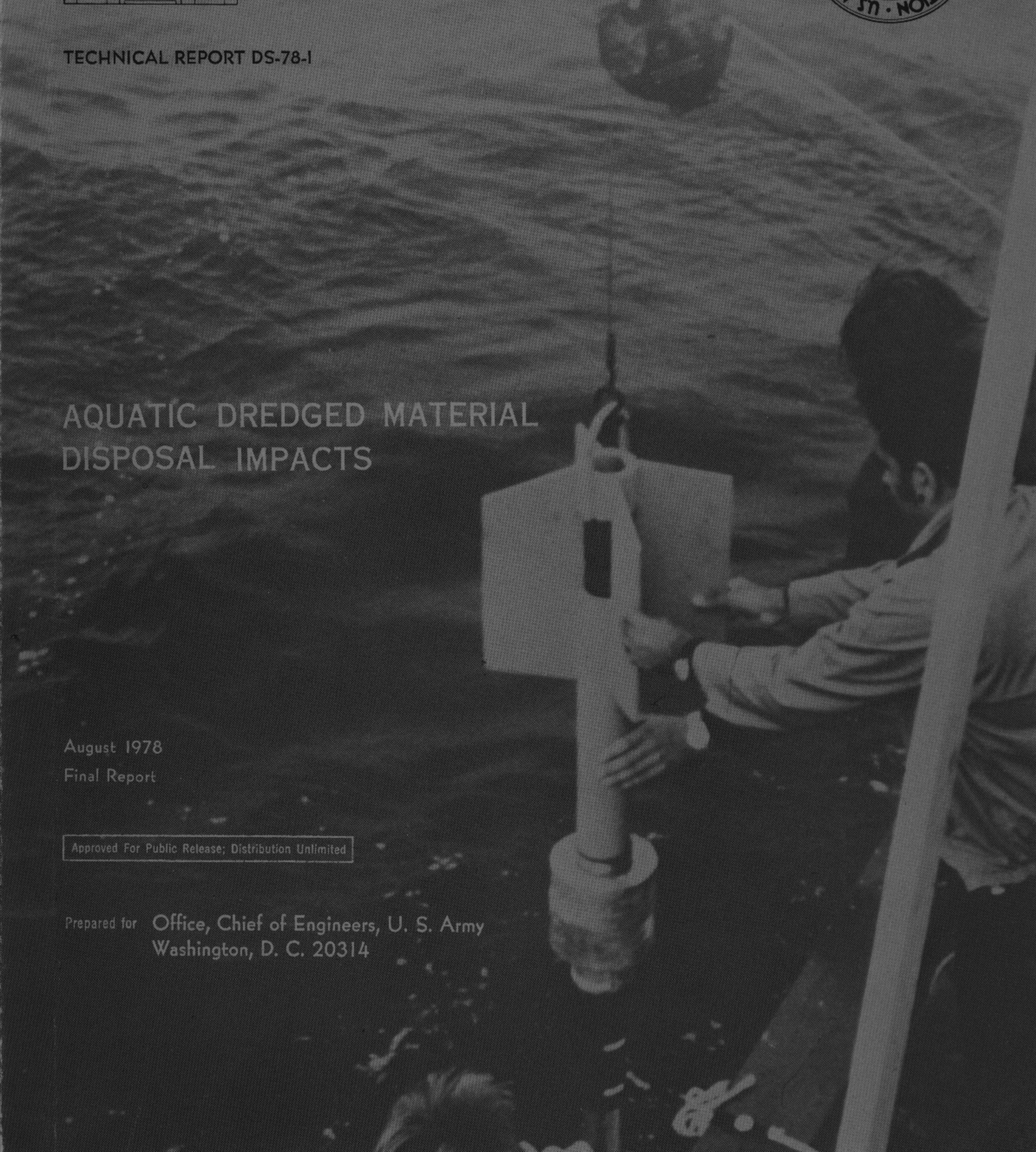
SYNTHESIS OF RESEARCH RESULTS

DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT DS-78-1



AQUATIC DREDGED MATERIAL DISPOSAL IMPACTS

August 1978

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

THE DMRP SYNTHESIS REPORT SERIES

Technical Report No.	Title
★ DS-78-1	Aquatic Dredged Material Disposal Impacts
DS-78-2	Processes Affecting the Fate of Dredged Material
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report DS-78-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AQUATIC DREDGED MATERIAL DISPOSAL IMPACTS		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Thomas D. Wright		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DMRP Task 1A
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE August 1978
		13. NUMBER OF PAGES 57
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

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

Dredged material disposal
Environmental effects
Open-water disposal
Sediment
Waste disposal sites

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

Under the Dredged Material Research Program (DMRP), studies of the impact of dredged material disposal in open-water systems (Aquatic Disposal Field Investigations (ADFI)) were conducted at five locations: New York (Eatons Neck), Ohio (Ashtabula River), Texas (Galveston), Oregon (Columbia River), and Washington (Duwamish Waterway). The sites were representative of a variety of disposal practices, dredged materials, and aquatic habitats. Disposal did not occur during the course of the Eatons Neck ADFI but did at the other four

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20. ABSTRACT (Continued).

sites. This report summarizes the findings of the investigations.

In general, there were few significant impacts as a result of disposal. The only physical impacts noted were the creation of mounds of material within the disposal sites and increased turbidity in the water column during disposal operations. The turbidity was transient and soon disappeared as a result of mixing processes and settling of particulate matter. There were, in several instances, releases of ammonia, phosphorus, and manganese into the water column, but the pelagic community did not appear to be adversely affected. PCB's were released during the Duwamish ADFI. Other chemical substances were also released, but the releases were of small magnitude and short duration.

Following disposal, the mounds were observed to persist for a considerable period of time (>1 year) and to migrate away from the initial point of disposal. Mound dispersal was a function of grain size, currents, waves, and water depth. Other than the PCB release during the Duwamish disposal operation, chemical changes were minimal; at Ashtabula and Galveston, metal concentrations in the disposal areas were lower after disposal than before. Disposal did have an impact upon the benthic community, with the numbers and kinds of organisms usually being reduced by disposal. Recovery was generally rapid, and in some cases there were more organisms present after disposal than in adjacent reference areas. However, the kinds of organisms present after disposal suggest that a change in biological communities had taken place. Whether this change was permanent or merely indicative of biological succession could not be determined. Most of the changes involved benthic invertebrate organisms, with finfish exhibiting minimal impact.

It was not possible to determine the factors responsible for the impacts on the benthic community because very few samples were taken in such a fashion that physical, chemical, and biological variables could be simultaneously examined. Available information, however, suggests that the observed changes were related to a physical phenomenon (burial) rather than chemical toxicity.

There was little evidence of the uptake of chemical substances (such as metals, pesticides, PCB's, etc.) by organisms. In most instances, concentrations of these substances in organisms were a reflection of concentrations (and perhaps availability) in the sediments.

The findings for the ADFI sites tend to agree with those from complementary studies carried out in the laboratory. The complementary laboratory work is reported in other DMRP synthesis reports.

As there were few impacts observed from open-water disposal within authorized disposal areas (where impacts are allowable), it is concluded that impacts outside designated areas would not be of great significance.

PREFACE

As a part of the 1970 River and Harbor Act (Public Law 91-611), Congress authorized the Corps of Engineers to initiate and conduct studies on dredging and dredged material disposal. This synthesis report describes a portion of these studies, the Aquatic Disposal Field Investigations (ADFI), conducted under the Dredged Material Research Program (DMRP) sponsored by the Office, Chief of Engineers, U. S. Army. The ADFI were carried out at five locations considered to be representative of a variety of dredging and disposal operations. These included an Atlantic estuary, the open Gulf of Mexico, the Great Lakes, a Pacific estuary, and the open Pacific Ocean. Physical, chemical, and biological investigations of the environmental impacts of disposal were carried out in such a manner as to evaluate different dredging techniques (such as hopper and mechanical dredging), different sediments (coarse to fine, clean to contaminated), and different disposal environments (freshwater, estuarine, and open ocean).

The majority of the work at the various ADFI sites was carried out through interagency agreements with various governmental agencies or under contract with academic institutions and private concerns. The overall study was under the direction of Dr. John Harrison, Chief, Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The ADFI manager was Dr. R. M. Engler, EL, and the site coordinator was Mr. S. P. Cobb, EL. Initial site managers (EL) were Mr. J. R. Reese (Eatons Neck), Mr. C. G. Boone (Columbia River), Dr. J. R. Seelye (Ashtabula), Mr. D. B. Mathis and Dr. T. D. Wright (Galveston), and Mr. J. H. Johnson and Dr. H. E. Tatem (Duwamish Waterway). This report was prepared by Dr. Wright.

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

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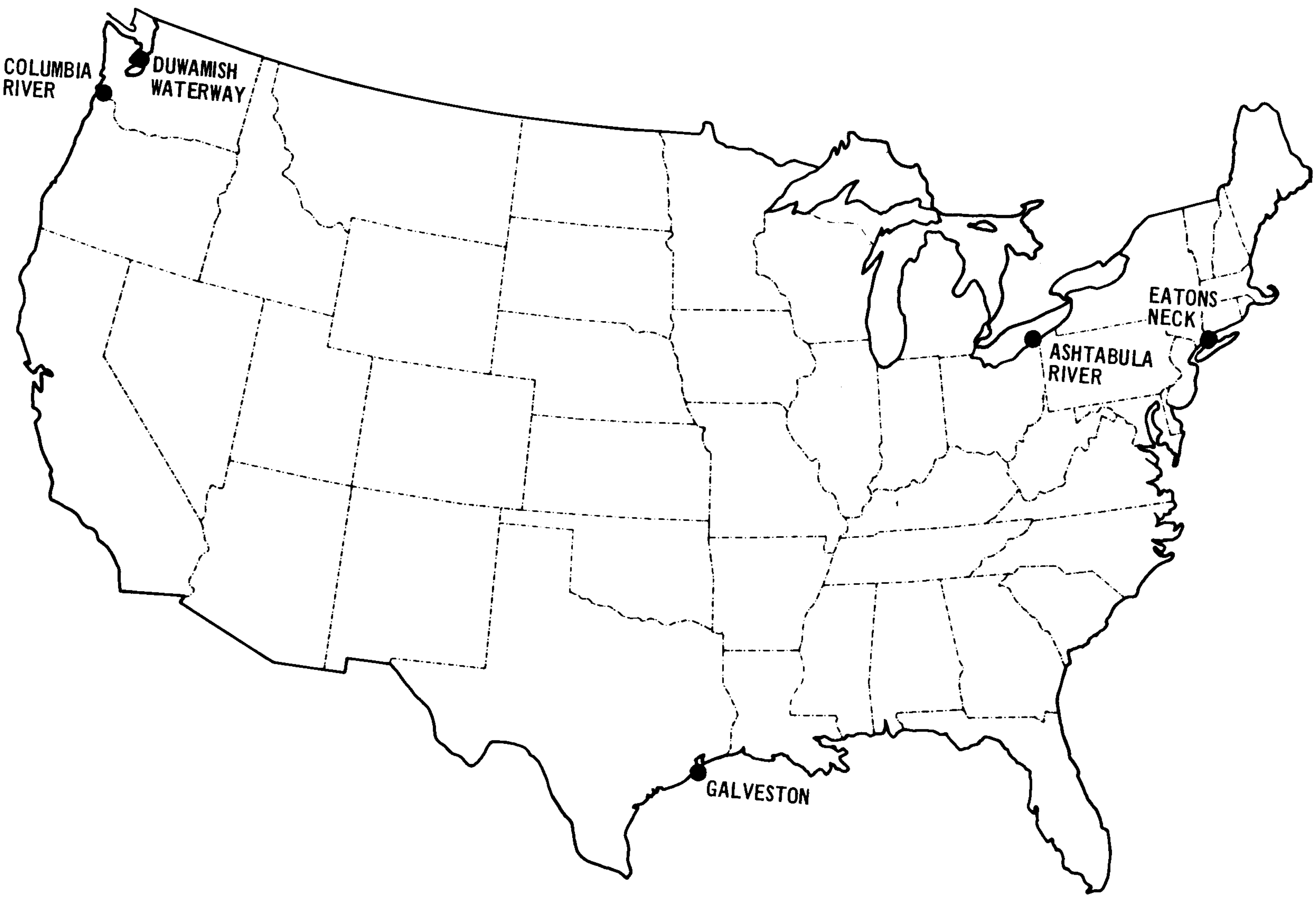

Figure 1. Locations of ADFI sites

AQUATIC DREDGED MATERIAL DISPOSAL IMPACTS

PART I: INTRODUCTION

Background

1. The River and Harbor Act of 1970 (Public Law 91-611, Section 123) authorized the Corps of Engineers to initiate and conduct a comprehensive nationwide study of dredging and dredged material disposal operations. Of particular interest were environmental impacts, productive uses of dredged material, and new and/or improved dredging and disposal practices.

2. The U. S. Army Engineer Waterways Experiment Station (WES) was assigned responsibility for the research program; the program was designated as the Dredged Material Research Program (DMRP).

3. The planning and implementation of the DMRP were the responsibility of an interdisciplinary team established at WES as part of the Environmental Laboratory (EL). The thrust of the program involved four major research projects:

- a. Environmental Impacts and Criteria Development Project (EICDP).
- b. Habitat Development Project.
- c. Disposal Operations Project.
- d. Productive Uses Project.

4. This synthesis report is primarily concerned with the findings from Task 1A, the Aquatic Disposal Field Investigations (ADFI), of the DMRP and observations from the five sites (Figure 1) which were selected to meet ADFI goals. Findings from related work will be referenced in this synthesis as appropriate.

5. The overall objective of the ADFI was to provide definitive information on the environmental impact of dredging and disposal operations and, where undesirable impacts were observed, to suggest means of eliminating or reducing such impacts. As such, this also included

studies on water and sediment quality and the rate and extent of the recolonization of disposal sites by bottom organisms, impacts on bottom animals, and responses of swimming and free-floating organisms to disposal.

6. The basic approach involved the selection of field sites on the basis of representativeness of different geographic regions (environments) and disposal operations. Appropriate strategies were then developed for the collection and analysis of biological, chemical, and physical samples. Samples were then taken during controlled disposal operations and compared to samples obtained under baseline conditions and from reference sites.

7. These efforts involved some 29 work units (6 in-house, 16 under contracts, and 7 through interagency agreement) and an aggregate expenditure/obligation of approximately $4.6 million. Of these work units, 20 were carried out at the five major field sites.

Research Sites

8. For the purpose of evaluating potential open-water disposal sites for detailed investigations, the continental U. S. was divided into six geographic regions:

- a. North Atlantic, from Cape Hatteras north.
- b. South Atlantic, from Cape Hatteras south.
- c. Gulf of Mexico.
- d. South Pacific, from Cape Mendocino south.
- e. North Pacific, from Cape Mendocino north.
- f. The Great Lakes.

In all, some 119 coastal open-water disposal sites were evaluated to select the five sites used in the ADFI. A general description of each site and the operations at it is given below.

Eatons Neck (New York)

9. This site is located in Long Island Sound and is a historic (over 75-year-old) disposal site. Disposal operations were to consist of the placement of mechanically dredged, fine-grained, contaminated

sediments at an estuarine disposal site. However, no disposal took place as the project was terminated after the baseline studies. Because of local opposition to disposal-related research in Long Island Sound the baseline studies were used to prepare an environmental inventory of the site.

Columbia River (Oregon)

10. This disposal site is located off of the mouth of the Columbia River. Disposal operations consisted of oceanic disposal of medium- to fine-grained, clean, hopper dredged material. Studies were conducted to determine acute and long-term effects of disposal.

Lake Erie (Ashtabula, Ohio)

11. Seasonal aspects of spring and summer hopper dredge disposal of contaminated and uncontaminated sediments from Ashtabula Harbor were investigated at this site. In addition, the long-term impacts at a historic disposal site were evaluated. This was the only site located entirely in freshwater.

Gulf of Mexico (Galveston, Texas)

12. Open-gulf disposal of hopper-dredged fine-grained and coarse-grained material from the Galveston Bay Entrance Channel were studied at the Galveston site. In addition, a small quantity of highly contaminated sediments from the Texas City Turning Basin was also placed in the disposal site.

Duwamish Waterway (Puget Sound, Washington)

13. This site was chosen for investigations of the disposal of contaminated sediments in an estuary. Fine-grained sediments contaminated with polychlorinated biphenyls (PCB's), metals and petroleum hydrocarbons were mechanically dredged from the waterway, barged to an Elliott Bay (Puget Sound) site, and disposed of in 60 m of water.

Research Rationale

14. In general, a multidisciplinary team approach was used at each site to investigate the effects of dredged material disposal. The primary variables studied were physical, chemical, and biological

parameters as follows:

- a. Physical: Currents, waves, tides, meterology, bottom profiles, sediment movement, sedimentology, geochemistry, and mineralogy.
- b. Chemical: Water quality, sediment quality, toxicant release/removal, and nutrient release/removal.
- c. Biological: Fish, shellfish, benthic macroinvertebrates, phytoplankton, zooplankton, contaminant bioaccumulation, and recolonization.

Not all variables were investigated at each site.

15. Although there were site-specific modifications, the general schedule consisted of predisposal surveys to establish baseline (ambient) conditions, one or more disposal operations with frequent sampling to determine acute impacts, and postdisposal monitoring to assess chronic impacts, recolonization by benthic organisms, and the rate of return to predisposal conditions. Whenever possible, physical, chemical, and biological data were obtained concomitantly so that cause-and-effect correlations and relationships could be adequately investigated.

16. The research at each site was conducted through interagency agreements and contracts by various agencies, institutions, and private firms. This resulted in a series of site-specific reports; these reports were published as appendices to the summary reports for each site (Table 1). These summary reports and their appended contract reports, together with the other EICDP reports, form the basis of this synthesis report on the ADFI; specific citations to source these documents are not included in the text.

EICDP/ADFI Relationship

17. Three other task areas within the EICDP were closely related to the ADFI. These were: Movements of Dredged Material (Task 1B), Effects of Dredging and Disposal on Water Quality (Task 1C), and Effects of Dredging and Disposal on Aquatic Organisms (Task 1D). The research for these tasks was, for the most part, carried out in the laboratory under controlled conditions. As such, the results are useful

Table 1

ADFI Summary Reports and Appendices

Technical Report Number	Main Title	Subtitles	Contractor or Mode of Conduct*	Authorship
TR D-77-6	Aquatic Disposal Field Investigations, Eatons Neck Disposal Site, Long Island Sound	An Environmental Inventory	EL	S. P. Cobb et al.
		Appendix A: Investigation of the Hydraulic Regime and Physical Characteristics of Bottom Sedimentation	Yale University	H. Bokuniewicz et al.
		Appendix B: Water-Quality Parameters and Physiochemical Sediment Parameters	SUNY at Stony Brook	Marine Science Research Center
		Appendix C: Predisposal Baseline Conditions of Benthic Assemblages	NYOSL	D. K. Serafy et al.
		Appendix D: Predisposal Baseline Conditions of Demersal Fish Assemblages	NYOSL	R. J. Valenti and S. Peters

(Continued) (1 of 6 sheets)

* EL - Environmental Laboratory
SUNY - State University of New York
NYOSL - New York Ocean Science Laboratory

Table 1 (Continued)

Technical Report Number	Main Title	Subtitles	Contractor or Mode of Conduct*	Authorship
TR D-77-6 (Continued)	Aquatic Disposal Field Investigations, Eatons Neck Disposal Site, Long Island Sound	Appendix E: Predisposal Baseline Conditions of Zooplankton Assemblages	NYOSL	R. I. Caplan
		Appendix F: Predisposal Baseline Conditions of Phytoplankton Assemblages	NYOSL	R. Nuzzi
TR D-77-30	Aquatic Disposal Field Investigation, Columbia River Disposal Site, Oregon	Evaluative Summary	EL	C. G. Boone et al.
		Appendix A: Investigation of the Hydraulic Regime and Physical Nature of Bottom Sedimentation	University of Washington	R. W. Sternberg et al.
		Appendix B: Water Column, Primary Productivity, and Sediment Studies	Oregon State University	R. L. Holton et al.
		Appendix C: The Effects of Dredged Material Disposal on Benthic Assemblages	Oregon State University	M. D. Richardson et al.

(Continued)

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Table 1 (Continued)

Technical Report Number	Main Title	Subtitles	Contractor or Mode of Conduct*	Authorship
TR D-77-30 (Continued)	Aquatic Disposal Field Investigations, Columbia River Disposal Site, Oregon	Appendix D: Zooplankton and Ichthyoplankton Studies	Oregon State University	R. L. Holton and L. F. Small
		Appendix E: Demersal Fish and Decapod Shellfish Studies	NMFS	J. T. Durkin and S. J. Lipovasky
TR D-77-42	Aquatic Disposal Field Investigations, Ashtabula River Disposal Site, Ohio	Evaluative Summary	GLL SUNY at Buffalo	R. Sweeney
		Appendix A: Planktonic Communities, Benthic Assemblages, and Fishery	GLL SUNY at Buffalo	R. Sweeney
		Appendix B: Investigation of the Hydraulic Regime and Physical Nature of Bottom Sedimentation	Nalco Env	L. J. Danek et al.

(Continued)

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* NMFS - National Marine Fisheries Service
GLL - Great Lakes Laboratory

Table 1 (Continued)

Technical Report Number	Main Title	Subtitles	Contractor or Mode of Conduct*	Authorship
TR D-77-42 (Continued)	Aquatic Disposal Field Investigations, Ashtabula River Disposal Site, Ohio	Appendix C: Investigation of Water-Quality and Sediment Parameters	GLL SUNY at Buffalo	R. K. Wyeth and R. A. Sweeney
TR D-77-20	Aquatic Disposal Field Investigations, Galveston, Texas, Offshore Disposal Site	Evaluative Summary	EL	T. D. Wright
		Appendix A: Investigation of the Hydraulic Regime and Physical Nature of Sedimentation	TAMRF	E. L. Estes and R. J. Scrudato
		Appendix B: Investigation of Water-Quality Parameters and Physicochemical Parameters	UT Dallas	G. F. Lee et al.
		Appendix C: Investigation of the Effects of Dredging and Dredged Material Disposal on Offshore Biota	TAMU	D. E. Harper

(Continued)

(4 of 6 sheets)

* TAMRF - Texas A&M Research Foundation
UT Dallas - University of Texas at Dallas
TAMU - Texas A&M University

Table 1 (Continued)

Technical Report Number	Main Title	Subtitles	Contractor or Mode of Conduct*	Authorship
TR D-77-24	Aquatic Disposal Field Investigations, Duwamish Waterway Disposal Site, Puget Sound, Washington	Evaluative Summary	EL	H. L. Tatem and J. F. Johnson
		Appendix A: Effects of Dredged Material Disposal on Demersal Fish and Shellfish in Elliott Bay, Seattle, Washington	NMFS	J. R. Hughes et al.
		Appendix B: Role of Disposal of PCB-Contaminated Sediment in the Accumulation of PCB's by Marine Animals	NMFS	V. F. Stout and L. G. Lewis
		Appendix C: Effects of Dredged Material Disposal on the Concentration of Mercury and Chromium in Several Species of Marine Animals	NMFS	F. M. Teeny and A. S. Hall

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Table 1 (Concluded)

Technical Report Number	Main Title	Subtitles	Contractor or Mode of Conduct*	Authorship
TR D-77-24 (Continued)	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 I - January-June 1976	EPA	D. J. Baumgartner et al.
		Volume II - September-December 1976	University of Washington	S. Sugai et al.
		Appendix E: Release and Distribution of Polychlorinated Biphyenyls Induced by Open-Water Dredged Material Disposal Activities	EPA/University of Washington	S. Pavlou et al.
		Appendix F: Recolonization of Benthic Macrofauna Over a Deep-Water Disposal Site	SCC	R. A. Harman and J. C. Serwold
		Appendix G: Benthic Community Structural Changes Resulting from Dredged Material Disposal, Elliott Bay Disposal Site	EL	C. R. Bingham

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* EPA - U. S. Environmental Protection Agency
SCC - Shoreline Community College, Seattle, Washington

for understanding known impacts and for predicting others that may occur. They cannot, however, be directly applied to field conditions without verification but can be considered as "worst case" evaluations. As such, they are useful in defining boundary conditions expected with aquatic discharge.

18. Results obtained in the field studies may be site-specific. Dredging and disposal will almost always cause some degree of environmental disruption. Disposal, for example, will usually cause the burial of organisms. The amount of burial and the degree of survival of the buried organisms will depend on a variety of physical variables (such as depth, sediment nature, type of discharge, etc.) and the characteristics of the buried organisms.

19. The apparent absence of an impact does not definitively demonstrate that one did not occur. Rather, it may reflect a deficiency in experimental design, inappropriate methods, or analytical error. This is a particular problem in the case of chronic or long-term impacts because these may not become evident for months or years after the causal event.

Organization of Report

20. This synthesis report was written for a large and diverse readership. It consists of five site-specific sections (one for each ADFI site) which summarize the findings at each site and an additional section which consists of a general discussion of common relationships to other DMRP studies. A final section consists of conclusions reached from the ADFI.

21. Because of the diverse audience for which it was prepared, this report is non-technical in the sense of presenting detailed information. Those desiring more specific information are encouraged to consult the summary reports and/or their respective appendices. The majority of the raw data for each appendix are on file at WES and are available for detailed examination.

PART II: EATONS NECK DISPOSAL SITE, NEW YORK

Discussion

22. The Eatons Neck disposal site is located in western Long Island Sound (Figure 2). This is a moderately stratified estuary with a large-scale estuarine circulation pattern superimposed on the more dominant tidal flow. Most of the bottom is covered by a homogeneous layer of silty sediment, with sand and gravel on reefs and in nearshore areas. There is some oxygen depletion in the deeper waters during thermal stratification.

23. There is an important commercial fishery for a number of fish and shellfish. The dominant species include winter flounder, menhaden, herring, summer flounder, American lobster, and oysters. In particular, the Eatons Neck disposal site is the most productive lobster ground in the Sound. Recreational fishing occurs for striped bass, black sea bass, bluefish, and weakfish.

24. The site has been used for dredged material disposal since the turn of the century. In addition, building rubble, derelict ships, and other material have been placed at the site. Water depths at the site range from 12 to 55 m and sediments are generally quite fine-textured.

25. Physical studies were carried out at the site from 1974 through 1976. These included bathymetric surveys, sediment sampling, bottom photography, current and wave measurements, vertical transmissivity measurements, salinity measurements, and meteorological observations.

26. Chemical measurements were obtained from the site and other locations in the western sound from 1974 through 1976. Both water and sediment samples were taken, and analyses included temperature, salinity, dissolved oxygen, nutrients, metals, and chlorophyll.

27. Benthic organisms were sampled in 1974 and 1975. Collections included both macrofauna and meiofauna. Plankton were also collected in 1974 and 1975 as were finfish. In 1975, 20 lobsters were obtained from the site and analyzed for heavy metals concentrations in tissue.

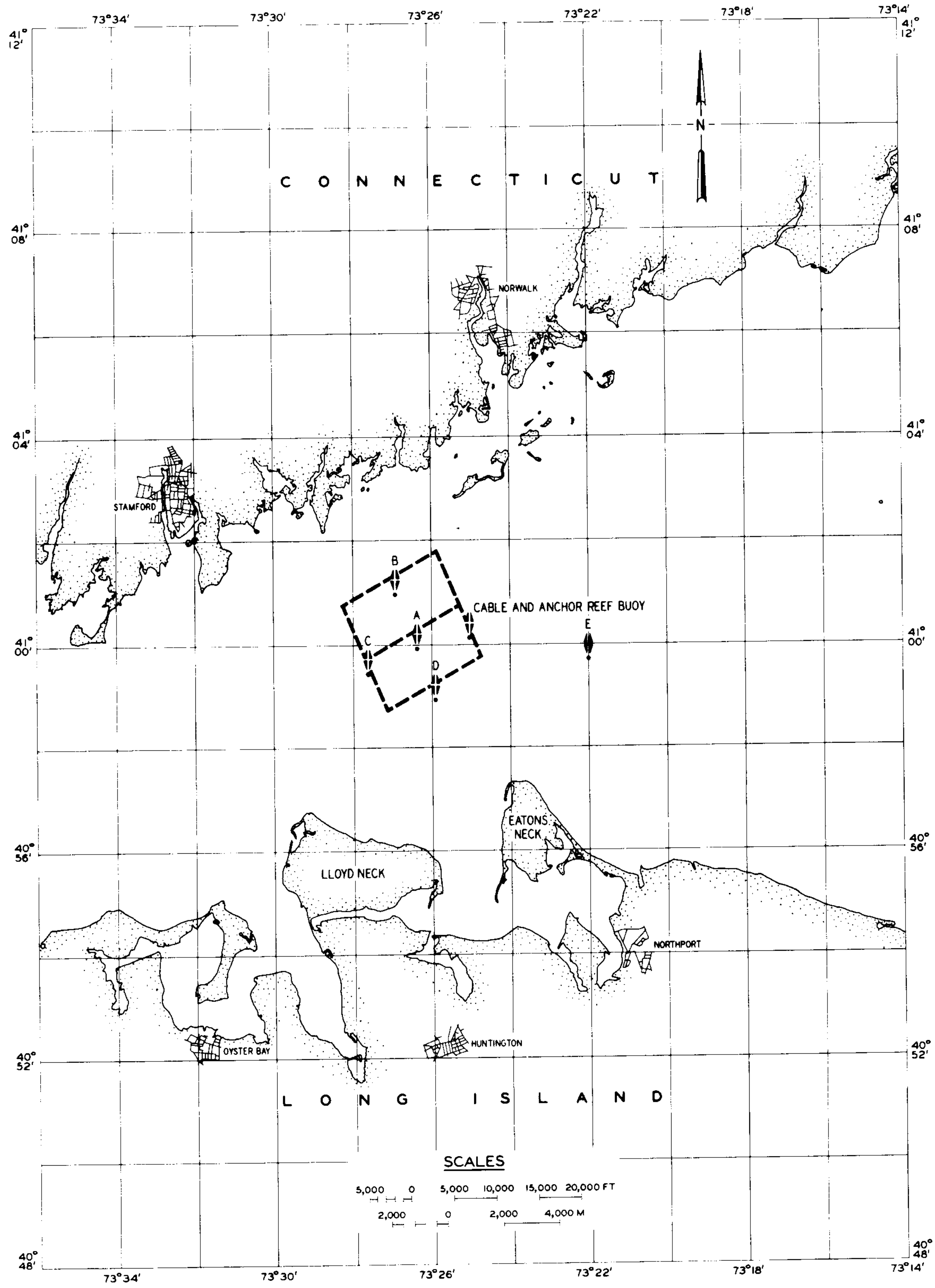

Figure 2. Locations of the Eatons Neck disposal site, the northern extended area, and the marker buoys

Fecal coliforms (1975) were analyzed at the site, in a reference area, and in two harbors proposed for dredging and disposal at Eatons Neck.

28. Because the planned disposal operation was not allowed to take place during the study period, the Eatons Neck ADFI consisted only of predisposal information. At the time that the data were collected (1974-1976), at least 4 years had elapsed since the most recent disposal operations. Whether or not any of the differences observed between the disposal site and the reference sites indicate residual effects from previous disposal, other perturbations by man, or resulted from basic differences between the two areas is not clear.

Findings

29. The physical studies showed clear evidence of disposal mounds that changed little over the 2 years of observation. This would indicate that material placed in the disposal site tends to remain in place and does not become dispersed. It was concluded that, on a physical basis, the site is suitable for dredged material disposal because of minimal postdisposal movement of sediment.

30. There were few differences in sediment texture or chemistry between the disposal and reference sites. Ammonia, organic carbon, and organic nitrogen were slightly higher (based on bulk analysis) at the disposal site, probably due to the previous disposal of dredged material. However, no oxygen depletion was observed at the disposal site. Ammonia was significantly higher in sediment interstitial water at the disposal site.

31. Particulate carbon, particulate nitrogen, and ammonia were somewhat higher in the disposal site water column than in the reference site. Whether or not this difference was correlated with the disposal site or may have been a function of tides, currents, regional sewage and river discharge, or other factors could not be determined.

32. Benthic organisms did not differ in abundance or species composition between disposal and reference sites. However, there were but few sampling stations outside the disposal site so that this

generalization must be somewhat qualified. Lobsters were quite abundant in the disposal site; this is probably a reflection of the rubble and other material forming a suitable substrate for these semiburrowing animals. No elevated metal concentrations were found in the lobsters. It is possible that disposal may have had a beneficial effect upon lobster populations. As lobsters are benthic feeders, the benthic community must be sufficiently productive to support these important shellfish.

33. It also appears that the disposal site supports as many economic fish species than the reference site or more. This conclusion must be tempered by the small number of sampling stations and the pronounced spatial and temporal variation observed for finfish.

Summary

34. The Eatons Neck ADFI indicated that, 4 years after the cessation of 75 years of disposal, little in the way of chemical and biological effects could be observed although the disposal mounds were still evident. However, caution is advised concerning this conclusion because the times and/or locations of sampling were such that natural fluctuations and human perturbations (such as sewage, industrial waste, and river discharge) could not be adequately taken into account.

PART III: COLUMBIA RIVER DISPOSAL SITE, OREGON

Discussion

35. The Columbia River ADFI site is located off of the mouth of the Columbia River (Figure 3). This river is the navigable approach to the Portland-Vancouver area and there are eleven ports between the Pacific Ocean and Portland.

36. Sediments in the study area are variable and consist of nearshore beach sands or Columbia River bedload material. In general, these are fine to very fine sand with minor amounts of silt and clay. There is a tidal delta off of the mouth of the river. Prevailing northwesterly currents sort the material, with the net result that magnetite-rich heavy sediments are left near the northern half of the river mouth and lighter sediments are transported to the northwest.

37. Water chemistry in the area is highly variable as is often the case in such a dynamic nearshore environment. Surface water currents flow to the north, while bottom currents may move toward the river mouth or to the north and northwest. The chemistry is dependent upon tides, river discharge, mixing, and upwelling. This leads to fluctuations in such variables as dissolved oxygen, salinity, turbidity, nutrients, and dissolved trace substances.

38. The lower river estuary and adjacent waters support a diverse and abundant assemblage of animals. Worms, crustaceans, and mollusks dominate the benthic assemblage, with communities varying according to substrate and distance from shore. Plankton are abundant and also quite variable as they interact with fresh, salt, and mixed-water masses. Many species of anadromous and marine fish are found in the area and are of both commercial and recreational importance. Among the more prominent are salmon, sturgeon, and shad. There is a very active dungeness crab fishery in the nearshore area adjacent to the river.

39. The Columbia River ADFI consisted of four phases: a pilot survey, the predisposal baseline study, disposal monitoring, and the postdisposal study. The first two phases were accomplished in 1974 and

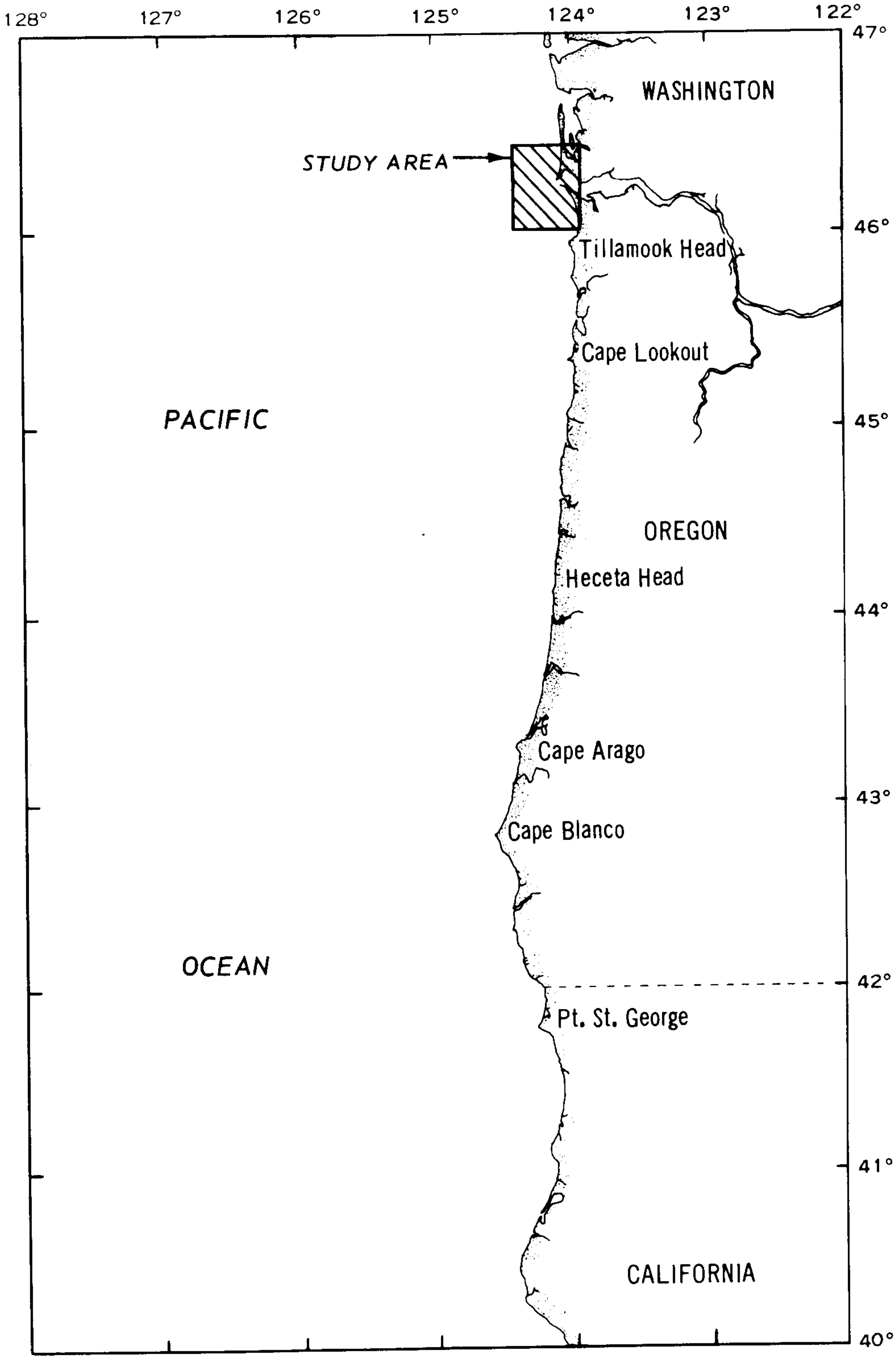

Figure 3. Location of study area, Columbia River disposal site, Oregon

1975; disposal operations were conducted in the summer of 1975, and postdisposal monitoring continued through June 1976.

40. Among the physical variables that were evaluated were bathymetry, currents, winds, waves, suspended sediment, and grain size and mineralogy of sediments. In conjunction with basic bathymetry, side-scan sonar, subbottom profiling, and underwater photography were employed to determine disposal mound characteristics and orientation.

41. Chemical investigations involved the water column, bulk sediment, and sediment interstitial water. For the water column, the primary variables of interest were nutrients, oxygen, temperature, salinity, chlorophyll, primary productivity, pH, light penetration, particulate carbon and nitrogen, and particulate and dissolved heavy metals. Bulk sediment and interstitial water analyses included heavy metals, nutrients, ammonia, and ammonium. Other variables, such as total organic carbon, organic nitrogen, pH, Eh, grease, cation exchange capacity, silicates, and sulfides, were measured for one or the other sediment fraction but not both.

42. Grab samples were taken for the analysis of numbers and kinds of benthic invertebrates. Plankton (including fish larvae) samples were obtained throughout the study and some were incubated with carbon-14 to determine primary productivity. Trawls were conducted to investigate demersal fish and shellfish in the area. In addition, stomach content and food habit studies were carried out on the dominant fish species.

Findings

43. The disposal of 459,000 m^3 of dredged material by hopper dredge in 1975 resulted in a distinct mound with a radius of 460 m. This mound persisted throughout the remainder of the study although there was some evidence of movement to the northwest. Movement appeared to result from the resuspension and transport of fine material from the mound; the coarser material exhibited much greater stability and will probably persist for some years.

44. There appeared to be no important chemical changes in the water column or in the sediments as a result of disposal operations. In the water column, there was a slight elevation of nickel following disposal; this was so small as to be of no biological significance. However, previous disposal (prior to the ADFI) in another area may have resulted in increased values for nutrients and metals over those in an adjacent area presumably not affected by disposal. The sediments in the previous disposal area are fine-grained and contain higher quantities of organic material. It is possible that the metals here resulted from sorption/chelation phenomena rather than being evidence of transport via dredged material.

45. Disposal appeared to cause several biological impacts. Burial by dredged material reduced the number of benthic organisms present and increased the biological diversity. The reduction in numbers persisted for at least 8 months after disposal, while the diversity increase was evident until the end of the study (10 months after disposal). These impacts affected the densities of about half of the organisms, with the remainder being relatively unimpacted. The overall degree of impact was a function of distance from the center of the disposal site, with stations located near the center (greatest deposition) exhibiting the greatest impact, an intermediate impact on the slope and near the edge of the deposit, and little or no impact outside the deposition area. Because there was essentially no change in chemical variables, the biological impacts appear to have resulted from a physical phenomenon (burial).

46. Demersal finfish were also affected by disposal. The number of demersal fish and the species diversity were lower after disposal than before disposal. This difference was observed for some time after disposal but recovery was noted after several months had elapsed. The feeding habits of finfish also appeared to have been altered by disposal; there was a shift from the consumption of small prey items to larger ones. Decapod shellfish appeared to have been un-impacted by disposal.

Summary

47. Disposal appeared to have minor, if any, impacts upon sediment and water column chemistry but did affect the benthic invertebrates and demersal finfish. The observed effects would be considered deleterious, with the impact being more severe for the invertebrates (because of slow recovery) than for finfish (relatively rapid recovery).

48. There may have been chemical changes and impacts upon the nature of the sediment and upon planktonic organisms which were not detected. This unknown, in part, is a result of the disposal area being affected by natural sedimentation from the Columbia River and of there being a variety of water masses present. Under such circumstances, the day-to-day changes are so great that unless an almost continual sampling effort is established, natural change and variation tend to obscure disposal effects. Likewise, because variations from a "normal" or average condition in such an area are large, the organisms present are adapted to cope with such variations, and large changes must often occur before there is a measurable organism response.

PART IV: LAKE ERIE DISPOSAL SITE, OHIO

Discussion

49. The Ashtabula ADFI site is located in Lake Erie just north of the entrance to Ashtabula Harbor (Figure 4). The movement of surface water in the lake is counterclockwise although reversals do occur with northeast winds. A compensating current is found in the deeper waters of the lake during thermal stratification (June-October). Because of the configuration of the lake, any contaminants which are released along the south shore tend to move eastward along the shore. Oxygen depletion occurs in the deeper water during the summer.

50. Sediment in the disposal area primarily originates from material transported by the longshore current and, to a lesser extent, from the Ashtabula River which enters Lake Erie through Ashtabula Harbor. The sediment consists of about equal parts of sand and silt with a small amount ($\leq$ 10 percent) of clay. There is apparently little variation in grain size with depth.

51. Although there have been severe water quality problems in the lake, striking improvements have been noted in recent years. At the Ashtabula ADFI site, water quality variables tended to be quite uniform throughout the water column except during stratification. The expected differences resulting from stratification were observed; during periods of upwelling, deeper (hypolimnetic) water was often found quite near the surface.

52. A variety of invertebrates and fish inhabit the area. The former includes mollusks, worms, insect larvae, and crustaceans. These form a food supply for the 40-odd species of fish which were observed. Yellow perch were the most abundant species, with alewife, gizzard shad, and white sucker being quite common. Moderate to abundant populations of both zooplankton and phytoplankton occur throughout the lake.

53. The Ashtabula area is heavily industrialized and is a major port facility. There are a number of industrial and agricultural sources of contaminants in the immediate vicinity and there are two

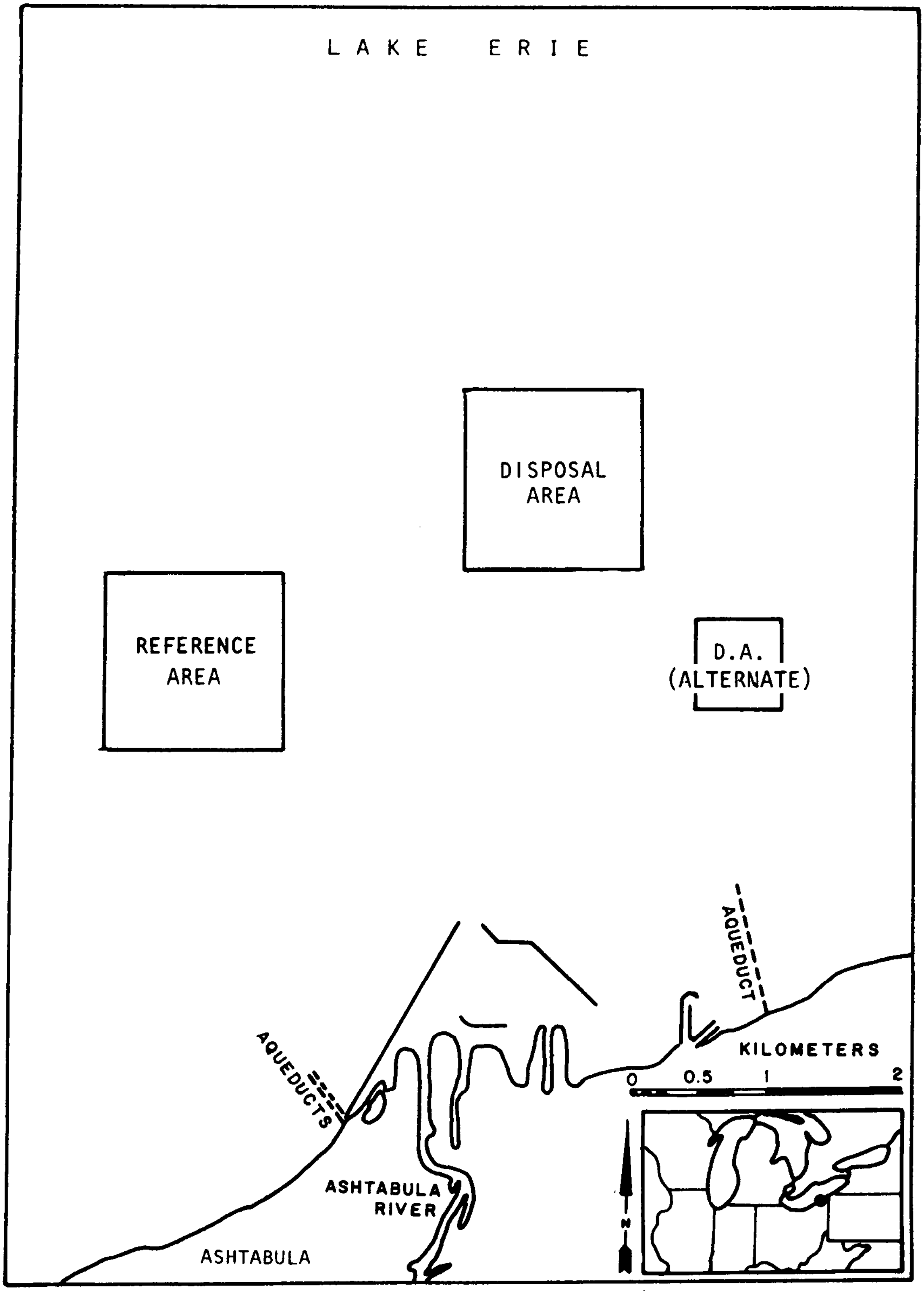

Figure 4. Locations of disposal and reference areas, Ashtabula River disposal site, Ohio

fossil-fuel generating stations east of Ashtabula. These discharge almost 2300 × 10^6 ℓ/day of cooling and waste water into Lake Erie.

54. The Ashtabula ADFI spanned 3 years (1975-1977). The study consisted of four phases: a pilot survey (1975), predisposal sampling (1975), disposal operations (1975-1976), and postdisposal sampling (1975-1976). Samples for various parameters were obtained from a disposal area and an adjacent reference area.

55. The physical variables measured included currents, temperature, light transmission, meteorology, waves, bathymetry and subbottom profiles, grain size, sedimentology, and hydrology.

56. Both pumped samples and grab samples were obtained for analyses of conductivity, pH, turbidity, dissolved oxygen, nutrients, alkalinity, metals, organic carbon, silicates, and sulfate in the water column. Bulk sediment and sediment interstitial water were analyzed for nutrients, metals and organic carbon; bulk sediments were further examined for pH, Eh, percent water, and cation exchange capacity. In addition, in-place sediment oxygen demand measurements were carried out.

57. Phytoplankton and zooplankton samples were evaluated in terms of species present and abundance; primary productivity was estimated by pigment analysis and carbon-14 uptake. Elutriate from dredged samples was added to phytoplankton samples to determine if inhibititory or stimulatory effects were present. Bottom grabs were obtained for investigation of macro- and meiobenthic organisms. As with plankton, these samples were evaluated to determine the numbers and kinds of organisms present.

58. A variety of fishery studies were carried out. These included sampling with gill nets and otter trawls, tows for fish larvae, age determination, and examination of stomach contents. Both fish and invertebrates were analyzed for heavy metals.

Findings

59. Spring and summer disposal by hopper dredged resulted in the formation of mounds of dredged material in the disposal area. These

mounds were 30 to 50 cm high, and, rather than a single mound being present, there were numerous small mounds. Disposal also created a small (< $2^{o}C$) transient increase of temperature in the water column; during thermal stratification, disposal did not alter the thermal structure. There was little change in grain size after disposal and those few changes observed had disappeared within 3 months. Erosion of the mounds occurred as a result of fall and winter storms, and there was a net transport of material to the northwest and southeast.

60. Almost all of the chemical variables measured in the water column were affected by disposal. Effects were not great, however, and an essentially complete return to ambient predisposal conditions was noted within a few minutes to several weeks. The overall impact of disposal is not clear as some constituents increased, presumably through release, while other decreased. The latter phenomenon probably resulted from sorption onto settling dredged material.

61. There were changes in interstitial water (of sediment) chemistry after disposal. A return to predisposal conditions took from 30 to 90 days. It should be kept in mind that the sediments were eroding and being compacted and/or reworked after disposal. This process in itself could bring about various changes in interstitial water chemistry.

62. The greatest chemical effect of disposal appears to have been observed in the sediment. Following disposal, nutrients increased in the sediment, but metals (except mercury) decreased. This effect is not surprising as it reflects the relative concentrations of nutrients in lake sediments and harbor sediments.

63. Overall interpretation of the results of sediment chemistry are difficult because of the behavior of dredged material when released and of the natural lake sediments. Rather than there being an overlay of dredged material upon natural lake bottom, the physical impact of the dredged material striking the bottom resulted in bottom currents. These currents pushed lake bottom to the periphery of the study area and on top of previously deposited dredged material. Hence, alternating series of dredged material and natural bottom resulted, with subsequent

compaction and reworking serving to further obscure differences between the two sediment types.

64. Disposal operations at Ashtabula had essentially no measurable impact upon planktonic organisms. Benthic organisms were impacted in several ways. There was no change in the number of species present in the disposal area following disposal, but there were a number of changes in species composition, with new species transported from the harbor replacing those which had been eliminated. In addition, there was a large increase in the number of organisms in the disposal area. Many of the changes did appear to be initially confined to the immediate area of disposal. As erosion spread the dredged material over a larger area, faunal changes in the expanded area were observed. Of interest was the finding that gross animal groups (such as the family level of identification) were not sufficient to determine impacts; rather, an examination at the species level was required.

65. Adults and young of pelagic fish did not appear to be impacted by disposal. However, bottom-dwelling fish showed a negative response to disposal and migrated from the area. Within an hour after disposal these fish had migrated back into the disposal area. Overall, the effects of disposal upon fish were of small magnitude and only persisted for a short period of time.

66. Heavy metals in fish and invertebrates showed little change as a result of disposal. The relative concentration of metals in fish were the same as those observed in the sediment, whereas a decrease was noted in some of the invertebrates. Hence, bioaccumulation did not occur.

Summary

67. There were but few important impacts as a result of dredged material disposal at the Ashtabula disposal site. Some chemical changes were observed, but these were of small magnitude and transient in nature. There were changes in the benthic community which persisted throughout the study; these primarily consisted of species replacement

and an increase in the abundance of some organisms. Because these benthic organisms are of importance as food for fish, these changes would be of concern were it not that the feeding activities of fish in the area did not seem to be altered.

PART V: GULF OF MEXICO DISPOSAL SITE, TEXAS

Discussion

68. The Galveston ADFI site is located in the Gulf of Mexico southwest of the Galveston Bay Entrance Channel (Figure 5). The entrance channel provides access to the ports of Galveston, Texas City, and Houston and connects to Galveston Bay, Trinity Bay, and East Bay. Freshwater discharges from the Trinity River and other streams enter the Gulf of Mexico through the entrance channel. Because of the proximity of the channel to the disposal area, the disposal area exhibits semi-estuarine conditions.

69. The disposal area sediment ranges from clay to moderately coarse sand. In previous years, disposal of dredged material in the disposal area appears to have been minimal (except perhaps in the extreme northeast corner) because of the availability of other sites less distant from the dredging site. Salinity, temperature, and other chemical characteristics in the disposal area are quite variable and depend, in large part, on the interactions among tides, currents, freshwater discharge, and other factors. Extreme events, such as hurricanes, rapid increases and decreases in temperature, and periods of severe drought/extreme rainfall, are common and exert a major influence on local conditions.

70. There are numerous sources of contaminants for channel and harbor sediments. Ship traffic through the area is heavy, and the dominant industries produce petrochemical derivatives, metallurgical products, pesticides, plastics, pulp and paper products, caustics, paint, rubber, fertilizer, and similar products. Runoff, domestic sewage, industrial waste, and agricultural drainage are also present. In spite of these many sources for potential contaminants, most of the material dredged from the channel area is not considered contaminated by the U. S. Environmental Protection Agency (EPA). This results from the Channel being filled with clean sediment that is transported into it by the prevailing longshore current. This current generally moves

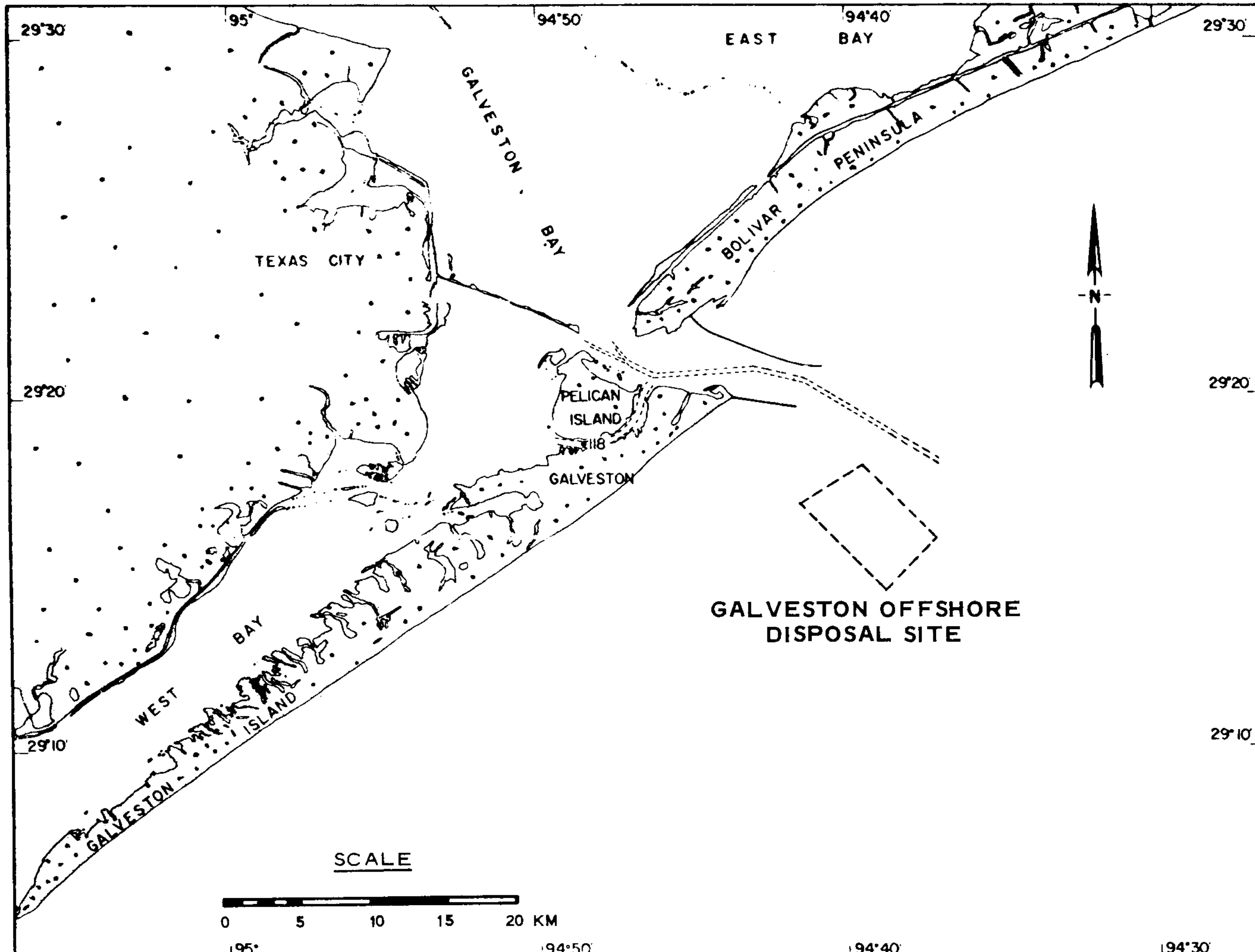

Figure 5. Location of Galveston, Texas, offshore disposal site

from east to west along the shore, and, as the channel is oriented northwest-southeast, sediments carried by the current are deposited in the channel and create shoaling conditions.

71. There are a number of commercially and recreationally important organisms present in the bay and the disposal area. Significant invertebrates include white and brown shrimp, blue crabs, and oysters (the latter are not common in the disposal area). In fact, the largest commercial fishery for shrimp and oysters in Texas estuaries is found in Galveston Bay. Seatrout (weakfish), drum, sheepshead, croaker, flounder, and species of lesser importance are sought by both commercial and recreational fishermen. Because of the close proximity of large population centers, fishing pressure in the area is quite intense.

72. The Galveston ADFI consisted of a pilot survey (1975) and predisposal (1975), disposal (1975-1976), and postdisposal phases (1975-1976). Three experimental disposal sites and two reference areas were selected within the disposal area. Disposal occurred twice in 1975 and once in 1976 at one disposal site; at the other two, there was a single disposal operation in 1975. All of the material disposed of at these sites was uncontaminated (by EPA criteria). An additional site was utilized for the disposal of a small amount of material contaminated with nutrients and heavy metals from Texas City.

73. Physical studies were carried out to measure currents, waves, sediment transport, turbidity, sediment stratigraphy, suspended sediment, mineralogy, grain size, and bathymetry. Both grab and core samples were obtained for analyses. Marked (with a fluorescent dye) sand grains were employed to determine the movement of deposited sediment.

74. Chemical analyses of water column variables were conducted before, during, and after disposal. Measurements were made of nutrients, light transmission, metals, oil and grease, pesticides, PCB's, dissolved oxygen, conductivity, carbon, pH, salinity, turbidity, and temperature. Similar analyses were employed on bulk sediment samples, and a few measurements were made of selected variables in sediment interstitial water.

75. Biological investigations included macro- and meiobenthic organisms, plankton, biomass, and trawl samples for fish. Pigment analyses were carried out on some plankton samples, and a limited amount of food habit information was obtained from stomach analyses of fish. Of the biological investigations, only those involving macrobenthic organisms were considered to be sufficiently comprehensive and accurate to allow their use in estimating the impact of disposal upon organisms.

Findings

76. Disposal of almost 800,000 m^3 of material by hopper dredge resulted in distinct mounds of material. Because of errors in bathymetry, the extent of the mounds was not accurately determined. Some erosion occurred after deposition, with the eroded material generally being transported to the southwest. Some sorting and reworking of the material seemed to occur after deposition; this primarily consisted of the removal of the finer fractions, thus leaving a protective cap of shell hash or cohesive clay over the remainder of the dredged material mound.

77. Disposal resulted in an increased concentration of some nutrients and some metals in the water column. It is not thought that these persisted for any great length of time because of dispersion and/or dilution. Samples taken several months after disposal indicated a return to ambient conditions; however, the extreme variability of the water column in the area as a result of natural phenomena renders the determination of ambient conditions quite difficult. Small-scale changes in sediment chemistry (as determined by bulk analysis) took place. In general, these consisted of decreases in the concentrations of many variables. These decreases probably resulted from relatively coarse sand (with a low adsorption capacity) being placed upon finer natural sediments (with a high adsorption capacity).

78. The only chemical constituents which warrant concern as a result of open-water disposal at Galveston are ammonium-nitrogen and manganese. Both of these exhibited increases in water column

concentrations (manganese increased during seven of nine Galveston Channel disposals and ammonium-nitrogen increased during the second disposal of Texas City material). They could pose a potential, although small, threat to aquatic organisms which may not have been able to swim out of the disposal plume.

79. Disposal did not seem to have any great impact upon benthic organisms. Through chance, disposal coincided with what appeared to be a general seasonal decline in the numbers of these organisms. Thereafter, in general, changes were as great or greater in the reference areas as where disposal had taken place. Detailed analyses of the 19 species of benthic macroinvertebrates considered to be of the greatest ecological significance indicated that several appeared to respond in either a positive (increase) or negative (decrease) manner to disposal. These responses, however, were not consistent and were difficult to relate to disposal. It was found that the benthic organisms exhibited large variations in abundance at the reference and disposal sites. These variations may have served to obscure any changes which did occur.

Summary

80. The Galveston ADFI showed few impacts as a result of disposal operations. With the exception of manganese and ammonium-nitrogen, there was virtually no change in water column chemistry, and even these changes were relatively minor. Disposal resulted in the formation of distinct mounds; these were eroded by waves and currents, with the rate and degree of erosion being a function of water depth and the cohesiveness of the material. There was a suggestion of an impact upon benthic invertebrates. However, organism behavior in the reference areas was sufficiently similar to that in the disposal area that no definitive impacts could be firmly established. It was found that the disposal site was a highly variable and dynamic system with natural perturbations in the chemistry, physical aspects, and biota being very large. These large variations may have served to obscure impacts associated with dredged material disposal.

PART VI: DUWAMISH WATERWAY DISPOSAL SITE, WASHINGTON

Discussion

81. The Duwamish River enters Elliott Bay, a part of Puget Sound. The entire river is tidal with horizontal and vertical variations in salinity. These depend upon tidal stage and river discharge. Low (< 3-mg/ℓ) dissolved oxygen concentrations occur near the bottom of the river. Although quite important as a waterway, the Duwamish is also a major migration route for salmon and trout.

82. Elliott Bay is a rather typical estuarine system with a surface layer of low salinity water being present over a deeper layer of more saline water. During the summer, density stratification is present but in the winter colder fresh water from the waterway entrains and mixes with warmer saline water. Hence, there is usually no stratification in the winter. Because it is an estuary, water column chemical constituents tend to be rather variable. The waterway has created an underwater delta along the south side of the bay. The deltaic sediments consist mainly of silty sand mixed with wood and other organic debris. The dominant demersal fish in the bay during the winter are assorted soles, and the dominant benthic invertebrate is the pink shrimp. Worms and various mollusks are also important components of the bottom fauna.

83. Dredging has ordinarily been done in the waterway with a hydraulic pipeline dredge and upland disposal has been used. However, the increasing cost of upland disposal required a shift to the use of mechanical dredging and open-water disposal with barges. In 1974, there was a spill of almost 1000 ℓ of PCB's at Slip 1, in the maintenance dredging area of the river. The highly contaminated sediments were hydraulically dredged and placed in an impervious containment area (Blazevich et al., 1977) while the remaining, less contaminated material, was removed by a clamshell dredge, placed in barges, and transported to the experimental disposal site. The dredged and disposal of the highly contaminated sediments were carefully monitored by the EPA. The EPA

found that there was a minimal release of metals, nutrients, and hydrocarbons (Blazevich et al., 1977).

84. The ADFI was divided into four phases: a pilot survey and predisposal, disposal monitoring, and postdisposal studies. During the pilot survey, an experimental disposal site was chosen for disposal, and two reference sites (to the east and west) were selected to provide comparative data (Figure 6). The studies were initiated in 1975 and completed in 1976.

85. Physical investigations conducted for the various phases included grain size analyses and measurements of currents, waves, light transmission, fall velocity of dredged material, and the vertical distribution of dredged material in the water column following disposal. In addition, subbottom profiles and the overall bathymetry of the area were obtained to estimate the volume of material disposed of at the site.

86. Chemical studies were carried out on the water column and the sediments. Variables measured in the water column included temperature, turbidity, suspended solids, dissolved oxygen, pH, salinity, nutrients, PCB's, and heavy metals. Several approaches were employed in the measurement of sediment variables. These were bulk analysis, interstitial water, and elutriate tests. In all cases, PCB's and heavy metals were evaluated. Nutrients were analyzed only in interstitial water and during the elutriate testing. Bulk analyses included percent water, volatile solids, organic carbon, sulfides, Eh, pH, and oil and grease.

87. Bottom grabs were taken to characterize the types, abundance, and biomass of benthic organisms. Demersal organisms were collected by trawling and were analyzed in terms of species composition, number/unit of effort, length, and weight for the dominant finfish. Diet studies for finfish were also undertaken. The concentrations of PCB's and heavy metals in the tissue of fish and shrimp were determined to evaluate uptake and/or bioaccumulation of these substances. In addition, organisms were suspended in cages over the disposal mounds to examine toxicity and uptake of contaminants.

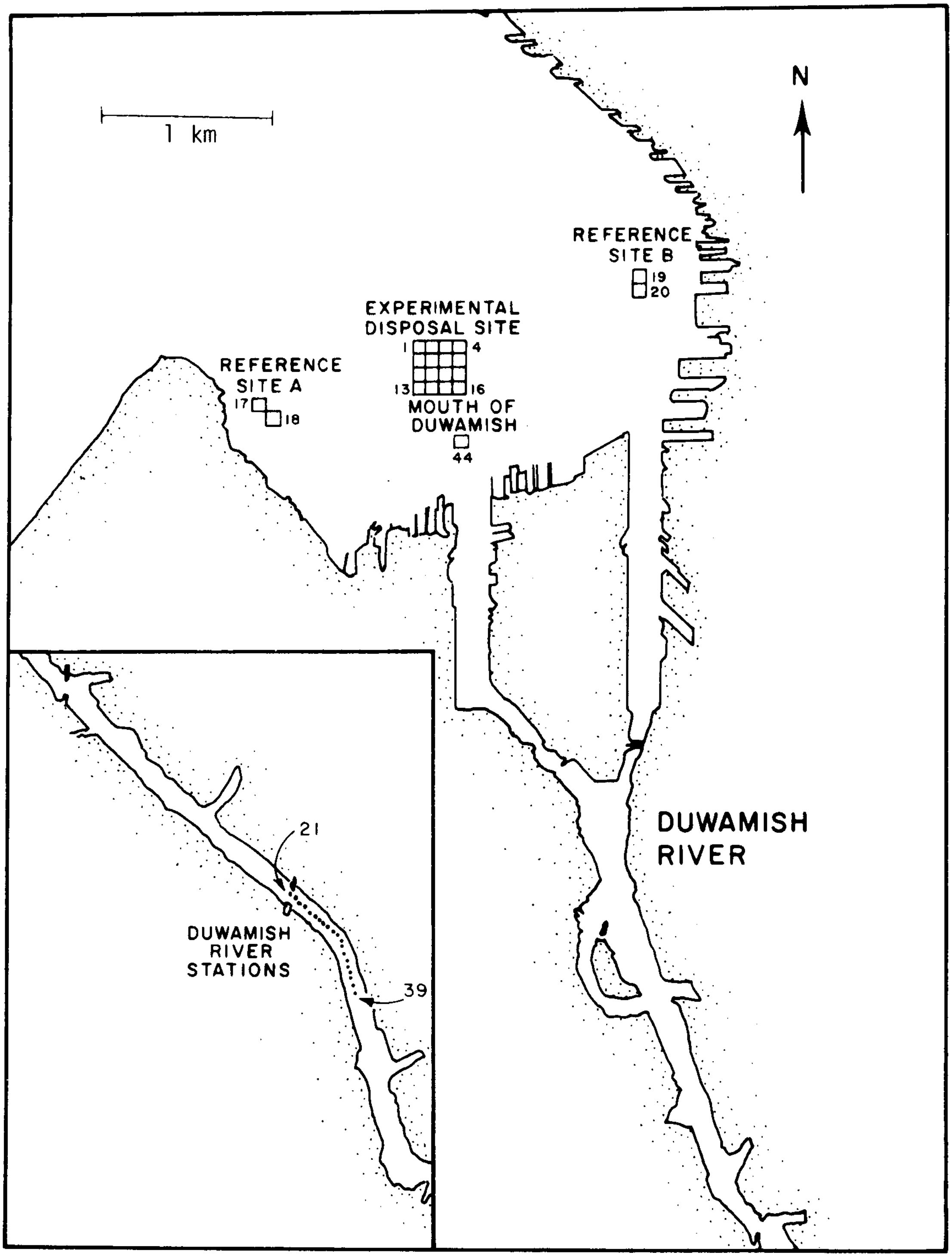

Figure 6. Locations of Duwamish Waterway disposal and reference sites, Puget Sound, Washington

Findings

88. The dredged material was an oily, black, fine organic silt with a plastic texture. It was found to leave the disposal barge in clumps or as a well-defined mass and fall to the bottom with velocities of up to 180 cm/sec. Upon impact with the bottom, a dense surge of material flared outward at about 36 cm/sec and could be detected more than 200 m from the point of impact. Suspended solids returned to ambient conditions within 10 min, but a slight reduction in light transmittance persisted for several hours.

89. The disposal of 114,000 m^3 resulted in numerous mounds 2 to 3 m in height with a maximum radius of approximately 200 m. Subsequent chemical analyses for PCB's at 6 and 9 months after disposal indicated that the mound was gradually spreading. This movement was probably brought about by currents gradually redistributing the dredged material. The spreading was not of sufficient magnitude to move the contaminated sediments beyond the boundaries of the disposal site.

90. The majority of chemical changes in the water column during disposal were relatively minor. There were increases in dissolved manganese, ammonia, phosphorous, and total PCB's. These changes occurred with increases in suspended particulate matter, and, when particulate matter decreased, so did the concentrations of contaminants. The increase in particulate matter and associated chemical variables was of extremely short duration, usually less than 30 minutes. It is of interest that, prior to disposal, the concentration of PCB's in the water column exceeded EPA criteria and these concentrations increased after disposal. It is possible that PCB's were entering Elliott Bay from the Duwamish Waterway and had approached equilibrium saturation values prior to disposal.

91. As would be expected, the chemical changes observed in the sediment are a reflection of the nature of the dredged material. Metals, nutrients, PCB's, and oil and grease were present in the disposal area sediment in greater concentrations after disposal than before disposal.

92. A number of biological variables were investigated during the Duwamish ADFI and a few showed major changes as a result of disposal. The number of species, density, biomass, and diversity of benthic invertebrates at the disposal site were depressed after disposal (when compared to predisposal values). These effects were most apparent for the central stations of the disposal site and least noticeable for the corner stations. Some decreases in the above parameters were also noted at the two reference stations. Nine months after disposal the number of species present at the disposal site was comparable to the numbers present at the two reference sites although the biomass values continued to be depressed for the central and side stations of the disposal site. There was evidence that animals at the edges of the disposal site were stimulated by the dredged material.

93. There was essentially no uptake of metals or PCB's by fish or most invertebrates analyzed during or after the disposal operations. Pre- and postdisposal specimens were collected from the disposal site and locations outside Elliott Bay. In addition, caged animals were held at the disposal site for up to 3 weeks. Mussels held in cages at the disposal site accumulated PCB's to levels above background but the increase was not statistically significant. It should be pointed out, however, that some of the animals collected from Elliott Bay prior to disposal contained substantial amounts of PCB's so a slight uptake may not have been statistically significant.

94. Demersal fish and shellfish (shrimp) seemed to ignore disposal. There were fewer present during disposal at the disposal site than at the east reference site but about the same number as at the west reference site. After disposal the number of fish decreased at the disposal site and at both reference sites; this decrease suggests a seasonal change in these organisms rather than an impact of disposal. The number of shrimp captured at the disposal site after disposal increased compared to those obtained prior to disposal. Shrimp at the reference sites either remained at the same level (east reference site) or increased erratically from month to month (west reference site). Overall, more shrimp were found at the disposal site after disposal than at either

reference site, indicating that the shrimp were attracted to the disposal site.

Summary

95. Disposal of material contaminated with PCB's in Elliott Bay during the Duwamish Waterway ADFI appeared to have a minimal impact. A disposal mound was created which gradually spread during the post-disposal period. There were minor changes in the chemistry of the water column. These appeared to be associated with a transitory increase in suspended particulate material, and, as soon as this material had settled, values for chemical parameters returned to predisposal conditions.

96. There was no significant uptake of PCB's or metals by organisms inhabiting the disposal area or by caged animals which were held in close proximity to the disposed material for up to three weeks. Some changes were noted in the abundance, diversity, and species composition of benthic invertebrates in the disposal area; however, similar changes in the reference area populations make it unlikely that disposal was wholly responsible for the changes.

PART VII: GENERAL DISCUSSION AND OVERVIEW

The Nature of Disposal: A Perspective

97. Although there are a variety of dredging and disposal methods, only two were investigated during the ADFI task. At three of the sites (Ashtabula, Galveston, and Columbia River), a hopper dredge was employed; at the Duwamish site, dredging was accomplished with a clamshell dredge and the material was transported to the disposal site by barge.

98. As the material is released, a number of complex chemical and physical events occur which, prior to the completion of aquatic disposal research in the DMRP, were poorly understood. Indeed, many could only be hypothesized from a theoretical standpoint although some had been demonstrated in laboratory studies.

99. Upon release, the material may fall as a coherent unit that entrains ambient water and descends as a dense mass. Water column interaction is minimal as descent to the bottom occurs in a matter of seconds.

100. If the material does not fall as a cohesive mass, the opportunity exists for it to interact with the water column. If the water depth is sufficient, the dense mass may entrain enough ambient water to create a neutrally buoyant plume. In this case, maximum water column interaction occurs and little bottom impact will occur. Such interaction may result in the formation of a turbid plume and the exchange of chemical substances between the dredged material and the water column. This interchange depends on a number of variable factors such as particle-size distribution, the chemical nature of the sediment and the water column, the presence of currents, and variable water density. These interactions will tend to be minimized if the sediment is of such a nature as to descend as a more or less cohesive unit.

101. The duration of the turbid plume depends on particle size, currents, turbulent mixing, and similar phenomena. A turbid plume composed of very fine particles will persist longer than one made up

of coarser particles. Depth is a factor as, in many instances, bottom waters are more dense than surface waters. A plume which has disappeared from the surface may persist at intermediate depths or near the bottom because of the rate of particle settling.

102. Ultimately, the disposed sediment will reach the bottom. If it is cohesive and falls as a mass it may produce a mound or existing sediment may become displaced with a turbidity current and/or shock wave which travels outward from the impact point.

103. If the material is not cohesive, it will tend to settle gently upon the bottom. A pronounced mound may not be present and a greater area will be covered with a lesser thickness of material. Under most field conditions, a combination of these two types of impact is expected because the dredged material is generally heterogeneous.

104. Following impact, material may remain in place for a long period of time or may undergo relatively rapid erosion and dispersal. Which event (or combination) occurs depends on the nature of the material and bottom currents. The latter, of course, are influenced by depth and the adjacent subaqueous topography. After deposition, whether or not extensive erosion and movement occurs, the dredged material may become mixed and incorporated with the underlying natural sediment.

105. These events are of concern because of the potential effects that they may have upon biological communities. To discuss these in proper perspective, the general nature of the various communities involved and the components of disposal which may impact them is required.

Biological Communities and Potential Impacts: A Perspective

106. The pelagic community would be expected to receive the initial impact of disposal. This community consists of plants and animals which have low mobility and which tend to drift with currents (plankton) as well as organisms with moderate to high mobility (such as fish). If disposal releases contaminants (such as metals, ammonia, pesticides, etc.) pelagic organisms in the plume may suffer adverse impacts. This is of greater significance to planktonic organisms than

to more mobile ones as the latter (if they can detect the toxic material) can leave the area. If the turbid plume is moving, planktonic organisms may be carried with it and suffer a longer exposure time than mobile animals.

107. The pelagic community could also be affected by reductions in dissolved oxygen if the disposed sediment has a high immediate oxygen demand. As with toxicity, this effect in part depends upon concentration-time of exposure relationships as most organisms can withstand a moderate decrease in dissolved oxygen for a relatively long period of time whereas a slightly greater decrease may not be at all tolerable.

108. Bioaccumulation phenomena may also affect pelagic organisms. These consist of the accumulation or concentration of substances from the external environment to higher concentrations within an organism. Although commonly referred to as "food-web magnification," this concept is generally misapplied to aquatic organisms. Unlike terrestrial organisms, which do concentrate substances from lower to higher trophic levels, aquatic organisms tend to bioaccumulate directly from the environment through respiratory and other external body surfaces. Hence, if soluble substances are released into the water column during disposal then they may be incorporated into the body tissues of aquatic organisms. Such substances may include metals, hydrocarbons, pesticides, and similar materials.

109. Because a significant component of the pelagic community consists of plants (phytoplankton), the potential impact of nutrients is of concern. An excess of plant nutrients (especially phosphorus or nitrogen) which removes a limiting factor can bring about a "bloom" or shifts in species dominance. As these plants are planktonic, they will tend to move with the impacted portion of the water column and have a maximum opportunity to react to the presence of excessive nutrients. Phosphorus is generally limiting (in short supply) in freshwater while marine systems are most often limited by nitrogen. In an estuary, where marine and freshwater systems mix, either element may be limiting, and the control may change on an almost daily basis.

110. As with nutrients, turbidity induced by disposal may affect the phytoplankton by decreasing the amount of light that is available to them. Such a decrease, if it persists for a significant period of time or over a large area, can reduce photosynthesis and decrease the productivity of the system because phytoplankton, rather than rooted plants, are the basic primary producers for open-water communities.

111. When the disposed material settles upon the bottom the benthic community may be impacted. This community consists of mobile and nonmobile (sessile) organisms. Among the former are fish and some invertebrates, while the latter consist almost entirely of invertebrates. Sessile organisms may either burrow in the sediment or live primarily at the sediment-water interface. The bottom-dwelling invertebrates are often of direct commercial importance (shrimp, crabs, lobsters, mollusks, etc.), and, even when they are not, they form an extremely important component of the food of sport and commercial fish.

112. Dredged material may physically bury sessile (and possibly some mobile) organisms. Although some may be able to burrow out of the material, most may suffer severe consequences. In addition, if a high degree of turbidity is associated with disposal, the suspended particles may clog gills and feeding apparatus.

113. Depending on the nature of the material, a drastic habitat change can occur. This will be most severe when the disposed sediment is quite different from the existing bottom as, for example, when fine material is placed on coarse sand or vice versa.

114. If toxic substances are present in the disposed material in a biologically active and/or available form, the benthic community may be adversely affected. Such substances include metals, pesticides, oil and grease, PCB's, ammonia, sulfides, and similar elements and compounds. After disposal, these substances may not only remain toxic in the sediment but may also move across the sediment-water interface into the water column.

115. Oxygen-consuming constituents of dredged material, such as organics and other reduced compounds, can pose problems if they result in anoxic conditions or low concentrations of dissolved oxygen.

Because of a variety of chemical interactions, anoxic conditions may increase the damage potential of toxic substances.

116. Nutrients are of little direct concern to the benthic community because, in most disposal situations, there are few, if any, photosynthetic organisms present on or near the bottom. However, if nutrients do escape from the sediments after disposal and enter the water column, the potential exists for an impact upon the pelagic community.

117. Bioaccumulation is of considerable importance in the benthic community because the organisms present are in close proximity to substances which have uptake potential. Unlike pelagic organisms, where exposure time is apt to be of short duration and transient, benthic organisms which burrow in or live upon the surface of the disposed material may undergo lifetime exposure. In addition, many benthic organisms are deposit feeders; that is, they ingest large quantities of sediment. While the sediments are passing through the digestive tract of these organisms, changes in pH, digestive enzymes, and other factors may increase the mobility of some substances (especially metals) and cause them to be absorbed into the tissues. Moreover, as carbon dioxide is given off, a "microzone" of reduced (acidic) pH is often observed. This may enhance uptake of metals and other substances.

118. The impacts described above may be broadly classified as acute (short-term or direct) and chronic (long-term or indirect). Acute effects are usually relatively easy to measure and assess because they take place in a short period of time and are often manifested by the death of organisms or their disappearance from the community. Chronic impacts are generally long-term and may result in decreased growth, reproductive impairment, behavioral abnormalities, and similar phenomena or may result in unexpected changes in organisms or communities other than those expected to be impacted. Consequently, chronic impacts are often quite difficult to evaluate. Although portions of the ADFI task did address chronic (long-term) effects, the majority of the effort was concentrated on acute impacts.

ADFI Impacts

119. In general, disposal of dredged material at the four active ADFI sites and at Eatons Neck demonstrated few significant impacts. This is not surprising, as many of the laboratory studies and other investigations of dredged material disposal under conditions similar to those at the ADFI sites also failed to demonstrate that many of the conceptually anticipated impacts actually occurred.

Pelagic

120. Laboratory studies (Burks and Engler, 1978) indicated that metal release to the water column during disposal is generally small as metal oxides are relatively insoluble. In some cases, hydrous iron oxide scavenges other heavy metals from the water column and reduces their concentrations. Only manganese was observed to be released to the water column to any extent during disposal. This occurred at the Galveston, Ashtabula, and Columbia River sites. The release was transient, however, and a return to ambient conditions usually occurred within minutes to hours. There did not appear to be any effects on the pelagic community as a result of the increase in manganese.

121. Some of the heavy metals appeared to be released to a slight degree at some of the sites. These releases did not follow a consistent pattern and were difficult to interpret. As with manganese, the releases were small and did not persist.

122. The plant nutrients, phosphorus and nitrogen, were released to the water column at most of the ADFI sites. Phosphorus release was quite common but persisted only for minutes to hours. Similar releases have been reported by other investigators (Sly, 1977) in evaluations of dredged material disposal.

123. Nitrogen was released at most of the ADFI sites in the form of ammonium (NH_4^+ -N). This converted to ammonia (NH_3) in the disposal site water at a pH near 8. Although plants (phytoplankton) can use ammonia as a source of nitrogen, primary concern centered on the toxic effects of ammonia. As with phosphorus, the elevated levels of ammonia in the water column were of short duration. As the oxidation of ammonia

to nitrite and nitrate is quite slow and since ammonia is not readily sorbed by particulate matter, the observed return to ambient conditions most probably resulted from dilution. It is thought that the concentration-time exposure relationships (Brannon, 1978) were such that no damage occurred to pelagic organisms. Because of ammonia's potential toxicity, ammonia concentrations should be carefully monitored during disposal (Burks and Engler, 1978).

124. With the exception of PCB's at the Duwamish site, there was no significant release of oil and grease or chlorinated hydrocarbons into the water column. These compounds are quite insoluble in water and readily sorb upon particulate matter, so little release was expected (DiSalvo et al., 1978). In the case of PCB's in Elliott Bay, the EPA criterion for these compounds was exceeded; however, the background concentration in Elliott Bay also exceeded the criterion. Actual increases over the high background values were quite small and did not appear to be of particular biological significance. Suspended solids were elevated to a maximum of 500 to 800 ppm during all of the disposal operations, and there was an accompanying decrease in light transmission. Settling and dispersal were rapid, and the increased turbidity did not persist for more than several hours. Any decrease in light will tend to decrease the photosynthetic activity of phytoplankton. Because of the short period that the increased turbidity persisted and the small area involved, this finding is of little biological significance. Moreover, it was found at most of the ADFI sites that storms, river discharge, and other natural phenomena resulted in turbidity increases of much greater magnitude than those associated with disposal.

125. There were essentially no demonstrable biological effects as a result of water column changes during disposal operations. There were a number of physical and chemical changes which, when they occurred, were of low magnitude, short duration, or both. Only in rare cases were existing criteria exceeded and, even then, these "worst situation" instances were such that concentration-time of exposure considerations (Brannon, 1978) seem to preclude significant biological impacts.

Benthic

126. Most of the significant impacts associated with disposal occurred in the benthic community and primarily affected invertebrate organisms. Demersal finfish were little affected.

127. In general, the disposal sites were in areas which would be considered to be naturally stressed because normal environmental conditions are variable rather than stable. Organisms which occur under such conditions are generally able to better withstand stresses and recover more rapidly than those in stable environments (Oliver et al., 1977). Estuaries are typical of naturally stressed environments because of the high variability of chemical conditions which result from the interactions of fresh and marine waters. Likewise, nearshore (shallow) areas which are subject to wave action and high current velocities present a hostile environment for many organisms. This fact is particularly true when the substrate consists of relatively coarse material (sand) which is constantly being shifted about by waves and currents.

128. It was not possible to establish a cause-and-effect relationship between the observed biological changes and the disposal of dredged material with the possible exception of benthic community changes resulting from direct burial. In general, the abundance and number of species decreased immediately following disposal. It appears that this effect was caused by burial although the influence of chemical factors cannot be completely discounted.

129. Disposal did not appear to have any lasting effect on the sediment chemistry. There were some small changes in dissolved oxygen, metals, and nutrients but these did not appear to be large enough to have a significant impact on the benthic community. There was little evidence of biological uptake of oil and grease (DiSalvo et al., 1978) or heavy metals (Neff et al., 1977) in the laboratory. Likewise, there was virtually no evidence of uptake under field conditions at the ADFI sites.

130. There appeared to be some degree of short-term avoidance of the disposal site by finfish at several of the sites; at another, however, there was evidence of greater numbers of finfish after disposal.

Some question exists as to whether this behavior represented avoidance of the material or was a result of the normal seasonality of fish and the sampling techniques that were used.

131. A wide variety of problems was encountered in evaluating the overall ecological significance of the observed changes in the benthic community. Little is known of the role that many of the organisms play in the entire ecosystem. Although recolonization of the impacted area usually took place within months, the colonizing organisms were often different from those which had been present prior to disposal. This change probably represents successional phenomena, and, if the sites were to be revisited in 2 to 5 years, the original communities may be found to have returned. Alternately, habitat alteration (i.e., a change in the physical nature of the substrate) by disposal may favor the more or less permanent establishment of a community quite different from that which previously existed. Hirsch et al. (1978) documented a number of instances where habitat change and succession have taken place following dredged material disposal.

132. The physical habitat alteration resulting from dredged material disposal may persist for long or short periods of time (Holliday, 1977). This depends on the nature of the material and the effectiveness of natural phenomena in restoring predisposal conditions. At the Duwamish ADFI, dredged material migrated outward from the center of the disposal area; as it did, benthic communities were affected. Again, it was not clear whether the effects were due to physical factors or to some of the chemical constituents of the material (especially PCB's). At other sites, there was a reasonably rapid return to predisposal conditions so far as physical and chemical characteristics of the sediment were concerned, but this was not accompanied by a concurrent return of the benthic community to predisposal conditions.

133. Where changes in the benthic community did occur as a presumed effect of dredged material disposal, there is little that can be said as to whether these changes were adverse. As noted above, many of the communities are poorly understood and the substitution of one species assemblage for another cannot be easily evaluated. In general,

a decrease in biomass or in the number of organisms present would be considered undesirable as would the establishment of a completely different community from that which existed prior to disposal. On the other hand, it appears that many years of disposal at the Eatons Neck ADFI site was, at least in part, responsible for the creation of conditions which have led to increased populations of lobsters. Likewise, open-water disposal in Lake Superior resulted (at least on a short-term basis) in an increase of organisms which are considered to be an important component of the diet of fish species of recreational and commercial importance (Wright, et al., 1975). In the former instance (lobsters), an enhancement seemed to result from the dredged material providing a more suitable substrate for burrowing animals, and, in the latter, the deposition of organic material upon a relatively sterile bottom increased the population of detritus feeders.

Limitations and Application

134. The results of the ADFI studies must be applied carefully. Because there was not active disposal at the Eatons Neck ADFI, the number of actual disposal sites was reduced to four; three of these were in an essentially estuarine environment and the other was in freshwater. All but one involved hopper dredging. However, evaluation of hydraulic dredged material disposal is summarized in reports by Hirsch et al., (1978), Brannon (1978), and Barnard (1978).

135. Much of the overall effort was expended in the pursuit of objectives which proved unattainable. An example is the effort devoted to determining the effects of disposal upon pelagic organisms. An excellent review is presented by Sullivan and Hancock (1977) concerning zooplankton; their conclusions are equally valid for phytoplankton and other members of the pelagic community. In essence, they concluded that temporal and spatial variations from natural causes are so large that an almost infinite sampling effort would be required to obtain results concerning the impact of disposal. Likewise, considerable effort was devoted to the analysis of the stomach contents of fish; because fish

are highly mobile and are opportunistic feeders, little useful information was obtained from these studies.

136. An additional limitation is the lack of concomitant data. Ideally, samples should have been taken simultaneously to evaluate biological communities, chemical parameters, physical parameters, and similar variables. For a number of reasons, (see summary reports) there are no means by which changes in abiotic factors can be related to biological changes.

137. Appropriate statistical methods were not always used to analyze results. In some instances this approach was justified since the data were subjective. This often led to the use of qualifying terms in the evaluation of significance rather than the more rigorous statistical approach of hypothesis acceptance or rejection. Hence, many of the findings should be considered as trends rather than unequivocal conclusions. As the ADFI progressed, it became apparent that the natural variation of many parameters was so great that it would not be possible to take sufficient samples (to reduce variation and error) for the application of conventional statistical methods and techniques.

138. Considerable difficulty was experienced by some of the researchers in determining position location; that is, in the ability to return repeatedly to a given site or station for repetitive sampling. Because disposal often resulted in discrete mounds rather than the dispersal of dredged material over a wide area, there was doubt at times as to whether a given sample was composed of dredged material or natural bottom. At the same time, however, this problem also indicates that it is often quite difficult to distinguish dredged material from natural bottoms.

139. To adequately assess disposal impacts, reference areas which are biologically, chemically, and physically comparable to the area(s) which are subjected to dredged material disposal are needed. The purpose of reference areas is to provide a baseline for natural changes so that these will not be confused with the impacts of dredged material disposal. In some instances, the reference areas were later shown not to be appropriate. In light of the fact that disposal generally took

place in dynamic and environmentally unstable environments, this development is not surprising. It was not uncommon for reference areas to not be comparable with each other. This development, again, is taken as an indication of the great degree of natural variability inherent in an unstable environment. Consequently, when changes were observed in a disposal area, the possibility that they may have occurred as a result of a natural phenomena could not always be eliminated.

140. The ADFI were primarily concerned with impacts within a designated disposal area. This focus is a limitation since impacts not only are expected but also are permitted within a disposal area. To prohibit impacts within a disposal area would be as irrational as prohibiting solid waste disposal within a sanitary landfill site; it is recognized that disposal will have an impact and that such an impact may be deleterious. More concern over impacts outside of the designated disposal area rather than a concentration of effort within the disposal area would have been useful. In essence, a worst-case approach was employed in that it was assumed that, if impacts were minimal within the disposal area, they would almost certainly be less outside of the disposal area. There is no firm reason to suspect that this was not the case, but it should be recognized that a lack of effects outside the disposal area is, in general, assumed and has not been exhaustively demonstrated.

PART VIII: CONCLUSIONS

141. Within the limitations described above, it appears that open-water disposal had a negligible impact upon physical, chemical, and biological variables. However, the impacts observed were usually site-specific, suggesting that the results from the five ADFI sites cannot be universally applied or cited as being conclusive in all situations. In view of the limitations associated with the ADFI task, the lack (apparent absence) of definitive impacts should not be construed to indicate that none existed. It may be a reflection of inadequate study design and great natural variability in the field, or a combination of these and other factors.

142. The release of manganese and ammonia during and after disposal may pose a problem, and there is limited evidence that this conclusion may also apply to iron, mercury, and PCB's. This factor must be addressed by adequate biochemical evaluation prior to dredging and through the use of the appropriate regulations concerning discharge evaluation procedures. Disposal does affect the benthic community, but the ecological significance of the effects is not clear. There is a general lack of understanding concerning the role of most benthic organisms; a shift in community structure, organism abundance, or other parameters is almost impossible to categorize as good, bad, or indifferent. Most of the impacts appeared to be physical in nature (burial or smothering) although it was not possible to completely rule out chemical (toxic) effects.

143. Overall, most impacts seemed to be relatively short-term. The condition of the water column associated with disposal generally returned to ambient within minutes to hours. Chemical changes in the sediment persisted for days to weeks (where they occurred at all), while physical changes often lasted for several months. An exception concerned PCB's; however, PCB's are a rather unusual constituent of dredged sediment, and the fact that they were detectable long after disposal is not an indication that other contaminants behave in a similar manner.

144. Although there appeared to be no long-term impacts, it is essential to recognize that the ADFI would have detected, at best, what could best be described as intermediate-term impacts. "Long-term" generally implies, at a minimum, several generations or several biological years. At Eatons Neck, of course, some years had elapsed from the end of 75 years of disposal to evaluation. This study could possibly be considered as long-term evaluation but, for the other sites, "long-term" could best be applied to the evaluation of impacts within 2 years or less from disposal.

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