US Army Corps of Engineers

DREDGING OPERATIONS TECHNICAL
SUPPORT PROGRAM

TECHNICAL REPORT D-84-5

LONG-TERM IMPACT OF DREDGED MATERIAL AT TWO OPEN-WATER SITES: LAKE ERIE AND ELLIOTT BAY

Evaluative Summary

by

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November 1984
Final Report

Prepared for
DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

The D-series of reports includes publications of the Environmental Effects of Dredging Programs:

Dredging Operations Technical Support

Long-Term Effects of Dredging Operations

Interagency Field Verification of Methodologies for Evaluating Dredged Material Disposal Alternatives (Field Verification Program)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Technical Report D-84-5	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) LONG-TERM IMPACT OF DREDGED MATERIAL AT TWO OPEN-WATER SITES: LAKE ERIE AND ELLIOTT BAY; Evaluative Summary		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Henry E. Tatem		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Environmental Laboratory PO Box 631, Vicksburg, Mississippi 39180-0631		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Dredging Operations Technical Support Program
11. CONTROLLING OFFICE NAME AND ADDRESS DEPARTMENT OF THE ARMY US Army Corps of Engineers Washington, DC 20314-1000		12. REPORT DATE November 1984 13. NUMBER OF PAGES 37
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dredged material--Lake Erie (LC)
Dredged material--Elliott Bay (Wash) (LC)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Dredged material disposal sites in Lake Erie and Elliott Bay were studied in 1975-1976. This report describes results of studies conducted at these locations in 1979-1980, 3 or 4 years after the disposal events.

The Lake Erie study area included two control and three disposal sites, sampled once in 1979. Disposal sites contained more gravel and sand compared to control areas. Numerous macrofaunal and meiofaunal animals were found at

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

all of the sites. In general, control sites contained more macrofaunal animals and species while the disposal sites were richer in meiofauna. Substrate type and variety, which was influenced by the disposal events, determined which animals were found where. None of the sites were devoid of animals and there was no indication that sediment contaminants affected benthic communities at the disposal sites. There were no differences in mercury or cadmium concentrations in sediment samples from the various sites.

Samples taken at the Elliott Bay disposal site revealed that the disposal mound, created in 1975-1976, was still present and had stabilized physically and chemically. The mound area contained more animals than the surrounding bottom areas. Bivalves and polychaetes were the dominant animals found at the disposal site. The numbers of these animals at the site increased from 1976 to 1979-1980. Sediment at the center of the disposal site contained polychlorinated biphenyls (PCB); however, other areas of Elliott Bay, removed from the dredged material mound, also contained PCB at concentrations similar to those observed at the site. Some animals taken from the disposal mound contained PCB at levels slightly higher than sediment levels which were in the 2.0- to 3.0-ppm range.

PREFACE

This report summarizes results of two field studies conducted at open-water dredged material disposal sites in Lake Erie and Elliott Bay. These study sites are the same sites studied in 1975 and 1976 as a part of the comprehensive Dredged Material Research Program. Samples were collected once from Lake Erie in 1979 and four times at the Elliott Bay site during 1979-1981. The study was sponsored by the Dredging Operations Technical Support (DOTS) Program funded by the Office, Chief of Engineers (OCE) through the Water Resources Support Center, Dredging Division (WRSC-D). DOTS is managed through the Environmental Effects of Dredging Programs (EEDP) of the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES). Mr. Charles C. Calhoun, Jr., was EEDP Manager and Mr. Thomas R. Patin was DOTS Coordinator in EEDP. The work was monitored by Mr. David B. Mathis, WRSC-D.

The study at the Lake Erie site was conducted by Roy F. Weston, Inc., of West Chester, Pa. The study at the Elliott Bay site was conducted by the URS Company, Seattle, Wash. The studies were managed by personnel of the EL Environmental Research and Simulation Division (ERSD). Dr. Henry E. Tatem, ERSD, wrote this report under the general supervision of Drs. Richard K. Peddicord and Charles R. Lee, ERSD, and Mr. Donald R. Robey, Chief, ERSD. Contracting Officer's Representative was Dr. Robert M. Engler, ERSD. Dr. John Harrison was Chief, EL.

Acknowledgement is made to those individuals who assisted in this study. Dr. Kenneth J. Salamon of Roy F. Weston prepared the final report on the Lake Erie samples. Dr. Robert N. Dexter, Mr. D. Anderson, and Ms. E. Quinlan of the URS Company prepared the final report on the Elliott Bay work. Dr. Spyros Pavlou played an important role in planning the Elliott Bay study.

Commanders and Directors of the WES during the period of these studies were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

Tatem, H. E. 1984. "Long-Term Impact of Dredged Material at Two Open-Water Sites: Lake Erie and Elliott Bay; Evaluative Summary," Technical Report D-84-5, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

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Evaluative Summary

PART I: INTRODUCTION

Background

1. The US Army Corps of Engineers is responsible for maintaining the Nation's waterways, which requires dredging and disposal of millions of cubic yards of sediments annually. In the past much of the dredged material was routinely placed at open-water disposal sites, generally located near the dredging location. This was due to economic considerations since building containment sites or transporting material inland to fill areas is expensive. Also, there was the general contention that most dredged material was not environmentally harmful. During the 1970's, however, environmental laws passed by Congress authorized the Corps of Engineers (CE) to conduct studies of dredging and dredged material disposal practices. Environmental impacts were to be considered as well as economic factors when making decisions on dredging and disposal alternatives. These laws also assigned to the CE the permitting authority for disposal of dredged material.

2. Public Law 91-611, the River and Harbor Act of 1970, authorized the Dredged Material Research Program (DMRP), a comprehensive, nationwide study of dredged material disposal. An early study by Boyd et al. (1972) described potential dredging and disposal problems and research needed to address those problems. Over a 5-year period, beginning in 1973, the DMRP conducted a series of conceptual, laboratory, and field studies in association with scheduled dredging projects designed to understand potential environmental impacts. Saucier et al. (1978) summarized the significant findings of the DMRP.

3. An important segment of the DMRP research was the Aquatic Disposal Field Investigations. The physical, chemical, and biological effects of open-water disposal were studied. Studies at five open-water disposal sites were designed to evaluate predisposal, disposal, and postdisposal conditions (Wright 1978). Sites were monitored for up to 1 year after disposal. Long-term (chronic) physical, chemical, and biological effects of the disposal

operations were not studied under the DMRP because of time constraints imposed by the 5-year duration of the program.

4. It became apparent during the DMRP that it would be necessary to continue technology transfer activities after a program of such magnitude was completed for the results to have maximum benefits. Also the need was apparent to continue monitoring selected DMRP field sites to better establish long-term trends and to verify and refine procedures developed during the program. To meet these needs, the Dredging Operations Technical Support (DOTS) Program was established in 1978.

5. The DMRP open-water disposal studies included a site in Lake Erie near Ashtabula, Ohio, and one in Elliott Bay near Seattle, Washington (Sweeney 1978, Tatem and Johnson 1978). Both sites were monitored for about 1 year after disposal and were selected for long-term monitoring under DOTS.

6. Sediments disposed at Lake Erie in 1975 and 1976 and in Elliott Bay in 1976 were known to contain chemical contaminants such as heavy metals or polychlorinated biphenyls (PCB). The documented environmental impacts, however, were mostly physical and not chemical. Benthic communities were smothered by the deposited material, but there was no evidence that the dredged material was toxic. At the Lake Erie site, some species transported with the dredged material established viable communities.

7. Data obtained during the DMRP studies indicated that the benthic communities at the two sites were recovering; species were different after disposal; and there was evidence that the animal community at the Elliott Bay site had not completely recovered in terms of biomass and diversity. All effects on water quality such as increased turbidity, ammonia release, or changes in dissolved oxygen were gone within hours or days after the disposal events. Chronic effects on animals at the disposal sites were not studied under the DMRP.

Purpose and Scope

8. Studies discussed in this Evaluative Summary were conducted to determine the current (1979-1980) status of the two disposal sites. The primary questions were whether the disposed material had remained at the disposal site and could be identified, and whether the benthic communities had recovered to predisposal conditions. Also of interest was whether animals living at the

two sites contained chemical contaminants at elevated levels. Additional sampling was conducted at Lake Erie in the summer of 1979 and at Elliott Bay during the period February 1979 to March 1980. These studies were part of the DOTS Program. The Evaluative Summary is based on two separate reports: a report on the Lake Erie work by Salamon (1984) and another describing the Elliott Bay work by Dexter et al. (1984).

Objectives

9. Objectives of the Lake Erie DOTS study were:

   a. Description of the benthic communities at the previous disposal and reference areas and comparison with the communities described in the DMRP studies.

   b. Description of the sediment physical parameters at the previous disposal and reference sites.

   c. Quantification of mercury and cadmium in the sediment, interstitial water, and benthic animals with comparisons between disposal and reference sites.

10. Objectives of the Elliott Bay DOTS study were:

    a. Examination of the stability of the dredged material deposit.

    b. Determination of the effects of the dredged material on benthic macrofauna at and around the original disposal site.

    c. Evaluation of the stability of the PCB associated with the dredged material.

    d. Examination of the uptake of PCB by macrofauna.

PART II: DESCRIPTION OF THE STUDY AREAS

Lake Erie

11. The Lake Erie study area is located approximately 5 km from the shore of Lake Erie north of Ashtabula, Ohio. The Ashtabula River runs from northeast Ohio into Ashtabula Harbor, which is formed by man-made stone breakwaters. The harbor is used for shipping coal and ore; the river receives waste from the City of Ashtabula plus industrial wastes. The Buffalo District of the CE is responsible for dredging to maintain navigation channels in the river and the harbor.

12. Sweeney (1978) and Salamon (1984) contain detailed descriptions of the study area. Figure 1 shows the locations of the disposal and reference areas sampled during the DMRP study as well as the sampling locations for the DOTS study. Water depth throughout the study area is 15 to 18 m.

Elliott Bay

13. The study area in Elliott Bay, a part of Puget Sound, is located off the eastern shore of the bay at Seattle, Washington. The Duwamish River drains into Elliott Bay around Harbor Island. The Duwamish River is a major shipping channel and receives municipal and industrial waste from the Seattle area. Thus, the Duwamish sediments would be expected to contain elevated levels of many chemical contaminants. In addition, there was an accidental spill of 984 ℓ of PCB at Slip 1 on the Duwamish River in September 1974 (Tatem and Johnson 1978). Most of the material containing high levels of PCB was removed using special dredging techniques to minimize release of the material to the water column. Some of the less contaminated material was dredged and placed at the approximate center of the Elliott Bay disposal site. The PCB could be detected at very low concentrations by sophisticated chemical measurements that allowed the researchers to document the precise location and movement of the dredged material at the Elliott Bay site. Additional references that discuss PCB levels in Elliott Bay and Puget Sound are given in Dexter et al. (1984).

14. Tatem and Johnson (1978) and Dexter et al. (1984) contain descriptions of the Elliott Bay study area and show the locations of the disposal and

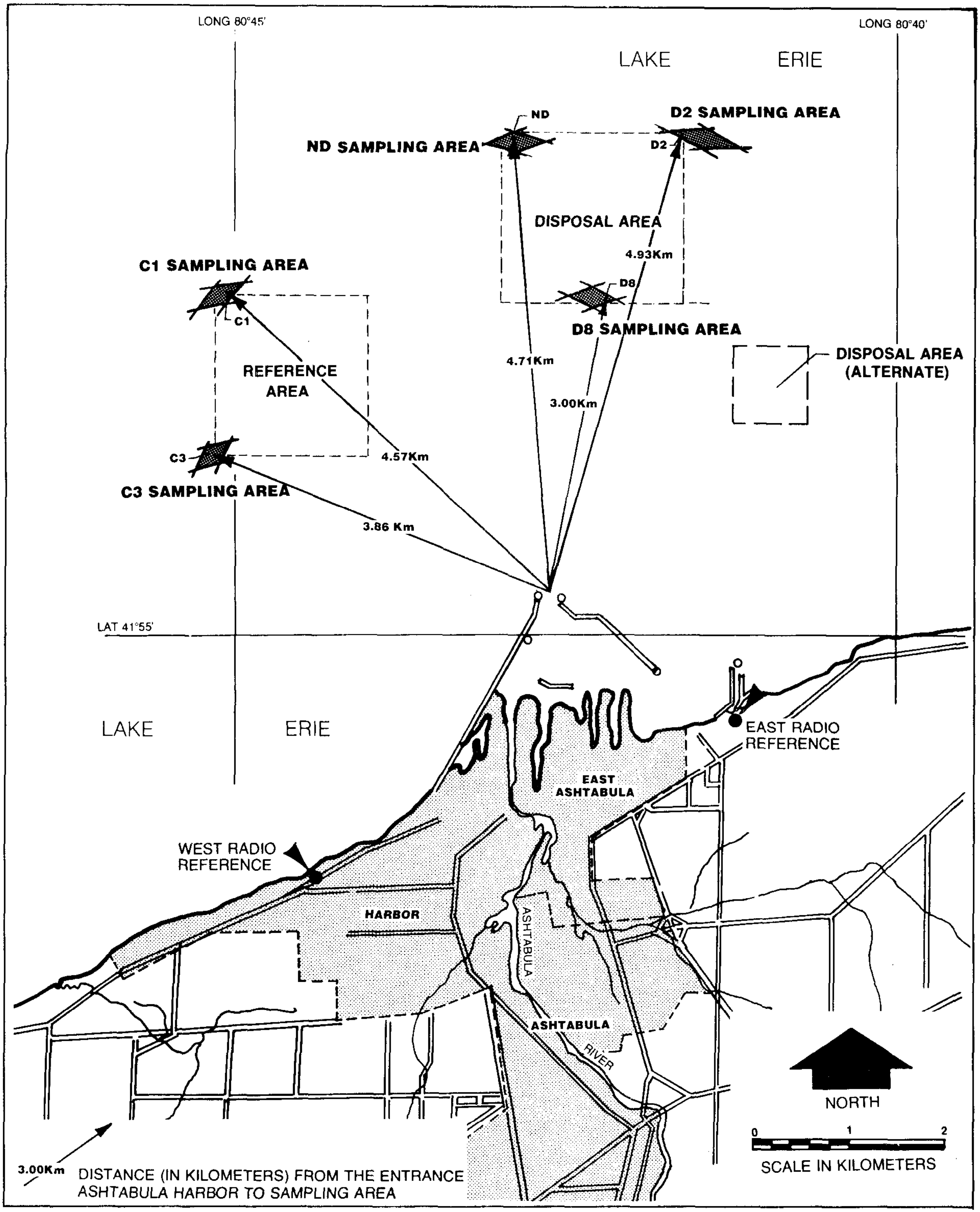

Figure 1. Location of Lake Erie study sites showing DMRP reference and disposal areas and DOTS sampling areas (Salamon 1984)

reference areas. Stations occupied during the DOTS study (Dexter et al. 1984) were at or near the DMRP experimental disposal site. Figure 2 shows the dredging locations on the Duwamish River and the disposal and reference areas monitored during the DMRP. Sampling stations for the DOTS study were within and at increasing distances from the experimental disposal site.

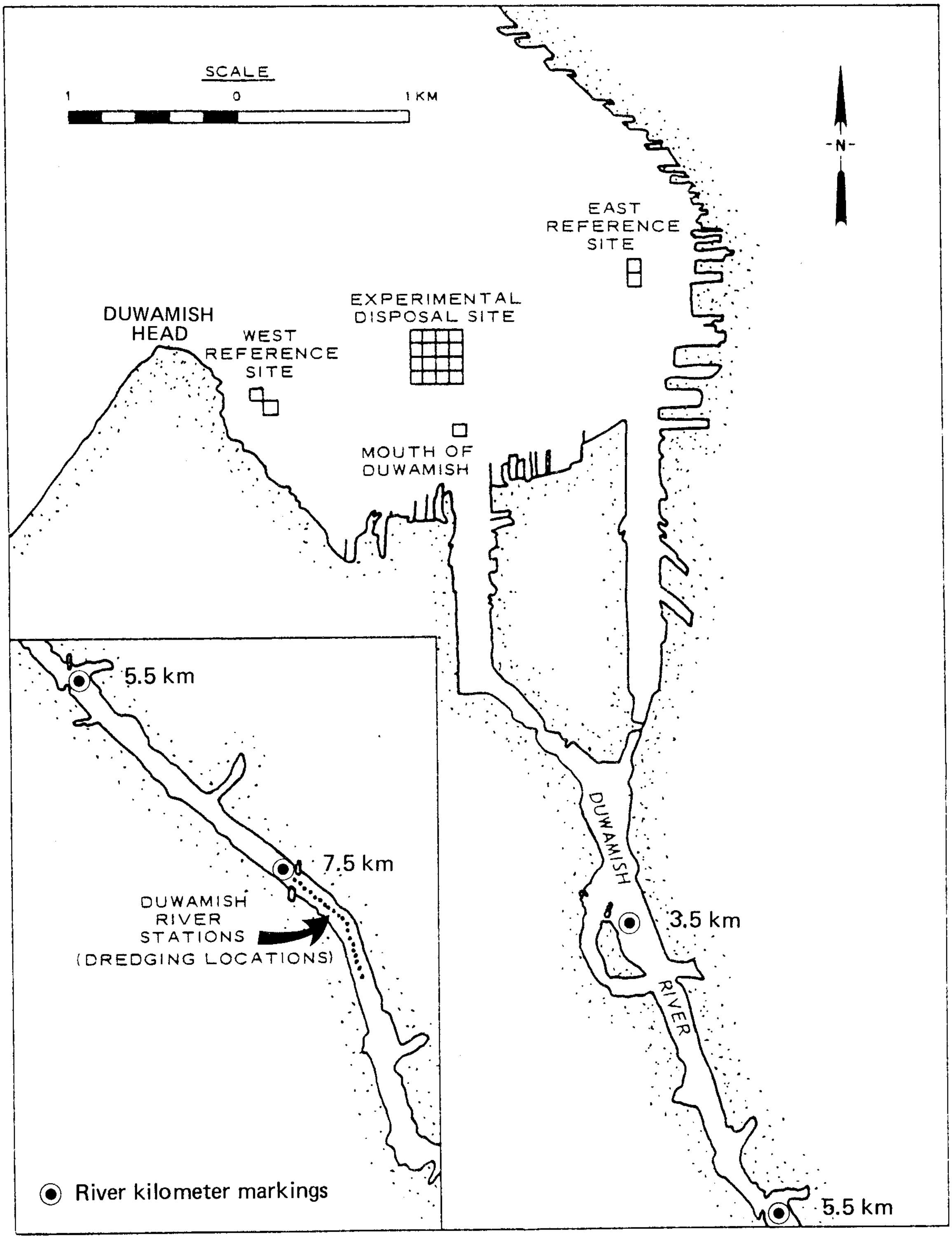

Figure 2. Location of dredging operations in the Duwamish River and DMRP disposal and reference sites in Elliott Bay (DOTS study sites were related to the DMRP disposal site)

PART III: DMRP STUDIES

15. Sediments disposed in Lake Erie and in Elliott Bay contained low levels of chemical contaminants. Water-column impacts included short-term increases in turbidity and some release of ammonia, phosphorus, and manganese. All effects on water quality such as increased turbidity, release of ammonia, and changes in dissolved oxygen or pH disappeared within hours or days after the disposal events.

16. Benthic communities were affected by the deposited material. The postdisposal monitoring indicated that the benthic communities at the sites were recovering; species at the sites were different after disposal; and there was evidence that the animal community at the Elliott Bay site had not completely recovered in terms of biomass and diversity.

Lake Erie

17. Research at the Lake Erie disposal site during the DMRP involved samples and measurements taken prior to, during, and after disposal events in August 1975 and May 1976. Samples were taken for approximately 1 year after the August 1975 operation and for 90 days after the May 1976 operation. Data indicated no lasting adverse impact on water quality or water-column communities, including phytoplankton and zooplankton, due to disposal. The physical and chemical nature of the sediment at the site was changed as a result of the disposal operation, but functioning benthic communities were generally established within 1 year of disposal. Some of the animals found living at the disposal site were presumed to have been transported with the sediment. Thus, the material that was contaminated with heavy metals was not toxic or devoid of life either before or after it was dredged. This site was selected for study under the DOTS Program to determine the makeup of the benthic communities 3 years after disposal at the previous (DMRP) disposal and reference sites. Also of interest were the levels of mercury and cadmium in sediments, interstitial water, and animals at the Lake Erie disposal and reference sites.

Elliott Bay

18. The DMRP studies at the Elliott Bay disposal site examined various

environmental samples taken before, during, and 9 months after the disposal operation of February-March 1976. Disposal created a mound of dredged material 2.0 to 2.5 m in height near the center of the disposal area. This had a rather dramatic physical impact on the benthic community at the site. At the center of the site, the number of species present was reduced and animal density and biomass were adversely affected. Chemical analyses of the dredged material indicated that it contained higher levels of PCB than sediment at the disposal site. Demersal fish, shrimp, and other animals captured at the disposal site were analyzed for PCB, mercury, and chromium. Data collected indicated no conclusive evidence that animals in the vicinity of the disposal site contained higher contaminant levels compared to reference area animals. Mussels held in cages at the site for 3 weeks accumulated PCB to levels slightly above background; however, the increase was not statistically significant.

19. Three factors were the basis of selection of the Elliott Bay site for additional study:

a. The PCB in the dredged material would allow researchers to map the material and evaluate the stability of the disposal mound.

b. The benthic community, especially at the center of the disposal site, had not fully recovered 9 months after disposal (the last monitoring effort under the DMRP).

c. The potential for movement of PCB from sediment to animals was present.

PART IV: EXPERIMENTAL DESIGNS

Lake Erie

20. Figure 1 shows the location of the sampling stations and disposal areas for the DMRP study and the DOTS study. Sampling sites for the DOTS study were chosen based on those selected during the DMRP study. They were designated C1 and C3 for the reference sites and D2, D8, and ND for sites at the disposal areas. These designations were based on proximity to previously occupied DMRP stations. Sediment, tissue, and interstitial water samples were collected over a 1-week period in August 1979. Benthic animals were taken from the sediment samples for identification and tissue analyses. Details of the methods used are in Salamon (1984).

Elliott Bay

21. Sampling stations for the DOTS study of the Elliott Bay disposal site were chosen at and near the previous 16 disposal site stations (Figure 2). Some of the previous DMRP stations were retained for comparative purposes. Other stations both within the DMRP sampling grid as well as in the surrounding area were chosen in a random fashion. Details of how the stations were chosen are given in Dexter et al. (1984). The contractor conducted four separate cruises to the disposal site area: a reconnaissance cruise in February 1979 and three study cruises in May and October 1979 and in May 1980. There were differences in the sampling scheme for the reconnaissance cruise compared to the three study cruises. During the reconnaissance cruise, sediment was collected from each of 30 stations for identification of the benthic fauna and for PCB and particle-size analyses. Five stations were sampled more intensively for triplicate sediment samples. During the three study cruises, the same total number of stations were sampled, but five different stations were chosen for intensive sampling. Water samples were also taken from these five stations.

PART V: RESULTS AND DISCUSSION

Lake Erie

Sediment physical parameters

22. Grain-size analyses were performed for each sediment sample from each of the sites to characterize sediment at the five study areas. The original study plan was to take 38 separate samples from each area, but persistent marginal weather and the abundance of rock and shale in the disposal areas prevented this. Table 1 shows data summarized from Salamon (1984) on the percent gravel, sand, silt, and clay for each of the five sample areas.

23. The majority of samples taken from area ND contained such a high percentage of rock and shale that they were discarded. Thus there were only 17 usable samples from area ND, compared to 22 from area D8 and from 26 to 29 for the other areas. The data clearly show the differences between reference and disposal areas in that two of the disposal areas contained considerably more gravel or sand than the two reference areas. Disposal area D2 contained about the same amount of gravel as the two reference areas. The three disposal

Table 1

Summary of Grain-Size Data from Reference and Disposal Sites in Lake Erie

Sample Identification (Number of Samples)	Grain Size, percent			
	Gravel	Sand	Silt	Clay
Reference sites				
C1 (N = 29)	0.1 ± 0.3	5.7 ± 2.2	59.4 ± 4.9	34.7 ± 4.7
C3 (N = 27)*	0.1 ± 0.3	11.3 ± 6.5	57.2 ± 5.7	31.3 ± 5.4
Disposal sites				
D2 (N = 27)*	0.1 ± 0.3	17.4 ± 18.9**	55.4 ± 12.6**	27.0 ± 10.4
D8 (N = 22)	11.6 ± 17.6	17.0 ± 9.2	46.0 ± 14.1	25.3 ± 7.7
ND (N = 17)	2.6 ± 4.4	44.7 ± 20.6	39.4 ± 16.3	13.2 ± 6.0

* These data differ slightly from Tables 3-2 and 3-3 of Salamon (1984) due to elimination of outliers.
** N = 26 for sand and silt data at site D2.

areas tended to contain more sand and generally less silt and clay compared to the reference areas. Disposal area ND differed most from the two reference areas.

24. The dredged material deposited in 1975 contained more coarse sand than the site material, thus indicating that some of the dredged material deposited in 1975 remained in place at the 1979 sampling time. Samples taken during the DMRP study showed an increase in fine sand at the disposal areas after disposal. This was not observed with the DOTS samples. There are two explanations. The first is that there has been disposal of gravel and shale and possibly some coarse sand at the disposal sites between the DMRP work and the DOTS study. Secondly, currents in the area are thought to be sufficient to move fine sand. In relation to the research objective to describe the current state of the sediment at the former disposal and reference sites, it seems that, except for the additional rock and shale in the area, the site sediments have not changed. The dredged material contains more sand than the natural sediments, and this material has moved around somewhat either by currents or additional dumping.

Benthic communities

25. Macrofauna. Over 100 benthic macroinvertebrate samples were collected during August 1979 from the five sampling areas. Species identifications and counts showed a heterogeneous bottom community, i.e., many different species scattered throughout the study area. Animals were identified in two sediment horizons with the majority found in the upper 10 cm--the surface horizon. A summary of the number of animals found (surface horizon) per square metre is presented in Table 2, which was adapted from Table 3-6 of Salamon (1984). These data show that many groups of animals were found at all five sampling areas with few dramatic differences between control and disposal areas. One polychaete species and numerous oligochaetes were found at most of the sampling sites. The oligochaete *Aulodrilus* was more abundant at the two reference sites. Three other oligochaetes were more abundant at the disposal sites. Reference site C3 revealed the greatest number of oligochaetes both with and without the immature tubificids (Table 2). The tubificids were more abundant at the two reference sites. A mean of 51 leeches, *Helobdella*, were found at the two reference sites compared to a mean of 26 at the three disposal sites. In general more amphipods, *Asellus*, were found at C1 and C3 compared to ND, D2, and D8; however, the numbers at C1 and D8 were essentially

Table 2

Summary of Upper-Strata Macrofauna at the Five Lake Erie Sampling Sites

Species	Sampling Area (organisms/m^2)				
	C1	C3	ND	D2	D8
Polychaeta	0	18	18	2	5
Oligochaeta					
Aulodrilus	486	816	79	361	68
Limnodrilus	65	136	127	164	126
Peloscolex	18	12	173	44	82
Potomothrix	24	31	62	45	38
Immature Tubificidae	777	872	347	738	509
Styloria	18	43	29	49	--
Naididae	12	16	3	20	29
Total Oligochaeta except Tubificidae	623	1,054	473	683	343
Hirudinea					
Helobdella	59	43	24	28	27
Crustacea					
Asellus	140	208	47	107	138
Gastropoda	2	2	21	14	12
Pelecypoda					
Musculium	105	35	18	8	--
Pisidium	28	39	--	16	11
Sphaerium	205	192	36	53	32
Total Pelecypoda	338	266	54	77	43
Insecta					
Chironomus	49	12	12	14	27
Procladius	26	33	18	14	41
Chironomidae	57	51	9	45	32
Total Insecta	132	96	39	73	100
Nematoda	30	22	6	6	23
Overall Total except Tubificidae	1,324	1,709	682	990	691

the same. For gastropods, the numbers were generally low, but these animals preferred the disposal areas over the two reference areas. This is probably related to the greater amounts of gravel and sand at sites ND, D8, and D2.

26. One group of animals that did show some difference was the bivalves (Pelecypoda) where the mean number found at the reference sites (302) was about five times the mean number found at the disposal sites. Slightly more insects, chironomids, and nematodes were found at the reference sites compared to the disposal sites. Eight major groups of animals are listed in Table 2. Calculation of the mean numbers for each group for the reference and disposal areas reveals no difference for one group (polychaeta). Six groups of animals (oligochaeta, leeches, crustaceans, bivalves, insects, and nematodes) were more abundant at the reference sites, while one group (gastropoda) was more likely to be found at the three disposal sites.

27. Overall, more animals were found at the reference sites compared to the previous disposal sites. These data show that none of the sampling areas are devoid of life; however, one group of benthic samples taken once during a yearly cycle does not give much basis for drawing definitive conclusions. Differences observed are as likely due to substrate differences (percent gravel and sand) rather than to any long-term harmful impact of the dredged material. Site C3 contained the most animals overall while sites ND and D8 were similar and contained approximately 40 percent of the numbers of animals at the most populated reference site.

28. Bar-chart data from Salamon (1984) of the mean numbers of organisms and taxa at the five sampling areas as well as the mean diversity are shown below:

Sample Area (Number of Samples)	Macrofauna Mean No. Organisms/m^2	Mean No. Taxa	Mean Diversity
C1 (N = 28)	36.4	9.5*	2.2
C3 (N = 29)	42.9	9.9*	2.2
ND (N = 20)	19.3	6.5	1.7
D2 (N = 27)	30.6	8.3	1.9
D8 (N = 24)	22.0	7.2	1.7

* Significantly higher (P < 0.05) than the three disposal areas.

The data indicate that in August 1979 the two reference sites contained more animals and more different kinds of animals compared to the disposal sites. In general, the mean number of organisms was not statistically different except for the pelecypoda, which were higher at the reference stations. Certain individual species were generally associated with either reference or disposal sites, but most of these species were present at low levels. Although the reference areas contained more animals than the disposal areas, the only significant difference was between the number of taxa at the two areas. The type of sediment at the various sites influenced the kinds of animals found at the site (Salamon 1984). Since the disposal operations caused changes in the sediment, i.e. higher percentages of sand and gravel, it could be argued that one result of the disposal was the creation of a different substrate which supported fewer numbers of animals. An evaluation of whether this change was harmful to the Lake Erie benthic environment should consider the facts that (a) the relative area affected was probably less than 1 percent of the central basin of Lake Erie; (b) many animals were found at the previous disposal sites; and (c) these data result from one sampling effort. Of more importance, perhaps, is how these results relate to those obtained during the DMRP studies. Salamon (1984) cites Cook and Johnson (1974), who found the Lake Erie benthic community to be dominated by oligochaetes, chironomids, and sphaeriid bivalves. All of these animals were found at both reference and disposal sites during the DOTS study. Sweeney (1978) summarized the DMRP work at Lake Erie and found oligochaetes to be the most common animal in the Lake Erie benthic community. Two adult oligochaetes, *Aulodrilus* and *Limnodrilus*, generally retained their dominance between the DMRP and DOTS studies (Salamon 1984). *Aulodrilus* were more abundant at the reference areas, while *Limnodrilus* were found in greater numbers at the disposal sites. Finally, Sweeney (1978) observed differences between the number of clams and gastropods at the proposed reference and disposal areas prior to the disposal operations. Thus, some of the differences seen in Table 2 may have been normal and not related to the disposal events.

29. Meiofauna. Meiofauna animals (those smaller than macrofauna but larger than microorganisms) in the upper and lower sediment horizons were also identified and counted. There were many more box core samples obtained from the upper sediment horizon (down to 10 cm) compared to those obtained for the lower horizon. Table 3 shows data from Salamon (1984) on the number of organisms per square metre for the reference and disposal areas upper horizons.

Table 3

Summary of Upper-Strata Meiofauna at the Five Lake Erie Sampling Sites

Animals	Sampling Areas (organisms/m^2)				
	C1	C3	ND	D2	D8
Turbellaria	0	212	122	604	182
Gastrotricha	0	53	122	0	455
Rotatoria	2,334	1,910	3,305	439	3,456
Nematoda	21,432	101,962	32,687	37,428	40,833
Annelida	11,883	26,949	21,179	15,641	7,094
Cladocera	637	1,273	1,224	988	271
Copepoda	24,474	43,713	28,768	14,762	28,555
Ostracoda	1,202	3,767	27,668	22,391	6,093
Isopoda	0	371	122	110	182
Insecta	283	371	367	0	909
Pelecypoda	71	371	245	0	0
Total	62,316	180,952	115,809	92,363	88,030

These data indicate that there are a number of meiofaunal groups present at each of the areas. No clear patterns emerged. In many cases when one of the reference areas contained numerous animals, the other reference area contained fewer animals than some or all of the disposal areas. In general, all five sampling areas contained large numbers of meiofauna (Table 3). Area C3 contained the greatest number of animals overall followed by disposal site station ND. This is the same station that contained the least number, overall, of the macrofauna. The control area C1 was found to contain the least number of meiofaunal animals. These data, then, differ from the macrofauna results and further indicate that none of the disposal areas are devoid of life. Abundances of some animal groups were greater at disposal sites compared to control sites. However, analysis of variance did not indicate any significant ($P < 0.05$) differences between disposal and control areas.

30. Bar-chart data describing the mean number of organisms, taxa, and diversity are summarized from Salamon (1984).

Sample Area (Number of Samples)	Meiofauna Mean No. Organisms/m^2	Mean No. Taxa	Mean Diversity
C1 (N = 29)	19.4	5.2	1.51
C3 (N = 30)	56.9	7.2	1.58
ND (N = 14)	38.0	7.0	1.93
D2 (N = 29)	29.0	5.9	1.70
D8 (N = 19)	28.2	6.8	1.72

There were no significant differences at the 0.05 level for the meiofauna. The fact that these data show the disposal areas to have abundances of animals between those of the reference areas and taxa (species) and to show generally greater diversity than the reference areas indicates that disposal of the dredged material had no harmful effects on these small benthic animals. The two control areas appeared to have a more uniform population structure (mean diversity) than the disposal areas. The meiofauna data (upper horizon) differed from the macrofauna data in that one of the reference areas (C1) contained the least number of animals. Thus, the overall number of meiofaunal animals at the disposal sites was closer to the overall number from the reference areas than was the macrofauna data. A number of macrofauna groups (crustaceans, clams, and, to a lesser extent, oligochaetes and insects) were more abundant at the reference areas. The meiofauna data showed many groups more abundant at the disposal sites in comparison to the reference sites.

Mercury and cadmium levels

31. Levels of mercury and cadmium were determined for sediments, interstitial water, and benthic molluscs and oligochaetes. Insufficient biomass was collected for replicate analyses of oligochaetes (Salamon 1984). Results of the analyses for the sediments are shown below:

Parameter	Sediment Metal Content* µg/g (No. of Samples) Control Areas	Disposal Areas
Mercury	0.9 ± 0.08 (N = 20)	0.7 ± 0.01 (N = 9)
Cadmium	4.85 ± 0.36 (N = 20)	5.3 ± 0.6 (N = 9)

* Dry weight basis.

32. There was little difference in the mercury or cadmium values between control or disposal sediment. Interstitial water analyses found both metals to be below detection limits. Tissue analyses generally indicated that molluscs from the control areas contained almost double the amount of mercury (0.9 μg/g) compared to animals obtained at the disposal sites. The same was true for cadmium: more cadmium was found in control animals. The tissue data are shown below:

Parameter	Tissue Metal Content for Molluscs ng/mg (dry weight) Control	Disposal
Mercury	0.9	0.5
Cadmium	0.8	0.3

From these limited data, it is clear that the disposal site sediments were similar to reference sediments in levels of mercury and cadmium, and there was no uptake by clams.

Summary

33. Material dredged from Ashtabula Harbor and River contained more sand than the natural Lake Erie sediments. Thus, it was possible to distinguish between dredged material and natural material 3 years after disposal. It appears that some of the dredged material has moved and that some additional dumping of shale and gravel has occurred (Salamon 1984). Disposal areas D8 and ND showed the most contrasting pattern of sediment distribution; some areas were all sand and gravel, whereas disposal area D2 was most similar to the control area sediments. There were differences between the previous DMRP studies and the DOTS work with regard to the amount of shale and coal fragments in the disposal areas and the level of fine sand at the disposal sites. This is understandable since some additional dumping has occurred and because currents were judged to be strong enough to move fine sand.

34. Although identification of the animals at the different sampling sites showed differences between the reference and disposal areas, most were not statistically significant. Many different animal groups, both macrofauna and meiofauna, were found at each of the sites. Many of the animals found during the DOTS study were similar to those identified during the DMRP study (Sweeney 1978) and also correspond with data of others who have quantified benthic animals in Lake Erie (Cook and Johnson 1974).

35. A number of studies have shown that many animals begin to repopulate dredged material mounds as soon as the mounds are created. The results of this study have shown that stable communities developed at the Lake Erie disposal sites and that 3 years after disposal there were few differences between disposal and reference areas.

36. Analysis of the macroinvertebrate community at the control and disposal sites in Lake Erie indicated that these communities were similar to naturally occurring communities found in open-water regions of Lake Erie. The same animal groups dominant in other areas of Lake Erie were found to be dominant at the five study sites. Since the DMRP research, differences in macrofaunal groups at control and disposal areas have decreased. When the DOTS data on animals were compared by looking only at similar sediment types between control and disposal areas, there were few differences. This shows that substrate type, which was influenced by the disposal events, determined what animals were found where. There was no indication that sediment contaminants affected the benthic communities at the disposal sites.

37. The meiofauna were somewhat more abundant in the disposal areas due primarily to a wider range of substrate types such as gravel, fine sand, silt, and clay. More ostracods were found at the disposal areas. The meiofaunal communities at both types of sites appear to be moving toward stability (Salamon 1984).

38. Levels of mercury and cadmium in sediment from various areas were comparable to the DMRP data. Few animals were obtained for chemical analyses. Results indicated little difference between either sediments or animals from control or disposal areas; more cadmium and mercury were found in molluscs from control areas.

39. Results of this study indicate little long-term alteration in community structure and abundance. Similar species and groups of animals are found at both types of sites, and there was no heavy metal uptake shown (Salamon 1984).

Elliott Bay

Stability of dredged material deposit

40. Bathymetric surveys by the CE's Seattle District were used to construct bottom contour maps of the Elliott Bay disposal area. The dredged

material mound created in 1976 was still apparent as was evidence that some dredged material had spread over much of the original disposal grid. The bathymetric data in general indicated virtually no change in the disposal area from 1976 to 1979 (Dexter et al. 1984). The visual characteristics of sediment from the disposal area consisted of distinct layers of fine black material with greenish-grey sediment either underlain or overlain. Sediments from areas removed from the disposal grid were generally uniform with depth and were greenish grey in color.

41. In addition to determination of the percent sand, silt, and clay in various sediment samples, the sediment texture was examined by ranking size classes (phi-size distribution) in order of abundance. Thus, the majority of the sediment samples could be classified into size groups based on patterns of the most abundant phi sizes. The following sediment types were identified from samples taken at and near the Elliott Bay disposal site:

Sediment Type	Symbol
Clay	CL
Silt-clay	SC
Silt	SI
Sand-silt	SS
Medium sand	MS
Sand	SA

42. The two sediment types generally associated with the black sediment and to a lesser extent with the greenish-grey sediment layer were the SS and SI types. These particle-size types were typical of material that had the appearance of previously dredged material. The location of these sediments also suggested dredged material. The SA was the least common type while the SI was found in most of the sediments (greenish grey under black sediment, uniformly greenish-grey material, strictly surface material, etc.) except for the distinctly black layers. Comparisons of the percentages of the sediment types generally indicated that the black sediment was primarily deposited dredged material and that the greenish-grey sediment under the layer of black was the original surface material prior to disposal. Greenish-grey sediment overlying black material contained biologically reworked dredged material (Dexter et al. 1984).

43. Currents at the disposal site were measured using current meters

deployed at different distances from the bottom. Extreme values were calculated to determine whether the currents were strong enough to move sediment particles. Sediments were generally cohesive and therefore more difficult to move. The data indicated that the currents were weak, moving only in response to tidal fluctuations, and therefore would not be expected to move much sediment. The area could be characterized as a depositional zone rather than an erosional zone. It is possible that some silt and clay material could have been suspended or resuspended for a small percentage of the time. However, bottom photographs were very clear, indicating no permanent resuspension of sediment particles. Specific features such as worm holes were recognizable in many photographs.

Effects of dredged material on benthic macrofauna

44. Identification of animals collected from stations at the original disposal site and nearby indicated that, for the most abundant taxa, there were few differences from earlier results obtained during the DMRP investigation. Table 11 of Dexter et al. (1984) compares the mean number of animals found in 1976 (DMRP) with results of the DOTS study for selected taxa. The data show that the commonly found benthic animals (bivalves and polychaete worms) were more abundant in 1979-1980 than in 1976. Data from this table are summarized in the following tabulation:

	Select Taxa Mean Abundances number of animals per 0.1 m^2			
	DMRP	DOTS		
Taxa	Jun 76	May 79	Oct 79	May 80
Axinopsida (bivalve)	145	270	294	227
Macoma (bivalve)	28	25	189	54
Capitellidae (polychaete)	11	58	40	69
Euclymenidnae (polychaete)	9	51	52	39

45. The 1976 data are from the corner stations (the least impacted) of the original DMRP sample grid. The 1979-1980 data indicate that the overall number of taxa (species) was similar when sample stations inside the original disposal grid were compared to outside stations. Dexter et al. (1984) provide three tables listing the rankings of the most common species by abundance, biomass, and frequency of occurrence. Over 21 species fall into this most common category; the rankings showed little change between May 1979 and 1 year

later. These results indicate that after 3 to 4 years, the disposal area supports a diverse benthic community that differs little from surrounding areas. Many species were present at low levels, so most of the discussion relates to the dominant organisms. Many important species were found to exhibit a central tendency (found in greater numbers or biomass in the vicinity of the disposal site). Computer-generated mapping of selected species, shown in Figure 3, illustrates this point. Subjective interpretation of these maps was used to determine whether a central tendency was exhibited.

46. Another method used to group the stations by abundance and biomass data was numerical classification analysis or cluster analysis. The overall results of a number of cluster analyses showed that the group of animals now found at the original disposal site differs with respect to abundances and biomass. It appears that many of the same species are at the disposal site as compared to animals outside, but they are more abundant than the species found outside the disposal site. Overall, the cluster analyses tended to support the conclusions drawn from mapping. Thus, the DOTS studies indicate that the macrofaunal community at the disposal site differs in abundance and biomass from stations located outside the original disposal area. The disposal site sediments support a large, growing community of benthic animals.

47. Spatial autocorrelation analysis was used to test the hypothesis that abundances of species were randomly distributed. Results of analysis of the abundances of the 17 most dominant taxa in May 1979 showed that many species were more abundant on the disposal mound than surrounding areas. The Wilcoxon two-sample test showed, for dominant taxa, higher abundance and biomass at the disposal site. Thus, while there were differences in 1979 and 1980 between the disposal site and nearby areas, the differences were the opposite of those documented immediately after disposal, i.e., a decrease in abundance and biomass. Now these parameters are significantly elevated.

48. Most attempts to relate abundances of particular species with abiotic factors failed. Most of the species that showed any correlation were with sediment grain size rather than with any chemical factors such as total organic carbon or total PCB. Higher abundances that were seen in a few cases were associated with coarser sediments (or greater percent sand and lower mean phi size). There was no indication that animals from the area avoided the dredged material deposit.

49. In summary, results of the biological analyses (mapping of taxa,

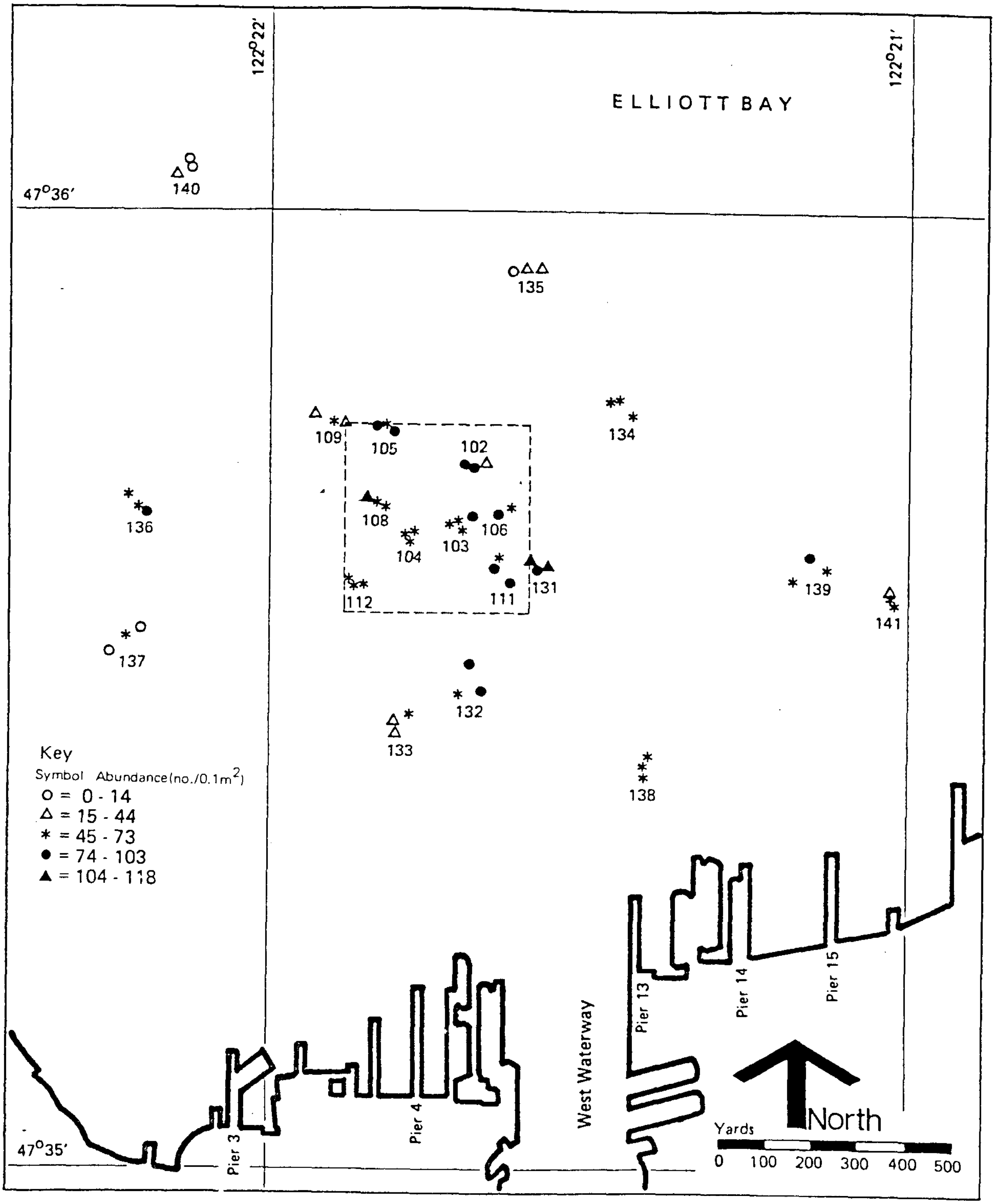

Figure 3. Spatial distribution of polychaete family Capitellidae (Dexter et al. 1984, Figure 43)

cluster analysis, spatial autocorrelation, Wilcoxon two-sample test, and correlation testing) showed that, unlike the initial effect of reduced animal abundance and biomass, the major long-term effect was an increase in dominant macrofauna in the area of the disposal site. Climax species identified during the earlier DMRP study as not being present 9 months after disposal were found during the later investigation. There was some association of increasing abundances with coarser sediments, but no consistent relationships between animals and levels of PCB in the sediment were found. More individuals and greater biomass in general were found to be associated with the dredged material mound compared to the surrounding area. The number of species was similar on and off of the previous disposal site. It was concluded that the biological conditions at the disposal site were generally stable, and the increased abundance of animals will continue for a number of years.

Stability of PCB associ-
ated with dredged material

50. Sediment. It was assumed from earlier work at this disposal site that the total PCB levels plus the type (degree of chlorination) of PCB could be used to discriminate between actual dredged material and the natural sediments of Elliott Bay. However, sediment analyses for PCB showed a high degree of spatial heterogeneity. In other words, in some cases, samples from the same area, separated by relatively minor vertical or horizontal distances, showed large differences in PCB levels. These findings made it difficult to establish trends and to pinpoint the dredged material. An earlier conclusion of the DOTS study was that much of the dredged material from the Duwamish River had been distributed deeper in the sediment layers due to biological activity while natural sedimentary processes covered some of the material. Using the highest total PCB values obtained from all the sampling stations, Dexter et al. (1984) showed contour plots of PCB in the area of the disposal site. Elevated PCB levels were clearly associated with the sediments at the disposal site. The range within the disposal grid was 0.46 ppm (μg/g) to 7.73 ppm total PCB (t-CB) on a dry weight basis. The center of the mound showed ~2.0 ppm with other areas of Elliott Bay at 1.0 ppm PCB (Figure 4). Trichlorobiphenyls (3-CB) were at higher levels in the dredged material than background sediments. The 3-CB levels of 0.3 to 0.4 ppm in the mound area were approximately three to four times higher than other areas of Elliott Bay. There was no evidence that these levels were harmful to animals in the area or

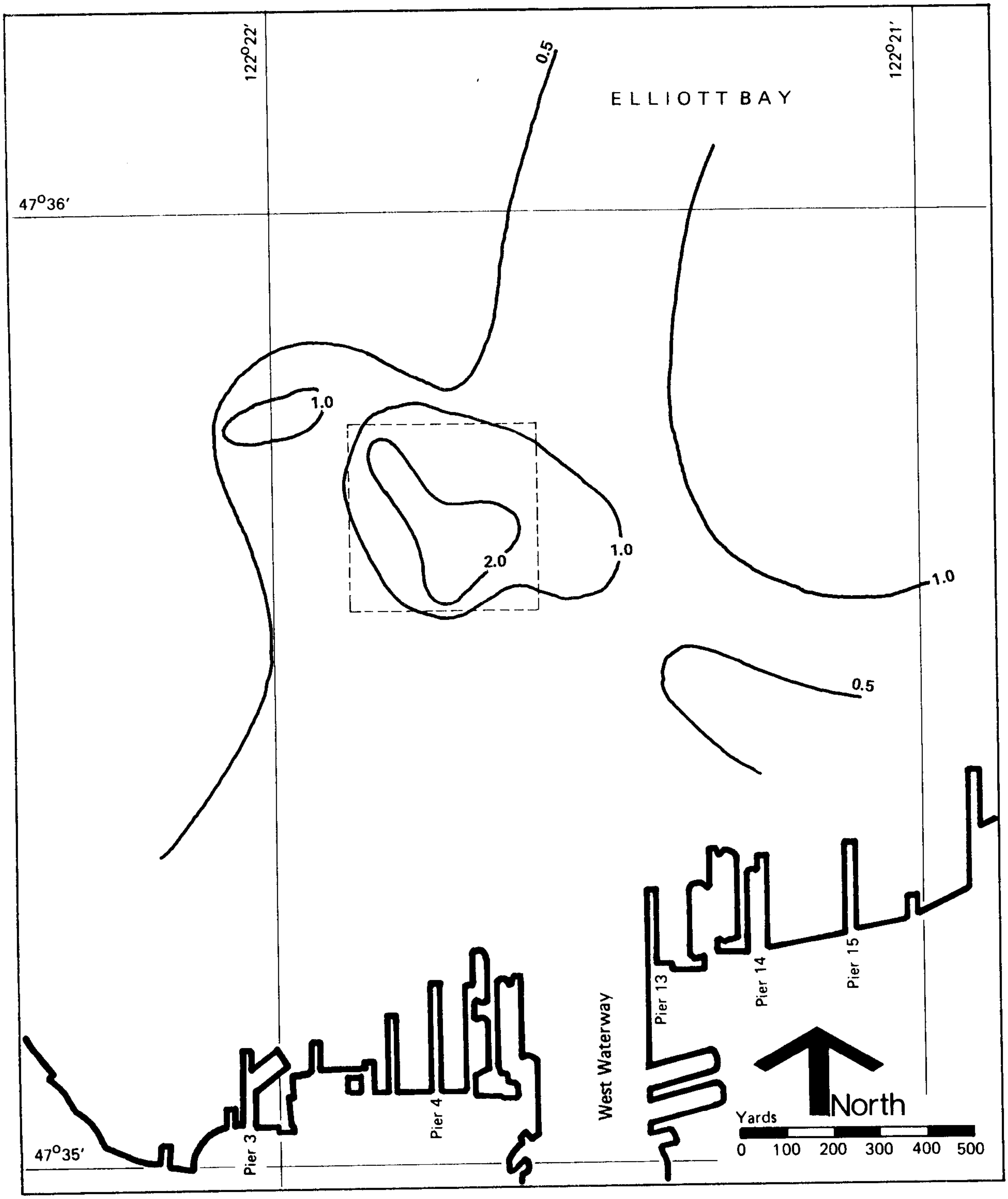

Figure 4. Approximate distribution of t-CB (μg/g) in surface sediments (Dexter et al. 1984, Figure 54)

that animals avoided the sediments. In fact, there was evidence that more animals were found in association with the dredged material during the DOTS study.

51. The PCB data from the reconnaissance cruise (February 1979) were subjected to cluster analysis, which showed that the majority of the disposal site samples fell into one group--samples high in both t-CB and 3-CB. Yet there were some discrepancies. For example, some stations from the corner areas of the disposal site did not fall into this group, whereas some outside stations did. Two central stations showed some surface material that did not fall into this group as would be expected. The PCB analyses generally supported the results of the sediment texture analyses and indicated that the dredged material mound has not changed since the DMRP studies. The following tabulation, taken from Dexter et al. (1984), shows chemical parameters of the dredged material compared to background material.

	Mean Concentrations (± One Standard Deviation)*			
Sediment	t-CB μg/g	3-CB μg/g	Total Organic Carbon, %	Oil and Grease, mg/g
Dredged material	2.07 ± 1.22 N = 30	0.34 ± 0.20 N = 30	2.97 ± 1.34 N = 27	2.41 ± 0.98 N = 12
Nondredged material	0.61 ± 0.43 N = 33	0.04 ± 0.4 N = 33	2.88 ± 1.25 N = 23	1.46 ± 0.74 N = 17

* Data are expressed on dry weight basis.

52. The PCB levels in sediment samples from cores at the disposal site (the lower horizons thought to be below the dredged material deposits) plus levels in surficial sediments from areas outside the disposal site showed areas of Elliott Bay, primarily to the east of the disposal site, that were as contaminated with PCB as the disposal area. Also there were data that showed PCB levels in the disposal area were variable both in individual sediment cores and around the disposal area.

53. The following tabulation compares data from the DMRP study on PCB levels in the upper 10 cm of sediment at the center of the disposal grid with data from the DOTS study. The comparison indicates that no major changes in overall PCB levels have occurred since disposal.

Study	Sample Date	PCB, μg/g
DMRP	Mar 76	2.20 ± 1.2
	Apr 76	2.13 ± 0.9
	Jun 76	2.19 ± 1.1
	Sep 76	2.94 ± 1.3
	Dec 76	3.44 ± 2.1
		2.58 ± 0.59
DOTS	May 79	2.70
	Oct 79	2.21 ± 0.89
	May 80	3.54 ± 2.4
		2.82 ± 0.68

Data from the surface horizons of sediment samples taken during the DOTS work indicated that surface sediments contained similar levels of PCB compared to underlying dredged material. Also there was no evidence that the 3-CB isomers had decreased from 1976 to 1980. Thus, these data indicate that PCB at the disposal site is not moving into the water column or away from the disposal area. Much variability was evident in samples from outside the disposal area with upper or surface horizons generally revealing higher PCB levels compared to lower (>10 cm depth) horizons. Various hot spots of anomalous PCB levels were found that may reflect spills or previous disposal of contaminated materials.

54. Total organic carbon (TOC) measurements were performed on the sediment samples, and samples from the disposal area were compared to those taken from outside the area. The TOC data, summarized by cruise and horizon and divided into dredged material and nondredged material, are discussed in Dexter et al. (1984). The percent TOC for dredged material ranged from 2.40 to 3.25 percent. Comparable data for nondredged material are 1.09 to 2.52 percent TOC. The TOC values for sediments from the disposal site appeared to be slightly higher than those from outside the site, but there were no significant differences.

55. While the range for oil and grease (O&G) levels associated with the dredged material was higher, there was considerable overlap between O&G levels associated with the dredged material and those from background sediments. The O&G ranges were 1.51 to 3.35 mg/g for dredged material areas and 0.79 to

2.03 mg/g for nondredged material (Dexter et al. 1984). Again, no significant differences were found.

56. Correlations between physical and chemical parameters were examined. Weak correlations were found for total PCB/percent sand (negative) and gravel and TOC/O&G (positive) for dredged material sediments. There were no correlations between physical and chemical parameters for the nondredged material sediments.

57. Other chemical parameters determined included PCB, sulfides, nitrate, nitrite, reactive silicate, orthophosphate, and ammonia in interstitial water. There were no dramatic trends or differences between disposal site areas and other areas for any of these parameters. Data for PCB levels in interstitial water were quite variable due to the small sample size (200-500 ml) and the presence of suspended sediment particles. There was only a slight trend for higher PCB levels in interstitial waters associated with sediments containing higher PCB levels. Most of the dredged material sediments were black, indicating reducing conditions. Nutrients were higher in interstitial water compared to overlying water, but the levels were not high enough to cause any biological impact. Silicate, orthophosphate, and ammonia were generally higher with depth in the sediment cores. Nutrients from the interstitial water samples were not related to other physical or chemical characteristics of the sediments except that higher concentrations were associated with dredged material.

58. <u>Water column.</u> Salinity and temperature in the water column for all locations during the study period were as expected and were related to rainfall and the time of the year. The effect of the Duwamish River discharge on salinity was much greater than any effect of the dredged material or differences in physical parameters due to the dredged material. Dissolved oxygen values were also typical with higher values at the surface. There were no differences in dissolved oxygen in the water column that could be attributed to the disposal of dredged material. Nutrients in the water column such as phosphate, nitrate, and silicate were often highest in the low-salinity surface layer, reflecting the input of the Duwamish River. Both hydrographic and nutrient parameters reflected the normal responses of Puget Sound to seasonal changes. None of these parameters indicated any differences between disposal site stations and those outside the disposal site.

59. The PCB levels were determined for water samples from the water

column at the disposal site and at outlying stations. The PCB compounds were found at very low (nanograms per litre or parts per trillion) levels. Some samples showed anomalously high concentrations. These high values, found randomly throughout the data set, were considered to be suspect and were deleted from the data analysis. There was some indication that PCB levels were slightly higher in samples taken 1 m above the bottom compared to those taken 10 m from the bottom; however, the differences were not statistically significant. Comparisons of PCB levels from water and suspended samples from disposal site stations and nondisposal site areas also revealed no significant differences. Levels were similar to those found in the DMRP studies of the disposal operations, and there was a similar trend where PCB concentrations in the water column were inversely correlated with salinity. This demonstrates the effect of the inflow of the Duwamish River fresh water to Elliott Bay. Analyses of suspended particulates showed that this component of the system contained much higher levels of total PCB compared to the water. Data for samples taken 1.0 m from the bottom are as follows:

	Total PCB			
	Water, ng/ℓ		Suspended Sediment, ng/g	
Date	DS*	NDS	DS	NDS
May 1979	3.7	2.2 ± 1.1	1,352 ± 705	1,033 ± 583
Oct 1979	0.6 ± 0.3	0.7 ± 0.9	154 ± 56	200 ± 144
May 1980	1.3 ± 0.3	1.3 ± 0.6	1,129 ± 553	926 ± 423

* DS indicates disposal site stations; NDS indicates nondisposal site stations.

60. Analysis of the complete data set for the water-column samples indicated no significant differences between PCB levels in either water or suspended particulates for the various stations. Therefore, values found are not related to the previous disposal of dredged material. The data did show that PCB compounds are associated with suspended sediment in much higher concentrations than are found dissolved in the water.

PCB levels in benthic organisms

61. Although numerous species of animals were obtained from each sampling station during each cruise, sufficient biomass for PCB analyses was not easily obtained, and in some cases different species were analyzed based on the biomass available. The PCB concentrations were determined on a dry weight

basis for whole animals and not specific organs or parts of the animals. The data generally indicated a positive correlation between PCB levels in benthic macrofauna and surface sediment levels at the same sampling station. The data yielded an overall correlation coefficient of 0.84 for total PCB in animals and sediments. Variability in the measured PCB levels in the sediments from different stations and in different animal groups analyzed precluded detailed statistical verification of the trend of animal/sediment correlation. Data showing mean levels of PCB in animals and sediments for all cruises are shown in the following tabulation:

Sample Station*	Location (Original Grid)	Total PCB Levels, μg/g (Dry Weight) Biota	Sediment**
	Cruise 2, May 79		
103 (8)	Center	3.91 ± 3.0	2.59 ± 1.24
109 (5)	Edge	2.03 ± 2.7	0.43 ± 0.31
131 (6)	Edge	1.56 ± 0.9	0.81 ± 0.42
133 (4)	Removed-south	0.46 ± 0.4	0.59 ± 0.29
139 (1)	Most removed	0.21 --	0.96 ± 0.35
	Cruise 3, Oct 79		
100 (5)	Center	1.72 ± 1.09	3.01 ± 2.47
103 (4)	Center	3.52 ± 2.66	3.33 ± 2.23
109 (5)	Edge	0.85 ± 0.48	1.56 ± 0.72
145 (4)	Removed-north	0.21 ± 0.13	0.44 ± 0.26
148 (4)	Most removed	0.20 ± 0.12	0.16 ± 0.04
	Cruise 4, May 80		
100 (6)	Center	2.48 ± 1.93	2.73 ± 1.64
103 (5)	Center	2.45 ± 1.56	1.83 ± 0.81
152 (4)	Edge	0.48 ± 0.32	0.32 ± 0.19
155 (4)	Removed-northeast	0.40 ± 0.10	0.82 ± 0.34
187 (4)	Removed-east	1.08 ± 1.16	1.75 ± 1.10

* Parenthetical entries are number of organisms per sample (including some replicate samples).
** All sediment values were based on six samples.

62. These data clearly show that biota and sediment collected from the center of the previous disposal grid contain higher PCB levels compared to samples taken from areas away from the disposal mound (removed-south, north, etc.). Some areas of relatively high PCB content were identified away from the disposal area toward the east (cruise 4). The least contaminated area was to the north of the disposal grid (cruise 3). Although the highest PCB levels were found at the center of the disposal grid (station 103), there was some indication that PCB levels may be slowly decreasing in this area from May 1979 to May 1980. While this decrease from 3.91 μg/g PCB in May 1979 to 2.45 μg/g in May 1980 was consistent with time, the variability of the data was substantial, and no statistically significant differences were apparent.

63. The concentrations of PCB in the various species of animals analyzed were examined for obvious trends. The available data did not show any clear trend for PCB bioaccumulation in relation to feeding habits of the animals. Some of the benthic animals revealed reasonably strong correlations between levels of PCB in animals versus the corresponding sediments. The PCB level in one animal, *Goniada brunnea*, a carnivorous errantian polychaete, was not correlated with the PCB levels in the sediment and contained PCB levels approximately ten times the sediment levels. The other species examined were generally between one and two times the sediment levels. Dexter et al. (1984) caution that the limited data and the lack of replication of tissue samples preclude definite conclusions other than the general trend of the animals reflecting mean sediment PCB levels. It is possible that mobile animals feeding on benthic organisms at the disposal site represent a mechanism for movement of PCB from the area, but the amount available for movement in relation to the amount bound to the sediments is negligible. Also, it has not been proven that consumption of contaminated food by predators results in comparable contamination of the predator with no losses during the process. Mobile animals would not be expected to feed exclusively at the previous disposal site.

Summary

64. Results of this study show clearly that the dredged material deposited at the deep-water disposal site in Elliott Bay in 1976 has been stable both physically and chemically. The material has not been moved by currents, and suspended sediment levels at the disposal site are low. In general there are more animals at the disposal mound than at surrounding areas. The common

bivalve, *Macoma carlottensis*, was found in abundance at the site with young settling and developing at the site. The concentration of PCB at the site is somewhat higher than in surrounding sediments; however, hot spots of PCB contamination were identified at locations far removed from the site. It appears that some areas of Elliott Bay to the east of the disposal site areas that are larger than the disposal site contain total PCB at levels similar to or exceeding the levels at the disposal site. Animals at the center of the previous disposal site contained PCB at levels slightly higher than sediment levels, which were in the 2.0- to 3.0-μg/g range. Some reference area sediments contained 1.8 μg/g total PCB while most were less than 0.5 μg/g total PCB. Animals did not appear to be harmed by these levels as shown by the increased numbers at the disposal site. Finally, it appears that most, if not all, of the major changes that might occur at the site have occurred and that the mound is physically and chemically stable.

PART VI: CONCLUSIONS

65. Studies conducted in the summer of 1979 under the DOTS Program at the Lake Erie disposal site have identified some long-term impacts. Sediment physical parameters, such as percent sand and gravel, differ between the three disposal sites and the two reference sites with the disposal sites containing more sand and gravel. Reference sites, in general, contained greater numbers of animals, except for gastropods; however, differences were not statistically significant. Many different groups of animals, both macroinvertebrates and meiofauna, were found at all five sites. Dominant groups of animals identified by Sweeney (1978) during the DMRP were also found dominant during the DOTS studies. Differences in major groups of animals noted during the DMRP were not as great 3 years later. There were more bivalves at the reference sites in 1979, yet this situation was also observed by Sweeney (1978) prior to the initial disposal event in 1975. Chemical analyses of sediment samples from the reference and disposal sites revealed no significant differences; reference area sediments contained more mercury while disposal area sediments contained more cadmium. Molluscs from the reference areas were shown to contain higher levels of both metals compared to disposal area animals. The primary long-term impact was the change in percent sand and gravel at the disposal sites with few significant differences among the animals at the two kinds of sites. There was no indication of sediment or tissue contamination problems. Since the disposal areas differ little from the reference areas in kinds and numbers of animals present, it appears that the ecological significance of open-water disposal of dredged material at this Lake Erie site is minimal.

66. Studies conducted at Elliott Bay during the period February 1979 to May 1980 under the DOTS Program have documented long-term impacts associated with the open-water disposal of dredged material. Three years after the disposal events there is still a prominent mound of sand-silt and silty material at the center of the disposal area. Some of the darker dredged material is now overlain with a greenish-grey layer of biologically processed dredged material and newly deposited natural material. Numerous animals were found at and around the previous disposal site. Various statistical analyses discussed by Dexter et al. (1984) showed, in general, the same number of species on and off of the disposal site, but increased abundances and biomass at the disposal

site. Some important animals not found during the DMRP studies were found 3 years later. Sediments placed at the Elliott Bay site were known to contain PCB, but a number of chemical analyses of sediments at and near the disposal site showed disposal site sediment to contain only 1.0 to 2.0 ppm total PCB compared to large areas of Elliott Bay that contained approximately 1.0 ppm total PCB. The PCB found in the sediments at the disposal site does not appear to be moving into the water column at detectable levels. Animals were found to contain PCB at levels similar to those seen in the disposal site sediments. Thus, some animals found at the center of the disposal site contained total PCB at the 2.0- to 4.0-ppm range. These numbers tended to decrease somewhat from May 1979 to May 1980 although a statistically significant decrease was not shown. Animals at the edge of the disposal area were less affected. The levels of PCB in animals removed from the disposal area ranged from 0.2 to 1.0 ppm total PCB. It was concluded that 3 years after disposal, the area is stable both physically and chemically and that the immediate disposal area supports greater numbers of animals compared to other parts of Elliott Bay. The dredged material was not toxic, yet animals found at the disposal mound contained elevated levels of PCB. It is considered unlikely that this situation will result in any measurable increase in the PCB levels of higher members of the food web such as demersal fish; however, there are no data to support this contention.

67. The overall results of the DOTS studies at the Lake Erie and Elliott Bay disposal sites indicated that both sites were physically stable 3 years after the disposal events. The most permanent changes caused by disposal were related to changes in the substrate--both areas contained more sandy material after disposal. Animals recolonized both areas rapidly and, for the most part, the same kinds of animals were found at the disposal sites as found at nearby reference sites. There were generally fewer numbers of benthic species at the Lake Erie site compared to the reference areas, whereas the opposite was true for the Elliott Bay study area. Sediments at the Lake Erie site were no more contaminated with the metals mercury and cadmium than reference sediments. At the Elliott Bay site, the disposal area contained sediment that was contaminated with PCB, and animals at the site reflected the PCB levels of the sediment.

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