawater samples

9. Sufficient water was pumped to determine suspended solids, trace metals, and nutrients. To determine suspended solids, 2 to 10 litres of water were filtered through weighed 0.4 μ m Nuclepore filters and stored in plastic petri dishes. Samples for determination of chromium (Cr), manganese (Mn), and arsenic (As) were collected in acid-cleaned 2-litre polyethylene bottles and acidified to pH 1.0 with 2 ml/l doubly distilled

6 M hydrochloric acid (HCl). Mercury (Hg) samples were collected in acid-cleaned 1-litre polyethylene bottles and acidified with 2 ml/l of doubly distilled 16 M nitric acid (HNO₃), to give a pH of less than 1.0, and stored frozen. Nutrient (nitrate, reactive silicate, inorganic phosphate, ammonia) samples were frozen at -15°C in 250-ml polyethylene bottles.

Sediment samples

10. For each of the two casts (two cores per cast) taken at a station, the top 10 cm of one core was extruded into a nitrogen-filled polyethylene bag, the next 15 cm extruded into a second bag, and the excess discarded. The second core on each cast was processed for the trace organics program of S. Pavlou. Each sample was homogenized, subsampled, and stored at 5°C.

Processing of Sediment Samples

11. In the field initial measurements of Eh, pH, and free sulfide (S⁼) in the sediments were made using appropriate probes while working in a nitrogen-filled glove box. Upon return to the laboratory, in a nitrogen-atmosphere glove box, sediment samples were divided into two sections: one for Eh, pH, S⁼, total sulfide, percent water, and heavy metals analyses; and the other for centrifugation to remove interstitial water for trace metal and nutrient determinations. Particle size analyses were made on the sediment remaining after centrifugation.

12. After Eh, pH, and free sulfide were determined on the first aliquot of sediment, 30 g was removed and oven-dried at 70°C to determine the percent water. The dry aliquot was retained for heavy metal analyses.

13. In the nitrogen atmosphere of the glove box, 100 g of the second sediment aliquot was sealed into a 250-ml centrifuge bottle and centrifuged at 5°C for 20 minutes at 9000 rpm. Upon return to the glove box the interstitial water was decanted into a 10-dram vial, extracted from the vial with a 25-cc clean polyethylene syringe, and filtered through a 0.4 µm Nuclepore® filter into a tared, clean 60-ml polyethylene

bottle. One aliquot was frozen at 15°C for nutrient analyses, and a second aliquot was acidified with 25 µl/ml of 6 M doubly distilled HCl for heavy metals analyses.

Analytical Procedures

14. The analytical methods used in determining chemical parameters in the seawater and sediment are given below.

Seawater and interstitial water

15. Arsenic. Twenty mg of ferric ion was added to a measured aliquot of acidified seawater or interstitial water in an acid-cleaned polyethylene bottle and mixed. Concentrated ammonium hydroxide (NH_4OH) was added to raise the pH of the sample to between 9 and 10 to coprecipitate As with ferric hydroxide ($\text{Fe}(\text{OH})_3$), digested at 80°C for 30 min and allowed to cool. Samples were then filtered through 0.45 µm Millipore or 0.4 µm Nuclepore filters and precipitates were rinsed with deionized distilled water. Filters were removed and placed in 2/5 dram neutron activation analysis (NAA) vials to dry at room temperature. When dry, vials were sealed and irradiated for 2 hours along with As standards sorbed to silica gel and National Bureau of Standards (NBS) orchard leaves.²

16. Mercury. Distilled 8 M HNO_3 and reagent grade 18 M sulfuric acid (H_2SO_4) were added to the 470-500 ml seawater and 0.5 - 5 ml interstitial water samples. These samples were then loosely capped and digested in a 90°C water bath for 1 hour. Saturated potassium thiosulfate ($\text{K}_2\text{S}_2\text{O}_8$) was added and the solution allowed to cool. Analysis of the mercury concentration was then made using the flameless atomic absorption method of Melton, Hoover, and Howard.³

17. Manganese. Acidified seawater and interstitial water samples were diluted 1:10 with acidified, deionized distilled water and analyzed by flameless atomic absorption using the method of standard additions.

18. Nutrients. Nitrate, inorganic phosphate, ammonia, and reactive silicate were determined using a Technicon Autoanalyzer. Nitrate was analyzed by the cadmium-copper reduction of nitrate to nitrite with

corrections made for nitrite measured in samples.^{4,5} Inorganic phosphate was determined by the ascorbic acid reduction method, ammonia by the phenate procedure, and reactive silicate by reduction of silicomolybdate complexes by a solution of Metol and oxalic acid.⁶

Sediment samples

19. Free sulfide. Free sulfide was measured using an Orion specific ion electrode and a Chemtrix Model 60A pH/pIon meter. The sulfide electrode was calibrated by bubbling H_2S (gas) through buffered solutions at different pH values. After the electrode reached equilibrium with the saturated solution (changes of < 1 mv/min), the millivolt reading and pH of the solution were recorded.

20. Manganese. To each 2-gram aliquot of dried sediment, 20 ml of dionized water and 20 ml of distilled HNO_3 were added. The samples were heated, 5 ml of perchloric acid was added, and then the samples were evaporated to dryness. Subsequently, 10 ml of distilled HCl and 50 ml of dionized distilled water were added and the samples were boiled 10 to 15 min. Samples were then filtered and filtrates were combined with washings of the filter. Volume of filtrate was measured and concentration of manganese was determined by flameless atomic absorption.

20. Arsenic. Weighed aliquots of dried sediment were sealed in 2/5 dram vials and irradiated for 2 hours. Arsenic concentration was determined by comparison with As standards sorbed on silica gel and NBS standardized orchard leaves.

22. Mercury. Sediment samples were leached with distilled HNO_3 and reagent grade H_2SO_4 in a water bath at $90^\circ C$. Saturated $K_2S_2O_8$ was added to each sample and samples were then treated as the seawater and interstitial water samples. Mercury in leachate was determined by flameless atomic absorption.

23. Chromium. Weighed aliquots of dried sediment were sealed in 2/5 dram vials and irradiated for 8 hours. Chromium concentration was determined by comparison with Cr standards sorbed on silica gel and NBS standardized orchard leaves.

24. Total (acid soluble) sulfide. Sulfide was separated by acidifying the sediment samples to produce hydrogen sulfide (H_2S) which was

bubbled and trapped quantitatively in a zinc (Zn) solution as zinc sulfide precipitate. Iodometric titration was then used to determine the sulfide in the precipitate and solution. The total (acid soluble) sulfide determination measured dissolved HS^- , H_2S , and soluble metal sulfides.⁷

25. Particle size analyses. Following the removal of the interstitial water from the sediment by centrifugation, the particle size distributions of samples were determined by procedures suggested by H. P. Guy.⁸

Statistical Treatment of Experimental Data

26. A listing of the experimental data broken down by position, time, and depth is tabulated in Table 1. The data reduction and analysis was done by use of SPSS (Statistical Package for the Social Sciences) programs.⁹

27. The statistical treatment of experimental data was divided into the analysis of the independent variables and the correlation of dependent variables. For water and sediment samples, the independent variables of time (sampling date), depth (in core or water column), and position (station location) were analyzed by analysis of covariance using position as the factor with time and depth as the covariates. The response parameters for these analyses of covariances were the dependent variables listed in paragraph 31. The strength of association between dependent variables in both the water and sediment was evaluated by means of the Pearson product-moment correlation.

Analytical treatment of independent variables

28. Using the analysis of covariance to test independent variables, the effect of time and depth was isolated and checked for significance at the 95 percent ($S \leq 0.05$) and 99 percent ($S \leq 0.01$) confidence levels. This approach allowed position effects to be examined after being corrected for time and depth. The corrected means are tabulated in the multiple classification section of the analysis of covariance tables.

The assumptions for analysis of variance (ANOVA) were assumed valid for all data and the covariate-by-factor interaction was assumed to be zero.

29. Analysis of covariance for water samples. In the water samples the treatment design was a $5 \times 2 \times 3$ factorial. The factor was position with the five levels being the five stations: 6, 10, 17, 19, and 44. The first covariate was time with the two levels being September 1976 and December 1976. The second covariant was depth with the three levels being 2 m from surface, 10 m from bottom, and 1 m from bottom. The position effects were compared pairwise with the corrected means given in the multiple classification analysis of Scheffé's multiple comparison test.¹⁰ The time and depth effects were broken down into three parts by a further analysis of covariance. Three areas were examined (disposal site, stations 6, 10; reference sites, stations 17, 19; and Duwamish River mouth, station 44) so that the disposal site could be compared with the reference sites.

30. Analysis of covariance for sediment samples. The sediment samples were analyzed in a manner similar to that used for the water samples. However, the data for the sediment were reduced into four categories to aid in interpretation. The first group was the central disposal site consisting of stations 6, 7, 10, and 11. The second and third groups were the west (stations 17, 18) and east (stations 19, 20) reference sites. The fringe area of the disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, and 16) was included in the fourth group. After the data reduction, the treatment design was a $4 \times 2 \times 2$ factorial. The factor was position with the four levels described above. The first covariate was time with the two levels being September 1976 and December 1976; and the second covariate was depth with the two levels being 0 to 10 cm and 10 to 25 cm in the core. The significant effects of time, position, and depth were compared, as with the water samples, except that time and depth were broken down into only disposal and reference sites.

Analytical treatment
of dependent variables

31. Pairwise matrices were constructed to examine the linear

correlations between response parameters. The correlation coefficients not only summarized the strength of association between a pair of variables, but also provided an easy means for comparing the strength of relationships between one pair of variables and a different pair. In order to evaluate whether elements were behaving differently in the disposal and reference sites, two correlations were done for each dependent variable: disposal and reference. The dependent variables for the water samples are as follows: suspended solids, As, Mn, Hg, nitrate, ammonia, inorganic phosphate, and reactive silicate. The dependent variables for the sediment samples are as follows: pH, Eh, sediment manganese (Mn(Sed)), interstitial water manganese (Mn(IW)), sediment arsenic (As(Sed)), interstitial water arsenic (As(IW)), sediment mercury (Hg(Sed)), interstitial water mercury (Hg(IW)), sediment chromium (Cr(Sed)), free sulfide, inorganic phosphate, ammonia, and particle size coarse fractions (CF1-CF6), silt, and clay. The data were assumed to be normally distributed and the linearity of the correlation was determined by inspection of scattergrams.¹¹

PART III: RESULTS AND DISCUSSION

32. The concentrations of four trace metals (Mn, As, Hg, Cr) and four nutrients (nitrate, ammonia, reactive silicate, inorganic phosphate), and supporting chemical and physical information determined in water, sediment, and interstitial water of Elliott Bay are listed in Tables 2-11.

Chemical Characteristics of Elliott Bay Water

33. The concentrations of suspended solids, trace metals, and nutrients at the Elliott Bay dredge disposal site (stations 6, 10), Duwamish River mouth (station 44), and two reference sites (stations 17, 19) are shown in Table 2. The significance of temporal, depth, and spatial differences in the chemical parameters as determined by analysis of covariance is tabulated in Table 12.

Temporal differences in chemical parameters

34. Suspended solids measured over the disposal site decreased between September and December 1976 sampling cruises although no significant changes occurred in the reference sites. Seawater arsenic concentrations at the disposal site were lower in December than in September although arsenic in the reference sites remained constant. Other observed temporal changes occurred at both disposal and reference sites and therefore were likely seasonal rather than disposal effects.

Position differences over depth in the water column

35. Over the disposal site, manganese concentrations were higher in bottom waters than in surface waters, while in reference sites the opposite trend was observed.

Spatial differences in chemical parameters

36. Concentration levels of the various trace metals and nutrients measured in the water above the disposal site were not statistically

different from levels measured at the reference sites except for mercury concentrations in September. In September, the mercury concentrations at the east reference site (station 19) were approximately two to three times higher than levels in other parts of Elliott Bay.

Chemical Characteristics of Elliott Bay Sediment

37. The pH, Eh, and free and total sulfide concentrations are tabulated in Table 3. Concentrations of arsenic, chromium, manganese, and mercury in sediments are shown in Tables 4-7. Particle size distribution and percent water values are given in Table 8. Tables 9 and 10 list the concentrations of arsenic and manganese in interstitial waters. Inorganic phosphate, reactive silicate, and ammonia concentrations are tabulated in Table 11. The significance of temporal, depth, and spatial differences in the chemical parameters as determined by analysis of covariance is tabulated in Table 13.

Sediment parameters

38. pH. Sediment pH was lower at the Elliott Bay disposal site than at reference sites for both sampling cruises and decreased between September and December (Table 3). No temporal effect was observed for the west reference site. In addition, pH values for the central disposal site increased from the top to bottom sections of the core.

39. Eh. Eh values were more negative in December than in September for central disposal and reference sites (Table 3). The Eh values in the west reference site were higher than values obtained in the central disposal area and in the fringe of the experimental disposal area. No Eh differences were observed with depth in the core.

40. Free sulfide. No spatial or temporal differences were observed for free sulfide concentrations in Elliott Bay (Table 3).

41. Manganese. Manganese concentrations in sediment from the disposal area were greater in December than in September (Table 6). Concentrations in the central disposal area were higher than those in the east reference site.

42. Arsenic. The arsenic concentration in sediment from the

central disposal site was higher in the top section of the core than in the lower section (Table 4). No temporal differences were observed and differences in concentration between the central disposal site and the west reference station were not significant.

43. Mercury. Mercury concentrations in sediment at the disposal site increased between the September and December sampling cruises (Table 7). The concentration at the disposal site decreased from the top to the bottom sections of the cores. Mercury concentrations were two to three times greater in sediments from the east reference site than elsewhere in Elliott Bay.

44. Chromium. Chromium concentrations in sediment were higher at the west reference station than at the central disposal, fringe disposal, or east reference sites (Table 5). The chromium concentration in sediment at the disposal site decreased with depth in the core. No temporal differences were observed.

45. Particle Size. Coarse fractions 1 (>2 mm) and 2 (1-2 mm) decreased with depth in the cores taken from the central disposal area while coarse fractions 3 (0.5-1 mm) and 4 (0.25-0.5 mm) increased with depth (Table 8). No particle size variation with depth was seen for the west reference site. CF₂ was higher at the west reference site than at either the central disposal area or the east reference site. CF₄ was higher at the disposal site than at the east reference site. The silt fraction was higher at the disposal site than at the west reference site.

Interstitial water parameters

46. Manganese. Manganese concentrations in interstitial waters from Elliott Bay sediments were significantly higher within the disposal site than at reference stations (stations 17-20) (see Table 10). No consistent pattern of increasing or decreasing manganese concentration was observed with depth or distance from the center of the disposal site. No temporal effect upon concentration was seen for disposal site sediments. A decrease in manganese concentration with depth was seen at the west reference site.

47. Arsenic. No statistically significant differences in

concentration of arsenic were observed between disposal and reference sites or with depth in the cores (Table 9).

48. Phosphate. Inorganic phosphate concentrations decreased from September to December for the central disposal site (Table 11). The phosphate concentration at the central disposal region was higher than that observed at either of the reference sites. No concentration gradients were observed with depth in the core.

49. Ammonia. Ammonia concentration was significantly higher at the center of the disposal site than at the reference sites and concentrations were generally higher in December than in September for both the disposal and west reference sites (Table 11). No significant concentration differences were observed with depth.

Discussion of Results

Correlations between various chemical and physical parameters

50. Seawater. Table 14 lists the Pearson product-moment correlation coefficients, R, for seawater samples taken at stations 6 and 10 of the disposal site. A similar matrix constructed for the reference stations (stations 17, 19) is shown in Table 15. The only significant correlations ($S \leq 0.01$, 99 percent confidence limit) present in the reference stations are between the various nutrients: nitrate and phosphate, nitrate and silicate, and phosphate and silicate. In the disposal site there is also a correlation between suspended solids and manganese ($S \leq 0.001$) and between arsenic and phosphate ($S \leq 0.005$).

51. Sediment. Correlation coefficient matrices for sediment parameters in disposal and reference stations are given in Tables 16 and 17, respectively. At the reference stations, arsenic in sediment correlates ($S \leq 0.001$) with arsenic and mercury in interstitial water and with mercury and chromium in sediment. Arsenic in interstitial water correlates strongly with mercury in interstitial water and with chromium in sediment. At the disposal area pH correlates with Eh ($S \leq 0.003$), with manganese (0.006), arsenic (0.001), and mercury (0.001) in sediment,

and with manganese in interstitial water (0.001). However, the strong correlations between the various heavy metals seen at the reference stations were not observed.

Choice of reference sites

52. When undertaking a study of the effect of a perturbation upon a natural system it is important to have a reference area that is similar to the study area in every way except that it is not subject to the experimental stress, in this case disposal of dredged material. However, in this study the east reference site, located offshore from the Seattle piers, had mercury concentrations in the water, sediment, and interstitial waters which were elevated with respect to both the disposal and west reference sites. In addition, Eh and Cr(Sed) values at the east reference site were significantly lower than values measured at the west reference site. Sediments at the east reference site had a much greater percentage of finer particle size material than either the west reference site or the disposal area. Thus, the choice of the reference sites for sediment and water chemistry comparisons was not ideal. Only stations 19 and 20 were used in Table 1.3 for determinations of temporal and depth differences between the central disposal site and the undisturbed areas of Elliott Bay.

Improper storage and pretreatment problems

53. Although estuarine samples can contain airborne and waterborne contamination from industrial and human sources which result in elevated concentrations of heavy metals relative to pristine open ocean areas, parts per billion levels necessitate that care be exercised to minimize metal contamination or loss during collection, storage, and analysis. Without adequate protection of sample integrity, spatial and temporal changes in metal concentration which occur in the natural marine system cannot be determined. Threats to the sample integrity include metal contamination or loss in the laboratory and care must be taken to quantify these problems.

54. Following centrifugation, interstitial water samples that were to be analyzed for trace metals were acidified with HCl and stored at

room temperature in polyethylene bottles. Because samples were not frozen, considerable amounts of arsenic and mercury were lost to the container walls in the 5 to 6 months the December samples were stored before the analyses were completed.

55. Arsenic. Table 18 shows the effect of storage upon the observed arsenic concentration in interstitial waters collected in September. The first arsenic concentration, As1, was measured in November within about a month of collection. As2 is a second aliquot taken from the same storage bottle and analyzed in May, approximately 6 months later. As shown in Table 18, the percent change in arsenic concentration ranged from -75 percent to +231 percent of the value determined in November. Although adsorption of metals on the walls of containers is probably the most likely mechanism for change in concentration, resulting in a decrease in observed concentration, contamination can increase the measured concentration. Samples from the December cruise were not analyzed until 5 months after collection and were considerably lower in concentration reflecting the loss of arsenic to the container walls. Thus, the only arsenic concentrations reported were from the September cruise.

56. Mercury. A similar problem was encountered in analyses for mercury in interstitial waters. Acidified aqueous solutions initially containing 0.34 mg/l have been observed to lose more than 65 percent of the original mercury when stored in polyethylene containers for 10 days.¹² Table 19 shows the change in mercury concentration measured in September samples following 7 months of storage. Because December samples were stored 6 months before analyses, the results were not reported. September samples were stored for over a month and therefore are also questionable and not reported. Lindberg and Harriss¹³ indicate that interstitial dissolved mercury is much greater than that in the overlying water. Results of this study did not support this observation, and, rather than being indicative of unique conditions in the study area, measured mercury concentrations in interstitial water are believed to reflect the improper storage of the samples. Seawater samples to be analyzed for mercury were frozen immediately after the collection,

but interstitial water samples were not.

57. Nitrate. Nitrate values for interstitial waters are not reported because samples were mistakenly stored in bottles that had been soaked in nitric acid which contaminated the samples for this nutrient.

PART IV: SUMMARY AND CONCLUSIONS

58. Disposal of dredged material from the Duwamish River into Elliott Bay has resulted in minimal long-term changes in concentrations of trace metals observed in water above the disposal site. Six and nine months after the disposal of dredged material, the only significant difference between water at the disposal site and at the two reference sites was a higher mercury concentration in waters of the east reference site located near the Seattle waterfront. The concentrations of suspended solids and arsenic in the water column above the disposal area decreased between September and December although no significant change in concentration was observed at the reference sites.

59. Alteration in chemical parameters of the disposal site sediments was significant six and nine months after disposal when compared to one or both reference stations. In September and December 1976, the sediments of the disposal area had pH and Eh values significantly lower than those determined at the west reference station. At the disposal site, concentrations of manganese, inorganic phosphate, and ammonia in the interstitial waters were higher than at both reference sites, while chromium was highest in sediments at the west reference site.

60. Significant temporal changes in the sediment chemistry of the disposal site were observed between September and December 1976; pH, Eh, and inorganic phosphate decreased at the disposal site and mercury and manganese concentrations in sediment increased. At the reference stations only Eh was significantly different in December than in September and also, in December, the sediments became more reducing in nature.

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APPENDIX A'

ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS TABLES FOR SEAWATER AND
SEDIMENT VARIABLES WITH SIGNIFICANT POSITION EFFECTS

ANOVA Table for Seawater Mercury by Position with
Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 10,) west reference site (station 17,) east reference site (station 19)

Time = Sampling date (September, December 1976)

Depth = Depth in water column (2m from surface, 10m above bottom, 1m above bottom)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 110.008 | 2 | 55.004 | .193 | .825 |
| Time | 30.343 | 1 | 30.343 | .106 | .746 |
| Depth | 79.665 | 1 | 79.665 | .279 | .600 |
| Main effects | 4318.674 | 4 | 1079.669 | 3.782 | .009 |
| Position | 4318.674 | 4 | 1079.669 | 3.782 | .009 |
| Explained | 4428.682 | 6 | 738.114 | 2.586 | .029 |
| Residual | 14844.381 | 52 | 285.469 | | |
| Total | 19273.063 | 58 | 332.294 | | |
| Covariate | Beta | | | | |
| Time | -1.434 | | | | |
| Depth | -1.411 | | | | |

60 cases were processed

1 case (1.7 PCT) was missing

Multiple Classification Analysis for Seawater Mercury
by Position with Time and Depth as Covariates

Grand Mean = 26.26

| <u>Variable + Category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|------------------------------|----------|-------------------|-------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV#N</u> | <u>Eta</u> | <u>Independents</u> | <u>Beta</u> | <u>indepedents</u> | <u>+ Covariates</u> |
| | | <u>DEV#N</u> | <u>Beta</u> | <u>DEV#N</u> | <u>Beta</u> | <u>DEV#N</u> | <u>Beta</u> |
| Position | | | | | | | |
| St. 6. central disposal site | 11 | -5.39 | | | | -5.35 | |
| St. 10 central disposal site | 12 | -2.46 | | | | -2.47 | |
| St. 17 west reference site | 12 | -2.26 | | | | -2.27 | |
| St. 19 east reference site | 12 | 16.58 | | | | 16.57 | |
| St. 44 Duwamish River mouth | 12 | -6.92 | | | | -6.93 | |
| | | | | .47 | | | .47 |

ANOVA Table for Seawater Manganese by Position with

Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 10,) west reference site (station 17), east reference site (station 19),

Time = Sampling date (September, December 1976)

Depth = Depth in water column (2m from surface, 10m above bottom, 1m above bottom)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 334.604 | 2 | 167.303 | 31.388 | .001 |
| Time | 212.105 | 1 | 212.105 | 39.794 | .001 |
| Depth | 122.500 | 1 | 122.500 | 22.983 | .001 |
| Main effects | 264.417 | 4 | 66.104 | 12.402 | .001 |
| Position | 264.417 | 4 | 66.104 | 12.402 | .001 |
| Explained | 599.023 | 6 | 99.837 | 18.731 | .001 |
| Residual | 277.165 | 52 | 5.330 | | |
| Total | 876.187 | 58 | 15.107 | | |
| Covariate | Beta | | | | |
| Time | -3.793 | | | | |
| Depth | 1.750 | | | | |

60 cases were processed

1 case (1.7 PCT) was missing

Multiple Classification Analysis for Seawater Manganese
by Position with Time and Depth as Covariates

Grand Mean = 18.35

| <u>Variable + Category</u> | <u>N</u> | <u>Unadjusted</u> <u>DEV/N</u> <u>Eta</u> | <u>Adjusted for</u> <u>Independents</u> <u>DEV/N</u> <u>Beta</u> | <u>Adjusted for</u> <u>Independents</u> <u>+ Covariates</u> <u>DEV/N</u> <u>Beta</u> |
|------------------------------|----------|--|--|---|
| Position | | | | |
| St. 6 central disposal site | 11 | -1.52 | | -1.39 |
| St. 10 central disposal site | 12 | 3.80 | | 3.77 |
| St. 17 west reference site | 12 | .32 | | .28 |
| St. 19 east reference site | 12 | -.33 | | -.36 |
| St. 44 Duwamish River mouth | 12 | -2.39 | | -2.42 |
| | | | .56 | .55 |

ANOVA Table for Sediment pH by Position
with Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11, west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 1.044 | 2 | .522 | 8.622 | .001 |
| Time | .430 | 1 | .430 | 7.100 | .009 |
| Depth | .614 | 1 | .614 | 10.144 | .002 |
| Main Effects | 10.130 | 3 | 3.377 | 55.751 | .001 |
| Position | 10.130 | 3 | 3.377 | 55.751 | .001 |
| Explained | 11.174 | 5 | 2.235 | 36.900 | .001 |
| Residual | 8.721 | 144 | .061 | | |
| Total | 19.896 | 149 | .134 | | |

| Covariate | Beta |
|-----------|-------|
| Time | -.107 |
| Depth | .128 |

160 cases were processed
 10 cases (6.3 PCT) were missing

Multiple Classification Analysis for Sediment pH
by Position with Time and Depth as Covariates

Grand Mean = 6.86

| <u>Variable + Category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV#N</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>independents</u> | <u>+ covariates</u> |
| | | <u>DEV#N</u> | | <u>DEV#N</u> | | <u>DEV#N</u> | <u>Beta</u> |
| Position | | | | | | | |
| 1 Central disposal | 31 | -.16 | | | | -.17 | |
| 2 West reference | 16 | .50 | | | | .50 | |
| 3 East reference | 16 | .50 | | | | .50 | |
| 4 Fringe disposal | 87 | -.13 | | | | -.12 | |
| | | | .72 | | | | .71 |

ANOVA Table for Sediment Manganese by Position with Time
and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 32881.749 | 2 | 16440.875 | 5.006 | .008 |
| Time | 32516.971 | 1 | 32516.971 | 9.901 | .002 |
| Depth | 277.986 | 1 | 277.986 | .085 | .772 |
| Main Effects | 39583.925 | 3 | 13194.642 | 4.017 | .009 |
| Position | 39583.925 | 3 | 13194.642 | 4.017 | .009 |
| Explained | 72465.674 | 5 | 14493.135 | 4.413 | .001 |
| Residual | 492668.236 | 150 | 3284.455 | | |
| Total | 565133.910 | 155 | 3646.025 | | |

Covariate Beta

Time 28.881

Depth -2.671

160 cases were processed

4 cases (2.5 PCT) were missing

Multiple Classification Analysis for Sediment Manganese
by Position with Time and Depth as Covariates

Grand Mean = 255.88

| <u>Variable + Category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV#N</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>independents</u> | <u>+ covariates</u> |
| | | <u>DEV#N</u> | | <u>DEV#N</u> | | <u>DEV#N</u> | <u>Beta</u> |
| Position | | | | | | | |
| 1 Central disposal | 32 | 28.00 | | | | 27.86 | |
| 2 West reference | 16 | -11.56 | | | | -11.71 | |
| 3 East reference | 15 | -28.63 | | | | -27.93 | |
| 4 Fringe disposal | 93 | - 3.03 | | | | - 3.07 | |
| | | | | | .27 | | .26 |

ANOVA Table for Sediment Mercury by Position with Time and Depth
as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 11.822 | 2 | 5.911 | 3.568 | .031 |
| Time | 2.326 | 1 | 2.326 | 1.404 | .238 |
| Depth | 9.557 | 1 | 9.557 | 5.768 | .018 |
| Main effects | 42.977 | 3 | 14.326 | 8.646 | .001 |
| Position | 42.977 | 3 | 14.326 | 8.646 | .001 |
| Explained | 54.799 | 5 | 10.960 | 6.615 | .001 |
| Residual | 250.191 | 151 | 1.657 | | |
| Total | 304.990 | 156 | 1.955 | | |
| Covariate | Beta | | | | |
| Time | .243 | | | | |
| Depth | .493 | | | | |

160 cases were processed

3 cases (1.9 PCT) were missing

Multiple Classification Analysis for Sediment Mercury by Position
with Time and Depth as Covariates

Grand Mean = .51

| <u>Variable + category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV#</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>Independents</u> | <u>+ Covariates</u> |
| | | <u>DEV#N</u> | | <u>DEV#N</u> | | <u>DEV#N</u> | <u>Beta</u> |
| Position | | | | | | | |
| 1 Central disposal | 32 | -.33 | | | | -.33 | |
| 2 West reference | 16 | -.28 | | | | -.29 | |
| 3 East reference | 15 | 1.59 | | | | 1.58 | |
| 4 Fringe disposal | 94 | -.09 | | | | -.09 | |
| | | | .38 | | | | .38 |

ANOVA Table for Sediment Chromium by Position with Time
and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 2537.371 | 2 | 1268.686 | 3.886 | .023 |
| Time | 124.786 | 1 | 124.786 | .382 | .537 |
| Depth | 2412.586 | 1 | 2412.586 | 7.390 | .007 |
| Main Effects | 37231.017 | 3 | 12410.339 | 38.014 | .001 |
| Position | 34231.017 | 3 | 12410.339 | 38.014 | .001 |
| Explained | 39768.388 | 5 | 7953.678 | 24.363 | .001 |
| Residual | 50275.372 | 154 | 326.463 | | |
| Total | 90043.759 | 159 | 566.313 | | |
| Covariate | Beta | | | | |
| Time | 1.766 | | | | |
| Depth | -7.766 | | | | |

160 cases were processed
0 cases (0 PCT) were missing

Multiple Classification Analysis for Sediment Chromium by
Position with Time and Depth as Covariates

Grand Mean = 76.79

| <u>Variable + Category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV#N</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>independents</u> | <u>+ covariates</u> |
| | | | | <u>DEV#N</u> | | <u>DEV#N</u> | <u>Beta</u> |
| Position | | | | | | | |
| 1 Central disposal | 32 | - 6.92 | | | | - 6.92 | |
| 2 West reference | 16 | 44.58 | | | | 44.58 | |
| 3 East reference | 16 | 5.25 | | | | 5.25 | |
| 4 Fringe disposal | 96 | - 6.00 | | | | - 6.00 | |
| | | | .64 | | | | .64 |

ANOVA Table for Sediment Coarse Size Fraction 1 (> 2mm) by
Position with Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 182.800 | 2 | 91.400 | 3.834 | .024 |
| Time | 6.400 | 1 | 6.400 | .268 | .605 |
| Depth | 176.400 | 1 | 176.400 | 7.399 | .007 |
| Main effects | 200.860 | 3 | 66.953 | 2.808 | .041 |
| Position | 200.860 | 3 | 66.953 | 2.808 | .041 |
| Explained | 383.660 | 5 | 76.732 | 3.219 | .009 |
| Residual | 3671.315 | 154 | 23.840 | | |
| Total | 4054.975 | 159 | 25.503 | | |
| Covariate | Beta | | | | |
| Time | - .400 | | | | |
| Depth | 2.100 | | | | |

160 cases were processed

0 cases (0 PCT) were missing

Multiple Classification Analysis for Sediment Coarse Size Fraction
1 (> 2mm) by Position with Time and Depth as Covariates

Grand Mean = 5.76

| <u>Variable + category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|------------|---------------------|-------------|---------------------|-------------|
| | | <u>DEV#N</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>+ covariates</u> | <u>Beta</u> |
| | | <u>DEV#N</u> | | <u>DEV#N</u> | | <u>DEV#N</u> | |
| Position | | | | | | | |
| 1 Central disposal | 32 | -1.29 | | | | -1.29 | |
| 2 West reference | 16 | 1.43 | | | | 1.43 | |
| 3 East reference | 16 | 2.61 | | | | 2.61 | |
| 4 Fringe disposal | 96 | -.24 | | | | -.24 | |
| | | | .22 | | | | .22 |

ANOVA Table for Sediment Coarse Size Fraction 2 (1 to 2mm) by
Position with Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 374.291 | 2 | 187.146 | 4.322 | .015 |
| Time | 15.191 | 1 | 15.191 | .351 | .555 |
| Depth | 359.101 | 1 | 359.101 | 8.293 | .005 |
| Main effects | 939.575 | 3 | 313.192 | 7.233 | .001 |
| Position | 939.575 | 3 | 313.192 | 7.233 | .001 |
| Explained | 1313.867 | 5 | 262.773 | 6.069 | .001 |
| Residual | 6668.195 | 154 | 43.300 | | |
| Total | 7982.062 | 159 | 50.202 | | |

| Covariate | Beta |
|-----------|-------|
| Time | .616 |
| Depth | 2.996 |

160 cases were processed

0 cases (0 PCT) were missing

Multiple Classification Analysis for Sediment Coarse Size Fraction
2 (1 to 2mm) by Position with Time and Depth as Covariates

Grand Mean = 10.98

| <u>Variable + Category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|-------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV#N</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>independents</u> | <u>+ covariates</u> |
| | | <u>DEV#N</u> | <u>Beta</u> | <u>DEV#N</u> | <u>Beta</u> | <u>DEV#N</u> | <u>Beta</u> |
| Position | | | | | | | |
| 1 Central disposal | 32 | -1.49 | | | | -1.49 | |
| 2 West reference | 16 | 5.39 | | | | 5.39 | |
| 3 East reference | 16 | -4.92 | | | | -4.92 | |
| 4 Fringe disposal | 96 | .42 | | | | .42 | |
| | | | .34 | | | | 34 |

ANOVA Table for Sediment Coarse Size Fraction 3 (0.5 - 1mm) by
Position with Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 263.081 | 2 | 131.540 | 1.869 | .158 |
| Time | 102.881 | 1 | 102.881 | 1.462 | .229 |
| Depth | 160.200 | 1 | 160.200 | 2.276 | .133 |
| Main effects | 3116.202 | 3 | 1038.734 | 14.757 | .001 |
| Position | 3116.202 | 3 | 1038.734 | 14.757 | .001 |
| Explained | 3379.283 | 5 | 675.857 | 9.601 | .001 |
| Residual | 10840.217 | 154 | 70.391 | | |
| Total | 14219.499 | 159 | 89.431 | | |
| Covariate | Beta | | | | |
| Time | -1.604 | | | | |
| Depth | -2.001 | | | | |

160 cases were processed

0 cases (0 PCT) were missing.

Multiple Classification Analysis for Sediment Coarse Size Fraction
3 (0.5 - 1mm) by Position with Time and Depth as Covariates

Grand Mean = 19.65

| <u>Variable + Category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV#N</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>independents</u> | <u>+ covariates</u> |
| | | | | <u>DEV#N</u> | | <u>DEV#N</u> | <u>Beta</u> |
| Position | | | | | | | |
| 1 Central disposal | 32 | - | .60 | | | - | .60 |
| 2 West reference | 16 | | 3.36 | | | | 3.36 |
| 3 East reference | 16 | | -12.80 | | | | -12.80 |
| 4 Fringe disposal | 96 | | 1.77 | | | | 1.77 |
| | | | | | .47 | | |
| | | | | | | | .47 |

ANOVA Table for Sediment Coarse Size Fraction 4 (0.25 - 0.5mm) by
Position with Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 150.783 | 2 | 75.391 | 1.728 | .181 |
| Time | 2.906 | 1 | 2.906 | .067 | .797 |
| Depth | 147.609 | 1 | 147.609 | 3.383 | .068 |
| Main effects | 3484.783 | 3 | 1161.594 | 26.623 | .001 |
| Position | 3484.783 | 3 | 1161.594 | 26.623 | .001 |
| Explained | 3635.566 | 5 | 727.113 | 16.665 | .001 |
| Residual | 6575.634 | 153 | 43.632 | | |
| Total | 10311.200 | 158 | 65.261 | | |
| Covariate | Beta | | | | |
| Time | .270 | | | | |
| Depth | -1.927 | | | | |

160 cases were processed

1 case (.6 PCT) was missing

Multiple Classification Analysis for Sediment Coarse Size Fraction
4 (0.25 - 0.5mm) by Position with Time and Depth as Covariates

Grand Mean = 19.03

| <u>Variable + Category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV/N</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>independents</u> | <u>+ covariates</u> |
| | | | | <u>DEV/N</u> | <u>Beta</u> | <u>DEV/N</u> | <u>Beta</u> |
| Position | | | | | | | |
| 1 Central disposal | 32 | - 2.23 | | | | - 2.24 | |
| 2 West reference | 16 | - .31 | | | | - .32 | |
| 3 East reference | 16 | -12.53 | | | | -12.53 | |
| 4 Fringe disposal | 95 | 2.91 | | | | 2.92 | |
| | | | .58 | | | | .58 |

ANOVA Table for Sediment Silt Size Fraction (0.002 - 0.05mm) by

Position with Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 17.640 | 2 | 8.820 | .042 | .959 |
| Time | 1.764 | 1 | 1.764 | .008 | .927 |
| Depth | 15.876 | 1 | 15.876 | .076 | .783 |
| Main effects | 10222.910 | 3 | 3407.637 | 16.321 | .001 |
| Position | 10222.910 | 3 | 3407.637 | 16.321 | .001 |
| Explained | 10240.550 | 5 | 2048.110 | 9.810 | .001 |
| Residual | 32153.261 | 154 | 208.787 | | |
| Total | 42393.811 | 159 | 266.628 | | |
| Covariate | Beta | | | | |
| Time | -.210 | | | | |
| Depth | -.630 | | | | |

160 cases were processed

0 cases (0 PCT) were missing

Multiple Classification Analysis for Sediment Silt Size Fraction
(0.002 - 0.05mm) by Position with Time and Depth as Covariates

Grand Mean = 43.47

| <u>Variable + category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>independents</u> | <u>+ covariates</u> |
| | | <u>≠N</u> | | <u>DEV</u> | | <u>DEV</u> | <u>≠N</u> |
| | | | | | | | <u>Beta</u> |
| Position | | | | | | | |
| 1 Central disposal | 32 | 6.39 | | | | 6.39 | |
| 2 West reference | 16 | - 8.25 | | | | - 8.25 | |
| 3 East reference | 16 | 19.77 | | | | 19.77 | |
| 4 Fringe disposal | 96 | - 4.05 | | | | - 4.05 | |
| | | | .49 | | | | .49 |

ANOVA Table for Sediment Clay Size Fraction (<0.002mm) by
Position with Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 40.107 | 2 | 20.053 | .742 | .478 |
| Time | 9.448 | 1 | 9.448 | .349 | .555 |
| Depth | 30.659 | 1 | 30.659 | 1.134 | .289 |
| Main effects | 683.896 | 3 | 227.965 | 8.430 | .001 |
| Position | 683.896 | 3 | 227.965 | 8.430 | .001 |
| Explained | 724.003 | 5 | 144.801 | 5.355 | .001 |
| Residual | 4110.354 | 152 | 27.042 | | |
| Total | 4834.357 | 157 | 30.792 | | |
| Covariate | Beta | | | | |
| Time | -.489 | | | | |
| Depth | -.881 | | | | |

160 cases were processed

2 cases (1.3 PCT) were missing

Multiple Classification Analysis for Sediment Clay Size Fraction
(<0.002m) by Position with Time and Depth as Covariates

Grand Mean = 3.52

| <u>Variable + category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV#N</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>independents</u> | <u>+ covariates</u> |
| | | | | <u>DEV#N</u> | <u>Beta</u> | <u>DEV#N</u> | <u>Beta</u> |
| Position | | | | | | | |
| 1 Central disposal | 32 | -1.04 | | | | -1.04 | |
| 2 West reference | 16 | - .19 | | | | - .19 | |
| 3 East reference | 16 | 6.16 | | | | 6.16 | |
| 4 Fringe disposal | 94 | - .67 | | | | - .66 | |
| | | | .38 | | | | .38 |

ANOVA Table for Interstitial Water Manganese by Position
with Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11, west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12,13,14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | .354 | 2 | .177 | .036 | .965 |
| Time | .354 | 1 | .354 | .072 | .789 |
| Depth | .000 | 1 | .000 | .000 | .993 |
| Main Effects | 324.870 | 3 | 108.290 | 22.062 | .001 |
| Position | 324.870 | 3 | 108.290 | 22.062 | .001 |
| Explained | 325.223 | 5 | 65.045 | 13.251 | .001 |
| Residual | 721.549 | 147 | 4.908 | | |
| Total | 1046.773 | 152 | 6.887 | | |
| Covariate | Beta | | | | |
| Time | .096 | | | | |
| Depth | -.003 | | | | |

160 cases were processed
 7 cases (4.4 PCT) were missing

Multiple Classification Analysis for Interstitial Water Manganese by
Position with Time and Depth as Covariates

Grand Mean = 3.26

| <u>Variable + category</u> | <u>N</u> | <u>Unadjusted</u> | | <u>Adjusted for</u> | | <u>Adjusted for</u> | |
|----------------------------|----------|-------------------|------------|---------------------|-------------|---------------------|---------------------|
| | | <u>DEV/N</u> | <u>Eta</u> | <u>independents</u> | <u>Beta</u> | <u>independents</u> | <u>+ covariates</u> |
| | | | | <u>DEV/N</u> | | <u>DEV/N</u> | <u>Beta</u> |
| Position | | | | | | | |
| 1 Central reference | 30 | .99 | | | | .99 | |
| 2 West reference | 15 | -2.81 | | | | -2.81 | |
| 3 East reference | 16 | -2.94 | | | | -2.94 | |
| 4 Fringe disposal | 92 | .65 | | | | .65 | |
| | | | .56 | | | | .56 |

ANOVA Table for Interstitial Water Inorganic Phosphate
by Position with Time and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 9030.382 | 2 | 4515.191 | 18.117 | .001 |
| Time | 8563.243 | 1 | 8563.243 | 34.359 | .001 |
| Depth | 527.040 | 1 | 527.040 | 2.115 | .148 |
| Main effects | 3182.612 | 3 | 1060.871 | 4.257 | .007 |
| Position | 3182.612 | 3 | 1060.871 | 4.257 | .007 |
| Explained | 12212.994 | 5 | 2442.599 | 9.801 | .001 |
| Residual | 32898.386 | 132 | 249.230 | | |
| Total | 45111.380 | 137 | 329.280 | | |
| Covariate | | | Beta | | |
| Time | | | -15.816 | | |
| Depth | | | - 3.909 | | |

160 cases were processed
 22 cases (13.8 PCT) were missing

Multiple Classification Analysis for Interstitial Water Inorganic
Phosphate by Position with Time and Depth as Covariates

Grand Mean = 13.13

| Variable + Category | N | Unadjusted | | Adjusted for independents | | Adjusted for independents + covariates | |
|---------------------|----|------------|-----|---------------------------|------|--|------|
| | | DEV#N | Eta | DEV#N | Beta | DEV#N | Beta |
| Position | | | | | | | |
| 1 Central disposal | 23 | 7.13 | | | | 5.91 | |
| 2 West reference | 13 | -10.27 | | | | -10.06 | |
| 3 East reference | 15 | -9.18 | | | | -7.89 | |
| 4 Fringe disposal | 87 | 1.23 | | | | 1.30 | |
| | | | .30 | | | | .27 |

ANOVA Table for Interstitial Water Ammonia by Position with Time
and Depth as Covariates

Position = Station location; central disposal site (stations 6, 7, 10, 11), west reference site (stations 17, 18), east reference site (stations 19, 20), fringe of disposal site (stations 1, 2, 3, 4, 5, 8, 9, 12, 13, 14, 15, 16)

Time = Sampling date (September, December 1976)

Depth = Depth in core (top 10 cm, bottom 15 cm)

| <u>Source of Variation</u> | <u>Sum of Squares</u> | <u>DF</u> | <u>Mean Square</u> | <u>F</u> | <u>Significance of F</u> |
|----------------------------|-----------------------|-----------|--------------------|----------|--------------------------|
| Covariates | 1786.749 | 2 | 893.375 | 6.272 | .003 |
| Time | 1442.863 | 1 | 1442.863 | 10.131 | .002 |
| Depth | 356.045 | 1 | 356.045 | 2.500 | .116 |
| Main Effects | 2605.421 | 3 | 868.474 | 6.098 | .001 |
| Position | 2605.421 | 3 | 868.474 | 6.098 | .001 |
| Explained | 4392.171 | 5 | 878.434 | 6.168 | .001 |
| Residual | 18373.146 | 129 | 142.427 | | |
| Total | 22765.316 | 134 | 169.890 | | |
| Covariate | Beta | | | | |
| Time | 6.548 | | | | |
| Depth | -3.249 | | | | |

160 cases were processed
25 cases (15.6 PCT) were missing

Multiple Classification Analysis for Interstitial Water Ammonia
by Position with Time and Depth as Covariates

Grand Mean = 7.99

| Variable + Category | N | Unadjusted | | Adjusted for independents | | Adjusted for independents + covariates | |
|---------------------|----|------------|-----|---------------------------|------|--|------|
| | | DEV/N | Eta | DEV/N | Beta | DEV/N | Beta |
| Position | | | | | | | |
| 1 Central disposal | 20 | 9.90 | | | | 9.57 | |
| 2 West reference | 13 | -5.60 | | | | -5.44 | |
| 3 East reference | 15 | -4.67 | | | | -4.99 | |
| 4 Fringe disposal | 87 | -.64 | | | | -.53 | |
| | | | .35 | | | | .34 |

In accordance with letter from DAFN-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.

Sugai, S

Aquatic disposal field investigations, Duwamish Waterway disposal site, Puget Sound, Washington; Appendix D: Chemical and physical analyses of water and sediment in relation to disposal of dredged material in Elliott Bay; Volume II: September-December 1976 / by S. Sugai ... et al., University of Washington, College of Fisheries, Laboratory of Radiation Ecology, Seattle, Washington. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

24, [106] p. : ill. : 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-24, Appendix D, v.2) Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW39-76-C-0167 (DMRP Work Unit No. 1A10D)

Tables 1-19 on microfiche in pocket.

References: p. 24.

1. Aquatic environment. 2. Bottom sediment. 3. Chemical analysis. 4. Dredged material. 5. Dredged material disposal.

(Continued on next card)

Sugai, S

Aquatic disposal field investigations, Duwamish Waterway disposal site, Puget Sound, Washington; Appendix D: Chemical and physical analyses of water and sediment ... 1978. (Card 2)

6. Duwamish Waterway. 7. Elliott Bay. 8. Field investigations. 9. Waste disposal sites. 10. Water analysis. 11. Water quality. I. United States. Army. Corps of Engineers. II. Washington (State). University. Laboratory of Radiation Ecology. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-24, Appendix D, v.2) TA7.W34 no. D-77-24 Appendix D v.2