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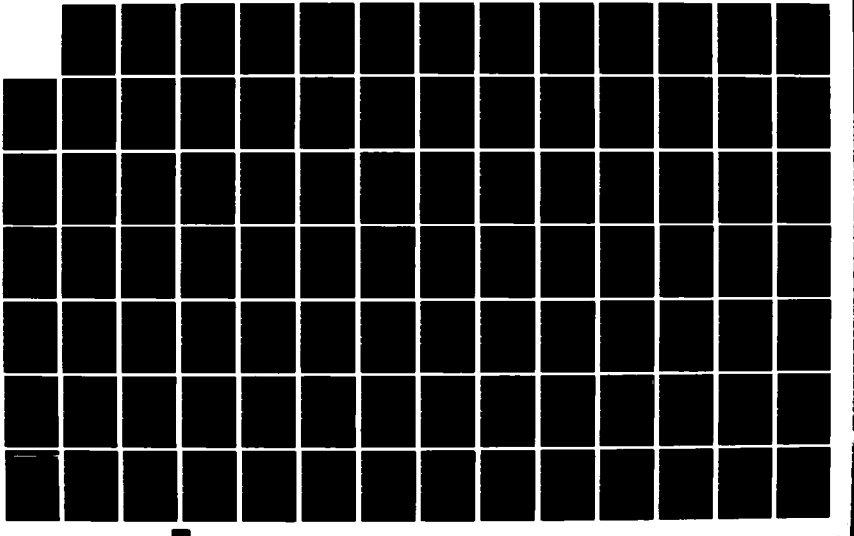

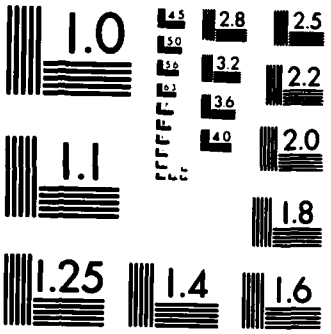

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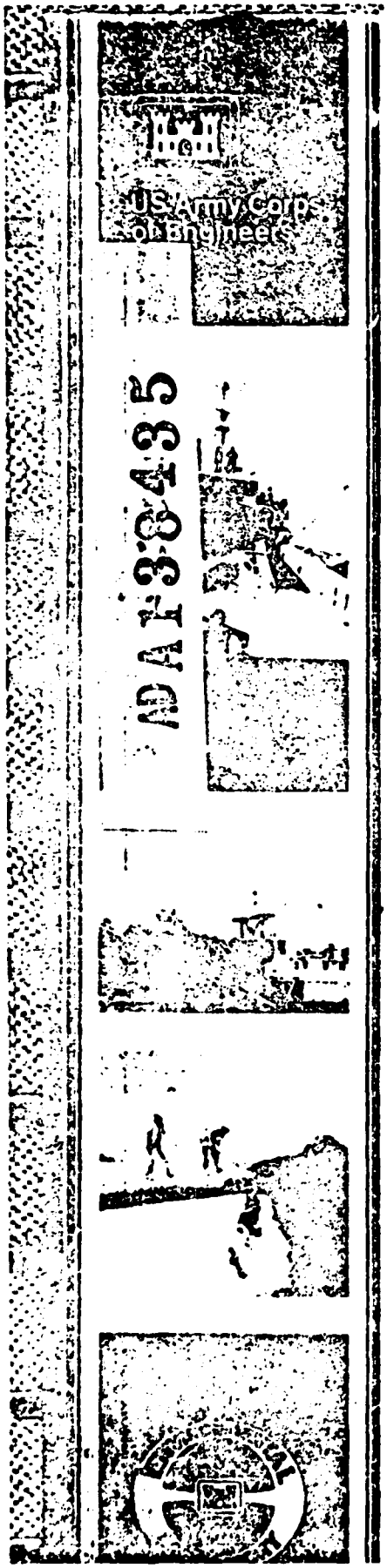

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DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM

TECHNICAL REPORT D-83-3

EVALUATION OF THE 1980 CAPPING OPERATIONS AT THE EXPERIMENTAL MUD DUMP SITE, NEW YORK BIGHT APEX

by

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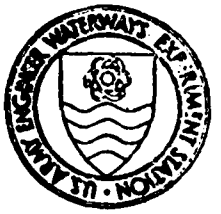

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Dredging Operations Technical Support

Long-Term Effects of Dredging Operations

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

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

Conflicting, multiple uses of the New York Bight impose various stresses on its physical and biological resources. Ocean disposal of waste poses a management problem which is regulated by no fewer than four pieces of Federal legislation and several State and Federal regulatory agencies. Dredged material disposal in the New York Bight is regulated by the U. S. Army Corps of Engineers. Current regulations dictate that contaminated dredged material be given special treatment. The special

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20. ABSTRACT (Continued).

treatment discussed in this report is the capping of contaminated dredged material with clean material to isolate and minimize transport of toxicants from the sediment to marine biota.

The objective of the project was to assess the potential for placing a cap at the experimental Mud Dump site, and to determine reductions in environmental impacts related to capping. Contaminated sediments from dredging projects in the Hudson Estuary, Newark Bay, and contiguous waters were capped first with fine sediments from the Bronx River and Westchester Creek, then with sand from the Ambrose Channel. The capping resulted in a layer of sand about 1 m thick lying atop the contaminated sediment. Physical, chemical, and biological studies were carried out to determine if the capping effort yielded an intact cap showing resistance to erosion, and if the effort reduced loss of organic and inorganic toxicants from the contaminated material to the water column.

It was determined that a cap was successfully placed at the experimental dump site. The cap was still intact and in place after 16 months. Cap erosion was minor; predictions of cap life were in excess of 20 years under normal meteorological conditions. Major storm events, however, are capable of eroding the cap and exposing the contaminated material. During the 16 months of study, the contaminated material decreased in volume by about 4%. Part of the decrease was due to compaction and part was due to loss of solids during dumping and deposition.

Chemical analyses showed that contaminant levels in the sand cap were lower than in the contaminated sediments. Bioaccumulation studies showed that less contaminant uptake occurred at the capping site than at uncapped dredged material sites and at sites in New York Harbor.

The available data show that capping can be performed successfully in the New York Bight and that the thickness and stability of the cap can act to reduce losses of contaminants to the water column.

Capping can serve as an alternative method for control of contaminants in dredged material. Capping can also be integrated with routine disposal operations to effectively cover and isolate contaminated dredged material at the designated dredged material disposal site.

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SUMMARY

Conflicting, multiple uses of the New York Bight impose various stresses on its physical and biological resources. Ocean disposal of waste poses a management problem which is regulated by no fewer than four pieces of Federal Legislation and several State and Federal regulatory agencies. Dredged material disposal in the New York Bight is regulated by the U. S. Army Corps of Engineers. Current regulations dictate that contaminated dredged material be given special treatment. The special treatment discussed in this report is the capping of contaminated dredged material with clean material to isolate and minimize transport of toxicants from the sediment to marine biota.

Regulations to control ocean dumping of wastes first appeared in the mid-19th century. Since that time marine disposal sites have gradually been moved offshore. Most of the research on the environmental impact of ocean dumping has concentrated on the sewage sludge dump site and the dredged material dump site. The greatest mass of wastes disposal in the New York Bight is dredged material (8.3×10^6 cubic meters per year; 1970-1978). Dredged material has formed a substantial mound in the New York Bight that has been studied since about 1968. The greatest environmental impact from dredged material disposal in the New York Bight has been habitat destruction. Little effect has been noted due to contaminant bioaccumulation.

Dredged material comprises about 80% of the solid wastes disposed of at sea each year in the U. S. Most research on impact has concentrated on the effects of particulate matter on marine biota. In 1968, studies were begun to determine the effects of contaminants in dredged material on organisms and ecosystems. Contaminants in dredged material may, under some circumstances, be directly available to biota or capable of leaching from the sediments. Both Japan and the U. S. have carried out studies to determine whether contaminants may be isolated by placement of a cap of clean sediments between contaminated material and the water column. Capping projects have been carried out in Hiroshima

Bay (Japan) and in Long Island Sound (U. S.). The results show that capping can suppress contaminant release and nutrient leaching from bottom sediments. The decision was made, therefore, to carry out a capping project in the New York Bight using sediments from seven dredging projects in the metropolitan New York area.

The objective of the project was to assess the potential for placing a cap at the experimental Mud Dump site and to determine reductions in environmental impacts related to capping. Contaminated sediment from dredging projects in the Hudson Estuary, Newark Bay, and contiguous waters were capped first with fine sediments from the Bronx River and Westchester Creek, then with sand from the Ambrose Channel. The capping resulted in a layer of sand about 1 m thick lying atop the contaminated sediment. Physical, chemical and biological studies were carried out to determine if the capping effort yielded an intact cap showing resistance to erosion, and if the effort reduced loss of organic and inorganic toxicants from the contaminated material to the water column.

It was determined that a cap was successfully placed at the experimental dump site. The cap was still intact and in place after 16 months. Cap erosion was minor; predictions of cap life were in excess of 20 years under normal meteorological conditions. Major storm events, however, are capable of eroding the cap and exposing the contaminated material. During the 16 months of study, the contaminated material decreased in volume by about 4%. Part of the decrease was due to compaction and part was due to loss of solids during dumping and deposition.

Chemical analyses showed that contaminant levels in the sand cap were lower than in the contaminated sediments. Bioaccumulation studies showed that less contaminant uptake occurred at the capping site than at uncapped dredged material sites and at sites in New York Harbor.

The available data show that capping can be performed successfully in the New York Bight and that the thickness and stability of the cap can act to reduce losses of contaminants to the water column.

Capping can serve as an alternative method for control of contaminants in dredged material. Capping can also be integrated with routine

disposal operations to effectively cover and isolate contaminated dredged material at the designated dredged material disposal site.

PREFACE

This report was prepared by the New York University (NYU) Medical Center, New York City, and Valley Ecosystems, Warwick, New York, for the U. S. Army Engineer Waterways Experiment Station (WES) and the U. S. Army Engineer District, New York (NYD), under Intra-Army Order NYD82-135 dated August 1982 and through Contract No. DACW39-82-M-2544. The study was jointly sponsored by the WES and NYD. The WES funding was through the Dredging Operations Technical Support (DOTS) Program funded through the Dredging Division of the Water Resources Support Center. This study will provide input to the Long-Term Effects of Dredging Operations (LEDO) Program work unit on Efficiency of Capping in Reducing Cumulative Effects of Dredged Material Discharge. The LEDO and DOTS Programs are assigned to WES under the management of the Environmental Laboratory (EL) Environmental Effects of Dredging Programs (EEDP). Dredging Division Technical Monitor for DOTS was Mr. David Mathis.

The field research and monitoring reports [Sediment Budget Investigations (Tavolaro 1982), Sediment Cap Stability (Freeland et al. 1982), Chemical Signature Study (NYUMC 1982), and Mussel Bioaccumulation Study (Koepp et al. 1982)] that form the basis for this evaluation are contained in this report in microfiche and are listed as Appendices A through D, respectively.

The report was prepared by Dr. Joseph M. O'Connor of the NYU and Ms. Susan G. O'Connor of Valley Ecosystems. The contract was managed by Dr. Robert M. Engler, Chief, Contaminant Mobility and Regulatory Criteria Group (WES), and Mr. James Mansky, Chief, Water Quality Section (NYD). The work was conducted under the general supervision of Mr. Donald L. Robey, Chief, WES Ecosystem Research and Simulation Division, and Dr. J. Harrison, Chief, EL. Mr. Charles C. Calhoun, Jr., was the Manager, EEDP.

Commander and Director of WES during the preparation of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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* Appendices A-D were prepared on microfiche and are enclosed in an envelope attached to the back cover of this report.

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

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

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
miles (U. S. nautical)	1.852	kilometers
miles (U. S. statute)	1.609347	kilometers
tons (short)	907.1847	kilograms

EVALUATION OF THE 1980 CAPPING OPERATIONS AT THE EXPERIMENTAL MUD DUMP SITE, NEW YORK BIGHT APEX

PART I: INTRODUCTION

1. The New York Bight is a prime example of conflicting, multiple uses for a single water body. Simultaneously, it supports commercial and recreational fisheries, boating, bathing and transportation, while receiving directly or indirectly the domestic and industrial wastes from a population of about 20 million people. Even prior to the environmental activism of the 1960's and 1970's, waste discharges in the metropolitan New York region were in conflict with human use patterns. A newspaper article from 1878 mentioned New York's waters as "having become impregnated by...kerosene refining factories..." and stated that "...the striped bass...have become so permeated...as to be unfit for the table." Such pollution, in conjunction with much flotsam and jetsam, instigated passage of the Rivers and Harbors Acts of 1890 and 1899. Since that time, dump sites for waste materials from New York City and surrounding towns have gradually been moved offshore, away from the city, to their present locations in the Apex of the New York Bight. Progressive relocation of the dredged material dump site is depicted in Figure 1 (Gross, 1976).

2. Ocean disposal of waste materials has received much attention from environmentalists and Federal regulatory agencies. The principal pieces of legislation governing waste disposal in the oceans are the Marine Protection, Research, and Sanctuaries Act (1972; amended most importantly in 1976) and the Federal Water Pollution Control Act of 1972, as amended in 1977. The National Advisory Committee on Oceans and Atmosphere (NACOA) pointed out the complex interactions of these and other acts (NACOA, 1981; Figure 2) while describing the jurisdiction in Congress for their administration. The National Ocean Pollution Planning Act of 1978 was passed to provide a "comprehensive, coordinated and effective Federal program for ocean pollution research, development and monitoring" (National Oceanic and Atmospheric Administration (NOAA), 1981). Whether the act will meet its rather lofty expectations remains to be seen.

3. Specific environmental concern over dredged material disposal

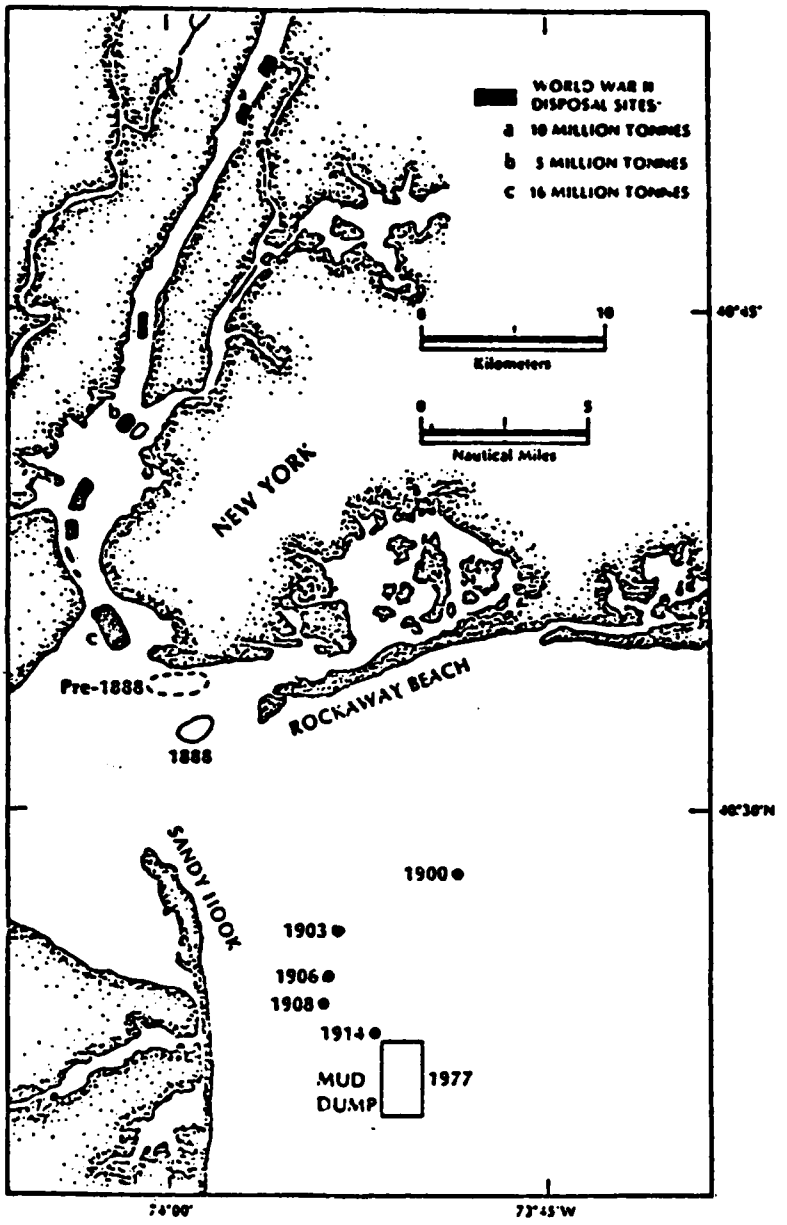
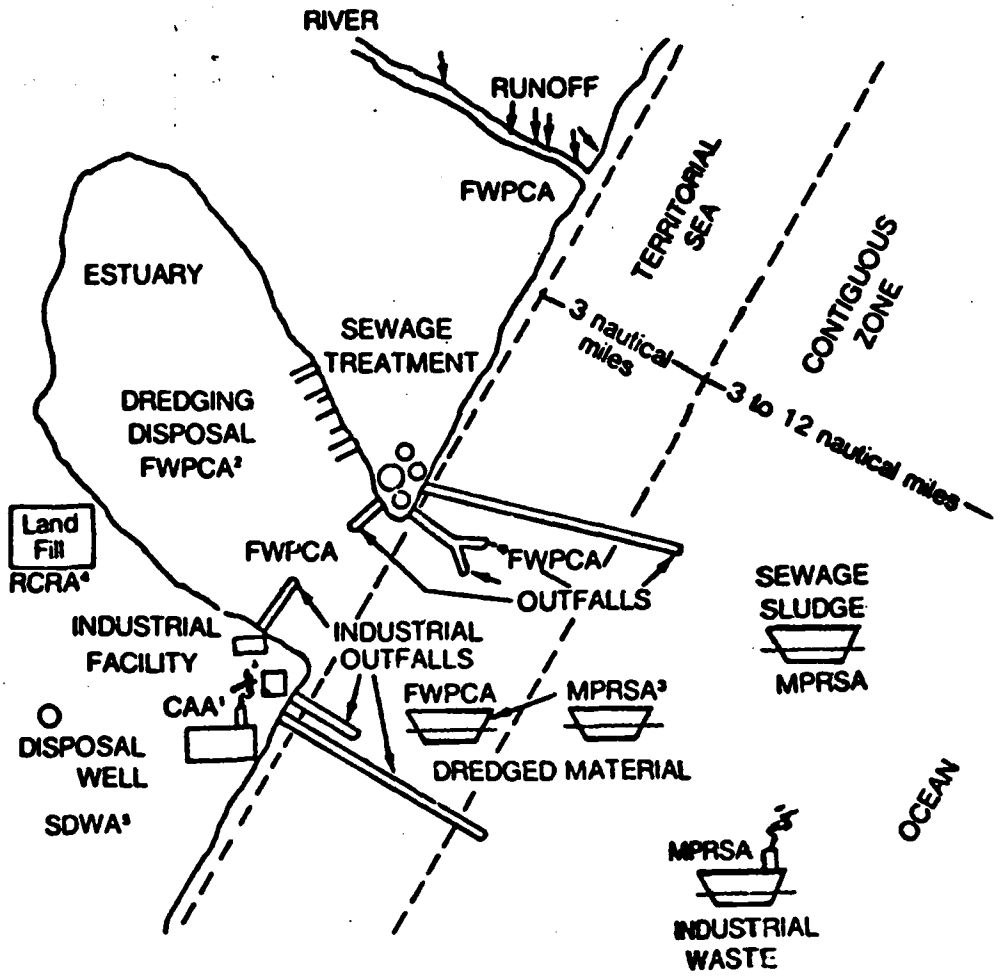


Figure 1. Summary of locations of the dredged material dump site from pre-1888 to the present. Adapted from Gross (1976)



1 Clean Air Act (CAA)
2 Federal Water Pollution Control Act (FWPCA)
3 Marine Protection, Research, and Sanctuaries Act (MPPSA)
4 Resource Conservation and Recovery Act (RCRA)
5 Safe Drinking Water Act (SDWA)

Figure 2. Jurisdictional boundaries of the key environmental laws mentioned in the text (NACOA, 1981)
(A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 7.

has over the years followed its own course, deriving from the Fish and Wildlife Coordination Act (1958), the National Environmental Policy Act (1969), and Title II of MPRSA (1972). These acts combine to give the U.S. Army Corps of Engineers (CE) permit refusal authority, a mandate to study dredged material disposal problems, and the responsibility to establish, in consultation with the Environmental Protection Agency (EPA), criteria for evaluating dredged material prior to disposal into ocean waters (Section 103, MPRSA). Most of these activities are carried out at the CE District level. A manual for evaluating the toxicity of dredged material has been jointly produced by the CE and the EPA (EPA/CE, 1977). Research related to the management of dredged material has, for the most part, been carried out by the CE Waterways Experiment Station under such programs as the Dredged Material Research Program (DMRP) and others (Herner & Co., 1980; Saucier et al., 1980). Such programs have greatly expanded understanding of the chemical, physical, and biological effects of dredged material disposal.

4. Nowhere has the disposal of wastes such as sewage sludge and dredged material received more public and scientific attention than in the New York metropolitan region and New York Bight (NACOA, 1981; Schubel et al., 1979). In 1948, Westman and Bidwell raised the question f whether ocean disposal of wastes was the cause of declines in fish harvest from the New York Bight region. At about the same time, Ayers (1951) and Ketchum and co-workers (Ketchum et al., 1951; Ketchum and Keen, 1955) initiated research in the Bight, and Redfield and Walford (1951) reported for the National Academy of Sciences on disposal of chemical wastes in the ocean. They concluded that the chemical waste disposal practices in effect at that time would not be expected to affect the New York Bight fisheries, but that close monitoring was necessary. Unfortunately, such monitoring was not initiated until 1968 (Gross, 1970; Pearce et al., 1973).

5. Since 1975 large amounts of chemical, biological, and physical data have been produced describing the New York Bight ecosystem and the possible effects of ocean dumping of dredged material, sewage sludge, and various chemical wastes. Appropriate reviews may be found in Gross

(1976). O'Connor and Stanford (1979), and Goldberg (1979) and updated collections of papers and data are now available (Mayer, 1982; Myers, 1982). A comprehensive bibliography of New York Bight publications is available (NOAA, 1974). A severe shortcoming is apparent in the available data; predictions and evaluations of environmental impact due to ocean dumping in the Bight have relied almost exclusively on estimates of contaminant mass loads to the system, and on interpretation by application of laboratory-derived bioconcentration factors (BCF). As more data are obtained, it is becoming clear that the major environmental impacts from ocean dumping are physical effects, i.e., habitat destruction and habitat alteration (NACOA, 1981; Boesch, 1982,

6. The presumption that organisms in nature will accumulate contaminants according to established "principles" of bioconcentration (Branson et al., 1975) appears to be inappropriate when applied to problems of ocean dumping. The appropriate research to determine whether and how contaminants move from ocean-discharged wastes to the biota was suggested as early as 1975 (Fulk et al., 1975; Schubel, 1977), but has only recently been undertaken for the Bight region (Rubinstein et al., in press).

7. While regulatory efforts to control ocean waste disposal intensify (see, e.g., EPA, 1981), it must be recognized that the oceans will continue to play a major role in the waste disposal strategy of the U.S. (NOAA, 1981; NACOA, 1981). Beginning with the DMRP there has developed a strong base of data and experience applicable to the question of how best to manage ocean disposal of at least one major source of wastes - dredged material.

8. The primary objective of this report is to provide an evaluation of a "natural" experiment carried out in the New York Bight Apex beginning in 1980. The experiment (Suszkowzski, 1981) consisted of an attempt to cover and isolate contaminated dredged material with clean capping material and thereby reduce possible environmental impact. Fine sediments from several locations in the Port of New York and New Jersey were precision dumped in the southeast quadrant of the Mud Dump site and

covered with fine-grained material from the Bronx River and Westchester Creek and with sandy material primarily from the main approach channels to New York Harbor. Justification for the project was based upon the success of capping efforts at Long Island Sound disposal sites (see paragraph 43 et seq) and the effectiveness of sand capping in isolating contaminated sediments in a variety of freshwater and marine environments in Japan (Hosokawa and Horie, 1981).

9. The New York Bight, however, is a high-energy environment compared to Long Island Sound or Hiroshima Bay. Therefore, several studies were undertaken to evaluate the capping experiment. These consisted of chemical analysis of dredged material (New York University Medical Center (NYUMC), 1982), an estimate of the sediment budget at the experimental dump site (Tavolaro, 1982), a study of contaminant bioaccumulation at the capping site (N.J. Marine Sciences Consortium (NJMSC), 1982), detailed mapping of the capped site (CE, 1982), and a study of hydrodynamics at the site (Freeland et al., 1982).

10. Together these data showed that: 1) capping can be carried out at an ocean disposal site; and 2) the cap can persist for at least two years. The final efficacy of capping can be evaluated only after detailed chemical studies and further evaluation of the effects of capping on contaminant bioaccumulation. However, capping seems to be effective and should be considered as an alternative management scheme for isolating contaminated sediments from direct contact with ocean waters.

PART II: DISPOSAL ACTIVITIES AND RELATED OCEANOGRAPHIC RESEARCH IN THE NEW YORK BIGHT APEX

11. National legislation was in place as early as 1890 to regulate waste disposal in rivers and harbors. This effectively resulted in the movement of disposal operations to ocean waters. Gradually, several sites evolved as most appropriate for the disposal of a variety of wastes, including acid-iron wastes, sewage sludge, cellar dirt and construction debris, derelict vessels, and dredged material. In the Bight region, these sites centered about the Christiaensen Basin (Figure 1). It is impractical to attempt evaluation of dredged material disposal sites without at least some familiarity with the nature and magnitude of the wastes dumped at neighboring locations.

12. Less than 70 years after Hudson's first visit (1609) to the North River (presently known as the Hudson River), governmental regulations aimed at controlling the disposal of waste materials into New York waters began to appear (Boyle, 1969; Gross, 1974; Gross et al., 1976). Regulations put in place about the middle of the 19th Century to control dumping in New York Harbor waters began the process, still apparent today, of gradually displacing waste disposal sites seaward. Gross (1974, 1976) and Gross et al. (1976) described the history of dredged material dumping in the New York region, including the approximate locations of dump sites from the earliest settlement of New York (1625) through 1977.

13. The other major mass of material disposed of in the New York region consists of sewage sludge from treatment plants in the metropolitan New York - New Jersey area. As with dredged material, "acceptable" (i.e., legislated) locations for the disposal of sewage effluent and sewage sludge have gradually moved seaward from their initial sites in the harbor region.

14. Surprisingly little site-specific research has been carried out at the dredged material and sewage sludge disposal areas in the New York Bight Apex. Prior to the initiation of the MESA-New York Bight

Project, only the National Marine Fisheries Lab (NMFS) at Sandy Hook (see NMFS, 1972) had sampled the water, sediments, and organisms of the Bight region at or near the dump sites. Thus, 20 years or more had passed since the time that Westman and Bidwell (1946) questioned the compatibility of waste dumping and sustained fisheries production in the Bight, and since Redfield and Walford's (1951) recommendation that the status of fisheries and fish habitats in and around the chemical (acid-waste) dump site be monitored.

15. Throughout the evolution of the data base for the different ocean disposal sites in the New York Bight, minimum attention has been given the sites for cellar dirt, construction debris, and acid-iron waste disposal. Discharges of construction debris and acid-iron wastes seem to be of minor import as potential sources of contamination or ecological impact in the Bight (Arnold and Royce, 1950; Redfield and Walford, 1951; Vaccaro et al., 1972; NOAA, 1975; Gross, 1976; Mueller et al., 1976, 1982). In addition, recent economic trends have caused reductions in quantities of construction debris for dumping (Mueller et al., 1982), and the use of the acid waste dump site has been gradually restricted; therefore, estimated annual quantities dumped have declined markedly from 1974 to 1980 (Mueller et al., 1976; EPA, 1982).

16. Most of the data relevant to ocean dumping in the New York Bight, therefore, come from direct or indirect evaluation of the dredged material dump site and the sewage sludge dump site. The dredged material dump site, which has been in use since the turn of the century, was surveyed by the Coast and Geodetic Survey in 1936 (Uchupi, 1970; Freeland et al., 1976; Dayal et al., 1981), and again in 1973, 1978, 1980, and 1981 (Freeland and Merrill, 1977; Dayal et al., 1981; CE, 1982). Dayal et al. (1981) provided a comprehensive record of sediment accretion on the Mud Dump from 1936 to 1978 and a discussion of forces which control the buildup of sediments at the site (Figure 3). A detailed examination of the sediment budget at the experimental Mud Dump site was performed by Tavolaro (1982) and is discussed later in this report.

17. The greatest mass of materials deposited in the Bight Apex is

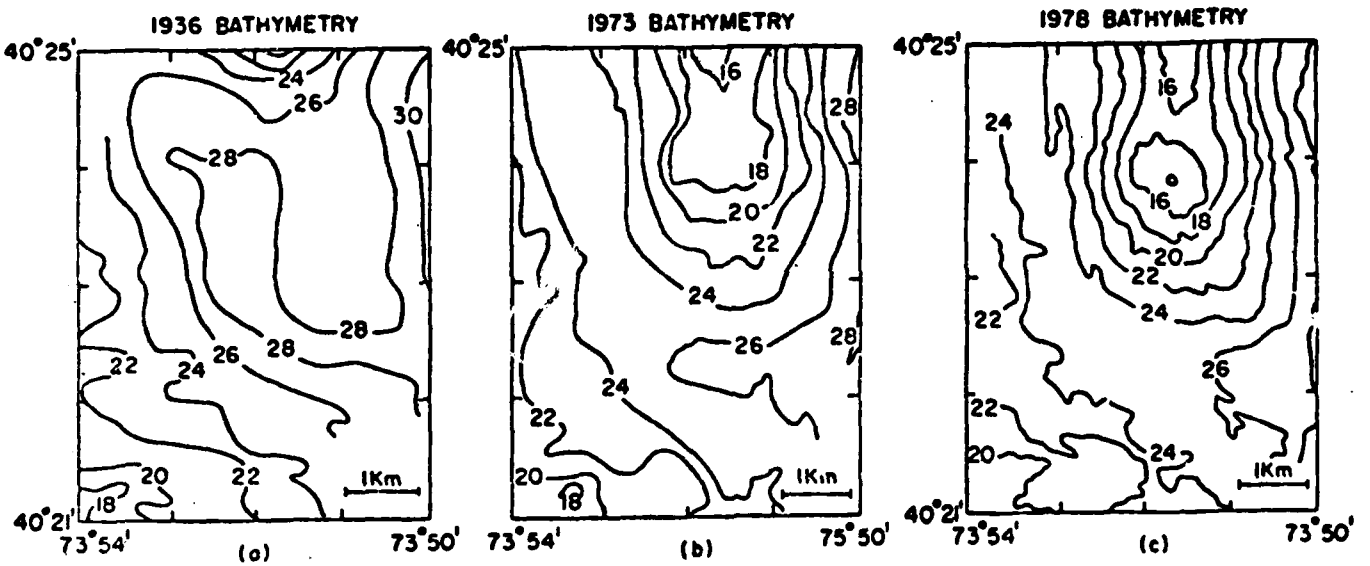


Figure 3. Results of bathymetric surveys conducted at the New York Bight Mud Dump (Dayal et al., 1981). Contours are in meters

dredged material (Gross, 1970, 1974). Most assessments of the Hudson-Raritan Estuary or the New York Bight region provide estimates of annual volume or mass of dredged material dumped in the Bight Apex (NMFS, 1972; Gross, 1970)(Table 1). Assuming the most recent summary of dredged material disposal to be the most accurate, we refer the reader to the most recent EPA environmental impact statement (1982) and to Dayal et al. (1981) for a thorough description of New York Bight dredged material dumping activities.

18. For the period 1970 to 1978, the average annual volume of dredged material dumped in the Bight was 8.3×10^6 cubic meters (10.6×10^6 cubic yards; Conner et al., 1979) of which 64% was from Federal projects and the remainder from non-federal projects. Conner et al. (1979) provided data on both the amounts and particle size distributions of dredged material from major Federal dredging projects between 1966 and 1978. Chemical data (bulk sediment analysis) for disposed dredged material are given by Conner et al. (1979) and NYUMC (1982).

19. The dredged material dump site represents a unique condition in the Bight Apex, that of raised relief on an otherwise flat plain of sandy and gravelly substrate (Freeland et al., 1976; Freeland and Swift, 1978). Changes in relief due to dredged material disposal have most recently been documented by Dayal et al. (1981), Freeland et al. (1982), and Tavolaro (1982).

20. The estimated quantity of material present at the Mud Dump represents some 80 to 95% of the material calculated to have been dumped (Dayal et al., 1981; Tavolaro, 1982). Tavolaro (1982) estimated that most of the losses which occurred derived from the dredging activity itself, and that the "short" estimates of dredged material volume at the Mud Dump result from several factors which affect accurate estimates of sediment volume between dredging site, barge loading, dumping, and settling. These factors (cohesiveness, bulk density, particle size, water content, etc.) and errors in their estimation have been discussed in detail by Gordon and co-workers (Gordon, 1974; Bokuniewicz and Gordon, 1980).

21. Pearce et al. (1981) showed that the mound at the Mud Dump

Table 1. Summary of quantities of dredged material released at the Mud Dump, 1966-1978. Values given are in thousands of cubic yards.

Year	Federal Projects*	Non-Federal Projects†	Section 103 Permits**	Totals
1966	4,165.5	-	-	-
1967	4,514.5	-	-	-
1968	4,931.6	-	-	-
1969	5,778.8	-	-	-
1970	4,053.4	1,663.5	-	5,716.9
1971	10,679.8	6,508.8	-	17,188.6
1972	13,070.0	2,990.4	-	16,060.4
1973	9,243.5	3,454.9	-	12,698.4
1974	6,119.1	3,706.5	-	9,825.6
1975	8,108.7	3,522.8	-	11,631.5
1976	7,617.2	1,673.1	(565.4)**	9,290.3
1977	4,378.8	-	995.5	5,374.3
1978	6,914.0	-	2,246.6	9,160.6
Totals	89,574.9	23,520.0	3,242.1	96,946.6
Averages	6,890.4	3,360.0		10,771.8††

* Conner et al. (1979).

† Conner et al. (1979, Table A-2).

** From CE Annual Report to Congress on administration of ocean dumping activities. 1976 value not included; believed to be low. Conner et al. (1979) estimate substituted in calculations.

†† For 1970-1978 only.

serves to attract marine organisms. Since the mound is made of sediments shown to contain a variety of organic and metallic contaminants (Mueller et al., 1976; Conner et al., 1979; O'Connor et al., 1982), it may serve as a source of contaminants to the biota (O'Connor et al., 1982). An understanding of the interactions between sediment-associated contaminants and the marine biota, therefore, is essential.

22. Chemical studies at the Mud Dump have been confined mostly to the period from 1968 to present. The greatest quantities of data have been accumulated for metals (see, e.g., Greig et al., 1977; Segar and Cantillo, 1976; Wenzloff et al., 1979; Dayal et al., 1981; Simpson and Payne, unpublished; review in O'Connor and Rachlin, 1982). At the present time, however, concern about environmental impact is strongly focused on organic contaminants, especially petroleum hydrocarbons and organochlorines, in ocean-disposed dredged material. While historical data on these compounds at the dumpsite are sparse (NMFS, 1972; Hatcher and Keister, 1976), the more recent literature provides an improved perspective. Survey data from West and Hatcher (1980), Energy Resources Co. (ERCO) (1980), Pequegnat et al. (1980), and MacLeod et al. (1981) (see also Bopp et al., 1981; O'Connor et al., 1982) generally demonstrate that sediments at the Mud Dump contain measurable levels of polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs), and persistent chlorinated pesticides.

23. Dredged material disposed at the Mud Dump may affect marine organisms in two ways: first, by exposing them to a range of particle sizes unlikely to exist at non-impacted areas; and, second, by providing a possible source of metallic and organic contaminants to organisms inhabiting the Bight Apex (O'Connor et al., 1982). Impact assessments performed to date have been based upon the assumption that the topographic low spot chosen for dredged material dumping in 1914 was similar, in all respects, to the surrounding seabed. Recent data from vibracore studies (Dayal et al., 1981) suggest this to be a reasonable assumption. Since some of the vibracores taken for the Dayal study penetrated the underlying natural seabed, it is tempting to suggest that the chemical data from such horizons represent conditions on the Apex floor prior to any dumping.

24. Pearce et al. (1973, 1981) demonstrated a reduction in diversity of benthic fauna at the mud disposal site in the Bight Apex. Studies of metals concentrations in shellfish from the middle Atlantic Bight and the New York Bight Apex suggest that metals associated with dredged material disposal and sewage sludge disposal result in higher body burdens in organisms from the Bight region (Greig et al., 1977; Wentzloff et al., 1979).

25. The accumulation of organic contaminants in organisms from the dump site has been assessed in both field and laboratory studies. O'Brien and Gere Engineers, Inc. (1979) and Pequegnat et al. (1980) evaluated bioaccumulation of PCBs and other organics with "natural" experiments. The dredged material dump site was one of several sites tested for accumulation. In each case, bioaccumulation of contaminants was observed at the dump site, but was seen to be less than that occurring within the Lower Bay complex (Gravesend Bay, Brooklyn). Both the O'Brien and Gere (1979) study and the results of Pequegnat et al. (1980) showed that the Mud Dump was no more a source of contaminants to the biota than sediments from other portions of the Bight, or sediments from inside the New York Harbor system.

26. Bioaccumulation information from such studies, however, is perhaps best viewed as input rather than as a conclusion. As pointed out in a variety of reports and publications (Wolfe et al., 1982; Mayer, 1982; O'Connor and Rachlin, 1982), the accumulation of a compound per se is neither conclusive nor symptomatic of effects. There exists among both organisms and ecosystems the potential to assimilate measurable levels of contaminants without showing symptoms of toxicity. True cause-effect relationships between contaminants and organisms are difficult to measure in natural environments.

27. Given the vast quantities of contaminants disposed into the New York Bight Apex each year (Mueller et al., 1976, 1982; O'Connor et al., 1982), it is interesting to note the rather low levels to which most marine biota have accumulated toxicants such as Cd, Hg, PCB, and PAH. Much ongoing research is directed toward determining the precise relationships between contamination of sediments, the availability of

contaminants to marine organisms, and the toxicity of the accumulated toxicant.

28. The question of bioavailability has many aspects, including chemistry, physics, and hydrology, all of which may affect the extent to which organisms are functionally exposed to contaminants in sediments. The alternatives available for dredged material disposal must be weighed primarily against the criterion of bioavailability. Using this criterion, couched sometimes in biological terms and sometimes in purely physical terms, decisions must be made regarding where and how to dispose of dredged material most effectively. The remaining chapters of this report provide an overview of various disposal alternatives, including capping, and their relationship to questions of contaminant bioavailability. A detailed discussion of the results of the sand capping operation at the New York Bight Mud Dump is also provided.

PART III: DREDGED MATERIAL MANAGEMENT PRACTICES IN THE COASTAL ZONE

29. Sherk (1971) estimated that dredged material comprised roughly 80% of the solid wastes disposed at sea each year in the U.S. This total, amounting to 22 x 10^6 metric tons (dry), represents a significant problem for coastal cities, such as New York, where sufficient space for upland disposal is not available, and for which disposal in rivers or harbors is an impractical and inefficient solution (Saila et al., 1968; Cronin, 1970; Schubel, 1977; Schubel et al., 1979). The sheer magnitude of the dredged material problem in the New York region is described by Gross (1969, 1974) and EPA (1982); these studies noted that ocean disposal of solid waste from New York, mostly dredged material, was the single largest source of sediment entering the western North Atlantic.

Environmental Impact of Dredged Material Disposal

30. The earliest studies of environmental impact from dredged material disposal (Lunz, 1938, 1942; Wilson, 1950; Ingle, 1952; Ingle et al., 1955) focused on mortality among fish, crustaceans, and oysters exposed in and near disposal operations. In general, these studies concluded that the primary impact of dredged material disposal was physical (see also Chesapeake Biological Laboratory, 1970; Sherk, 1971; Rogers in First, 1972; O'Connor et al., 1977). While organisms covered by disposed sand, silt, or clay were eliminated, the rapid dilution of suspended solids released during disposal operations resulted in very little mortalilty or other effects beyond the immediate impact zone (see, e.g., Pfitzenmyer, 1970; Ritchie, 1970; Macklin, 1961). However, Sherk (1971) noted that suspended sediments could cause effects some distance from the site of disposal if density flows were to form. A "density flow" is a condition in which silt and clay particles can mutually inhibit settling if concentrations exceed 10,000 mg/L. Density flows can move freely under the influence of tide and currents (Masch and Espey, 1967) and may affect organisms up to several kilometers from a disposal site.

31. To our knowledge, Saila et al. (1968) made the first statement

that chemical contaminant effects may be associated with disposal of dredged material. Servizi et al. (1969) reached a similar conclusion after studying the biological impact of contaminated sediments from Bellingham Harbor, Washington. Sherk (1971) suggested that a "satisfactory" investigation of dredged material disposal must include biological, mechanical (physical), and chemical (sorptive) studies of particles.

32. The results of studies on the effects of dredged material disposal from the early work of Lunz (1938) to the present may be summarized as follows: a) disposed dredged material kills most organisms which are buried at a given dump site; b) suspended solids from disposal operations are unlikely to cause significant ecological impact outside the dump site; c) suspended and deposited solids from disposal operations are potential sources for toxicants; and d) toxicants on particles (both in suspension and deposited) may harm marine organisms directly or indirectly.

33. It seems apparent that direct environmental impact from dredged material disposal is likely to be small, especially if disposal is restricted to a single site. If some containment mechanism can be found to mitigate or remove the potential hazard from contaminants sorbed to dredged sediments, ocean disposal of dredged material might be reduced to a problem of minor, if not negligible, magnitude.

Management of Contaminants in Dredged Material

34. Until recently, the bioavailability of contaminants in dredged material was either ignored or was addressed by locating disposal areas further and further from population centers. Little effort was made to reduce the availability of contaminants to the aquatic food chain. Considerations of alternatives to unconfined open-ocean disposal stemmed from the heightened environmental consciousness which came with the promulgation of environmental legislation such as the Marine Protection, Research, and Sanctuaries Act of 1972, as well as the exponentially increasing costs associated with transportation of dredged material to offshore locations.

Present Practices and Alternatives

35. At present, unconfined ocean disposal of dredged material is allowed in designated New York Bight areas, provided that the material has met certain criteria. These include bioassay tests to estimate sediment toxicity and bioaccumulation of selected contaminants (Cd, Hg, PCB, chlorinated pesticides), and evaluation according to a "matrix" predictive of food chain "biomagnification" effects (Engler et al., 1981; Pierce et al., 1981b). These evaluations are also conducted to determine compliance with the London Ocean Dumping Convention which prohibits ocean dumping of Hg, Cd, organohalogens, and petroleum hydrocarbons under certain conditions (Engler, 1980; Pequegnat, 1982). Suggested alternatives to unconfined ocean disposal were considered in a workshop sponsored by the U.S. Army Corps of Engineers (Table 2). Descriptions and practical evaluations of these alternatives appear in Conner et al. (1979). The list of alternatives (Table 2) is extensive, but few data are available on the technical feasibility and environmental success of any of the options. Data are essentially unavailable for some alternatives and they are not considered practicable at this time (e.g., deep ocean disposal, containerized ocean disposal, no dredging, offshore island disposal). The U.S. Army (CE, 1982) specifically addressed environmental impacts associated with current and alternative practices for disposal of dredged material. The Corps concluded, as did the EPA (1982), that continued use of the Mud Dump is preferred to any other disposal alternative, but noted that mitigation of potential impact from contaminated sediments disposed of at the site may be achieved through "special care" (viz., capping) to restrict contaminant bioavailability. Data from the evaluation of present practices at unconfined dumping sites can be compared to data from the evaluation of capped ocean disposal sites to assess the efficacy of capping as an environmentally acceptable method for ocean disposal of dredged material.

Table 2. Alternatives to Present Disposal Practices Currently Under Consideration for the New York District.

MAJOR ALTERNATIVE	ACTIONS (LOCATIONS) UNDER CONSIDERATION
Site Relocation	1. Relocate to Christiaensen Basin 2. Relocate to 106-mile Site 3. Relocate to "Outer Bight" (Northern Area/Southern Area) 4. River/Harbor Disposal (Subaqueous Borrow Pits) 5. Relocate to Long Island Sound
Confined Ocean Dumping	1. Capping for Confinement/Isolation
Upland Disposal	1. Isolate in "Standard" Landfill 2. Construct Containment Facilities (Cofferdams, Diked Containment) 3. Use in Beach Restoration/Beach Nourishment 4. Use as Sanitary Landfill Cover
Miscellaneous	1. Use for the "Creation" of Wetlands 2. Use for Creation of Artificial Reefs (Coastal Zone/Shelf Area)

Dredged Material Capping

36. Capping is considered to be a mitigating measure rather than an alternative to the present practice of dumping at the Mud Dump. It is also a means of complying with the London Ocean Dumping Convention constraints by "rapidly rendering harmless" the unacceptable dredged material through chemical, physical, and biological processes of the ocean (Engler, 1980; Pequegnat, 1982). In simple terms, capping is the burial of "contaminated" material with stable layer(s) of clean dredged material. Clean capping material is material which, at a minimum, meets the present criteria of the bioaccumulation bioassay and passes the "matrix" evaluation. The cap sediment should completely cover the underlying material and prevent its movement; at the same time, the cap should isolate contaminants from the water column and benthic organisms.

37. Capping is not being considered for use on a wide scale since impacts associated with most disposed dredged material have not been demonstrated to be significant enough to warrant modifications to existing methods (CE, 1982; EPA, 1982). Capping is being considered for use in the disposal of: 1) materials which contain substances capable of bioaccumulating or concentrating in exposed organisms; and 2) materials containing toxic substances which would otherwise be prohibited from ocean disposal (Engler, 1980; Pequegnat, 1982).

38. The extent to which contaminants are contained by the capping process is related to: 1) the character of the material dumped; 2) the time lag between deposition of the contaminated material and the capping material; and 3) the permeability of the cap to contaminants.

39. Capping contaminated dredged material with less contaminated material is an extension of the concept of "contaminant inactivation", originally developed for use when dredging was not feasible to remove contaminated sediments. Such situations generally occur in lakes or embayments suffering eutrophication from sewage or industrial discharges. In freshwater lakes, prevention of phosphorus release from the sediments (as well as removal of phosphorus from the water column) may be achieved by application of aluminum sulfate (alum) to the lake water. The floc that forms upon the addition of alum slurries to

phosphorus-laden water precipitates soluble phosphorus compounds and also traps phosphorus-containing particles. This precipitate then forms a seal over enriched sediments, effectively isolating the contaminated sediment from the overlying water. A comparison of the efficacy of this technique with dredging is provided by Peterson (1981). Capping is similar to the physical and chemical inactivation of nutrients in sediments in that: a) placement of a cap over contaminated sediment isolates the contaminated material from the water column; and b) various chemical reactions may take place at or near the interface between capped material and cap that reduce the mobility of the contaminants. The use of clean sediment overlays (capping) rather than a chemical floc to isolate contaminated sediments has been used or evaluated in both the U.S. and Japan. The results of these efforts are included in this summary since the techniques and aims are similar to those for capping of dredged material.

Major Capping Operations

40. Considering the simplicity of capping as a confinement or containment technique, it is surprising that it has been used infrequently. Table 3 summarizes the major capping efforts; the findings are summarized below.

Hiroshima Bay

41. The Japanese government initiated a Marine Environment Improvement Pilot Project (MEIP) designed to develop efficient and economic methods to improve the sea bottoms of inland bays and waterways. Most of the work is directed toward dredging. However, Hiroshima Bay in the Seto Inland Sea was selected for an evaluation of sand overlaying rather than dredging, as a means to reduce nutrient release (Takata, 1981). Sediments in Hiroshima Bay and Osaka Bay are heavily contaminated with sewage sludge which causes severe eutrophication in the water column. Nutrient-laden sediments were removed from Osaka Bay by dredging; in Hiroshima Bay a clean sand cap 0.3 to 0.5 m deep was laid over 6.4 hectares of nutrient-rich sediments (Kuroda and Fujita, 1981). Studies conducted six months after the capping in Hiroshima Bay

Table 3. Summary of Major Capping Operations Reviewed in This Report.

OPERATION	CAPPED MATERIAL	CAPPING MATERIAL	STATUS
Hiroshima Bay	Sludge laden muds 120 cm thick 1300 km^3	1. Clean Sand 2. Oyster Shell	1. Spreading method evaluated 2. Capping in Progress
Stamford-New Haven	Metals-laden harbor mud 37,800 m^3	Cohesive Silt 4 m thick 76,000 m^3	Capping Complete in 1979 Under Study
	Metals-laden harbor mud 26,000 m^3	Sand 3.5 m thick 84,000 m^3	Long Term monitoring in Progress
Norwalk Harbor	Contaminated Fine Sediment 20,000 m^3	Silt/Sand Sediments	Monitoring in Progress
New York Bight	Contaminated Fine Sediment 522,000 m^3	Fine Material 193,000 m^3 Fine Sand 1,172,000 m^3	Present Report

showed reduced rates of nutrient release in the capped areas, whereas nutrient release in Osaka Bay had not been reduced by dredging. Furthermore, a diverse macrobenthos community had replaced the previously polychaete-dominated benthic community in Hiroshima Bay. In summary, the short-term results indicated a resounding success and the pilot project has been continued.

42. Hosokawa and Horie (1981) developed a mathematic model to estimate the improvement in water quality that can be achieved by retarding nutrient release. The model was tested in a simple laboratory study conducted on phosphate release from sediments collected in Osaka Bay. Sediments were contained in glass cylinders and capped with 2-5 cm of clean mud or sand. The results confirmed the model prediction, that capping sediments can effectively reduce release rates and thus improve water quality (Hosokawa and Horie, 1981).

Central Long Island Sound

43. Since 1977, the New England Division of the U.S. Army Corps of Engineers has sponsored the Disposal Area Monitoring System (DAMOS) project. The major objective of the program is to monitor dredged material disposal sites located from Rockland, Maine, to Western Long Island Sound. Under the auspices of DAMOS, two major capping studies have been conducted, one using contaminated dredged material from Stamford, Connecticut, and the other using contaminated dredged material from Norwalk, Connecticut, Harbor. The sites of these capping operations are at the Central Long Island Sound site (Figure 4).

44. The Stamford-New Haven capping operation. The capping of Stamford dredged material with New Haven sediments appears to have been the first dredged material capping program carried out in the U.S. Bulk analysis of Stamford Harbor sediments showed high levels of heavy metals. In order to isolate the contaminated material from the water column and to protect benthic organisms in the disposal area, the Stamford materials were capped with sediments dredged from the "cleaner" New Haven Harbor. Two sites in the Central Long Island Sound Regional Dredge Material Disposal Area were chosen for disposal of the contaminated sediments (Morton, 1980a,b).

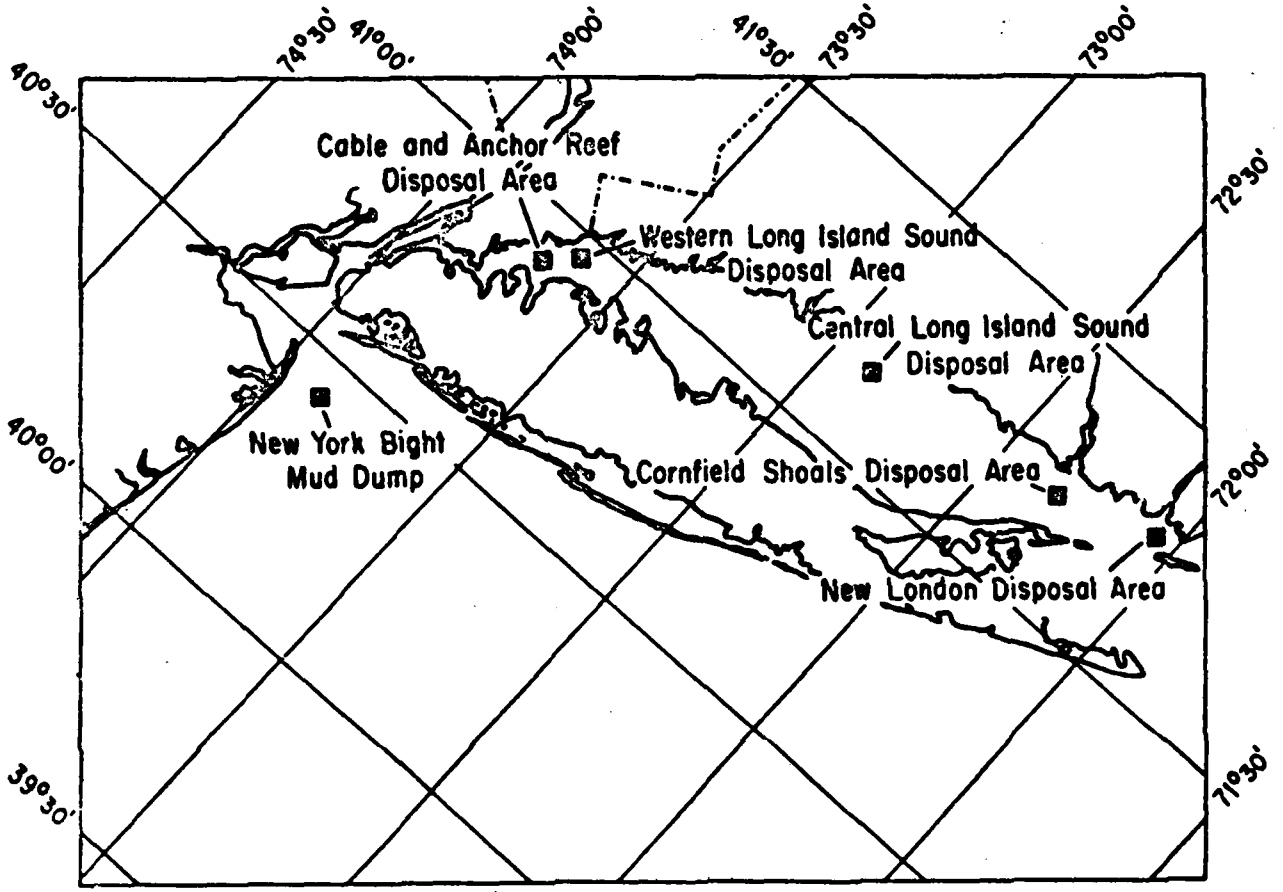


Figure 4. Locations of dredged material dump sites in the region of Long Island Sound, and in the New York Bight

45. One site received approximately 26,000 m^3 of contaminated sediments and was capped with 84,000 m^3 of sand. The other site received about 37,800 m^3 of contaminated material and was capped with 76,000 m^3 of silty, cohesive sediment. The sites were monitored to determine: a) the effectiveness of capping; and b) whether any differences existed between the sand cap and the silt cap.

46. Capping of both sites was completed in June 1979. A survey conducted in August indicated no significant change in the integrity and volume of either cap. However, the silt cap had resulted in a lumpy, rough-textured mound surface, while the sand cap had formed a smooth mound with gently sloped flanks.

47. In November 1979, survey data showed that approximately 10,000 m^3 of dumped material (or 12% of the total cap material) was missing from the center of the mound capped with silt (Morton and Miller, 1980). The sand cap at the other site appeared to be undisturbed. None of the underlying Stamford Harbor deposits were exposed at either site. Investigations to determine the causes of losses at the silt-capped site implicated unusually turbulent conditions in Long Island Sound, caused by a hurricane. Shear stresses generated by the hurricane's waves acting upon the rough surface of the silt cap were apparently sufficient to cause severe erosion.

48. Bulk chemical analysis of dredged material at the disposal sites was included in the capping study to estimate the contaminant load available to biota and the water column. Chemical data presented in DAMOS Annual Reports were limited to copper (Cu), which was presented as representative of the general chemical properties of the dredged material. Concentrations of Cu showed much variability among replicates; in general, the variability was greater among samples having higher Cu concentrations and less among samples having lower concentrations (Morton and Karp, 1981). Morton and Karp (1981) suggest that this localized heterogeneity in metal concentrations might be used to identify dredged material. Presumably, low variability reflects *in situ* sediments in relative equilibrium with themselves, while high variability reflects the incomplete mixing suggestive of contaminated sediments

which have been dredged and deposited at a disposal site.

49. Copper data for the sand-capped site were different from that for the silt-capped site. Pre-capping data for the sand-capped site showed Cu concentrations to be ≃ 70 ppm; variability among samples was low. Immediately after sand capping, Cu levels dropped to ≃ 4 ppm, but sample variation was higher than the baseline data from "natural" sediments (Morton and Karp, 1981). Successive post-disposal surveys (August 1979 and April 1980) resulted in data which approached the baseline in both concentration and variability. This "return to baseline" was interpreted as a result of deposition of natural sediments on the capping sand (Morton and Karp, 1981). The material under the cap was contaminated with Cu at levels of 400-500 ppm. Further monitoring is being conducted to determine whether the mound surface will maintain baseline concentrations or will show continued increases in Cu concentrations.

50. Fluctuations in Cu concentrations at the silt-capped site were similar to those described for the sand-capped site, except that the silt cap did not reduce Cu concentrations to baseline levels. The Stamford, Connecticut, dredged material deposited at the silt cap site contained approximately 750 ppm of Cu.

51. Bathymetric data and diver observations indicated that some areas of the original deposit of Stamford material at the silt-capped site were incompletely covered. Sediments from these areas showed extreme variability and ranged from 75-450 ppm Cu (Morton and Karp, 1981).

52. Although not originally related to the capping studies, DAMOS included a series of experiments to determine the effect of dredged material disposal on the accumulation of PCBs in the mussel Mytilus edulis (Arimoto and Feng, 1980). Groups of mussels were suspended in the vicinity of the New London disposal site, and samples were collected during and after disposal operations. PCB levels temporarily increased during dumping. However, disposal of dredged material was found not to be a controlling factor for PCB levels in mussel tissues; statistical analyses revealed that river discharge accounted for as much of the

temporal change in PCB levels as could be attributed to disposal operations.

53. At the two capping sites, mussels were suspended near the site and subsequently analyzed for heavy metals content. Data from both capping sites, along with data collected for the uncapped New Haven and the Norwalk disposal sites, were analyzed using 2-way ANOVA. No spatial or temporal variation was detected in data for Cd, Cr, and Ni. Data for Co, Cu, Hg, Zn and V fluctuated in time from April through June 1980 (Morton and Karp, 1981). No explanation for these fluctuations has been provided; presumably they are not related to the caps since no spatial differences were detected. Significant variation by both station and sampling data was detected in the data for Fe concentrations (Morton and Karp, 1981).

54. The Norwalk capping operation. Dredging of Norwalk Harbor resulted in the disposal of approximately 16,000 m^3 of contaminated dredged material and approximately 60,000 m^3 of material which was not considered contaminated. In order to isolate the contaminated material, a capping operation was designed (Morton, 1981). Disposal of the cleaner material was begun in the spring of 1980 and continued through the winter of 1980-81. Between January and April 1981 the contaminated material was dumped to the north of the site designated for uncontaminated sediments. Preliminary surveys conducted in late April indicated an error in the placement of the contaminated sediment. Thus, additional monitoring and redesign of the cap placement was required. Most of the capping material was to be deposited between April and June 1981. Data from post-capping surveys are not yet available; thus, the efficacy of the Norwalk operation cannot yet be evaluated.

Summary

55. Both the MEIP and DAMOS data indicate that capping can be successful in relatively shallow waters having low energy currents and waves. Results from the MEIP program demonstrate that, for nutrients, a relatively thin (0.3 to 0.5 m) sand cap can reduce contaminant release and isolate contaminated materials to the extent that a "normal" benthic

biota may develop. The MEIP program also resulted in the development of successful techniques for application of capping material in shallow waters.

56. The Stamford-New Haven capping project demonstrated the following:

a. Precision disposal and capping is feasible using taut moored buoys in waters of about 20 m depth.

b. The sand cap provided greater stability than the silt cap under conditions of very high energy, in this case a hurricane.

c. Both caps were stable under normal tide and wave conditions.

d. The silt cap resulted in an irregular surface topography which contributed to erosion under high-energy conditions.

e. Benthic organisms populated the surface of both caps within a year after disposal; however, the species composition was different and neither cap exhibited a benthic community similar to that of the surrounding sediments (Morton and Karp, 1981). This information should be considered preliminary. Significant recolonization should be expected to take several years.

57. As a result of the data obtained from the Stamford-Norwalk project, the managers of the project have made several recommendations for future capping projects (Semonian, 1981).

a. Cohesion of the material to be capped should be maintained, if possible.

b. The surface area of the capped mound should be minimized.

c. Cap material should present a smooth mound surface; thus, if it is cohesive in nature, clumps should be broken during the dredging operation or the surface smoothed after deposition.

PART IV: THE NEW YORK BIGHT DREDGED MATERIAL CAPPING PROJECT

58. The Port of New York and New Jersey cannot continue to operate without continuous maintenance dredging of 240 miles of Federally authorized navigation channel areas, as well as numerous privately maintained dockage areas, slips, and approach channels. For the period 1970-1978, the annual volume of dredged material removed from the harbor region averaged 8.3×10^6 m^3. Some of this dredged material contains significant quantities of bioavailable contaminants. According to Ocean Dumping Criteria (EPA/CE, 1977; Engler, 1980; Pequegnat, 1982), dredged material which causes bioaccumulation of prohibited materials (e.g., metals, pesticides, PCB) must be given special treatment. New criteria for ocean dumping of contaminated dredged material from New York Harbor are being developed according to a "matrix" procedure, in which physical, chemical and biological factors are used to estimate the potential for contaminants in sediments to accumulate in marine organisms (Engler et al., 1981; Pierce et al., 1981a). At present only bioaccumulation data are used to determine the potential environmental impact due to dumping dredged material.

59. During 1979 and 1980 the New York District CE determined that the sediment from several dredging projects in the metropolitan New York area caused contaminant bioaccumulation in test organisms. It was decided, therefore, that the material from these projects should be dumped in the present Mud Dump, and capped with silty material from the Bronx River and Westchester Creek and with sand from the Ambrose Channel. Since the overall efficacy of capping as a mitigating measure had not been proven, the decision to cap was also a decision to carry out studies evaluating the effect of capping at the dredged material dump site. The designated Mud Dump in the New York Bight was divided into quadrants, and each quadrant was evaluated for suitability as an experimental site. Based upon available dumping records (1966-1980), the southeast quadrant was least impacted, and was designated as the Experimental Mud Dump (EMD). The site was not undisturbed, however; the Mud Dump area has been in continual use since 1914 and dredged material has

accumulated in the EMD.

Elements of the Capping Project

60. The New York Bight Capping Study was designed such that the available baseline data from the MESA-New York Bight Study and the limited, but useful, capping data from the New England Division DAMOS project were fully utilized. Many of the principal components of the DAMOS project were integrated into the study of the New York Bight EMD. These included: 1) the Bathymetric Data Acquisition system (BDAS); 2) the Boundary Layer Turbulence system (BOLT); 3) chemical analysis of sediment cores; and 4) a study of contaminant bioaccumulation in the blue mussel (Mytilus edulis). Elements incorporated into the EMD study which were not part of DAMOS included a detailed analysis of sediment dry mass losses both at the dredging site and at the dumping site, and pre-dumping chemical analysis of dredged material aimed at constructing a chemical "signature" for dredged material at each project.

61. Pre-project bathymetry for the EMD was obtained in October 1978. These data were used as the baseline for bathymetric surveys carried out after disposal of contaminated dredged material (October 1980) and again after placement of the sand cap (November-December 1980).

62. Contaminated dredged material was removed from various sites in the metropolitan New York area between early March and mid-June 1980. Dumping did not occur sequentially; dumping of dredged material from the New York Port Authority Terminal occurred between 9 March and 7 April 1980 and dredging and dumping of sediment from the U.S. Gypsum facility at Stony Point, N.Y., occurred between 24 March and 15 April 1980. The Port of Newark dredging project lasted from 17 April to 8 May 1980, which overlapped the Seatrain-Weehawken project (23 to 30 April 1980). The two projects used for fine capping material (Bronx River and Westchester Creek) were carried out sequentially, the former between 21 July and 11 August 1980 and the latter from 11 to 23 August 1980. The prime capping material, sand from Ambrose Channel, was cut between 31 October and 10 November 1980. Capping was complete in mid-November, and the first core samples at the EMD were taken on 11

December 1980.

63. Bathymetric surveys and derivation of the sediment budget at the dredging sites and the EMD were carried out by New York District CE personnel. The mussel bioaccumulation study was performed by the New Jersey Marine Sciences Consortium. Research to determine the stability of the sediment cap at the EMD was carried out by the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML), and chemical and physical analysis of project sediments and EMD cores was carried out by the New York University Medical Center, Institute of Environmental Medicine.

Summary of Component Project Results

64. Documentation of methods can be obtained from the original reports comprising the Capping Project Study. These are included in microfiche at the end of this report.

Sediment budget

65. The Sediment Budget Study (Tavolaro, 1982) quantified the dry mass of dredged material involved in each stage of clamshell dredging and in disposal activities. The prime objective was to quantify losses of dredged material during dredging, overflow while attaining "effective load", and dispersion after discharge at the EMD.

66. Volumes of sediments were estimated before dredging (in place), in the barges (barge measurements), and after dumping (Mud Dump measurements). Sediment in-place volumes were estimated by before-after bathymetric measurements at each project site. Barge volumes were estimated by displacement, as calculated from measures of barge draft before and after loading. Sediment volumes at the Mud Dump were determined by bathymetry before and after dumping. All sediment volume data were reduced to dry density measurements using a variety of techniques (Bokuniewicz et al., 1978; Suszkowski, 1978; Tavolaro, 1982). Mass balance calculations for the Sediment Budget Study used dry mass, as determined from the volume and density data.

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dredging-overflow operation. Loss of material at the disposal site was not measured directly; rather it was estimated from the difference between the volume of the mound at the EMD and the volumes transported to the EMD for dumping. Correction factors were applied for compaction of the mound with time, based upon empirical data (Bokuniewicz and Gordon, 1980) and numerical modeling techniques (Conner et al., 1979). Mass losses from dredging and the barge overflow operations were estimated from empirical data on suspended solids concentrations obtained at project sites during active dredging.

68. Tavolaro's (1982) Sediment Budget Study estimated a loss of 5.6% of in-place sediment between initiation of a dredging project and disposal at sea (Table 4). The greater proportion of the loss (3.7%, or 66% of the total loss) occurred at the ocean disposal site. The remaining 34% was lost during the process of dredging and barge filling. More material was lost by actual dredging than by intentionally overflowing the barges to achieve "effective load".

Sediment cap stability

69. Analysis of the sediment cap stability (Freeland et al., 1982) encompassed field studies, laboratory studies and analysis, and numerical modeling carried out with data from a variety of sources. Data collection for the cap stability study was restricted to: 1) estimating surficial sediment characteristics at the EMD in November 1980 (immediately after placement of the cap) and in June 1981; 2) a determination of threshold erosional velocities for the sand cap in situ; and 3) current measurements in the water column immediately above the sand capping area.

70. Methods for surficial sediment analysis conformed to standardized procedures. Sediment grain sizes were presented as gravel, sand, fine sand, and "mud" (silt and clay) according to phi (ϕ) units. Erosional studies (Young and Gust, 1982) were carried out using SEAFLUME II (Young, 1977; Young and Southard, 1978) which conformed conceptually to the Boundary Layer Turbulence system (BOLT) used in the DAMOS studies of sediment cap stability in Long Island Sound (Morton, 1980b).

71. Since the EMD mound represents a new and unique topographic

Table 4. Summary of dredged material losses from dredging site to dump site for the materials included in the Capping Project.

	In Place Measurements	Barge Measurements	Mud Dump Measurements
Total Volume (cubic yards)	683,554	861,292	510,565
Percent Difference		20.6	40.7
Percent Difference (In Place vs. Mud Dump)			25.3
Total Mass (short tons)	359,764	350,116	337,787
Percent Difference		*2.0	*3.7
Percent Difference (In Place vs. Mud Dump)			*5.6

Source: Tavolaro (1982).
* indicates loss of organic matter accounted for in the estimate

feature of the Bight Apex which might well affect direction and velocity of currents, a water column current meter study was carried out in conjunction with SEAFLUME experiments. Current meters were deployed at selected sites on and near the EMD during the period November 1980 to July 1981. These data were employed in the cap erosion study, and were also applied in verifying the wave hindcasting study (Drapeau, 1982). Wave hindcasting, a statistical modeling process, was applied to available Bight Apex data to evaluate the impact of the seasonal "wave climate" on sediment cap integrity, and to estimate the likelihood that infrequent events such as hurricanes might breach the cap. The current meter studies (Young, 1982) were carried out using concentration-velocity probes located at three sites on the sand cap, and provided data on suspended solids concentration as well as on current velocities and directions.

72. The effectiveness of the sand capping operation in forming a physically stable layer of sand between the fines and the water column was studied by Freeland and colleagues. Their investigations included not only an evaluation of the cap *in situ* (presence, thickness, grain size, etc.), but also a series of studies to determine how long the cap is likely to persist under "normal" hydrographic conditions, and what impact major storms might have on the physical integrity of the cap.

73. In the study of surficial EMD sediments, Freeland et al. (1982) determined that an effective sand cap had been laid over the various Project muds as well as the muds from Westchester Creek and the Bronx River. Figures 5 and 6 provide percent sand data on the mound immediately after capping (November, 1980), seven months after capping (June 1981), and the percent change in cap sand at the EMD during seven months at sea.

74. Young and Gust (1982) estimated erosional potential of the sand cap based upon empirical data (SEAFLUME II and CV probes). Threshold shear velocities for the capping material were determined to be from 0.6 to 1.4 cm/sec. Estimated erosional velocities one meter above the bottom were similar just after capping (November 1980; 23 cm/sec) and after seven months (June 1981; 21 cm/sec). Sufficient agreement

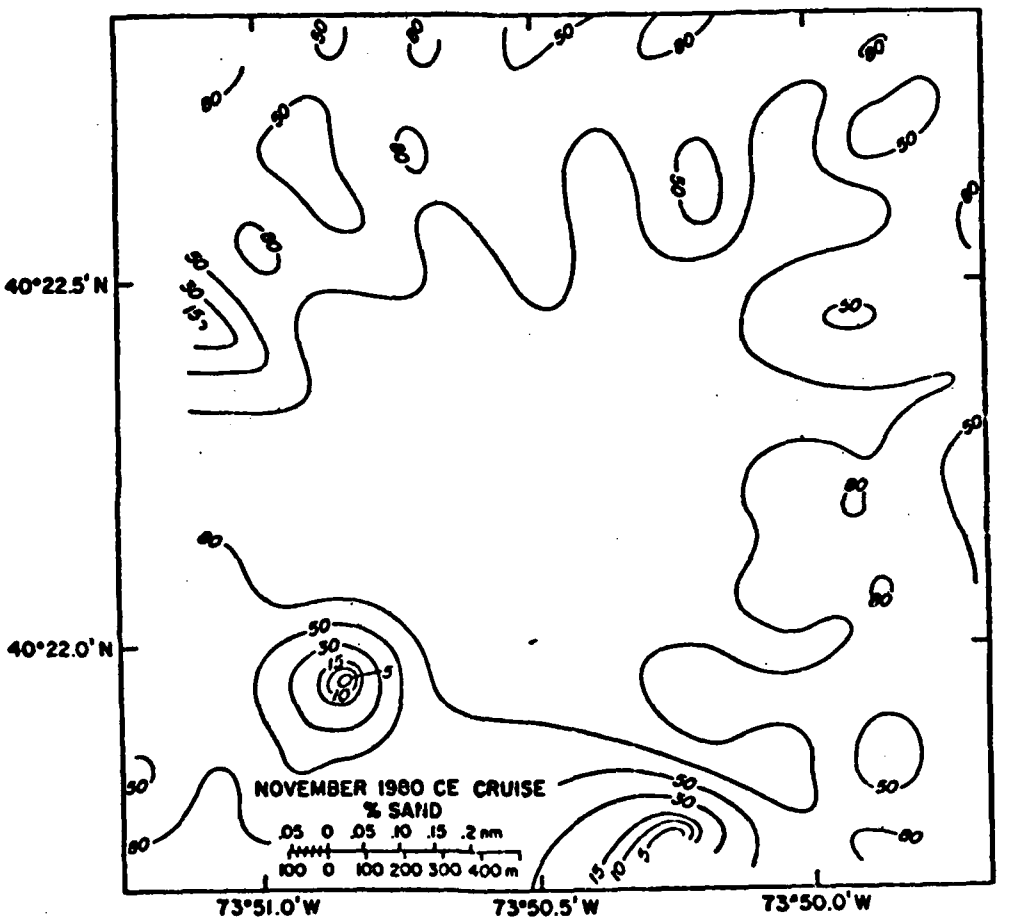

Figure 5. Percent sand in the surficial sediment of the Experimental Mud Dump site in November 1980. Source: Freeland et al. (1982).

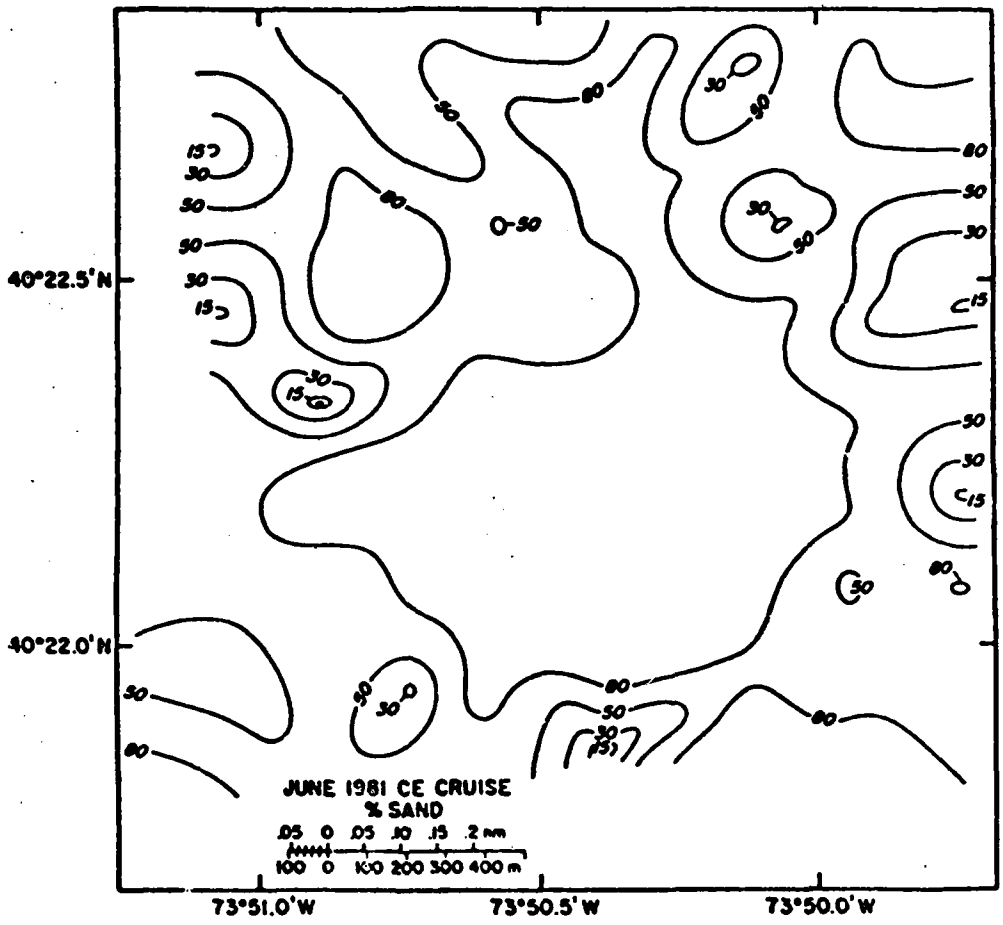

Figure 6. Percent sand in the surficial sediment of the Experimental Mud Dump site in June 1981. Source: Freeland et al. (1982).

was found between observed (SEAFLUME II) and expected values from models that the data were pronounced appropriate for use in estimates of sediment transport at the EMD (Young, 1982; Clarke, 1982), estimates for life of the sand cap, and predictive modeling to estimate the impact of unique meteorological events on the integrity of the sand cap (Drapeau, 1982).

75. Transport of bedload material at the EMD was to the south, and was from 100 to 2500 kg/m/yr, depending upon the calculations used. It is perhaps noteworthy that the cap at the EMD was fine sand, pointed out by Freeland et al. (1982) as the most easily eroded material. The surficial sediment data show an increase in percentage muds on the cap in June, 1981. Freeland et al. (1982) attributed this increase to erosion of fine sand, as well as deposition of fines transported to the site from peripheral locations. Erosion of the sand cap between November, 1980 and June, 1981 was minimal, less than the error associated with estimates of mound volume based upon bathymetry.

76. The erosion simulation model (Clarke, 1982) predicted that the expected net change of the EMD mound would be a loss of ~ 5 cm over a small area of the crest; overall the cap site would show some areas of sediment loss, as well as some areas of sediment accretion. The erosion simulations translate into a minimum of 18 to 46 years for erosional loss of 0.3 m at the EMD.

77. Such predictions are exclusively for "normal" conditions such as those measured by Young and Gust (1982), Young (1982), and Freeland et al. (1982). Further mathematical modeling (Drapeau, 1982) of the probable behavior of the sand cap based upon unusual events such as hurricanes showed that such storms could generate energies more than an order of magnitude greater than the combined wave/current maxima reported by Young (1982). Under such unusual conditions, it is likely that the cap would be breached, and the underlying contaminated muds would be exposed to the sea.

78. Freeland and co-workers stress that the major weakness of the EMD cap is that it is composed primarily of fine sand, the most easily eroded material. In their summary report (Freeland et al., 1982) they

note that, although the cap is likely to maintain its integrity under "normal" conditions,

> "for a margin of safety, it is recommended that additional cap material be placed over the present cap. This should be ... sand, silt and clay consisting of mostly mineral grains, with little or no organic matter, and ... relatively low water content."

Chemical signature study

79. The chemical signature study (NYUMC, 1982) consisted of a multi-component analysis of sediments from dredging projects to determine: 1) whether the project sediments (i.e., contaminated material) could be discerned from cap material; 2) whether the chemical characteristics of individual project subsamples were uniform from barge-load to barge-load; and 3) whether individual projects could be identified by chemical "fingerprint" after disposal at the dump site. New York District CE personnel provided samples of sediments from all projects consisting of aliquots taken from each barge loaded at each project site. Ten-to-fifteen aliquots from each project were subjected to grain-size analysis and processed to estimate dry-weight concentrations of organic content (loss on ignition), Cd, Cu, Pb, Zn, and PCB. Mercury, PAH, pesticides, and radionuclide analyses were performed on composited samples, the makeup of which was determined by a statistical evaluation of homogeneity among project samples. All physical analyses and chemical procedures were standardized according to the CE manual for analysis of sediments (Plumb, 1981) with the following exceptions: 1) some metals analyses were performed by plasma emission (ICAP) spectrometry to determine the comparability of the technique with standard atomic absorption methods; 2) PCB and PAH were analyzed by gas chromatography using glass capillary columns rather than with packed-column; and 3) radionuclide analyses, not included in the CE manual, were performed according to techniques developed by Singh et al. (1979) and Linsalata et al. (1980). Identification and verification of PCB, pesticide, and PAH compounds were exclusively by retention time relative to external and internal standards.

80. Core samples taken at the EMD were all gravity cores.

Depending upon the length of the core, these were either analyzed whole (as above) or according to a progression of depths in the core.

81. The levels of chemical contamination in New York Harbor sediments were greatest for metals, especially zinc; PCB levels were roughly similar throughout all the projects studied. However, unique chemical signatures were determinable only for the Staten Island Project. This was due primarily to very high levels of metals, especially zinc. Some chemical data for all the projects analyzed are given in Table 5.

82. Chemical and physical analyses of core samples showed the presence of a sand cap of varying thickness; X-ray analysis of vibracore samples taken at the Mud Dump site also demonstrated the presence of a sand cap. The depth of the cap was variable and ranged from a few centimeters to more than 1 meter.

83. It was concluded from the chemical signature study that dredged material from the New York Harbor region varies considerably in physical and chemical characteristics. Some regions (e.g., Port Newark and Staten Island) were unique in their high levels of chemical contamination, but no samples from dredging projects were found to contain unique chemicals; discrimination of projects must rely upon the combined levels of "typical" contaminants, especially heavy metals.

84. Levels of organic and inorganic contaminants (e.g., PCB, pesticides, PAH) at the Mud Dump site were equivalent to levels detected in the analysis of samples from individual dredging projects. In gravity core samples taken in December 1980 and August 1981, there was a sand cap containing low levels of contaminants. The cap covered fine-grained, highly contaminated material at some of the dump site sampling locations. Where the sand cap was found to be in place, contaminant levels in the sand, and thus in contact with the water column, were greatly reduced. The presence of a clean sand layer between contaminated fine-grained materials and the water column probably reduced the diffusional transport of most contaminants.

Mussel bioaccumulation study

85. The fourth component of the project was the NJMSC mussel bioaccumulation study (Koepp et al., 1982). The objective of the

Table 5. Mean values for selected chemical contaminants measured for capped dredged material and capping material in the Capping Project Study. Bronx River, Westchester Creek and Ambrose Sand comprised capping material.

	Chemical Contaminants				
	Component (µg/g dry)				
Project	Cd	Cu	Zn	Pb	ΣPCB
Stony Point	2.6	80.3	296.6	119.3	0.92
Weehawken	4.7	237.7	407.0	255.8	0.65
Yonkers	14.1	-	1303.1	558.8	2.03
Passaic River	11.8	692.8	1981.6	1235.6	2.64
Port Newark	14.0	465.1	806.9	439.1	1.59
NYPA	4.4	221.4	332.7	275.9	1.23
Staten Island	11.5	3565.6	10201.2	3168.2	1.94
Westchester Cr.	6.3	427.2	472.7	394.1	1.71
Bronx River	8.1	398.6	519.3	452.8	4.05
Ambrose Sand	0.08	2.5	48.4	6.2	0.10

Source: NYUMC (1982).

bioaccumulation project was to determine if mussels exposed to disposed dredged material accumulated any or all of a pre-established suite of contaminants to levels greater than those accumulated at "control" sites. Eight locations were chosen for mussel emplacement; four were in the vicinity of the EMD, although only one emplacement (Station X) was such that the effects of capping on accumulation may have been evaluated. While some mussels were deployed in the Bight prior to capping, none of the sites were on the EMD. Analyses were performed for Cd, Pb, Hg, PCB, and "No. 2 fuel oil" (petroleum hydrocarbons, PHC) on mussel tissues taken from emplacements throughout the New York Bight.

86. In general, the mussel bioaccumulation study showed bioaccumulation factors (BAF) of one or less relative to the sediments underlying the mussel bags. The body burdens accumulated were quite low, and could be due to bioconcentration from ambient water as much as from the nearby sediments.

87. Most revealing of all the mussel bioconcentration data was the comparison of final body burdens at each station with the initial analyses provided by Koepp et al. (1982). In Table 6, one can see that BAF values relative to the sediments, except for petroleum hydrocarbons (PHC), were uniformly low, 10^{-1} or less for the duration of the exposures. For PHC, the tissue values were essentially uniform although sediment values ranged over an order of magnitude. This suggests that the entire Bight region contains PHC in the water column at levels likely to result in some bioconcentration. It is interesting to note that the PHC data presented by Koepp et al. (1982) in blue mussels from the Cape May control station (50 ng/g) were similar to those reported by MacLeod et al. (1981) and O'Connor et al. (1982) for contaminated stations (~ 120 ng/g). Fuel oil concentrations in mussels from the dump site region were some four orders of magnitude greater, and significantly greater in organisms from the New York Harbor-Lower Bay region. We must consider that the PHC data, as presented (Koepp et al., 1982), may be erroneous.

Table 6. Comparison of contaminant levels in sediments (S) and blue mussels (M) for various stations where mussels were suspended during the bioaccumulation study (Koepp et al., 1982). All values are given as ug/g dry weight.

	Contaminant Levels							
	Hg		Pb		PCB		PHC	
Station	S	M	S	M	S	M	S	M
B	6.9	0.05	180	1.23	-	0.21	8	96
C	2.8	L	88	L	-	L	5	L
D	9.0	0.22	349	1.21	-	0.25	9	123
E	4.4	0.40	129	1.28	-	0.33	59	45
F	11.7	0.18	702	1.36	-	0.23	76	106
X	-	0.04	-	1.0	-	0.15	-	118
Y	-	0.03	-	1.0	-	0.15	-	90

Sources: Sediment data from NYUMC (1982) and Koepp et al.(1982). Mussel data from Koepp et al.(1982).

Station locations: B= Gravesend Bay; C= Long Beach, NY; D= Christiaensen Basin; E= NW Quadrant, Mud Dump Site; F= 1 mile W of Mud Dump Site; X= Capping Site; Y= Barnegat Light.

Dashed line indicates no data available
L indicates sample lost

Review and Discussion

88. The data gathered during the New York Bight Capping Project are well suited to an evaluation of capping as a method for mitigating the potential effects of dumping contaminated dredged material at sea. In the sections that follow, we have applied these data strictly to an evaluation of capping. It should be pointed out, however, that the content of the Capping Project reports comprises data of significance to the basic oceanography of the New York Bight, as well as to the question of capping.

Sediment losses at the Mud Dump

89. One way in which contaminated sediments at the Mud Dump may affect the environment of the New York Bight is through the transport of particulates and their associated contaminants from the dump site, and their distribution over some as-yet-undefined area. Two Capping Project studies provide data useful in evaluating sediment loss at the Mud Dump. Tavolaro's work (1982) provided estimates of the dry mass of sediment lost due to dumping, while Freeland et al. (1982) evaluated the actual and potential loss of materials at the Mud Dump due to erosion after capping.

90. Tavolaro (1982) estimated that 3.7% of the dry mass of dredged material was lost at the dump site. This estimate was based upon bathymetric determinations (depth-by-difference before and after dumping, using 0.3 meter contour intervals). The calculated loss of dry mass is based upon the assumption that pinpoint dumping at a taut-moored buoy is possible in a system such as the New York Bight. In fact, this assumption is well supported by a variety of studies from the New York Bight, Long Island Sound, and other locations. Science Applications Inc. (1980) showed that dredged material dumped in Long Island Sound could be accurately placed using either permanent buoys as dump site markers, or by using ship-board computers for navigational fixes. Mathematical models predicting the behavior of mud dumps from barges have been evaluated for a variety of sites, including the Duwamish Waterway in Washington, and the New York Bight (Holliday et al., 1978). These models, and the studies of Bokuniewicz et al. (1978), demonstrate that dredged material

from both barge dumps and hopper dredge dumps behaves in a predictable manner during descent and after impact with the bottom at disposal sites. Dredged material placement after dumping at a taut-moored buoy can be accurately predicted. Dry mass estimates of sediment loss, such as those performed by Tavolaro (1982), should provide an estimate of the magnitude of sediment losses during dumping. Recently completed surveys of the New York Bight dredged material disposal site (Dayal et al., 1981) concluded that 85% of all dredged material dumped between 1936 and 1980 remains in the mound. Such data are fully consistent with Tavolaro's (1982) suggestion of very small dredged material losses between March and June, 1980.

91. The causes of sediment losses during dumping and the ultimate fate of lost material were not investigated. We can speculate, however, that some portion of the dumped material was lost during the encounter with the bottom following convective descent to the mud-water interface. Typically an instantaneous dump of dredged material generates a bottom surge upon impact. This surge carries suspended material away from the impact point in all directions (Brandsma and Divoky, 1976; Holliday et al., 1978), spreading the initial mass over an area dictated by a variety of physical factors. As determined by direct observation in Long Island Sound (Stewart, 1980) and measurements taken in the New York Bight dump site, most particles in the bottom surge settle rapidly in a thin layer around the impact zone. Such areas may have avoided detection in bathymetric surveys, since the sensitivity of the determination was 0.3 m.

92. It is also quite likely that the finer particles in the bottom surge, those with low settling velocities, did not settle and were carried away from the EMD. These particles would become widely circulated within the New York Bight Apex, and represent a real loss associated with the dumping process. At present, no data exist to allow an estimate of the mass lost in this way. The potential loss of contaminants associated with the fines transported away from the dump site is treated below (paragraphs 98 and 99).

93. Part of the study conducted by Freeland and co-workers related

to the loss of sediments from the Mud Dump after placement of the sand cap. Clarke (1982) determined that the expected erosional loss of sediments from the material at the EMD amounted to about 5 cm in a small area at the crest of the mound in the seven months since capping took place. Simulation studies of cap losses, using data from Freeland et al. (1982), and Young and Gust (1982), showed that 28 to 46 years would be required before 0.3 m of the cap would be eroded. Thus, the cap placed at the EMD is highly stable under the hydrologic and meteorologic conditions which prevailed from November 1980 to June 1981. The net change in percent sand in the cap (Figure 6; Freeland et al., 1982) showed that erosion, settling and mixing occurred. Freeland suggested that the small amount of erosion observed in the sand cap could be reduced by placement of another cap; "a mixture of sand, silt and clay consisting of mostly mineral grains with little or no organic matter" (Freeland et al., 1982).

94. By combining data on erosional shear velocities for the cap material (Young and Gust, 1982) and expected maximum currents at the capping site (Wave Hindcasting; Drapeau, 1982), predictions were made as to the integrity of the cap during unique meteorological conditions such as hurricanes. Direct observation of hurricane effects on the Long Island Sound capping sites was possible due to the passage of Hurricane David in 1979. Morton (1980a,b) found that the effects of Hurricane David were different on the two capping sites. The site covered with fines was severely eroded and capped material was exposed; the site capped with sand maintained its integrity. It has been proposed (Morton, 1980a) that the surface features of the two caps were related to cap breaching, or the lack thereof. The cap of fine-grained material was observed to be irregular with lumps of cohesive sediment, whereas the sand cap was smooth. Presumably, the roughness of the cap of fine-grained material led to erosion, while the smoothness of the sand cap resisted erosion due to the lack of small, intense eddy currents forming down-current from irregularities.

95. The cap at the EMD was found to be rather smooth, with some regions identified as mostly sand (Figure 6) and some found to be

primarily muds (Figure 7). During the seven months from November 1980 to June 1981 it was determined with erosion and resettling of particles further smoothed the cap surface. Drapeau's (1982) model, however, predicted that major storms had the potential to generate energies more than an order of magnitude greater than the wave/current maxima reported by Young (1982), and well above the threshold shear velocities for the capping material, as reported by Young and Gust (1982).

96. The cap at the EMD, therefore, must be viewed as possessing the potential to be breached during major storms. Fortunately, such events are not frequent. The combination of a smooth, thick cap (> 1 m; NYUMC, 1982) at the EMD, comprised of materials rather resistant to resuspension and erosion (Clarke, 1982), guarantees the integrity of the EMD cap for a long time to come, under normal conditions of wind and tide. The addition of more material to the sand cap would increase its integrity, especially if any covering added to the cap consists of material less easily eroded than the fine sand already in place (Freeland et al., 1982).

Chemical losses at the dump site

97. A variety of organic and inorganic chemical contaminants are associated with dredged material (Mueller et al., 1976; 1982; O'Connor et al., 1982). Since many of these contaminants are sorbed to particulates, any loss of dredged material during ocean dumping may be inferred to be a loss of contaminants as well. The Capping Project allows a direct but crude estimate of chemical losses to the environment as a consequence of ocean disposal. We combined the dry mass loss estimates of Tavolaro (1982) with bulk chemical analyses (NYUMC, 1982) and determined how much of each contaminant might have been "lost", and possibly made available to marine populations during dumping.

98. In order to make such estimates of contaminant losses, two assumptions were made. First, we assumed that the dry mass estimates of loss associated with disposal were reasonably accurate. Second, we assumed that the contaminant levels of any sediment lost in the disposal process were similar to the levels of contaminant measured in bulk analysis from barge samples (NYUMC, 1982). Using bulk sediment data for

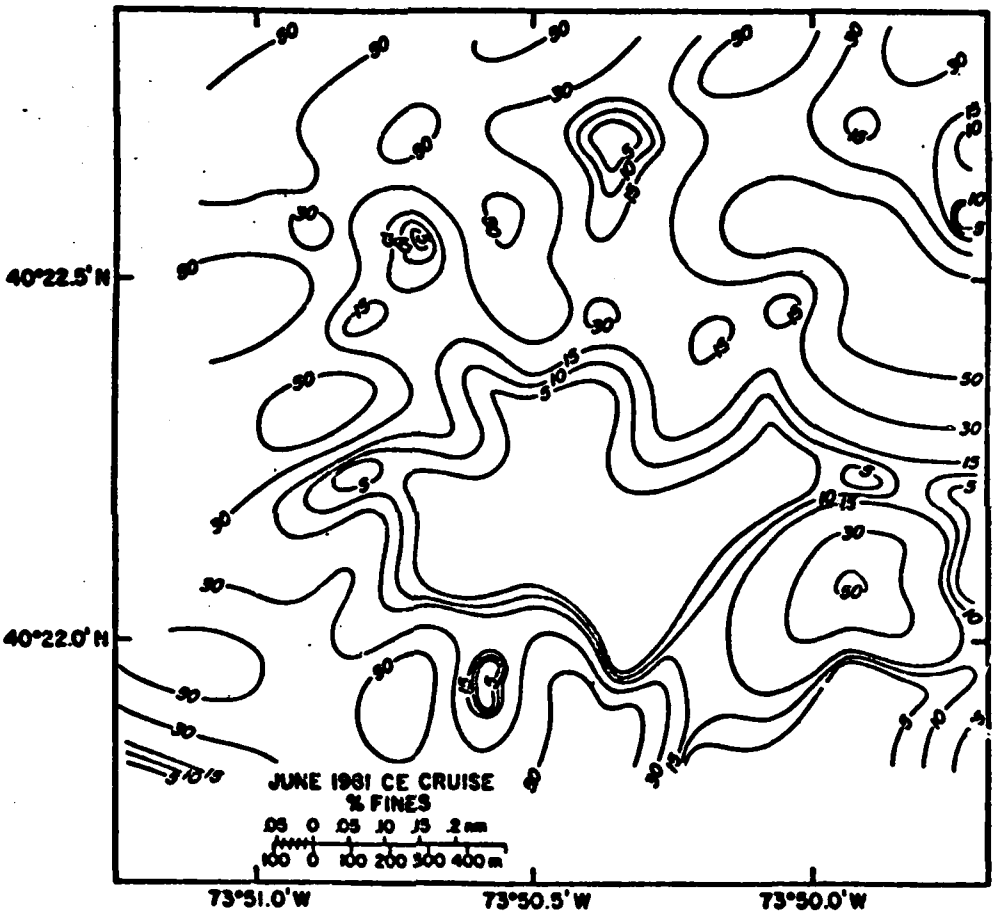

Figure 7. Percent fine sediments (muds) in the surficial sediments of the Experimental Mud Dump site in June 1981. Source: Freeland et al. (1982).

calculating contaminant losses is probably not a serious underestimate, since the majority of the material dredged and disposed in the Capping Project was silts and clays (NYUMC, 1982). Correcting for total volume on a project-by-project basis, and using the mean sand content of each project, we estimated that 16% of the material disposed of at the EHD was sand. Thus, estimates of contaminant loss should be underestimated by no more than 16%. Contaminant losses were calculated based upon Tavolaro's (1982) estimate of dry mass lost during ocean dumping and the NYUMC (1982) mean contaminant concentration by project. Calculated losses are given in Table 7.

99. There exist no data with which one might predict the proportion of particulate-bound contaminants which settle immediately adjacent to the mound, and those which disperse beyond the designated dump site. In previous studies of the bottom surge from instantaneous dumps in the New York Bight, the high levels of suspended solids initially encountered 800 feet from the dump decline to background levels in about 17 minutes, suggesting rapid redeposition of particles in the bottom surge. We can only speculate that the major fraction of lost particles settled to the bottom within the designated dump site.

100. A second mechanism for contaminant loss may be dissolution or desorption of the contaminants both prior to and after the cap has been put in place. Release of contaminants may occur prior to capping due to dissolution and desorption of contaminants from sediments, or due to extrusion of interstitial water as the dredged material mound compacts under its own weight (Bohuniewicz and Gordon, 1980; Tavolaro, 1982). Some contaminants must be released during dumping based simply upon the chemistry of various contaminants in seawater. For example, Segar and Cantillo (1976) have observed increased levels of Cd in Bight waters associated with dredged material dumps. Dayal et al. (1981) have shown that some release of sediment-associated metals may be expected at the dump site due primarily to cation exchange, dissolution, and extrusion of pore waters. Their estimates are not directly applicable, however, since they were not based upon analyses of capped sediments.

Table 7. Estimated dumping losses of major contaminants at the EMD. Percent of total losses, by project, is in parentheses. Losses of contaminants are calculated based upon dry mass losses of 3.7%.

PROJECT	CALCULATED MASS LOST AT EMD ($kg \times 10^6$)	CONTAMINANT LOSS (kg) Cd	Cu	Pb	Zn	PCB
Stony Point	3.19	8.3 (10.1)	260 (2.1)	380 (3.3)	940 (2.8)	2.9 (18.6)
Weekhawken	1.31	6.2 (7.5)	312 (2.5)	340 (2.9)	530 (1.6)	0.9 (5.4)
Passaic River	0.07	0.8 (1.0)	49 (0.4)	87 (0.8)	140 (0.4)	0.2 (1.2)
Port Newark	1.40	20.0 (23.8)	650 (5.3)	620 (5.4)	1100 (3.4)	2.2 (14.1)
Staten Island	2.90	33.0 (40.5)	10300 (83.9)	9200 (80.0)	30000 (88.6)	5.6 (35.7)
N.Y. Port Authority	3.20	14.0 (17.1)	700 (5.7)	880 (7.7)	1100 (3.2)	3.9 (24.9)

Based upon data from Tavolaro (1982) and NYUMC (1982).

Organic contaminants

101. The release of PCB, pesticides, and petroleum hydrocarbons during the dumping of dredged material and from the dredged material mound is a matter for conjecture. Most organic contaminants are less soluble in seawater than in estuarine water, which argues against dissolution; however, intense cation exchange activity on settling particles could temporarily displace organics to solution. It is our opinion that the tendency for sediments to strongly bind most organics would override the tendency toward their desorption and solution (Hiraizumi et al., 1979; Rossi and Thomas, 1981). The available data on dissolved PCB or PAH in seawater or estuarine water from the New York region are sparse. Estimates range from 0.01 to 0.1 µg/L (0.01 to 0.1 x 10^{-9} g/g seawater). Considering that average concentrations of PCB and PAH in sediments range from about 1.0 to 10 x 10^{-6} g/g, it can be seen that the tendency for dissolution is small (10^{-3} to 10^{-4}), and that organics will preferentially remain associated with finely divided solids.

102. There exist very few direct studies of the movement of organic contaminants from deposited sediments to the water column. Ditoro et al. (in press) working with Saginaw Bay sediments showed that vertical diffusion rates for PCB were < 1 cm/year. We know of no similar studies for petroleum hydrocarbons or PAH in deposited sediments. Based upon knowledge of sorptive characteristics of organic contaminants, however, it is possible to estimate the relative potential for vertical diffusion and release of organic contaminants from dredged material. The vertical diffusion constant should be related to: a) the partition coefficient of the compound; b) the particle size distribution of the sediment in question; and c) the organic content of the sediment (Ditoro et al., in press). Quantities of a contaminant released from a sediment will be primarily related to: a) the diffusion rate constant; b) the depth of sediment through which a contaminant must diffuse; and c) the concentration gradient of a contaminant at the mud-water interface. These factors are poorly understood at present, and not quantifiable for organics. Most authorities agree that, in the absence of data, it is reasonable to assume that the release of organics from deposited

sediments can be reduced by covering the contaminated sediments with clean sediments. Covering (i.e., capping) has the effect of: a) increasing the diffusional distance (and time) between contaminated material and the water column; b) decreasing, by dilution, the relative concentration of the contaminant as it approaches the mud-water interface; and c) increasing the probability that sediments will bind organics by providing an excess of sorptive surfaces. Bioaccumulation studies (discussed below; paragraphs 109-113) confirm these expectations.

Inorganic contaminants

103. The release of metals from deposited sediments has been studied in much greater detail than the release of organic contaminants. In undisturbed sediments, the release of sequestered metals requires several steps. The metals must first be released to the sediment interstitial (pore) water. Then the metal must diffuse to the sediment-water interface (often involving multiple sorption-desorption steps), and ultimately must pass through the interface and enter the water column. Many factors, including Eh, pH, bacterial activity, and the presence of various nonmetallic species (sulfides, chlorides, carbonates), combine to control this process (Lu and Chen, 1977; Neff et al., 1978; Forstner and Wittmann, 1979).

104. The release of metallic contaminants from dredged material is controlled by the same processes, but with the addition of substantial mixing, partial aeration, and dilution during dredging, disposal, and consolidation of the dredged material pile. The release of metallic contaminants from dredged material at New York's disposal areas has been estimated by Dayal et al. (1981), and by the DAMOS program in Long Island Sound (Morton and Karp, 1981). Brannon et al. (1980) have published the results of laboratory studies to determine the strength of binding and release potential for a variety of metals in waste dredged material.

105. The results of such field and laboratory studies demonstrate that, while actual release of metals from waste dredged material varies according to the physical characteristics of the dredged material, the potential for release of metals from disposed New York Harbor sediments

can be given. Brannon et al. (1980), using sediments from several sources, showed that Zn had the greatest release potential; Hg, Pb, Cd and As showed very little mass release to the water column. Field studies (Arimoto and Feng, 1980) and microcosm studies (Rubinstein et al., in press) confirm these predictions. Studies of Cu concentrations at capped sites in Long Island showed little migrating through capping material to the water column (Arimoto and Feng, 1980). New York Harbor sediments subjected to elutriate tests released very little Cd or Hg to the water (Rubinstein et al., in press).

106. Dayal et al. (1981) estimated that from 42 to 67% of the metals (Fe, Mn, Cu, Pb, Hg, Cd) associated with disposed dredged material was likely to remain in the deposit for long periods of time. Their estimate, based upon data from an uncapped portion of the New York Bight disposal site, includes losses due to several factors: particulate dispersion, pore water extrusion, bioturbation, and erosion. Based upon pore water analyses, they concluded in agreement with Brannon et al. (1980) that Cd, Cu, and Hg were likely to show little diffusive loss. Iron and Zn were assessed by Dayal et al. (1981) as having the greatest release potential at the uncapped Mud Dump.

107. As with organic contaminants, the overall effect on metals of capping waste dredged material would be: a) to increase the distance over which diffusion must occur if metals are to be released to the water column; and b) to decrease release to the water column by dilution and reduction of the metals concentration gradient at the sediment-water interface. Unlike the situation with organics, however, our understanding of metals geochemistry suggests an additional barrier to metals diffusion in a sand cap. This consists of an increased zone of oxygenation near the sediment-water interface which decreases the flux of chemical constituents into the overlying water. The combined effects of longer diffusional distance, and reduced concentration gradients with an oxygenated layer decreasing metals flux rates, strongly suggests that capping contaminated sediment with clean sand should reduce significantly the loss of metals to the water column.

108. The Chemical Signature Study (NYUMC, 1982) and the work of

Freeland et al. (1982) at the EMD may be applied to estimates of chemical loss, and the extent to which capping at the New York Bight EMD was a success. Freeland et al. (1982) showed a sand cap firmly in place over much of the dredged material mound. The cap, according to NYUMC (1982), had an average depth of 1 m or more, and the concentrations of contaminants in sand layers were significantly lower than in the underlying fine material. It is our conclusion that the sand cap has successfully isolated contaminated materials from the water column and, if not breached, should provide a barrier effective in reducing contaminant losses over long periods of time.

Bioaccumulation

109. There are several reports documenting bioaccumulation of contaminants at or near the New York Bight ocean disposal sites. Most of the available data have not come from the dredged material dump site and most of the analyses have focused on PCB and metals. O'Connor et al. (1982) have summarized the data from MacLeod et al. (1981) concerning PCB and PAH in biota from the Bight region. O'Brien and Gere (1979) and Pequegnat et al. (1980) studied bioaccumulation of PCB and PCB/metals, respectively, at the dredged material dump site and at a variety of "control" locations. As part of the Capping Project, Koepp et al. (1982) studied the accumulation of metals, PCB and petroleum hydrocarbons ("No. 2 fuel oil") at the EMD and several control sites.

110. Some caution must be observed when interpreting or applying the Capping Project bioaccumulation data (Koepp et al., 1982). First, as noted by the authors, before-after evaluation of contaminant accumulation by mussels cannot be made; mussels were not emplaced at the EMD prior to laying on the sand cap. Furthermore, mussels were in place at the EMD only from January to July 1981, whereas comparison sites were occupied from August 1980 through July 1981. Koepp et al. (1982) acknowledge that temperature differences may have affected the bioaccumulative response.

111. In general, the mussel study showed bioaccumulation factors (BAF) of one or less relative to the sediments underlying the mussel bags. The body burdens that accumulated were quite low overall and

there is an equal chance that the source was the ambient water rather than the nearby sediments.

112. Other bioaccumulation studies carried out on or near capped dredged material have shown essentially no increase in the accumulation of metals or of PCB compared to control stations (Morton and Karp, 1981). Such results are of little positive value in evaluating the efficacy of the capping effort as a means of isolating contaminants from either the water column or marine biota. Indeed, the vast majority of research carried out to determine whether marine organisms accumulate contaminants from sediments has so far yielded negative findings; namely, sediments, whether capped or uncapped, in-place or recently disposed, rarely cause elevated contaminant levels in natural or implanted biota (Gambrell et al., 1978; Pequegnat et al., 1978; Neff et al., 1978; Morton and Karp, 1981; Windom, 1973; Burks and Engler, 1978; Hirsch et al., 1978; O'Brien and Gere, 1979; Wright, 1978; Pierce et al., 1981a; Rubinstein et al., in press). The chemical basis for such results is rapidly becoming understood (Hiraizumi et al., 1979; Nau-Ritter, 1980; Klinkhammer and Bender, 1981; Hazen and Kneip, 1980; Dayal et al., 1981; Rossi and Thomas, 1981; Wright, 1978; NYUMC, 1982). Simply stated, the contaminants that are sorbed or otherwise particle associated, or which exist in precipitated and insoluble forms, tend not to dissolve or otherwise dissociate from sedimentary deposits. Even under conditions where contaminant-laden particles may form a portion of the diet, as for Nereis, bioaccumulation of metals and chlorinated organics is low (Rubinstein et al., in press).

113. The reviewed data of O'Connor et al. (1982) and O'Connor and Rachlin (1982), and the experimental data of O'Brien and Gere (1979) and Pequegnat et al. (1980) show that significant bioaccumulation is unlikely to occur, even at uncapped deposits of dredged material in the New York Bight region (see also Raltech, 1981). For studies in which reference stations were used, crustaceans, fish, mussels, and clams showed no greater contaminant accumulations at the dump site than at other stations in the Bight region. In fact, bioaccumulation rates within the New York Harbor proper (Gravesend Bay) were generally greater than at the

Mud Dump site. The laboratory data of Rubinstein et al. (in press) showed that the low rates of contaminant accumulation directly from sediments are due to the reduced bioavailabilities of metals and organics in finely divided, organic-rich harbor muds.

114. Any reduction of contaminant levels in the water column or the diet of marine organisms will lead to reduced rates of bioaccumulation of contaminants, as well as increased rates of elimination of existing body burdens (O'Connor and Rachlin, 1982; Pizza and O'Connor, in press). The presence of a cap at the EMD, by reducing contaminant levels in the water column and in the marine food chains of the New York Bight, will eliminate any increase in ecosystem degradation which might occur due to bioaccumulation of toxicants from contaminated dredged material.

PART V: CONCLUSIONS

115. The New York Bight Capping Project demonstrated that through precision dumping, contaminated dredged material may be covered with a cap of clean material. The cap material, consisting primarily of fine sand, resisted erosion for 16 months, at which time the cap averaged more than 1 meter in thickness. Natural sedimentation and mechanical reworking of the cap have resulted in a mound having a smooth contour with surficial sediments composed of fine sands and muds. Other studies have shown that these characteristics render dredged material deposits resistant to erosion.

116. The presence of a cap at the EMD is expected to reduce the movement of metals and organic toxicants from contaminated sediments to the water column. Other studies have shown that the release of nutrients and toxicants from contaminated sediments decreases after capping. In Japan, sand caps of 0.3 m depth have reduced losses of nutrients and metals from sediments; in Long Island Sound, caps on contaminated sediments reduced the movement of Cu, PCB, and other toxicants into the water column.

117. The sand cap at the New York Bight EMD should remain in place for as long as 20 years, under normal conditions of weather, tide, and current. Estimates of erosional rate show that it may take between 18 and 46 years for erosion to remove the top 0.3 m of the cap. Unique events or major storms will cause erosion and possible breaching of the cap.

118. Bioaccumulation studies were inconclusive as to the ability of capping to prevent or reduce contaminant uptake by blue mussels. However, the low bioaccumulation rates observed in the mussel study, and the results from other capping studies, allow the conclusion that contaminant uptake due to loss of metals or organics from the capped material is unlikely to occur.

119. Given the conditions prevailing in the New York Bight, capping can be an effective and efficient procedure for dealing with contaminated dredged material. The success of the Capping Project raises the possibility of integrating the management of contaminated dredged

material disposal with routine disposal operations. Since project-by-project capping could be impractical as a management scheme, we suggest that contaminated dredged material could be disposed of at any time, at designated sites, provided that clean materials are available for covering the contaminated material. Such procedures would constitute repeated, successive capping events. Such a management scheme would result in multiple layers of contaminated sediment at the dump site, covered to the maximum possible depth by layers of clean, fine-grained, and sandy materials.

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APPENDIX A

BIOACCUMULATION MONITORING IN THE NEW YORK BIGHT USING THE BLUE MUSSEL (MYTILUS EDULIS)

Final Report

U.S. ARMY CORPS OF ENGINEERS
NEW YORK DISTRICT

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NEW JERSEY MARINE SCIENCES CONSORTIUM

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LIST OF ABBREVIATIONS

Cd, Cadmium

DDT, 2, 2-bis(p-dichlorophenyl)-1,1,1-trichloroethane

EC, Electron Capture

FDA, Food and Drug Administration

Hs, Mercury

NAS, National Academy of Science

Ni, Nickel

NJDEP, New Jersey Department of Environmental Protection

Pb, Lead

PCB, Polychlorinated Biphenyls

UNEP, United National Environmental Program

WHO, World Health Organization

EXECUTIVE SUMMARY

In conjunction with ongoing assessment of the impact of ocean dredged material disposal, investigators representing the New Jersey Marine Sciences Consortium conducted a bioaccumulation monitoring study of blue mussels (Mytilus edulis) transplanted to eight New York Bight locations. Pooled tissue samples were analyzed for total concentrations of mercury, cadmium, lead, DDT, polychlorinated biphenyls (PCBs), and No. 2 fuel oil. Six stations were deployed in August, 1980. Two additional stations were deployed in January, 1981 (following completion of capping activities within the dredged material dumpsite). Four stations were situated in or around the dredged material dumpsite, while additional reference platforms were maintained in Lower New York Harbor, off of Jones Beach, New York, and Barnegat Light, New Jersey. Stations were sampled weekly for one month, after which bimonthly mussel collections were conducted through July, 1981. Untimely loss of mussel platforms due to both storm and human activities somewhat restricted sampling of four stations over the monitoring period. Of particular concern was the loss of the dredged material dumpsite station (E) in March, 1981.

Throughout the study DDT concentrations in mussels generally remained below analytical detection for all stations. Although the three metals (mercury, cadmium, and lead), PCBs, and No. 2 fuel oil were consistently detected at all stations, none of these contaminants were detected in excess of existing regulatory guidelines. For mussels deployed in August, bioaccumulation of mercury and cadmium was significantly greater for animals exposed at the dredged material dumpsite than at both immediate and distant

reference stations. Although the distribution of lead was somewhat more generalized, significantly higher levels were noted among those mussels deployed in and around the dumpsite.

Although net PCB bioaccumulation occurred at all stations, the pattern of uptake was erratic over time. PCB concentrations for exposed mussels were not significantly different from other stations within the dumpsite, thereby suggesting ubiquitous sources of this contaminant.

Mussels exposed at all stations exhibited a characteristic pattern of No. 2 fuel oil accumulation. Relatively minimal uptake during initial exposure was followed by a dramatic increase in early spring. Such a pattern is apparently characteristic of nearshore waters chronically contaminated with petroleum, and therefore cannot specifically be attributed to dredged material disposal.

Metal accumulation was negligible for mussels deployed at the capping and Barnegat (control) locations. However, these mussels did accumulate PCBs and No. 2 fuel oil in a manner consistent with those of August-deployed animals.

Mussel survival and lipid content did not statistically correlate with contaminant accumulation for any stations. The absence of ancillary contaminant data for sediment, water, and mussel food restricts the extent to which the observed contaminant accumulations can be more specifically related to dredged material disposal.

FIGURE 1

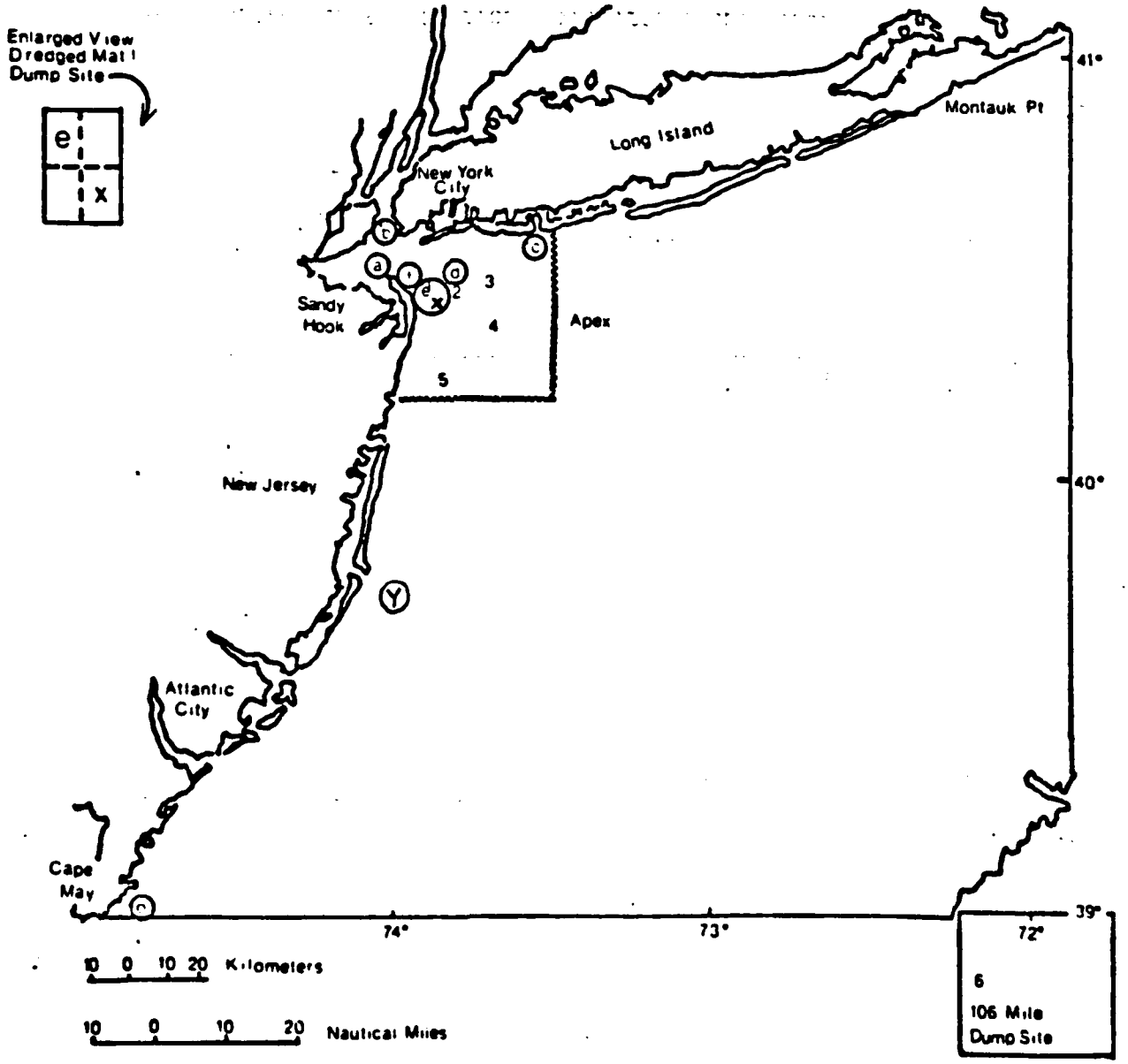
I OCEAN DISPOSAL SITES IN THE NY BIGHT

II BIOMONITORING SITES - AUGUST 1980 DEPLOYMENT (a-f)

III BIOMONITORING SITES - JANUARY 1981 DEPLOYMENT (x,y)

a. Sandy Hook/Rockaway Pt. Transect
b. Gravesend Bay
c. Long Beach, LI
d. Christiaensen Basin
e. NW Quad.-Dredge Mat'l Dump Site (DMD)
f. 1 naut. mi. due W of DMD Site
o. Stock Population from Cape May
x. Capping Site (DMD Site)
y. Barnegat Light

1. Dredged Material
2. Cellar Dirt
3. Sewage Sludge
4. Acid Waste
5. Wreck (inactive)
6. 106-Mile Dump Site



SECTION I: INTRODUCTION

I-1 PROJECT RATIONALE

The New York Bight apex, incorporating the 25 kilometer coastal zone adjacent to New York Harbor, represents one of the most heavily impacted inshore regions along the Atlantic coast of the United States. Over the past century demands of increasing population density and industrialization, particularly involving the Hudson River-Raritan Bay estuarine system, have severely affected both water quality and physical features of the region (Pearce, 1980). Only recently have comprehensive research efforts begun to identify effects of this stress on marine life of the New York Bight apex (Mahoney, et al., 1973; Pearce, et al., 1976).

Concern has been expressed about the environmental impact of ocean disposal of dredged material generated during routine harbor maintenance. Indeed, contaminants such as chlorinated hydrocarbons, toxic metals and petroleum hydrocarbons have been detected in New York Harbor dredged material as well as at the six-mile dumpsite (Mueller, et al., 1975; Carmody, et al., 1973). The potential for accumulation of these contaminants by marine biota should be determined as part of any assessment regarding dredged material disposal. Bioaccumulation is defined as the propensity of biota to concentrate chemical constituents in excess of the levels in their immediate environment. Such accumulation may result from direct uptake from water and sediment, or biomagnification through the food chain. Net bioaccumulation over time is modified by such factors as the chemical nature of the specific contaminant, selective depuration and the extent of incorporation into living tissues.

Since ocean disposal is the only option currently in use for the disposal of large quantities of dredged material, the New York District (US Army Corps of Engineers) has designed a plan with the objective of determining the continued use of this option and investigating mitigative procedures (i.e., capping) which can be employed. In regard to the latter, seven ocean disposal permits were recently issued to applicants with a provision for "pin-point" dumping and subsequent capping at a fixed location within the dredged materials dumpsite. These seven sites were subsequently covered with 504,527 cubic yards of clean fine-grained material from Westchester Creek and the Bronx River, followed by a final covering (1,245,941 cubic yards) from Ambrose Channel.

The ocean disposal plan further calls for the environmental monitoring of the capping operation and long-range monitoring of the entire dredged materials dumpsite, including quantification of bioaccumulative potential using transplanted populations of the blue mussel, Mytilus edulis. Mussels have been successfully used as bioaccumulation targets of coastal contamination, including metals (Alexander and Young, 1976; Phillips, 1976b; Feng, et al., 1979; McGreer, in press), chlorinated hydrocarbons (de Lappe, et al., 1972; Young and Heeson, 1975; McDermott, et al., 1974) and petroleum hydrocarbons (Clark and Finley, 1973; Disalvio, et al., 1975). Mussels are well recognized as sentinel organisms for monitoring coastal pollution in the International Mussel Watch (Goldberg, et al., 1978).

I-2 PROJECT DEFINITION AND SCOPE

Pursuant to the ocean disposal plan of the New York District (Army Corps of Engineers), investigators representing the New Jersey Marine

Sciences Consortium conducted a one-year biomonitoring of adult blue mussels transplanted at selected stations within the New York Bight apex (Figure 1) for accumulation of three metals (Hg, Cd, Pb), polychlorinated biphenyls, insecticide (DDT), and No 2 fuel oil. Stations were selected on the basis of proximity to the sand capping site within the six-mile dredged materials dumpsite or other potential contaminant inputs in the region (i.e., Hudson River discharge). The Sandy Hook/Rockaway Point Transect Station (A) was located near the southern end of the transect on Romer Shoal between the Sandy Hook and Ambrose navigation channels where the net current flow is seaward from the Hudson/Raritan estuary. Station B was located within Gravesend Bay in lower New York Harbor and received maximum influence from the Hudson River. Here such urban contributions as ship traffic, local oil spills, sewage effluents, and wind-carried debris must also be considered. Station C near Long Beach, Long Island, occupied a surf zone where wind and wave action represented the major influences. Water depths at Stations A, B, and C ranged from 7.6 to 10.6 meters.

Three stations were located in and around the mud dumpsite. Station D was situated two nautical miles northeast of the dumpsite within the Christiaensen Basin. Station E was located in the northwest quadrant of the dredged material dumpsite, with Station F positioned approximately one mile due west of the dumpsite. Water depths of these three stations ranged from 22.7 to 33.3 meters.

Following deployment in August, 1980, weekly sampling of the original six mussel biomonitoring platforms was attempted for the first month and bimonthly thereafter until July, 1981. Premature loss of mussel platforms occurred at three of the August deployment stations. The Sandy Hook

Transect rig (A) was destroyed immediately after deployment, while the Long Beach Island platform (C) was lost between the end of weekly biomonitoring (week 4) and the first bimonthly sampling effort (week 10). High current velocities and severe storm action were implicated as reasons for the loss of Stations A and C, respectively. The mussel platform deployed within the dredged material dumpsite (E) was irretrievably lost in March of 1981. At that time divers reported that the rig and all but one mussel bag were buried under tons of debris.

In order to assess effects of sand capping within the dredged materials dumpsite, a supplementary deployment of two mussel platforms was made during January, 1981 (Figure 1). Station X was located within the recently-capped southeast quadrant of the dredged materials dumpsite, while Station Y was situated three miles due east of Barnegat Light, New Jersey. Station X was sampled weekly for the first month, after which sampling of platforms at both Stations X and Y was interfaced with the ongoing bimonthly biomonitoring of remaining August-deployed platforms. Mussel platform X was destroyed by an unauthorized dumping operation sometime between the May (week 36) and July (week 45) samplings. Station Y was sampled without incident through the conclusion of field operations.

Individual mussel exposure bags retrieved at each sampling contained 100 adult mussels. Except in cases of extreme mortality, three subsamples of 25 mussels each were obtained from each primary sample. This design permitted statistical comparison of results within and between experimental mussel populations of the respective stations. Total concentrations of mercury (Hg), cadmium (Cd), and lead (Pb), DDT isomers, polychlorinated biphenyls (PCBs), and No. 2 fuel oil were compared with location and

duration of exposure as well as selected mussel parameters (i.e., wet weight and lipid content).

SECTION II: EXPERIMENTAL

II-1 SAMPLING

A relatively large, uniformly sized population of blue mussels (Mytilus edulis) was located 1.5 miles east of Wildwood, (Cape May designation) New Jersey, in 13.7 meters of water. Analysis of a representative sample (Table 4, Appendix A) of this population proved that it was of sufficient quality to act as stock for biomonitoring studies. A total of 7200 mussels from the Wildwood Station was collected, carefully cleaned of adhering epibiota, and transported to Sandy Hook, New Jersey, for subsequent transplantation at six stations in and around the New York Bight dredged material disposal site. Within 20 hours after collection, sets of 100 mussels were carefully placed into Vexar polypropylene mesh bags and suspended one meter from the bottom from specially designed platforms (Figure 3). Each of the six platforms supported twelve mesh bags and a sonar pinger to aid search and recovery operations. A similar protocol was followed during the supplementary January deployment of Stations X and Y.

Following deployment of the platforms in late August, 1980 and January, 1981 (Station X) individual mussel bags were retrieved weekly during the first month after incubation and bimonthly thereafter for the duration of the experiment. Only bimonthly sampling of Platform Y (January deployment) was attempted. Once a diver surfaced with a mussel bag and a sediment sample from a given platform, the bags were carefully wrapped in aluminum foil and transported within six hours to the laboratory at 2-4°C for

pre-analytical measurement and preparation. Coincident with mussel retrieval and sediment collection, the bottom water temperature, salinity, pH, and dissolved oxygen were recorded. Unfortunately, regular sampling was terminated at two stations due to loss of platforms (Table 1). These losses were attributed either to commercial and sport fishing activities or severe storm disturbances.

Following field collection and subsequent transport to the laboratory, all mussels were immediately cleaned using acid-rinsed stainless steel instruments, measured and weighed. Percent survival was determined and individual organisms subjected to pre-analytical preparation.

II-2 ANALYSIS

Rider College was responsible for sample homogenization and distribution to other laboratories and for coordination of all metal analyses. All petroleum hydrocarbon and selected chlorinated hydrocarbon analyses were performed at Ramapo College, while the bulk of PCB and DDT determinations were made by a contract laboratory, New York Testing Service. New Jersey Institute of Technology and Rutgers University acted as intercalibration laboratories for metals and organic contaminants, respectively.

II-2B METAL ANALYSIS

Each composite mussel sample was partially thawed prior to 5-minute homogenization in a blender pre-cleaned with acetone and methylene chloride. Blending was interrupted at one-minute intervals and the sample stirred with a teflon spatula. After blending, the sample was subjected to ultrasonic disruption for three minutes to complete the homogenization.

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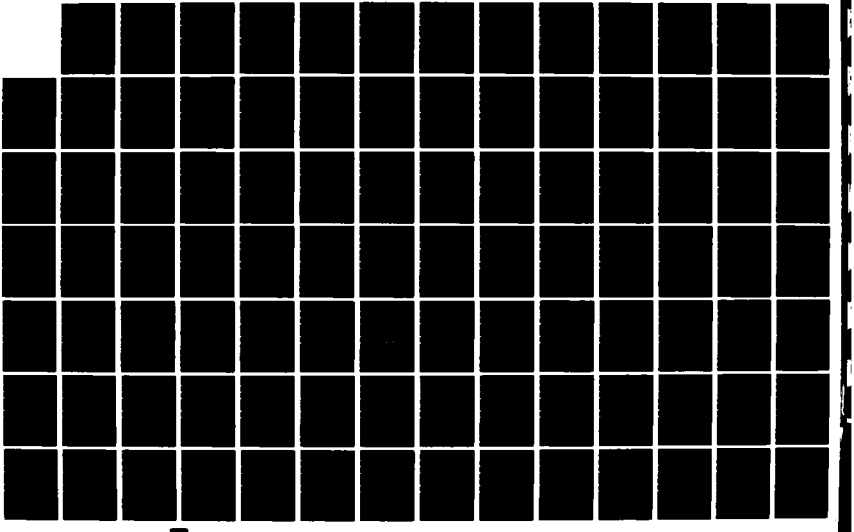

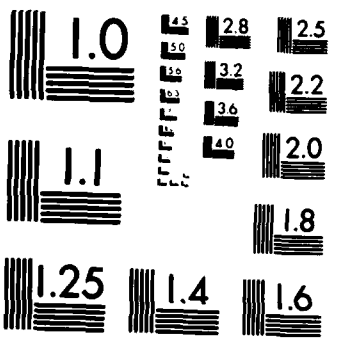

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Appropriate subsamples were then taken for metal analysis (including those for calibration) and specified organic analysis. Prior to actual analysis or further extraction treatments, the subsample fractions were stored at -10°C.

Before removal of aliquots for metal analysis, each subsample was re-homogenized to insure homogeneity. Triple aliquots were then digested and analyzed for mercury (Hatch and Ott, 1968), cadmium and lead (Gries and McGrath, 1977) using atomic absorption spectroscopy. Frequent spiking of subsamples with a 0.5 ppm standard provided assessment of the recovery efficiency of the analytical system used.

Appropriate subsample intercalibration portions were periodically forwarded to the New Jersey Institute of Technology where identical digestion and analytical protocols were employed.

All analytical results were forwarded by Rider College to the contract quality control officer, Mr. Santoro, for evaluation and incorporation into quarterly reports. In addition, all metal data were entered on the Rider College computer for eventual assessment using various statistical packages.

II-2C ORGANIC CONTAMINANT ANALYSIS

Following subsample rehomogenization, pesticides, PCBs, and No. 2 fuel oil were separated from the mussel tissue by subjecting the tissue to a continuous distillation and liquid extraction in a special apparatus designed by T. Sabatino of Rutgers (distributed by Wheaton Scientific). The three substances were finally obtained in a small volume of iso-octane which was subjected to gas chromatographic analysis in two different procedures to obtain both the No. 2 fuel oil and the insecticides, o,p-DDT; p,p'-DDT, p,p-DDD; p,p'DDD; p,p'-DDE and various PCBs.

The insecticides and PCBs were analyzed by gas chromatography using the following column: 1.5% SP-2250 and 1.95% SP-2401 on 100/120 mesh Supelcoport in a 6 ft. x 4 mm ID glass column, kept at 200°C and using nitroget gas at a flow rate of 70ml/min. An Electron Capture (EC) detector containing an electron source of Ni 63 was used. The areas of the chromatographic peak for each substance were measured and compared to those of standards in order to calculate the concentration of these pesticides and PCB compounds in the mussel tissue.

No. 2 fuel oil was analyzed by gas chromatography by means of the following column: 10% UCW 982 on 80/100 mesh WAW-DMCS B39 on a 20" x 1/16" OD stainless steel column. After injection of the sample the column was temperature programmed at a rate of 16°C/minutes to a final temperature of 225°C. The group of chromatographic peaks extending from a retention time of 3.0 to 11.0 minutes were totally integrated. The area was compared to a chromatogram for No. 2 fuel oil standard. The concentrations of No. 2 fuel oil were calculated from these data.

In preparation for lipid analysis, mussel tissue was treated as follows: The subsample was mixed with anhydrous sodium sulfate. A glass column 30 cm x 2.2 cm in diameter with a stopcock was prepared by placing a wad of glass wool in the stopcock end and filling with anhydrous sodium sulfate to form a layer 1-2 cm thick. Then the mussel tissue-sodium sulfate mixture was poured into the column. This mixture was covered by a layer of anhydrous sodium sulfate.

The mussel tissue was extracted with 200 ml of methylene chloride by allowing the solvent to percolate through the column at 3-5 ml/minute. The solvent was collected in a preweighed beaker, allowed to evaporate at room temperature, after which the extracted lipid is weighed and calculated as percentage of sample weight.

II-3 QUALITY CONTROL

During field and laboratory phases of this study appropriate measures were taken to prevent exogenous contamination of mussel samples. The quality control program consisted of two phases, pre-analytical and analytical. The pre-analytical phase included sample deployment, retrieval, and preparation prior to contaminant analysis. The analytical phase involved blanks, recoveries, extraction efficiencies, duplicates, intercalibration exercises and standard comparison.

Two basic types of errors can occur in the analytical program: systematic and random. The former result from faulty procedures and produce erratic results. Random errors are more difficult to diagnose since they are often related to a variety of extraneous factors dealing with analytical precision. The quality control program design used in this study permitted detection of both types of errors and subsequent correction of any problem.

II-3A PRE-ANALYTICAL QUALITY CONTROL

During collection and transport of stock mussels, great care was taken to avoid contamination and maintain viability. Immediately upon collection at the Wildwood location, all mussels were cleaned of epibiota and sorted into size groups as suggested by the NAS (1980). Accordingly, specimens ranging in total shell length between 50 and 80 mm were placed into ice chests and covered with ice packs for the three-hour trip to Sandy Hook. Upon arrival at the deployment base, mussels were further sorted into lots of 100 specimens each and wrapped into incubation bundles using Dupont vexar polypropylene netting. Within six hours these bundles were attached to appropriate platforms aboard the deployment vessel and, using diver support teams, subsequently lowered down to the eight benthic locations within the New York Bight.

Following retrieval by divers each bag of mussels was carefully opened, byssal threads cut, and mussel survival determined. Viable mussels were then randomly split into three subsamples of 25 animals each. (Note: in cases of severe mortality only two subsamples could be prepared.) Individuals within each subsample were then carefully cleaned of any epibiota, measured, weighed, and drained of liquor from the mantle cavity. Shucking followed, after which pooled liquor and viscera for each subsample were weighed and then placed in a clean analysis jar. All samples were stored at -20°C prior to initiation of analytical procedures. Every attempt was made to analyze tissues within one month of delivery.

During all phases of pre-analytical operations, laboratory personnel used sterile surgical gloves when handling mussels. All laboratory tables, surgical implements, measuring equipment and glassware were pre-cleaned with methylene chloride, acetone and distilled water washes (in that order).

II-3B ANALYTICAL QUALITY CONTROL

Accuracy and precision of residue determinations are dependent upon effluent extraction and fractionation, analytical materials which have uniform behavior and low background, as well as proper instrument maintenance and calibration. To evaluate these factors, duplicate and spiked samples were analyzed for a minimum of 10 percent of contracted samples. These analyses were distributed over the entire year. Detailed analytical quality control protocols are presented in the Appendix I.

II-4 STATISTICS

Triplicate analyses for each collection period were performed and examined for significant differences and then evaluated using the method

of standard error within each triplicate and over time. Lack of significant differences within each triplicate allowed a pooled mean to be used which was calculated by the following formula:

$$\bar{X}_{a+b+c} = \frac{(Na\bar{X}a + Nb\bar{X}b + Nc\bar{X}c)}{(Na + Nb + Nc)}$$

where xa+b+c is the pooled mean of groups A, B, and C; xa, xb, and xc are the means of groups a, b, and c; Na, Nb, and Nc are the sample sizes of groups A, B, and C, respectively.

Significant differences were noted by the end of the second week of incubation, with uptakes for lead and cadmium at $0.02 > P > 0.01$. An even more significant uptake resulted for mercury after the first week of incubation ($0.01, P > 0.001$).

Analytical sets were subjected to a two standard deviation exclusion criteria to exclude data which may be unreliable (those points not within a 95% probability range). Graphic presentation of this data is presented versus time. Trend lines for all stations were established using the method of least squares.

In addition, covariance, correlation coefficients, log curve fits, as well as exponential curve fits were established for each station and contaminant concentration. All resulted in poor correlations (r .5) when compared to mussel viscera weight and length.

In addition to trend and regression analyses, all organic contaminants were examined for fluctuations in pollutant levels versus lipid concentrations. Poor or indiscriminate correlations resulted.

As a first step in station comparison, analysis of variance was calculated for all replicates and dates, as well as between and among stations. Replicates for each date showed no significant differences among each other for all contaminants and stations (alpha = 0.05),

thereby confirming analytical reliability. Variance of the mean contaminant concentration for each station was then statistically tested to insure that a statistical difference existed for a given contaminant at the 95% confidence level. After significant differences were noted at each station for a contaminant, the data were then evaluated using a Duncans Multiple Range Test. The latter identified the degree of difference or homogeneity between stations. Any significant difference in this test would indicate that the station in question was distinct and separate from other stations relative to a particular contaminant.

When contaminant accumulation rates at all stations were analyzed over time using the Duncans Multiple Range Test, no further resolution of trends was apparent.

SECTION III: RESULTS

III-1 GENERAL

As previously stated, this project was designed to permit quantification of mercury, lead, cadmium, PCB, DDT, and No. 2 fuel oil in soft tissues of blue mussels transplanted within the New York Bight. Mussels selected for use in this experiment were of relatively uniform length and weight. Shell lengths ranged between 66.4 and 68.0 mm with visceral weights of 8.1 to 9.8 grams. Where appropriate, analytical results were evaluated statistically in order to discern meaningful data trends. Results are presented in Tables 4-34. DDT isomers present a special case. Since these contaminants were generally below analytical detection limits they were not statistically evaluated. All other data produced in this project were evaluated with response curves and trend lines. (Raw data are presented for each contaminant group followed by appropriate statistical evaluation.)

III-2 PHYSICAL PARAMETERS

Additional data collected concomitant with mussel collections included temperature, salinity, and dissolved oxygen measurements. These samples were taken at the station depth of incubating mussels (Table 2). In general, all three parameters exhibited seasonal fluctuations consistent with those previously noted in the New York Bight.

III-3 MUSSEL SURVIVAL

Survival data for retrieved mussels are given in Table 3. With the exception of reference stations C and F (Figure 1), survival was generally

greater than 70 percent for August-deployed animals. Throughout the exposure period mussels retrieved from Station F exhibited relatively depressed survival. No seasonal trend in survival was apparent for mussels of August-deployed stations. The negligible mortality observed among mussels deployed in January at Stations X and Y most likely reflects seasonality-dependent changes in mussel physiology--namely, reduced metabolism in response to winter temperatures.

III-4 CONTAMINANT PROFILE OF STOCK MUSSELS

Cadmium, lead, and mercury analyses of pooled subsamples of stock mussel tissues (prepared in conjunction with both August and January deployments) are presented in Table 4. Levels of cadmium and mercury in stock mussels are well below background. A slight elevation in lead concentration is apparent.

III-5 METAL RESIDUE IN MUSSEL TISSUE

Analyses of cadmium, lead, and mercury in transplanted mussel samples as well as intralaboratory quality control data are summarized in Tables 5-11. Mussel shell length, maximum values by station for the entire year, and visceral weight are also provided in these tables.

Uptake of cadmium by transplanted mussels over time is graphically presented in Figure 4. As early as three weeks following deployment, significant increases in cadmium were observed among August-deployed mussels. Despite an irregular stationwide pattern of uptake of this metal, regression analysis (Figure 5) indicated a higher rate of uptake for mussels collected from the dredged material dumpsite (Station E).

Data for both lead (Figure 6) and mercury (Figure 8) suggest a similar pattern of accumulation over time. After an initial elevation during the first month of incubation, a significant decrease in total concentration was followed by renewed accumulation. Trend lines suggest similar behavior among all stations relative to lead accumulation (Figure 7). In the case of mercury (Figure 9), significantly greater uptake is indicated for Station E at the dredged material dumpsite, both in terms of rate and total concentration.

No appreciable accumulation of cadmium, lead, or mercury is apparent for mussels exposed at Stations X and Y. However, since the latter mussel arrays were deployed in mid-winter, it is conceivable that these animals would possess significantly reduced metabolism, hence minimal feeding activity and less opportunity for metal bioaccumulation.

Duncans Multiple Range Tests for mean mussel concentrations of mercury, cadmium and lead are presented in Tables 29-31, respectively. Results for mercury (Table 29) indicate that all stations in and around the dredged material dumpsite (Stations D, E, and F) are significantly different (95% confidence level) than those stations outside the dumpsite area. Moreover, mercury concentration at Station E (within the dumpsite proper) is significantly different from those of the two adjacent reference stations (D and F). The mean mercury concentration is lowest for stock mussels collected at the Cape May station, a location significantly removed from the New York Bight apex.

Results for cadmium (Table 30) are similar to those described for mercury. Once again, the dumpsite showed the highest mean concentration

in mussel tissue, with Station E being statistically different from all other stations.

Duncans Multiple Range Test for lead (Table 31) failed to show a clear contamination pattern. Although Stations D, E, and F all show higher mean concentrations of lead than stations outside the dumpsite region, mussel concentrations for Station E (within the dredged material dumpsite) was not statistically different from Stations C (Jones Beach) and X (capping site).

III-6 POLYCHLORINATED BIPHENYL RESIDUES IN MUSSEL TISSUE

Mixed PCB residues in mussel samples are summarized in Table 12. After the third week of incubation, concentrations exceeded 0.6 ppm for mussels collected at Stations C, E, and F. A pronounced decline in levels of this contaminant was apparent ten weeks after deployment (with the exception of Station B) followed by a gradual increase during the spring.

Mussels deployed in January at Station X showed comparable increases to those of surviving August-deployed stations (between weeks 20 and 36). Mussels collected from all surviving stations in July showed net decreases in PCBs over levels observed in May-collected animals.

Linear regressions for PCB concentration versus time (Figure 10) resulted in positive correlation for mussels exposed at Station C. Conversely, Stations B and X showed no correlation with time. Data for Stations D, E, F, and Y are inconclusive. Subsequent evaluation of lipid-adjusted PCB concentration (Table 26) in mussel tissues does not show me ningful correlation. However, a weak positive correlation (r = ∪ 55, was noted for mussels incubated at Station E and a strong negative correlation (r = 0.92) for Station C mussels.

Duncans Multiple Range Test for PCBs is presented in Table 32. Jones Beach Station (C) exhibited the highest mean concentration of this contaminant, which is significantly different from all other stations including those in and around the dredged materials dumpsite. No significant differences were apparent between Station B (Gravesend Bay) and Stations D, E, and F. Cape May-collected stock mussels exhibited the lowest mean PCB concentration versus the New York Bight stations.

III-7 RESIDUES IN MUSSEL TISSUES

Although concentrations of this insecticide generally remained below the 0.02 ppm detection limit (Table 13), negligible accumulation was observed during the first three weeks of incubation among August-deployed mussels.

Analysis of variance for DDT residue concentration versus station and date resulted in no significant differences for either variable. Accordingly, Duncans Multiple Range Test was not applied to these contaminants.

III-8 No. 2 FUEL OIL RESIDUES IN MUSSEL TISSUES

No. 2 fuel oil levels in transplanted mussel tissues are summarized in Table 14. Subsequent response curves (Figure 11) showed a similar pattern of accumulation for mussels from all August-deployed stations. An initial accumulation (by week 4) is followed by a generalized decrease in No. 2 fuel oil by week 10 (first bimonthly collection). A dramatic increase in No. 2 fuel oil accumulation is evident for all stations between weeks 19 and 29. Interestingly, January-deployed mussels from Stations X and Y show a similar increased uptake during this same period of time.

Diminished No. 2 fuel oil levels were apparent among mussels collected from surviving platforms (B, D, F, and X) during the final sampling (week 36).

Trend lines (Figure 12) of No. 2 fuel oil over time indicate good correlation for mussels incubated at Stations B, D, E, F, and X. Poor correlation at Stations C and Y most likely reflect minimal sampling frequency, with Stations C, E, and F showing poor correlations and Stations B and D having good correlations. Similarly, Stations X and Y showed good correlation.

Duncans Multiple Range Test for No. 2 fuel oil is presented in Table 23. Both January-deployed Stations (X and Y) have significantly higher concentration of this contaminant as compared with August-deployed stations. Station E (within the dumpsite) has a relatively low mean concentration of No. 2 fuel oil.

Of those four stations which showed good linearity over time, Station X showed a significantly greater uptake trend ($r = .84$). No clear correlation could be found between No. 2 fuel oil and lipid content (Table 27) in collected mussels at all stations, with Stations C, E, and F showing poor correlations and Stations B and D having good correlations. Similarly, Stations X and Y showed good correlation values.

III-9 MUSSEL LIPIDS

Mussel lipid data are summarized in Table 28. Generally speaking, few, if any, seasonal trends are apparent for those stations sampled over the entire year.

III-10 SEDIMENT CONTAMINANT ANALYSES AND CHARACTERIZATION

Surficial sediment samples (top 5 cm) were collected in conjunction with mussel sampling. Analytical results of sediment parameters for sediments collected at the beginning of the study are presented with their respective contaminant profiles in Table 15. Station F contained the highest sediment values for all three metals. Sites F and E had No. 2 fuel oil concentrations of 76.1 ppm and 59.2 ppm, respectively. Sediments were found to be predominantly sandy and similar in percent water, organic matter, and grain size for all stations.

III-11 ANALYTICAL QUALITY ASSURANCE

In general, the Quality Control analyses were acceptable, with reproducibility in decreasing order:

Heavy metals > No. 2 fuel oil > PCBs > DDTs.

III-11A METALS

Reagent blanks for mercury, cadmium, and lead were 0.00, 0.01, and 0.02 ppm, respectively. In addition, all duplicate ratios (100%) were in the acceptable range of 1.0-3.0 (Table 16), and spike recoveries ranging from 95-100 percent recovery (Table 15).

III-11B POLYCHLORINATED BIPHENYLS

The preferred analytical precision range for mixed PCB analyses (1.0-3.0) contained 75 percent of all analyses (Table 17). Tissue and gas chromatograph spike recoveries were more variable than No. 2 fuel oil (34-115%) (Tables 18-20). This is similar to interlaboratory calibrations reported by Uthe (personal communication, 1981) while

comparing PCB analyses from five individual laboratories. The majority of the gas chromatograph spikes were above 86 percent. Interlaboratory comparisons of mixed PCBs in the present study show the primary laboratory (New York Testing) to be more reproducible at lower concentrations than the secondary laboratory.

III-11C DDT

DDT spike recoveries were the most variable, with recoveries ranging from 16-140 percent (Table 21). However, with the introduction of the primary laboratory (New York Testing) (Table 22) the reproducibility remained high, with 100 percent of their analyses within the acceptable range (1.0-3.0) (Table 23).

III-11D No. 2 FUEL OIL

Duplicate ratios for No. 2 fuel oil (Table 24) show good analytical precision, with 88 percent of all analyses within the acceptable range. Tissue and gas chromatograph spikes ranged from 52-100 percent with the majority of the spikes above 85 percent recovery (Tables 25-27, Figure 13).

SECTION IV: DISCUSSION

Bioaccumulation of trace metals in natural mussel populations exposed to contaminated sediments has been sporadically reported. Harris, et al. (1979), noted lead concentrations in excess of WHO food standards in mussels collected at 19 of 22 locations in Port Phillip Bay, Australia. Cadmium was found to increase in concentration linearly with shell length. McGreer, et al. (in press), reported bioaccumulation of zinc, copper, and lead by mussels transplanted near a shipyard facility in Vancouver Harbor. Interestingly, results for transplanted mussels were markedly different from those of indigenous populations, as well as from mussels used in controlled laboratory bioaccumulation tests. Although Feng, et al. (1979), reported net accumulations of metals in mussels transplanted near dredged material dumpsites along the New England coast, no cause and effect correlation with dredged material disposal could be verified.

In this investigation, accumulation of mercury, cadmium, and lead by mussels transplanted at the August-deployed platforms was observed. Both concentration and accumulation rates of mercury and cadmium were found to be statistically greater for mussels exposed at the dredged material dumpsite versus reference platforms. The untimely loss of Platform E in March of 1981 made it impossible to determine if concentrations continued to increase or to stabilize. Data for the adjacent reference platforms at Stations D and F indicated a leveling off in mercury concentrations between March and July of 1981. Such seasonal oscillations in metal concentrations for a given station have been described by other investigators (Boyden, 1977; Phillips, 1976b; Phillips, 1977; Karbe, 1977). This may reflect seasonal

variations in metal availability as well as biological parameters (i.e., lipid content, reproductive status, filtration rate and depuration) (Talbot, et al., 1976).

Options vary as to the extent to which PCB bioaccumulation in Mytilus edulis can be related to the presence of contaminated sediment. Young, et al. (1976), reported a twenty-fold increase in PCB concentration (from 0.05 to 0.94 ppm) in transplanted M. edulis exposed for 13 weeks (during the summer) near a Southern California sewage outfall site. A direct relationship was noted between PCB accumulation and the proximity of the mussels to contaminated sediments (as well as the wastewater plume). Within one week, PCB levels increased eighteen-fold, followed by net loss during the seventh week, and subsequent accumulation to maximum levels by week 13. Pearce (personal communication, 1981) reported that PCB concentrations ranged from 0.03 to 0.78 ppm for indigenous mussel samples collected from seven inshore sites within the New York Bight. Interestingly, highest tissue concentrations were detected for mussels collected from Shark River Inlet, New Jersey, whereas tissue concentrations near the entrance to heavily-contaminated New York Harbor were in the range of 0.1 to 0.2 ppm. Pearce further suggested that relating PCB accumulation by biological monitors such as Mytilus edulis to contaminated sediments cannot be adequately assessed until the relative importance of other routes of accumulation (such as overlying and interstitial water, diet, and sediment ingestion) have been determined.

In the present study, PCB concentrations were observed to increase fifteen- to thirty-fold during the first four weeks of exposure for mussels deployed in August of 1980 (Stations B, C, D, E, and F), after which a pronounced decline in PCB concentration was apparent between weeks 5 and 25

for all surviving stations except D. Renewed uptake to maximum levels was apparent by March for all stations. A second decline in PCB concentration was evident for those surviving stations sampled in July, 1981. Differences in PCB accumulation between stations were not statistically significant. Young, et al. (1976), while noting variation in PCB accumulation by Mytilus edulis, attributed such fluctuations to spawning and/or decreased availability of the contaminant. In this regard, the apparent lack of correlation between PCB levels with mussel lipids is puzzling, in light of the documented propensity of these contaminants for tissue lipids.

The pattern of No. 2 fuel oil accumulation exhibited stationwide by transplanted mussels in this study is consistent with that previously reported for bivalves transplanted in moderate to heavily-contaminated inshore waters. Relatively minimal accumulation was observed for the first three months of exposure, after which a hundred-fold increase in No. 2 fuel oil concentration was apparent in January and March, 1981. The latter increased accumulation may reflect increased availability of contaminant as well as changes in the mussels themselves, such as increased metabolic rates associated with onset of spawning and increased filtration activity. Fuel oil concentrations for mussels collected from remaining (intact) mussel platforms in July suggest that an equilibrium had taken place within mussels relative to this contaminant. Burns and Smith (1977) noted a similar equilibration between transplanted mussels and seawater petroleum hydrocarbon levels as early as 90 days post-deployment, after which no net additional accumulation was evident.

The relationship of sediment petroleum hydrocarbon levels to mussel tissue levels has not been conclusively established. Eaton and Zitko

(1979) have suggested, based upon transplantation studies, that bivalves are useful as indicators of gross differences in sediment petroleum hydrocarbon concentration, but only if such fluctuations are greater than two orders of magnitude. Gilfillan and Vandermeulen (1978) observed that five-fold differences in sediment concentration resulted in netincreases in bivalve accumulation of petroleum hydrocarbons.

In the absence of ancillary sediment and water data, it is not possible to relate elevated No. 2 fuel oil levels in New York Bight-transplanted mussels solely to sediment contamination (although we did demonstrate statistical differences). Petroleum accumulation in an estuarine region such as the New York Bight most likely reflects uptake of both water-soluble and particulate forms of these contaminants (Risebrough, et al., 1979). In this regard, Van Vleet and Quinn (1978) estimated that most fuel oil entering the New York Bight results from chronic input such as municipal wastewater or treatment plants rather than oil spills and operational discharges. Farrington (1977) theorized that ratios of alkylated phenanthrenes to parent phenanthrenes detected in mussel watch samples collected near Rockaway, New Jersey, suggest that these mussels are mainly subjected to combustion product aromatics rather than fuel oil or crude oil-derived aromatic hydrocarbons. In all probability, the observed No. 2 fuel oil levels in this study reflect a complex overall chronic petroleum hydrocarbon contamination resulting from several sources, including both coastal runoff and operations such as ocean dumping. The present state of the art regarding petroleum hydrocarbon analytical chemistry is such that the question of pathways into the mussel is speculative at best.

The evaluation of mussel contaminant bioaccumulation following sand capping was only partially effective due to delayed deployment, a comparatively short monitoring period, and the untimely loss of the capping site platform (X) following sampling in May, 1981. Seasonal differences in mussel activities, particularly reduced filtration rate and metabolism, could explain the scant mortalities observed at both stations (X and Y) as well as the minimal metal bioaccumulation at the capping site. However, accumulation of both No. 2 fuel oil and PCBs was consistent with those of August-deployed mussels. Rather high levels of No. 2 fuel oil detected among mussels collected from the Barnegat reference station platform (Y) appear to further substantiate the ubiquitous presence of these contaminants within the New York Bight.

Mussel survival did not statistically correlate with bioaccumulation of any contaminant for a given station. The comparatively high metal concentrations noted in Station F surficial sediment (taken at the August deployment) may have contributed to mussel mortality, but the absence of comprehensive water and sediment analyses for the entire year make this hypothesis tentative at best.

As implied several times in this discussion, the lack of corroborating water, sediment, and food data (for mussels) limits the degree to which mussel contaminant bioaccumulation may be specifically related to dredged material disposal at the six-mile dumpsite. Although the investigators routinely sampled sediments during the biomonitoring, funding limited analysis to only those samples taken at the August deployment. Any future monitoring study of this nature must include accommodation for such data.

SECTION V: CONCLUSIONS

1. DDT concentrations were generally below detection for mussels from all stations. All three metals (Hg, Cd, Pb), PCBs, and petroleum hydrocarbons were consistently detected in mussel samples. None of the contaminants were detected in excess of FDA action levels for fish and shellfish (Table 34).

2. Bioaccumulation of mercury and, to a lesser degree, cadmium were greater for mussels incubated at the dredged material dumpsite than at the other stations.

3. With the exception of mussels incubated in Christiaensen's Basin (Station D), PCB tissue concentrations were erratic over time. Mean PCB concentrations were generally below 0.5 ppm.

4. No. 2 fuel oil accumulation over time was similar for mussels incubated at all stations (excluding the Barnegat Reference Station). A dramatic stationwide increase (to over 100 ppm for all stations) was observed in the spring.

5. Metal accumulation was negligible for mussels deployed at the capping site. PCB and petroleum hydrocarbon levels were consistent with those of mussels in the August-deployed stations.

6. Contaminant bioaccumulation could not be statistically correlated with either physicochemical parameters or mussel condition.

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Table 1. Biomonitoring Stations and Dates of Deployment

Station	Location	Water Depth Meters	Date of Deployment
A. Sandy Hook/ Rockaway Point Transect	73° 59'W 40° 30'N	7.6	Aug. 21, 1980
B. Gravesend Bay	74° 08'W 40° 35'N	10.6	Aug. 21, 1980
C. Long Beach, Long Island	73° 35'W 40° 34'N	9.0	Aug. 28, 1980
D. Christiansen Basin 2 N. mi. NE of Dredge Material Dump Site	73° 48'W 40° 25'N	33.3	Aug. 28, 1980
E. NW quadrant of Dredge Material Dump Site	73° 51'W 40° 23'N	22.7	Aug. 27, 1980
F. 1 N. mi. due W of Dredge Material Dump Site	73° 52'W 40° 22'N	25.7	Aug. 27, 1980
X. Capping Site	73° 50'W 40° 22'N	29.3	Jan. 24, 1981
Y. 3 mi. due W of Barnegat Light	74° 05'W 39° 46'N	22.9	Jan. 24, 1981

TABLE 2 PHYSICAL PARAMETERS ASSOCIATED WITH THE MUSSEL WATCH SAMPLING STATIONS

LOCATION (CODE)	DATE	T °C	S °/oo	O_2 ppm
Gravesend Bay B	8/29	21.5	30.24	6.1
	9/5	22.0	30.1	5.2
	9/18	21.0	28.8	5.6
	9/25	18.0	30.1	6.45
	10/3	17.5	28.7	4.5
	11/6	12.0	27.52	7.3
	2/6	-1.0	29.02	10.5
	3/10	3.0	27.57	10.5
	5/8	12.0	27.31	6.6
	7/9	20.0	—	—
Jones Beach C	9/3	19.5	32.19	5.7
	9/18	20.0	31.96	6.45
	9/25	18.0	32.04	8.45
	10/3	17.0	32.22	6.1
	"Station Lost After 10/3"			
2 Miles Northeast of the Dredged Mud Dump D	9/12	14.0	—	5.4
	9/19	18.0	32.25	4.7
	9/24	16.0	33.03	5.65
	10/2	16.5	27.56	6.6
	11/5	12.0	33.39	6.45
	1/6	3.0	33.96	8.1
	3/10	3.0	32.58	11.0
	5/8	10.0	32.93	9.25
	7/9	20.0	—	—
At the Dredged Mud Dumpsite E	9/11	20.0	32.42	6.25
	9/19	18.0	32.33	4.0
	9/24	16.0	32.63	6.3
	10/2	17.4	32.3	5.6
	11/5	12.5	33.14	7.5
	1/6	4.0	33.76	9.7
	3/10	2.0	32.58	11.0
	3/12	2.0	30.58	—
	"Station lost after 3/12"			
1 Mile Southwest of the Dredged Mud Dumpsite F	9/11	19.0	32.2	7.5
	9/19	18.0	32.24	4.2
	9/24	16.0	32.87	5.64
	10/2	17.6	32.17	—
	11/5	12.6	33.21	7.3
	1/6	4.0	33.69	9.55
	3/12	2.0	—	10.55
	5/8	10.0	32.15	9.2
	7/13	21.1	31.03	—
The Capping Area at The Dredged Mud Dumpsite I	2/6	1.0	33.76	11.5
	2/13	1.0	33.67	—
	2/25	1.0	32.61	—
	3/12	3.0	31.81	11.75
	5/8	10.0	33.01	9.4
	"Station lost after 5/8"			
Barnegat Light Site Y	3/19	3.5	32.76	—
	5/7	—	32.12	9.8
	7/13	21.1	—	—

TABLE 3

PERCENT SURVIVAL FOR BLUE MUSSELS *Mytilus edulis* RETRIEVED FROM ALL SAMPLING STATIONS

STATION CODE	LOCATION	PERCENT SURVIVAL BY WEEKLY INTERVAL								
		Wk 1	Wk 2	Wk 3	Wk 4	Wk 10	Wk 19	Wk 29	Wk 36	Wk 45
B	Gravesend Bay	90	95	91	83	76	87	73	75	74
C	Jones Beach	54	50	90	80	-	-	-	-	-
D	2 Miles NE of the Dredged Mud Dumpsite	94	80	73	85	79	89	85	76	86
E	At the Dredged Mud Dumpsite	76	73	84	93	86	72	92	-	-
F	1 Mile SW of the Dredged Mud Dumpsite	66	63	62	59	72	71	65	75	60
X	At the Dumpsite Capping Area *	100	99	100	98	100 (Wk 12)	- (Wk 21)	end of study		
Y	Barnegat Light *	-	-	-	99	100	97	end of study		

* Not sampled concurrently with stations B through F.

TABLE 4. COMPARISON OF TRACE CONTAMINANT PROFILES FOR WILDWOOD STOCK MUSSEL POPULATIONS FOR THE AUGUST AND JANUARY DEPLOYMENTS IN THE NEW YORK BIGHT

Parameter	August 1981	January 1981
Cadmium ppm	.049 ± .007	.048 ± .008
Lead ppm	.85 ± .10	.82 ± .05
Mercury ppm	.019 ± .004	.03 ± .01
Lipids ppm	1.31	.86
Total Polychlorinated biphenyls ppm	.04 ± 0.0	.04 ± 0.0
Fuel Oil # 2	.01 ± .02	.05 ± .03
DDT isomers	.02 ± .16	.02 ± 0.0

TABLE 5

CADMIUM, LEAD AND MERCURY ANALYSES FOR COMPOSITE BLUE MUSSEL, Mytilus edulus SAMPLES COLLECTED FROM GRAVESEND BAY (STATION B). EXPRESSED AS PARTS PER MILLION WET WEIGHT

DATE	SHELL LENGTH (mm)	VISCERA WEIGHT (g)	METAL ANALYSES Cd ± $\bar{s}\bar{x}$	Pb ± $\bar{s}\bar{x}$	Hg ± $\bar{s}\bar{x}$	%RECOVERIES Cd	Pb	Hg	DUPLICATES Cd	Pb	Hg
8/29	68.6±5.5	13.3±3.5	.04±.006	.81±.05	.017±.006	98	96	98	1.25	1.12	2.0
"	68.6±6.3	11.4±3.4	.04±.01	.93±.16	.023±.006	-	-	-	1.66	1.41	1.5
"	66.4±7.4	13.8±3.7	.04±.02	.85±.10	.027±.006	-	-	-	2.5	1.26	1.5
9/5	66.6±7.9	10.5±3.0	.043±.006	.86±.08	.03±.01	97	95	98	1.25	1.19	2.0
"	65.6±7.6	10.9±3.8	.05±.01	.87±.07	.023±.006	-	-	-	1.5	1.18	1.5
"	66.3±7.5	11.7±3.5	.047±.006	.81±.02	.017±.01	-	-	-	1.25	1.06	3.0
9/18	69.7±5.98	11.0±3.1	.047±.006	.84±.02	.027±.006	-	-	-	1.25	1.06	1.5
"	64.2±6.3	9.4±3.0	.04±.01	.95±.03	.020±.006	100	100	98	1.66	1.06	2.0
"	66.0±5.2	9.6±3.0	.07±.01	1.03±.08	.03±.006	100	97	100	1.33	1.15	1.5
9/25	68.0±4.1	11.1±2.7	.06±.01	1.08±.06	.03±0.0	-	-	-	1.6	1.13	1.0
"	67.0±5.6	10.0±2.8	.04±.006	1.08±.02	.02±.006	-	-	-	1.25	1.05	2.0
"	67.0±7.0	10.0±2.3	.06±.006	1.27±.04	.05±.01	98	100	100	1.2	1.06	1.75
10/3	67.0±7.0	9.3±3.2	.08±.01	.97±.05	.04±.006	-	-	-	1.28	1.12	1.33
"	68.0±4.0	8.6±3.0	.06±.006	1.04±.09	.03±.006	-	-	-	1.20	1.19	1.33
"	67.0±6.0	9.5±3.0	.04±.006	.90±.03	.04±.006	-	-	-	1.25	1.06	1.33
11/6	67.0±6.7	7.1±2.8	.05±.01	1.01±.02	.05±.006	-	-	-	1.75	1.05	1.25
"	65.6±6.2	7.1±1.9	.06±.01	1.12±.08	.06±.006	98	96	100	1.4	1.15	1.2
"	68.0±.44	8.3±2.1	.06±.006	.97±.02	.04±.006	-	-	-	1.2	1.05	1.25
02/6	62.9±5.3	7.5±2.9	.08±.006	.88±.02	.06±.006	-	-	-	1.12	1.05	1.2
"	67.4±6.6	8.1±3.0	.07±.01	1.22±.07	.05±.006	100	100	100	1.33	1.13	1.25
"	64.0±4.9	7.9±2.1	.08±.006	1.10±.13	.06±.01	100	99	100	1.12	1.26	1.4
03/10	73.0±4.9	11.3±2.75	.08±.001	1.02±.05	.05±.001	-	-	-	1.12	1.09	1.2
"	69.9±5.5	11.3±2.9	.07±.001	1.00±.03	.04±.001	98	100	100	1.14	1.09	1.25
"	66.3±5.3	8.2±2.1	.08±.01	1.09±.07	.05±.001	-	-	-	1.28	1.17	1.2
05/8	70.2±8.2	13.4±3.7	.08±.001	1.15±.08	.06±.001	-	-	-	1.14	1.14	1.2
"	74.4±5.2	15.4±3.4	.08±.01	1.12±.12	.05±0.0	96	98	100	1.28	1.22	1.0
"	69.0±4.2	12.9±2.6	.08±.01	1.05±.07	.06±0.0	-	-	-	1.33	1.13	1.0
07/9	69.1±6.8	11.2±3.0	.09±.01	1.23±.05	.05±.01	-	-	-	1.28	1.08	1.5
"	70.0±6.7	11.7±2.8	.08±0.0	1.16±.05	.05±0.0	98	98	98	1.0	1.08	1.0
"	73.1±5.9	13.3±3.2	.07±.001	1.15±.15	.06±.001	101	98	100	1.14	1.29	1.16

TABLE 6

CADMIUM, LEAD AND MERCURY ANALYSES FOR COMPOSITE BLUE MUSSEL, Mytilus edulus SAMPLES COLLECTED FROM JONES BEACH, LONG ISLAND NEW YORK (STATION C).
EXPRESSED AS PARTS PER MILLION WET WEIGHT

DATE	SHELL LENGTH (mm)	VISCERA WEIGHT (g)	METAL ANALYSES Cd ± $\bar{sx}$	Pb ± $\bar{sx}$	Hg ± $\bar{sx}$	%RECOVERIES Cd	Pb	Hg	DUPLICATES Cd	Pb	Hg
9/3	65.0±5.5	11.0±3.4	.053±.01	.89±.12	.013±.006	98	97	99	1.5	1.25	2.0
"	68.1±5.9	13.1±2.5	.053±.006	.89±.03	.02±.006	-	-	-	1.2	1.07	1.5
"	61.7±5.3	8.75±1.7	.047±.006	.84±.06	.027±.006	-	-	-	1.25	1.14	1.6
9/18	67.0±7.0	11.1±2.9	.05±.01	.97±.04	.07±.01	-	-	-	1.5	1.10	1.6
"	68.0±6.0	10.6±3.2	.04±.01	1.09±.06	.10±.01	100	98	98	1.6	1.11	1.33
9/25	66.0±7.0	8.8±2.2	.04±.006	1.3±.03	.10±.01	-	-	-	1.25	1.05	1.37
"	70.0±5.0	10.0±2.9	.07±.006	1.14±.03	.06±.006	98	99	100	1.17	1.05	1.17
"	66.6±8.0	7.7±3.5	.07±.006	.96±.02	.04±.006	-	-	-	1.14	1.04	1.33
10/3	68.6±5.0	8.7±2.4	.06±.006	1.25±.03	.02±.006	100	100	100	1.17	1.05	1.5
"	61.0±7.0	7.9±3.1	.07±.006	.99±.06	.05±.01	-	-	-	1.16	1.12	1.75
"	69.0±6.5	9.3±2.4	.05±.006	.94±.03	.05±.01	-	-	-	1.25	1.07	2.0

TABLE 7

CADMIUM, LEAD AND MERCURY ANALYSES FOR COMPOSITE BLUE MUSSEL, *Mytilus edulus* SAMPLES COLLECTED FROM 2 MILES NORTHEAST OF THE DREDGED MUD DUMPSITE (STATION D). EXPRESSED AS PARTS PER MILLION WET WEIGHT

DATE	SHELL LENGTH (mm)	VISCERA WEIGHT (g)	METAL ANALYSES Cd ± $\bar{s}\bar{x}$	Pb ± $\bar{s}\bar{x}$	Hg ± $\bar{s}\bar{x}$	%RECOVERIES Cd	Pb	Hg	DUPLICATES Cd	Pb	Hg
9/12	64.7±5.8	8.9±2.2	.043±.01	.887±.12	.023±.006	99	98	97	1.66	1.25	1.5
"	66.5±7.5	8.0±2.4	.05±.01	.893±.03	.017±.006	-	-	-	1.5	1.07	2.0
"	65.7±5.0	8.5±2.4	.047±.006	.837±.06	.02±.01	-	-	-	1.25	1.14	3.0
9/19	66.0±13.0	7.4±2.0	.04±.006	.92±.03	.03±.01	-	-	-	1.25	1.07	2.5
"	67.0±6.0	9.2±3.8	.04±.006	.90±.02	.02±.006	-	-	-	1.33	1.06	2.0
"	64.0±6.0	8.0±2,8	.05±.006	1.1±.07	.29±.006	-	-	-	1.2	1.14	1.04
9/24	68.0±6.0	7.78±2.1	.06±.006	1.07±.09	.14±.02	-	-	-	1.2	1.17	1.33
"	65.0±6.0	8.4±2.5	.04±.006	.90±.04	.07±.01	-	-	-	1.25	1.08	1.33
"	68.0±6.0	10.0±2.4	.05±.006	.95±.03	.03±.006	-	-	-	1.2	1.07	1.5
10/2	69.0±5.0	8.9±2.5	.03±.01	1.03±.06	.05±.01	-	-	-	2.0	1.12	1.5
"	66.0±4.0	7.2±2.5	.07±.006	1.09±.05	.13±.006	-	-	-	1.17	1.09	1.08
"	72.0±5.0	8.9±2.2	.07±.01	1.16±.14	.09±.01	100	103	100	1.33	1.28	1.37
11/5	67.7±5.5	6.3±2.0	.07±.006	1.21±.05	.12±.01	-	-	-	1.14	1.09	1.18
"	67.3±6.4	6.4±2.0	.07±.01	1.22±.09	.12±.006	-	-	-	1.33	1.14	1.08
"	68.3±4.6	6.8±1.8	.05±.006	1.16±.05	.15±.01	96	100	100	1.2	1.09	1.14
01/6	66.3±6.7	7.9±3.4	.05±.01	1.22±.03	.14±.006	-	-	-	1.5	1.05	1.07
"	71.5±4.2	10.4±4.5	.07±.01	1.12±.04	.13±.01	-	-	-	1.33	1.06	1.16
"	67.7±4.5	7.4±1.9	.07±.01	1.28±.02	.16±.01	100	98	98	1.6	1.04	1.13
03/10	66.4±9.8	10.8±2.7	.08±.01	1.28±.08	.16±.001	96	98	100	1.28	1.13	1.06
"	72.0±6.6	11.8±3.6	.06±.001	1.25±.09	.14±.02	-	-	-	1.17	1.14	1.88
"	68.8±6.4	11.7±2.3	.07±.01	1.28±.01	.2±0.0	-	-	-	1.17	1.01	1.0
05/8	71.0±6.9	15.4±4.4	.06±.001	1.12±.13	.19±.001	100	96	100	1.17	1.25	1.1
"	70.7±5.6	16.6±4.7	.07±.01	1.27±.04	.22±0.0	-	-	-	1.33	1.06	1.0
"	71.4±5.0	16.7±3.7	.07±.001	1.25±.03	.22±.01	-	-	-	1.14	1.05	1.09
07/9	73.1±5.2	15.4±3.7	.06±.001	1.21±.11	.22±.001	96	100	99	1.17	1.4	1.5
"	73.0±6.7	15.1±3.1	.07±.01	1.27±.06	.18±.001	-	-	-	1.17	1.1	1.1
"	70.2±7.0	14.2±5.0	.07±.02	1.18±.06	.24±.001	100	95	99	1.05	1.6	1.04

TABLE 8

CADMIUN, LEAD AND MERCURY ANALYSES FOR COMPOSITE BLUE MUSSEL, Mytilus edulus SAMPLES COLLECTED AT THE DREDGED MUD DUMPSITE (STATION E). EXPRESSED AS PARTS PER MILLION WET WEIGHT

DATE	SHELL LENGTH (mm)	VISCERA WEIGHT (g)	METAL ANALYSES Cd ± sx	Pb ± sx	Hg ± sx	%RECOVERIES Cd	Pb	Hg	DUPLICATES Cd	Pb	Hg
9/11	61.5±10.0	8.3±4.2	.057±.006	.947±.055	.013±.004	96	98	100	1.2	1.11	2.0
"	63.7±7.8	8.0±2.8	.047±.006	.923±.07	.027±.006	-	-	-	1.25	1.16	1.5
"	63.7±8.0	7.1±2.7	.05±.01	.92±.11	.013±.006	-	-	-	1.5	1.27	2.0
9/19	68.0±6.0	10.0±3.0	.06±.006	1.13±.14	.03±.006	-	-	-	1.17	1.28	1.33
"	65.0±6.0	8.2±2.5	.07±.006	.90±.03	.02±.006	-	-	-	1.14	1.07	1.5
"	64.0±6.0	7.9±2.6	.08±.01	.86±.05	.04±.01	100	100	100	1.5	1.12	1.67
9/24	71.0±4.0	12.5±3.2	.05±.006	.99±.03	.05±.01	-	-	-	1.25	1.07	1.5
"	69.0±6.0	8.8±2.6	.06±.006	1.14±.11	.05±.006	-	-	-	1.17	1.22	1.2
"	67.0±7.0	10.6±3.2	.09±.01	1.03±.11	.32±.02	96	100	100	1.25	1.23	1.13
10/2	68.0±6.0	9.2±2.7	.07±.006	.91±.04	.28±.006	-	-	-	1.17	1.09	1.03
"	69.0±6.0	9.3±2.9	.07±.006	1.06±.08	.31±.006	-	-	-	1.13	1.11	1.03
"	67.0±5.0	8.3±2.3	.09±.006	1.04±.07	.27±.01	-	-	-	1.12	1.14	1.08
11/5	69.6±4.4	7.0±1.8	.08±.006	1.1±.05	.33±.01	98	98	100	1.12	1.1	1.1
"	67.5±4.9	6.0±1.3	.09±.01	1.1±.11	.29±.006	100	93	98	1.37	1.28	1.03
"	69.3±4.6	6.4± 1.7	.08±.01	1.13±.06	.34±.01	-	-	-	1.28	1.12	1.09
01/6	66.2±8.1	7.6±2.1	.09±.01	1.21±.03	.35±.11	-	-	-	1.25	1.05	1.06
"	67.1±7.8	8.5±2.4	.08±.006	1.09±.05	.38±.006	98	96	98	1.14	1.08	1.03
"	71.3±5.7	10.0±2.5	.09±.006	1.14±.05	.37±.01	-	-	-	1.12	1.09	1.05
03/10	71.6±5.3	11.0±2.5	.10±.01	1.22±.03	.38±.001	-	-	-	1.22	1.04	1.03
"	68.4±4.5	10.4±3.2	.14±.03	1.26±.03	.39±.001	95	99	98	1.7	1.04	1.03
"	67.0±5.4	8.7±2.0	.11±.01	1.28±.02	.37±.001	100	99	100	1.4	1.02	1.03
03/12	69.6±4.5	11.5±2.3	.10±.01	1.28±.03	.40±.01	-	-	-	1.4	1.04	1.05
"	68.9±6.4	10.5±2.3	.09±.01	1.3±.03	.40±.001	-	-	-	1.25	1.05	1.02
"	72.0±7.1	13.0±3.7	.10±.02	1.25±.03	.41±.001	-	-	-	1.33	1.04	1.02

TABLE 9

CADMIUM, LEAD AND MERCURY ANALYSES FOR COMPOSITE BLUE MUSSEL, Mytilus edulus SAMPLES COLLECTED 1 MILE SOUTHWEST OF THE DREDGED MUD DUMPSITE (STATION F). EXPRESSED AS PARTS PER MILLION WET WEIGHT

DATE	SHELL LENGTH (mm)	VISCERA WEIGHT (g)	METAL ANALYSES Cd ± sx	Pb ± sx	Hg ± sx	%RECOVERIES Cd	Pb	Hg	DUPLICATES Cd	Pb	Hg
9/11	68.0±6.1	9.2±2.8	.057±.006	.87±.056	.016±.011	98	94	100	1.2	1.13	3.0
"	67.0±7.0	9.7±2.8	.055±.008	.87±.078	.02±0.0	-	-	-	1.5	1.18	1.0
"	73.0±4.9	12.2±2.7	.053±.006	1.03±.07	.027±.011	-	-	-	1.2	1.14	2.0
9/19	66.0±6.0	8.8±2.8	.06±.01	.88±.03	.03±.006	-	-	-	1.75	1.08	1.33
"	68.0±6.0	8.6±2.9	.04±.006	1.23±.09	.33±.01	-	-	-	1.25	1.14	1.06
"	66.0±5.0	8.8±3.1	.06±.006	1.13±.22	.02±.006	-	-	-	1.2	1.48	2.0
9/24	67.0±7.0	9.5±3.3	.04±.006	.96±.06	.03±.01	100	100	100	1.25	1.13	2.5
"	64.0±6.0	8.5±2.7	.06±.01	1.05±.08	.03±.01	-	-	-	1.40	1.17	2.0
"	71.0±5.0	12.0±1.7	.06±.01	.89±.03	.03±.006	-	-	-	1.4	1.08	1.5
10/2	70.0±5.0	9.8±3.2	.05±.01	1.05±.07	.03±.006	-	-	-	1.5	1.14	1.33
"	63±6.0	7.7±2.9	.07±.006	1.13±.04	.09±.03	96	98	98	1.17	1.07	2.2
11/5	71.0±5.6	7.9±2.9	.06±.006	1.16±.046	.06±.006	-	-	-	1.2	1.08	1.2
"	66.2±6.3	7.6±2.7	.05±.006	1.14±.08	.10±.01	-	-	-	1.2	1.14	1.22
"	67.6±5.1	7.3±1.9	.05±.01	1.17±.01	.11±.006	98	96	100	1.5	1.02	1.09
01/6	71.1±6.5	9.7±2.8	.06±.011	1.28±.03	.10±.02	-	-	-	1.4	1.04	1.5
"	68.6±6.0	8.8±2.0	.07±.006	1.14±.021	.12±.006	-	-	-	1.14	1.03	1.08
"	68.6±6.0	9.1±2.2	.07±.011	1.18±.12	.13±.006	96	99	100	1.33	1.21	1.08
03/12	70.0±6.3	12.0±3.1	.08±.001	1.21±.03	.15±.001	-	-	-	1.14	1.09	1.07
"	73.5±4.3	13.1±3.0	.08±.001	.94±.02	.14±0.0	-	-	-	1.14	1.07	1.0
"	71.0±4.7	12.9±2.5	.07±.001	1.32±.04	.15±.001	-	-	-	1.17	1.05	1.07
05/8	71.7±6.2	17.2±4.1	.07±.001	1.32±.12	.16±.001	95	95	98	1.14	1.2	1.06
"	73.0±6.7	16.1±4.1	.08±.001	1.28±.03	.18±.001	-	-	-	1.14	1.04	1.06
"	72.2±7.7	16.5±4.3	.08±.001	1.35±.10	.16±.001	-	-	-	1.12	1.14	1.07
07/13	74.0±6.2	17.4±4.9	.10±.001	1.36±.03	.18±0.0	96	97	100	1.11	1.04	1.0
"	73.0±6.3	16.5±4.8	.10±.001	1.34±.04	.19±0.0	-	-	-	1.11	1.06	1.0

TABLE 10

CADMIUM, LEAD AND MERCURY ANALYSES FOR COMPOSITE BLUE MUSSEL, Mytilus edulus SAMPLES COLLECTED THE DREDGED MUD DUMPSITE CAPPING AREA IN THE NEW YORK BIGHT (STATION X) EXPRESSED AS PARTS PER MILLION WET WEIGHT

DATE	SHELL LENGTH(mm)	VISCERA WEIGHT (g)	METAL ANALYSES Cd ± $s_{\bar{x}}$	Pb ± $s_{\bar{x}}$	Hg ± $s_{\bar{x}}$	% Recoveries Cd	Pb	Hg	Duplicates Cd	Pb	Hg
02/6	69.6±6.1	11.6±4.0	.04±.006	.98±.02	.02±.006	-	-	-	1.25	1.05	1.5
"	69.9±5.4	12.1±2.9	.05±.01	1.08±.05	.03±.01	98	100	100	1.5	1.08	2.0
"	69.4±.5	12.3±2.2	.04±.01	1.04±.07	.02±.006	-	-	-	2.5	1.15	1.5
02/13	73.9±.41	12.6±3.22	.05±.006	.92±.03	.03±.006	-	-	-	1.2	1.07	1.5
"	67.4±.46	9.8±1.8	.03±.006	1.05±.09	.02±.006	98	96	100	1.33	1.18	1.5
"	69.6±.45	11.4±2.0	.05±.01	1.04±.07	.03±.01	-	-	-	1.5	1.13	2.0
02/25	66.9±5.3	11.2±2.1	.03±.001	1.0±.03	.03±.001	-	-	-	1.5	1.06	1.5
"	71.7±3.8	13.4±2.2	.04±.001	1.03±.05	.03±.001	-	-	-	1.33	1.09	1.3
"	70.2±4.7	12.6±2.2	.05±.001	1.09±.003	.04±.001	96	95	100	1.25	1.03	1.3
03/12	69.0±7.2	10.8±3.3	.04±.01	1.07±.05	.04±.001	-	-	-	1.67	1.1	1.2
"	65.9±1.4	10.8±3.4	.03±.001	1.17±.09	.02±.001	-	-	-	1.33	1.16	1.5
"	66.2±10.4	11.9±1.9	.04±.001	1.06±.03	.03±.001	-	-	-	1.33	1.06	1.3
05/18	74.0±3.8	20.5±3.7	.04±.01	.91±.03	.04±.001	96	100	100	1.67	1.06	1.3
"	75.7±4.6	20.1±3.1	.04±.001	1.08±.06	.04±.001	100	96	100	1.33	1.11	1.3
"	70.3±2.3	17.0±5.5	.04±.01	1.1±.1	.03±.001	-	-	-	1.67	1.18	1.3

TABLE 11

CADMIUM, LEAD AND MERCURY ANALYSES FOR COMPOSITE BLUE MUSSEL, *Mytilus edulus* SAMPLES COLLECTED AT THE BARNEGAT LIGHT STATION (SITE Y) EXPRESSED AS PARTS PER MILLION WET WEIGHT

DATE	SHELL LENGTH(mm)	VISCERA WEIGHT (g)	METAL ANALYSES Cd ± $\bar{s}\bar{x}$	Pb ± $\bar{s}\bar{x}$	Hg ± $\bar{s}\bar{x}$	% Recoveries Cd	Pb	Hg	Duplicates Cd	Pb	Hg
03/19	70.1±6.3	15.0±4.1	.03±.001	.91±.02	.06±.001	-	-	-	1.5	1.04	1.2
"	69.5±5.4	12.6±2.8	.03±.001	1.07±.05	.03±.001	-	-	-	1.5	1.1	1.3
"	70.7±4.3	14.6±2.4	.03±0.0	.97±.08	.03±.001	-	-	-	1.0	1.18	1.5
05/7	71.7±5.8	15.3±3.1	.03±0.0	1.03±.05	.04±.006	-	-	-	1.2	1.09	1.3
"	72.2±6.4	15.4±3.3	.04±.01	.99±.02	.04±.006	-	-	-	1.5	1.04	1.2
"	70.2±6.0	14.6±4.8	.04±.001	1.04±.07	.04±.005	-	-	-	1.33	1.14	1.0
07/13	71.8±5.3	16.9±4.8	.04±.006	.96±.065	.03±.006	-	-	-	1.33	1.15	1.33
"	75.2±6.7	18.4±4.6	.03±.006	1.04±.08	.04±.006	-	-	-	1.5	1.16	1.33
"	73.8±6.1	18.4±4.1	.04±.006	.99±.02	.02±.006	-	-	-	1.33	1.05	1.5

TABLE 12. TOTAL POLYCHLORINATED BIPHENYL CONCENTRATIONS* IN BLUE MUSSELS TRANSPLANTED WITHIN THE NEW YORK BIGHT (all means expressed as parts per million/ppm)

Station	Week 1	Week 2	Week 3	Week 4	Week 10	Week 19	Week 29	Week 36	Week 45
	September			October	November	January	March	May	July
B	.24± .03 (.21–.27) N= 3	.19± .14 (.07–.41) N= 7	.36± .21 (.07–.69) N= 8	.34± .02 (.32–.36) N= 3	.58± .04 (.53–.61) N= 3	.33± .11+ (.19–.48) N= 9	.46± .11 (.32–.59) N= 6	.48± .07 (.35–.57) N= 4	.21± .03 (.17–.26) N= 9
C	.19± .14 (ND–.43) N= 6	.46± .60 (ND–1.5) N= 6	.66± .56 (.08–1.1) N= 9	.73± .56 (.25–1.8) N= 8	---	---	---	---	---
D	.26± .30 (ND–.97) N =9	.20± .24 (ND–.78) N= 9	.28± .16 (.08–.51) N= 8	.25± .02 (.23–.27) N= 3	.26± .04 (.22–.29) N= 3	.22± .07 (.15–.36) N= 9	.31± .16 (.16–.57) N= 9	.39± .13 (.24–.56) N= 9	.25± .09 (.14–.40) N= 9
E	.24± .29 (.08–.94) N =9	.52± .45 (ND–1.2) N= 9	.61± .48 (ND–1.5) N= 9	.66± .04 (.61–.69) N= 3	.31± .02 (.29–.37) N= 3	.23± .09 (.12–.39) N= 9	.33± .04 (.26–.41) N= 9	---	---
F	.14± .14 (ND–.49) N =9	.52± .50 (.11–1.5) N= 9	.67± .51 (ND–1.6) N= 9	.22± .26 (ND–.74) N= 6	.34± .02 (.32–.37) N= 3	.38± .11 (.24–.56) N= 9	.15± .03 (.11–.22) N= 9	.37± .06 (.26–.42) N= 9	.23± .06 (.17–.31) N= 6
	February			March	(Week 12) May	(Week 21) July			
X	.10± .07 (.04–.23) N =9	.11± .02 (.08–.13) N= 9	.14± .08 (.05–.26) N= 9	.39± .07 (.30–.48) N= 9	.15± .04 (.09–.19) N= 9	---	---	---	---
Y	---	---	---	.14± .11 (.06–.29) N= 9	.17± .06 (.08–.27) N= 9	.15± .07 (.09–.26) N= 9	---	---	---

* Represents mixed Arochlors 1016, 1262, 1232, 1242, 1248, 1254

+ Represents week 23 of sampling

TABLE 13. CONCENTRATIONS OF TOTAL DDT METABOLITES IN BLUE MUSSELS COLLECTED DURING THE MONITORING PROGRAM,*
(all values are expressed in parts-per-million)

Station	Week 1	Week 2	Week 3	Week 4	Week 10	Week 19	Week 29	Week 36	Week 45
	September			October	November	January	March	May	July
B	ND	ND	.103	ND	ND	ND ++	ND	ND	ND
C	.033	ND	.083	ND	--	--	--	--	--
D	.049	ND	.034	ND	ND	ND	ND	ND	ND
E	.086	ND	.022	ND	ND	ND	ND	--	--
F	.022	.033	ND	ND	ND	ND	ND	ND	ND
	February			March	May (Week12)	July (Week 21)			
X+	ND	ND	ND	ND	ND	--	END OF STUDY		
Y+	--	--	--	ND	ND	ND	END OF STUDY		

* DDT isomers represented; pp'DDD, op'DDT, pp'DDE, pp'DDT and opDDD.

+ Not sampled concurrently with stations B through F.

ND = None detected at a detection limit of 0.02 ppm (mg/kg)

++ Represents week 23 of sampling

TABLE 14 FUEL OIL # 2 CONCENTRATIONS IN BLUE MUSSELS FROM THE STUDY AREA (all values expressed in parts per million)

Station	Week 1	Week 2	Week 3	Week 4	Week 10	Week 19	Week 29	Week 36	Week 45
	----------September----------			October	November	January	March	May	July
B	19.2±8.5 (<5-37.4) n=9	18.7±10.6 (10.2-37.7) n=9	10.1±7.1 (5.3-26.5) n=8	12.5±6.0 (7.9-27.0) n=9	5.4±1.4 (<5-9.1) n=9	8.5±4.3* (<5-16.8) n=9	70.7±36.0 (27.0-135) n=9	129.6±35.6 (87.7-212) n=9	96.2±35.8 (80.7-143) n=8
C	10.5±6.4 (<5-22) n=9	8.7±2.3 (<5-11.1) n=6	12.5±2.8 (7.3-15.0) n=9	10.2±3.3 (<5-14.7) n=9	--	--	--	--	--
D	12.5±7.3 (<5-27.1) n=9	17.6±11.5 (<5-36.8) n=9	11.9±4.7 (<5-17.3) n=8	6.3±1.7 (<5-10.1) n=8	5.8±1.9 (<5-10.6) n=9	5.7±2.0 (<5-9.7) n=9	61.7±26.0 (10.5-97.5) n=9	114.0±28.0 (69.0-143.0) n=8	123.5±38.9 (73.8-189.0) n=8
E	19.3±9.2 (<5-35.1) n=9	11.5±6.2 (<5-21.2) n=8	10.3±3.2 (7.0-16.9) n=9	8.2±3.6 (<5-14.1) n=9	6.9±3.2 (<5-13.9) n=9	22.0±23.0 (6.3-77.6) n=8	45.7±23.4 (<5-66.1) n=15	--	--
F	17.7±9.8 (6.5-31.3) n=9	16.1±13.4 (<5-37.8) n=8	11.4±2.8 (7.0-13.6) n=9	8.1±3.1 (<5-13.0) n=6	6.2±1.9 (<5-10.0) n=9	5.1±.41 (<5-6.1) n=7	63.5±26.0 (26.6-99.8) n=8	122.3±49.6 (82.3-248.0) n=9	106±24.3 (73.1-135.0) n=5
	----------February----------			March	May (WEEK 12)	July (WEEK 21)			
X +	25.7±16.0 (<5-56.2) n=9	27.9±25.9 (<5-83.0) n=8	88.0±31.6 (37.8-134.0) n=9	75.9±36.4 (43.2-143.5) n=8	118.3±40.7 (85.7-216.0) n=8	--	END OF STUDY		
Y +	--	--	--	84.3±13.3 (65.3-104.5) n=9	102.4±23.1 (64.6-134.0) n=9	89.9±27.4 (63.9-135.0) n=7	END OF STUDY		

+ Not sampled concurrently with stations B through F.

* Represents week 23 of sampling

TABLE 15 SURFICIAL* SEDIMENT ANALYSES FOR ALL SAMPLING STATIONS

Parameter		Stations B	C	D	E	F
% Water		49	63	77	56	91
% Organic matter		14	7	21	26	28
Mercury ppm		6.9±.12	2.8±.05	9.0±.14	4.4±.01	11.0±.08
Cadmium ppm		4.2±.3	1.46±.24	5.4±.06	2.6±.01	8.6±.04
Lead ppm		180±3.1	87.9±.40	349±3.7	129±.94	702±7.9
DDT isomers+		ND	.16	.81	10.3	11.7
Petroleum[x] hydrocarbons ppm		8.1	5	8.6	59.2	76.1
Polychlorinated biphenyls[i] ppm						
Sediment Grain Size	%sand	81	84	67	78	84
	%silt	6	5	14	7	6
	%clay	13	11	19	15	10

* Represented by the top 5 cm.
\+ Consists of the following isomers; pp'DDD, op'DDt, pp'DDT, pp'DDE, and opDDD.
x Represented by fuel oil # 2.
i Consisting of Arochlors; 1016, 1262, 1232, 1242, 1248, 1254.

TABLE 16. ANALYTICAL PRECISION ESTIMATES FOR MERCURY, CADMIUM AND LEAD IN BLUE MUSSEL SAMPLES

NUMBER OF ANALYSES	DUPLICATE RATIO RANGE	PERCENT FREQUENCY OF ANALYSES
	MERCURY	
129	1.0 - 2.0	96
6	2.1 - 3.0	4
	CADMIUM	
137	1.0 - 2.0	99
1	2.1 - 3.0	1
	LEAD	
138	1.0 - 2.0	100
0	2.1 - 3.0	-

TABLE 17. ANALYTICAL PRECISION ESTIMATES FOR MIXED PCB's IN BLUE MUSSEL TISSUES

NUMBER OF ANALYSES	DUPLICATE RATIO RANGE	PERCENT FREQUENCY OF ANALYSES
71	1.0 - 2.0	65
11	2.1 - 3.0	10
3	3.1 - 4.0	2
4	4.1 - 5.0	3
13	5.1 - 10.0	12
3	10.1 - 15.0	2
2	15.1 - 20.0	1
1	20.1 - 30.0	0.9

Consisting of Arochlors; 1016, 1262, 1232, 1242, 1248, 1254.

TABLE 18. TISSUE SPIKE RECOVERIES FOR MIXED POLY CHLORINATED BIPHENYLS* IN BLUE MUSSEL SAMPLES

SAMPLE	ANALYTICAL VALUE (ppb)	ANALYTICAL VALUE AND SPIKE+	PERCENT RECOVERY
1	628.3	1060	65 %
2	495	1430	96 %
3	490	1090	73 %
4	816	1420	78 %
5	545	582	38 %
6	1203.3	1123	51 %
7	383	580	42 %
8	160	585	50 %
9	230	1280	104 %
10	401.7	590	42 %
11	ND	668	66 %
12	ND	467	47 %
13	ND	1240	124 %
14	ND	1090	109 %
15	ND	582	58 %
16	ND	1123	112 %
17	ND	1280	128 %

* Consists of AROCHLORS; 1016, 1262, 1232, 1242, 1248, 1254.

+ Based on a 1000 part-per-billion (ppb) spike.

TABLE 19. GAS CHROMATOGRAPH SPIKE RECOVERIES FOR MIXED PCB's* IN BLUE MUSSEL SAMPLES

SAMPLE NUMBER	ANALYTICAL VALUE	ANALYTICAL VALUE AND SPIKE +	PERCENT RECOVERY
1	815	1820	100
2	465	1470	100
3	710	1110	65
4	1430	1774	73
5	ND	365	34
6	1355	1980	84
7	245	870	70
8	225	1280	104
9	325	900	67
10	ND	380	38
11	ND	730	73
12	ND	1070	107
13	ND	1110	111
14	ND	865	86
15	ND	980	98
16	ND	1150	115
17	ND	850	85
18	ND	940	94
19	ND	920	92
20	ND	950	95
21	ND	920	92
22	ND	910	91
23	ND	1040	104
24	ND	960	96
25	ND	910	91

* Consists of Arochlors; 1016, 1262, 1232, 1242, 1248 and 1254.

+ Based on a 1000 part-per-billion (ppb) spike.

TABLE 20. INTERLABORATORY COMPARISONS OF MIXED PCB CONCENTRATIONS IN SPLIT MUSSEL SAMPLES

SAMPLE #	SECONDARY LAB	PRIMARY LAB
1	.42	.25
2	.49	.34
3	2.87	.58
4	1.63	.25
5	1.92	.26
6	.94	.66
7	5.6	.34
8	1.32	.34

TABLE 21. TISSUE SPIKE RECOVERIES FOR DDT ISOMERS IN BLUE MUSSEL SAMPLES

SAMPLE NUMBER	ANALYTICAL VALUE	ANALYTICAL VALUE AND SPIKE+	PERCENT RECOVERY
1	ND	176	17.6
2	ND	626	62.6
3	ND	174	17.4
4	ND	355	35.5
5	545	1037	67.1
6	1137	450	21.0
7	ND	845	84.5
8	ND	161	16.1
9	ND	761	76.1
10	ND	500	50.0
11	100	1280	118.0
12	ND	535	53.5
13	ND	250	25.0
14	ND	278	27.8
15	17	1430	140.6
16	17	1330	130.7
17	ND	734	73.4
18	ND	1100	110.0
19	ND	706	70.6
20	ND	796	79.6
21	ND	896	89.6
22	ND	673	67.3
23	133	1133	100.0
24	ND	1040	104.0
25	33	1280	124.0
26	ND	850	85.0
27	ND	1150	115.0
28	ND	920	92.0
29	ND	940	94.0
30	ND	910	91.0

+ Spike value 1000 parts-per-billion (ppb)

DDT isomers represented; pp'DDD, op'DDT, pp'DDT, pp'DDE, and op DDD.

TABLE 22. INTERLABORATORY COMPARISONS OF DDT ISOMERS* IN SPLIT MUSSEL SAMPLES (all values in parts-per-million)

Sample #	SECONDARY LAB	PRIMARY LAB
1	.33	.02
2	.17	.02
3	.02	.02
4	.05	.02
5	.02	.02
6	.06	.02
7	.02	.02
8	.02	.02

* Consists of isomers; pp'DDD, op' DDT, pp'DDT, pp'DDE, and op DDD.

TABLE 23. ANALYTICAL PRECISION ESTIMATES FOR FUEL OIL # 2 IN BLUE MUSSEL SAMPLES

NUMBER OF ANALYSES	DUPLICATE RATIO RANGE	PERCENT FREQUENCY OF ANALYSES
97	1.0 - 2.0	67
30	2.1 - 3.0	21
7	3.1 - 4.0	5
5	4.1 - 5.0	3
4	5.1 - 10.0	3
2	10.1 - 15.0	1

TABLE 24. TISSUE SPIKE RECOVERIES FOR FUEL OIL # 2 IN BLUE MUSSEL SAMPLES

SAMPLE NUMBER	ANALYTICAL VALUE	ANALYTICAL VALUE AND SPIKE+	PERCENT RECOVERY
1	157.6	157	88
2	117.3	159	115
3	129.4	119	79
4	76.3	77.9	80
5	35.3	69.6	126
6	155	140	80
7	111.9	160	121
8	156.7	153	88
9	[illegible]	13	52
10	[illegible]	15	60
11	ND	16.9	68
12	ND	16.4	66
13	ND	14.4	58
14	ND	15.8	63
15	54	52.1	70
16	55.9	90.3	119
17	66.3	96.0	110
18	95.1	90.9	79
19	370.4	226	58
20	32.8	28.5	54
22	16.6	30.2	82
23	12.4	17.3	53
24	6.8	23.5	87
25	6.6	16.1	60
26	10.3	22.1	73
27	14.6	27	78
28	5.4	23	90
29	22.9	42	98
30	21.9	47.9	114
31	15	24.9	71
32	9.8	34.9	117
33	21.9	43	103
34	170.7	172	90
35	84.8	89.5	85

+ Spike value is 20 parts-per-million (ppm).

TABLE 25. GAS CHROMATOGRAPH SPIKE RECOVERIES FOR FUEL OIL # 2 IN BLUE MUSSEL SAMPLES

SAMPLE NUMBER	ANALYTICAL VALUE	ANALYTICAL VALUE AND SPIKE+	PERCENT RECOVERY
1	ND	13.6	54
2	ND	13.1	52
3	ND	15.5	62
4	ND	17.7	71
5	ND	17.3	69
6	ND	14.0	56
7	ND	12.2	51
8	5.4	17.3	68
9	5.1	22.0	88
10	14.7	37.9	109
11	13.0	38.9	118
12	10.2	26.8	89
13	14.7	36.4	104
14	15.0	27.8	79
15	6.3	14.1	54
16	9.9	27.4	92
17	15.9	39.9	111
18	189.0	234.0	117
19	92.6	112.0	99
20	277.0	288.0	97
21	212.0	152.0	65
22	85.7	119.0	112
23	80.2	93.1	91
24	35.8	61.6	110
25	8.9	33.3	115
26	643.0	442.0	67
27	110.0	147.0	113
28	45.0	66.2	101
29	57.3	85.1	110
30	53.9	96.1	130
31	66.2	80.1	92
32	75.6	89.6	93
33	69.9	116.5	129
34	195.1	281.6	131
35	147.3	176.9	105

+ Spike value is 20 parts-per-million (ppm).

Table 26. Correlation Coefficients for PCB Contaminants

	STATIONS						
	B	C	D	E	F	X	Y
r value for PCB vs. Time	0.19	0.97	0.49	-.47	-.31	0.14	0.29
r value for PCB vs. Lipid Concentration	-.02	-.92	0.06	0.55	0.38	0.23	1.00
r value for Adjusted PCB vs. Time	-.21	0.98	-.16	-.37	-.37	-.25	-.38

Table 27. Correlation Coefficients for Fuel Oil # 2 Analyses

	STATIONS						
	B	C	D	E	F	X	Y
r value for PHC vs. Time	0.87	0.24	0.91	0.83	0.88	0.84	0.27
r value for PHC vs. Lipid Content	0.80	-.05	0.72	0.10	0.49	0.89	0.09

TABLE 28: Percent Lipid in Blue Mussels Transplanted in the Study Area.

STATION	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 10	WEEK 19	WEEK 29	WEEK 36	WEEK 45
	---------September----------			October	November	January	March	May	July
B	1.35	1.83	1.43	1.64	1.05	1.83*	2.02	2.63	1.81
C	5.05	1.80	1.60	1.50	--	--	--	--	--
D	1.32	1.35	1.60	1.10	1.00	1.60	1.44	1.60	2.30
E	1.90	2.10	2.00	1.90	1.10	1.50	1.80	--	--
F	1.40	1.70	1.80	1.60	1.17	1.50	1.70	1.90	1.50

STATION	February			March	May (Week 12)	July (Week 21)
X◆	1.25	1.10	--	1.80	2.80	--
Y◆	--	--	--	1.40	2.60	1.80

* Represents Week 23 of Sampling.

◆ Not Sampled Concurrently with Stations B-F.

table 29
Ranking of Mercury Concentration by Station

Station	E	>	D	>	F	>	C	>	B	>	Y	>	X	>	CM
Mean contaminant concentration (ppm)	.242		.130		.104		.050		.041		.037		.030		.027

Duncans Multiple Range Test

		CM	X	Y	B	C	F	D	E
CAPE MAY	CM	X	NS	NS	NS	NS	S	S	S
CAPPING SITE	X	NS	X	NS	NS	NS	S	S	S
BARNEGAT LIGHT	Y	NS	NS	X	NS	NS	S	S	S
GRAVESEND BAY	B	NS	NS	NS	X	NS	S	S	S
JONES BEACH	C	NS	NS	NS	NS	X	S	S	S
1 ML SW DREDGED MUD DUMPSITE	F	S	S	S	S	S	X	NS	S
2 ML NE DREDGED MUD DUMPSITE	D	S	S	S	S	S	NS	X	S
DREDGED MUD DUMPSITE	E	S	S	S	S	S	S	S	X

NS - not significant S - significant, alpha = .05

table 30
Ranking of Cadmium Concentration by Station

Station	E	>	F	>	B	>	D	>	C	>	CM	>	X	>	Y
Mean contaminant concentration (ppm)	.081		.065		.062		.058		.054		.050		.041		.034

Duncans Multiple Range Test

		Y	X	CM	C	D	B	F	E
BARNEGAT LIGHT	Y	X	NS	S	S	S	S	S	S
CAPPING SITE	X	NS	X	NS	S	S	S	S	S
CAPE MAY	CM	S	NS	X	NS	NS	S	S	S
JONES BEACH	C	S	S	NS	X	NS	S	S	S
2 ML NE DREDGED MUD DUMPSITE	D	S	S	NS	NS	X	NS	S	S
GRAVESEND BAY	B	S	S	S	S	NS	X	NS	S
1 ML SW DREDGED MUD DUMPSITE	F	S	S	S	S	S	NS	X	S
DREDGED MUD DUMPSITE	E	S	S	S	S	S	S	S	X

NS - not significant S - significant, alpha = .05

table 31
Ranking of Lead Concentration by Station

Station	F	>	D	>	E	>	X	>	C	>	B	>	Y	>	CM
Mean contaminant concentration (ppm)	1.13		1.11		1.09		1.04		1.023		1.02		1.00		0.84

Duncans Multiple Range Test

		CM	Y	B	C	X	E	D	F
CAPE MAY	CM	X	S	S	S	S	S	S	S
BARNEGAT LIGHT	Y	S	X	NS	NS	NS	S	S	S
GRAVESEND BAY	B	S	NS	X	NS	NS	S	S	S
JONES BEACH	C	S	NS	NS	X	NS	NS	S	S
CAPPING SITE	X	S	NS	NS	NS	X	NS	S	S
DREDGED MUD DUMPSITE	E	S	S	S	NS	NS	X	NS	NS
2 ML NE DREDGED MUD DUMPSITE	D	S	S	S	S	S	NS	X	NS
1 ML SW DREDGED MUD DUMPSITE	F	S	S	S	S	S	NS	NS	X

NS - not significant S - significant, alpha = .05

table 32
Ranking of PCB Concentration by Station

Station	C	>	B	>	F	>	E	>	D	>	X	>	Y	>	CM
Mean contaminant concentration (ppm)	.59		.39		.37		.35		.30		.18		.16		.03

Duncans Multiple Range Test

		CM	Y	X	D	E	F	B	C
CAPE MAY	CM	X	NS	NS	S	S	S	S	S
BARNEGAT LIGHT	Y	NS	X	NS	NS	S	S	S	S
CAPPING SITE	X	NS	NS	X	NS	S	S	S	S
2 ML NE DREDGED MUD DUMPSITE	D	S	NS	NS	X	NS	NS	NS	S
DREDGED MUD DUMPSITE	E	S	S	S	NS	X	NS	NS	S
1 ML SW DREDGED MUD DUMPSITE	F	S	S	S	NS	NS	X	NS	S
GRAVESEND BAY	B	S	S	S	NS	NS	NS	X	S
JONES BEACH	C	S	S	S	S	S	S	S	X

NS - not significant S - significant, alpha = .05

table 33

Ranking of Fuel Oil #2 Conc. by Station

Station	Y	>	X	>	D	>	B	>	F	>	E	>	C	>	CM
Mean contaminant concentration (ppm)	92.7		66.7		40.1		38.5		37.6		20.1		10.6		0.05

Duncans Multiple Range Test

		CM	C	E	F	B	D	X	Y
CAPE MAY	CM	X	NS	S	S	S	S	S	S
JONES BEACH	C	NS	X	NS	S	S	S	S	S
DREDGED MUD DUMPSITE	E	S	NS	X	S	S	S	S	S
1 ML SW DREDGED MUD DUMPSITE	F	S	S	S	X	NS	NS	S	S
GRAVESEND BAY	B	S	S	S	NS	X	NS	S	S
2 ML NE DREDGED MUD DUMPSITE	D	S	S	S	NS	NS	X	S	S
CAPPING SITE	X	S	S	S	S	S	S	X	S
BARNEGAT LIGHT	Y	S	S	S	S	S	S	S	X

NS - not significant

S - significant, alpha = .05

TABLE 34: Comparison of Station Mean Tissue Contaminant Concentrations to Existing Regulatory Action or Alert Levels

	Mean Concentration (+Maximum) in ppm*								Regulatory Guideline (in ppm)		
									FDA**		WHO***
	B	C	D	E	F	X	Y	CM	Alert	Action	
Mercury	.04 (.06)	.05 (.10)	.13 (.28)	.24 (.41)	.10 (.33)	.03 (.04)	.04 (.06)	.03 (.04)	N/A	1.0	--
Cadmium	.062 (.09)	.054 (.07)	.06 (.07)	.08 (.10)	.065 (.10)	.04 (.05)	.03 (.04)	.05 (.06)	2.0	--	--
Lead	1.02 (1.22)	1.02 (1.30)	1.11 (1.28)	1.09 (1.30)	1.13 (1.36)	1.04 (1.17)	1.00 (1.07)	.84 (.96)	--	--	429
DDT	<.02 (.29)	.03 (.08)	<.02 (<.02)	.03 (.09)	.02 (.03)	.02 (.02)	.02 (.02)	<.02 (<.02)	--	--	--
PCBs	.39 (.87)	.59 (1.22)	.30 (.71)	.35 (.66)	.37 (1.13)	.18 (.46)	.16 (.29)	.03 (.04)	N/A	5.0	--
#2 Fuel Oil	38.5 (157.6)	10.6 (18.5)	40.1 (159.5)	20.1 (64.0)	37.6 (137.6)	66.7 (129.4)	92.7 (124.6)	<.05 (<.05)	--	--	--

*ppm = parts per million

**FDA = Food & Drug Administration

***WHO = World Health Organization

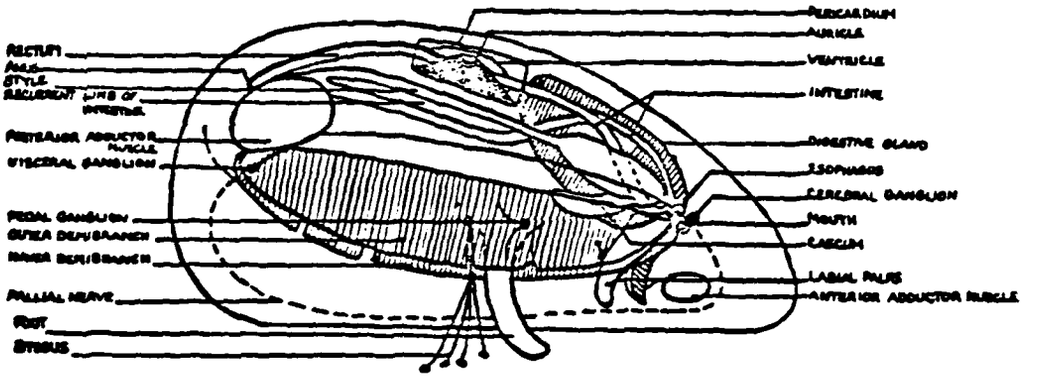
APPENDIX B

Figures

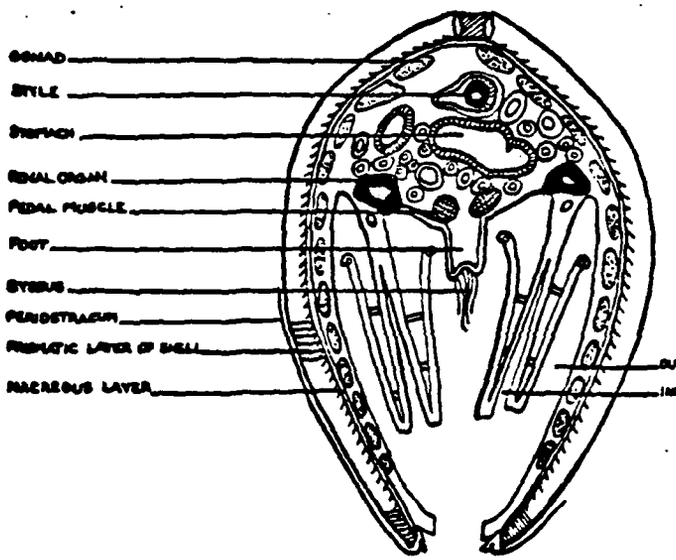
FIGURE 2

The Sea Mussel - *Mytilus*

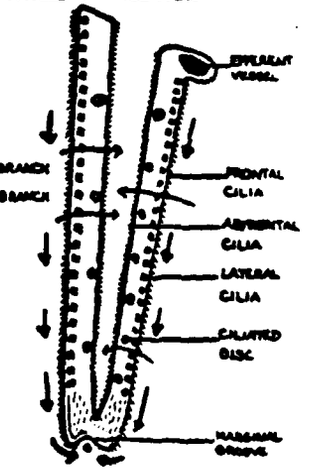
The pallial organs of *Mytilus*, as viewed from the right side - with dissection of the alimentary canal



Schematic cross section through the mantle cavity of *Mytilus*



A single gill filament of *Mytilus* of face view



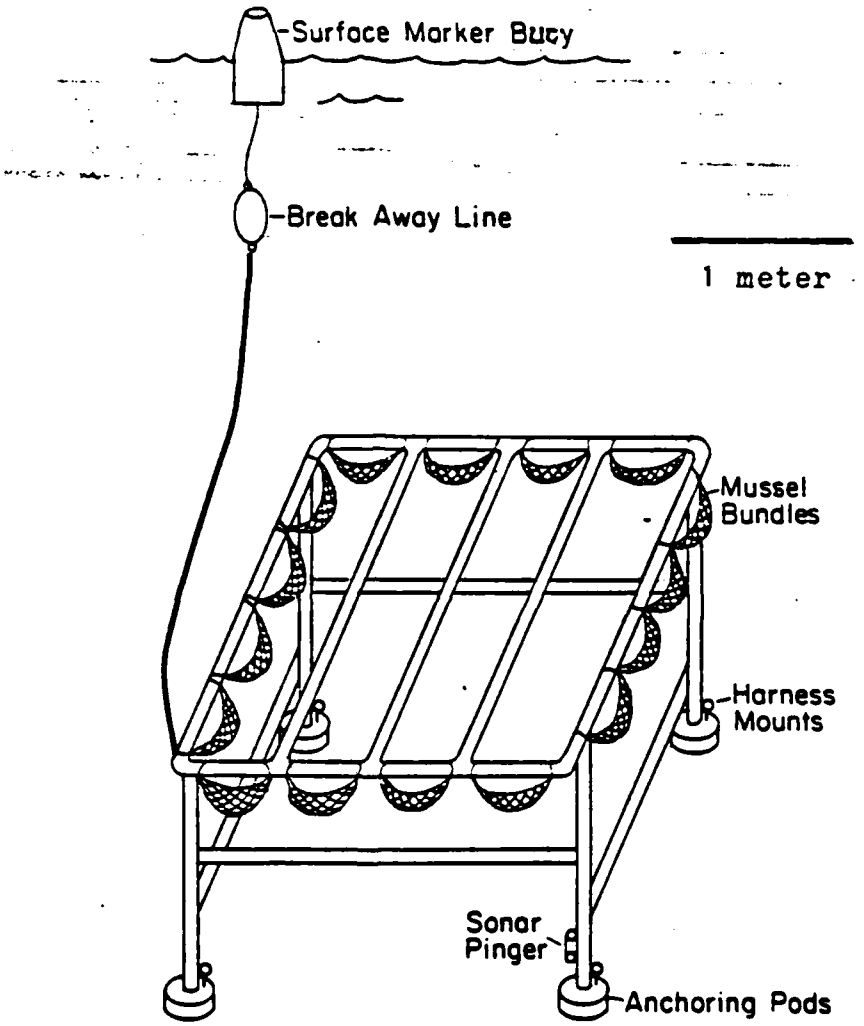


FIGURE 3. THE MUSSEL INCUBATION PLATFORM

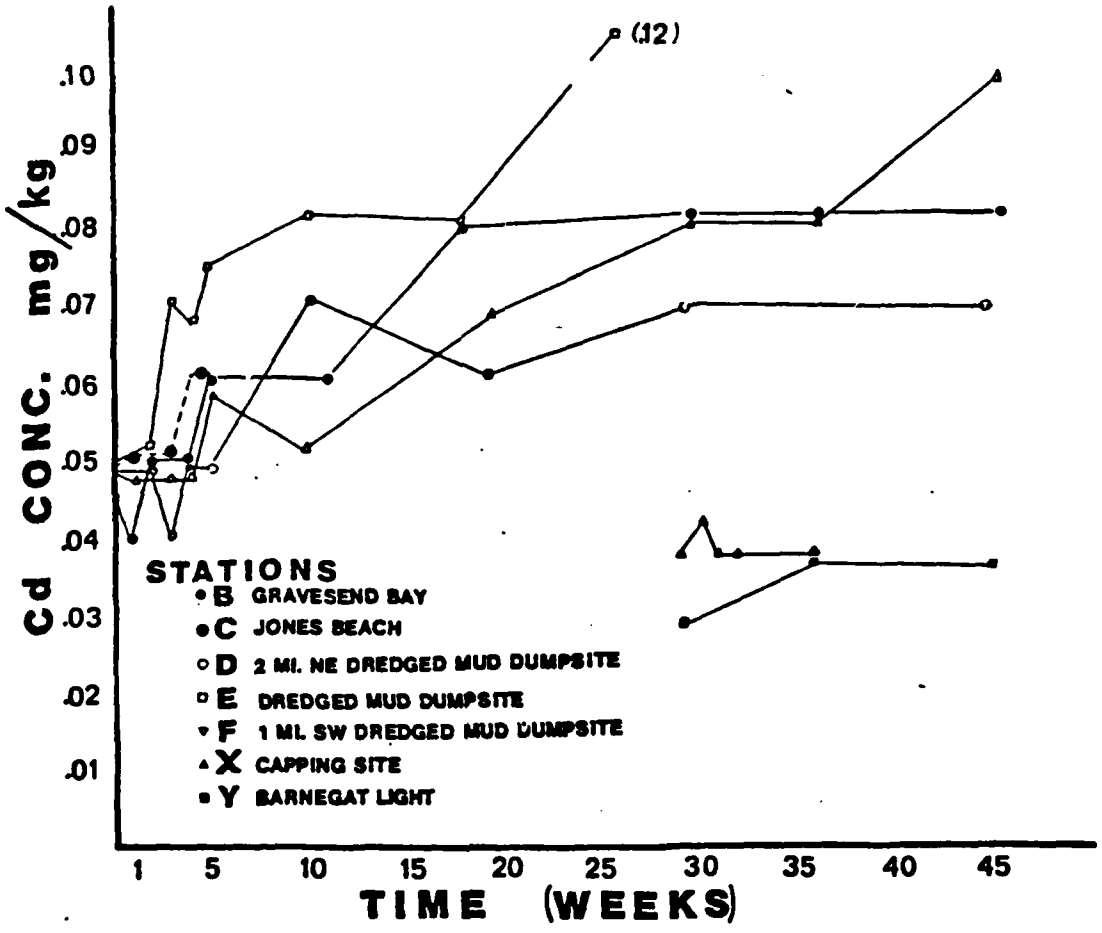
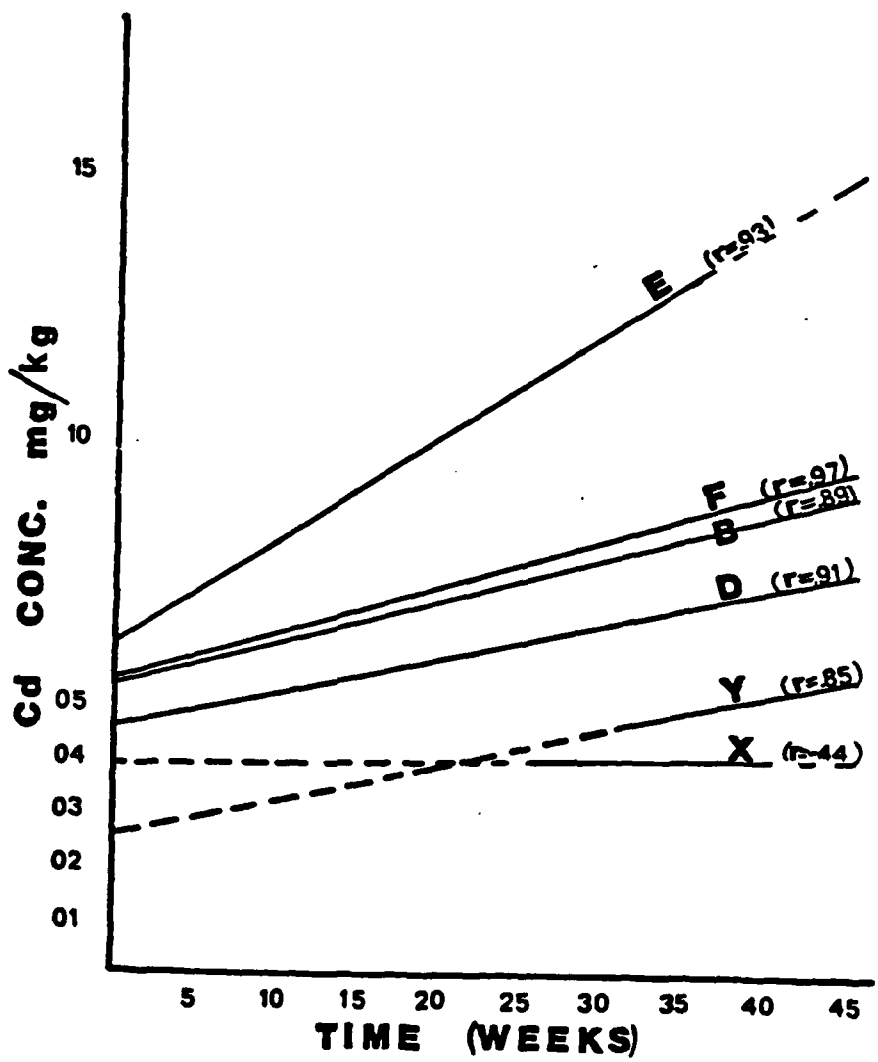


FIGURE 4 CADMIUM UPTAKE OVER TIME

FIGURE 5 CADMIUM REGRESSION



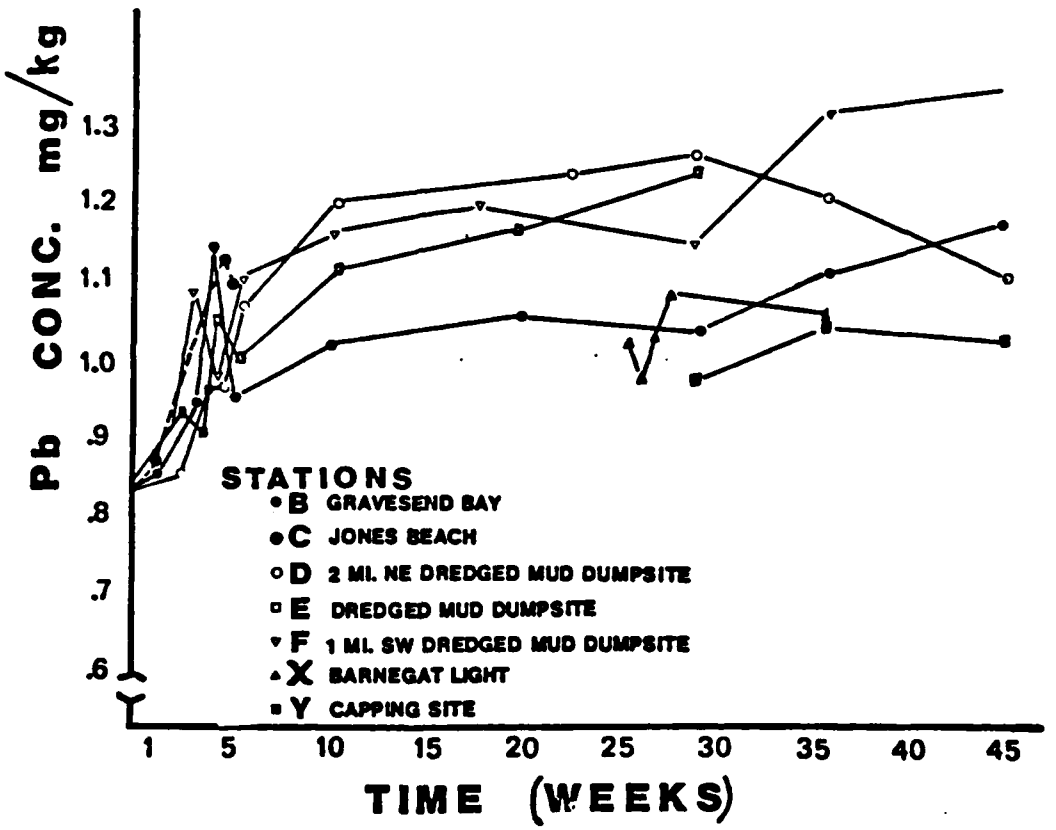


FIGURE 6 LEAD UPTAKE OVER TIME

FIGURE 7 LEAD REGRESSIONS

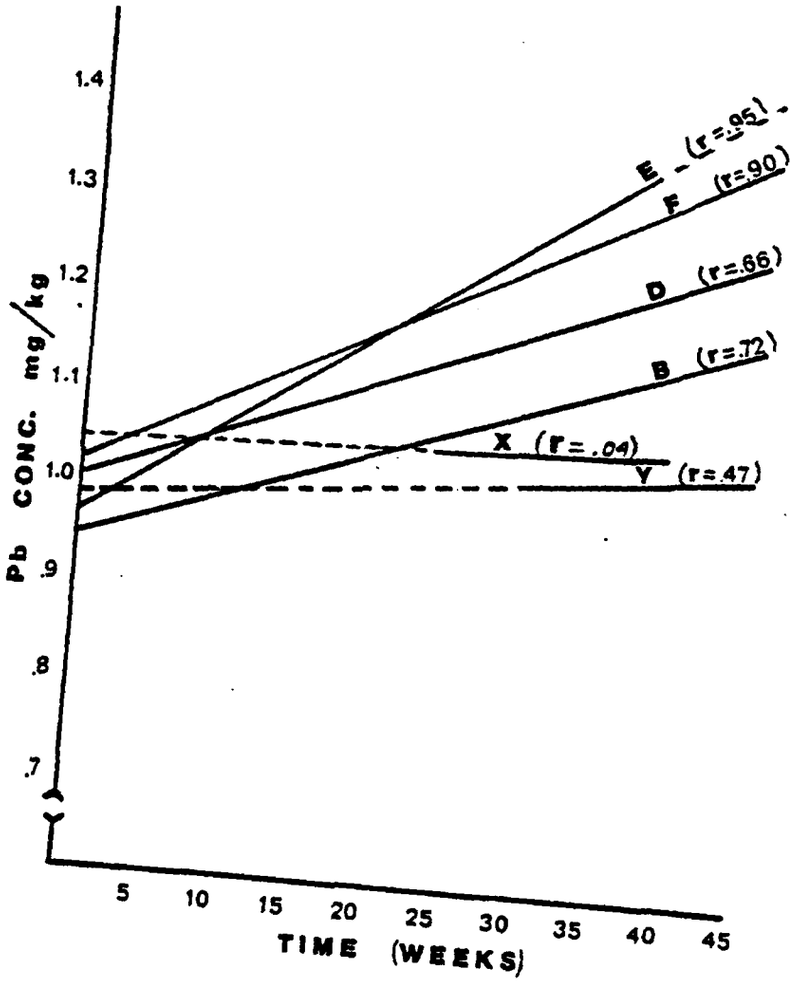


FIGURE 8 MERCURY UPTAKE OVER TIME

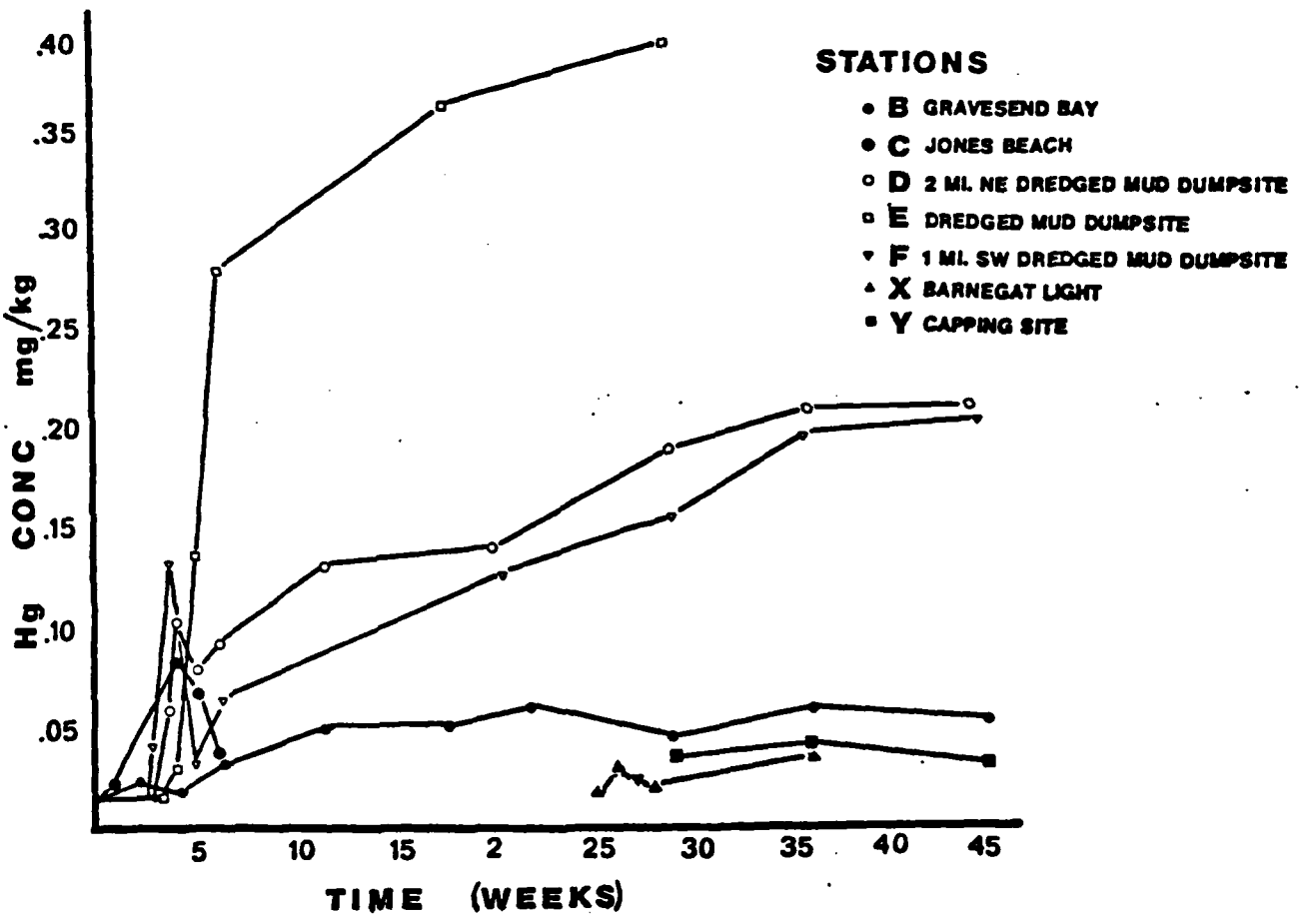


FIGURE 9 MERCURY REGRESSIONS

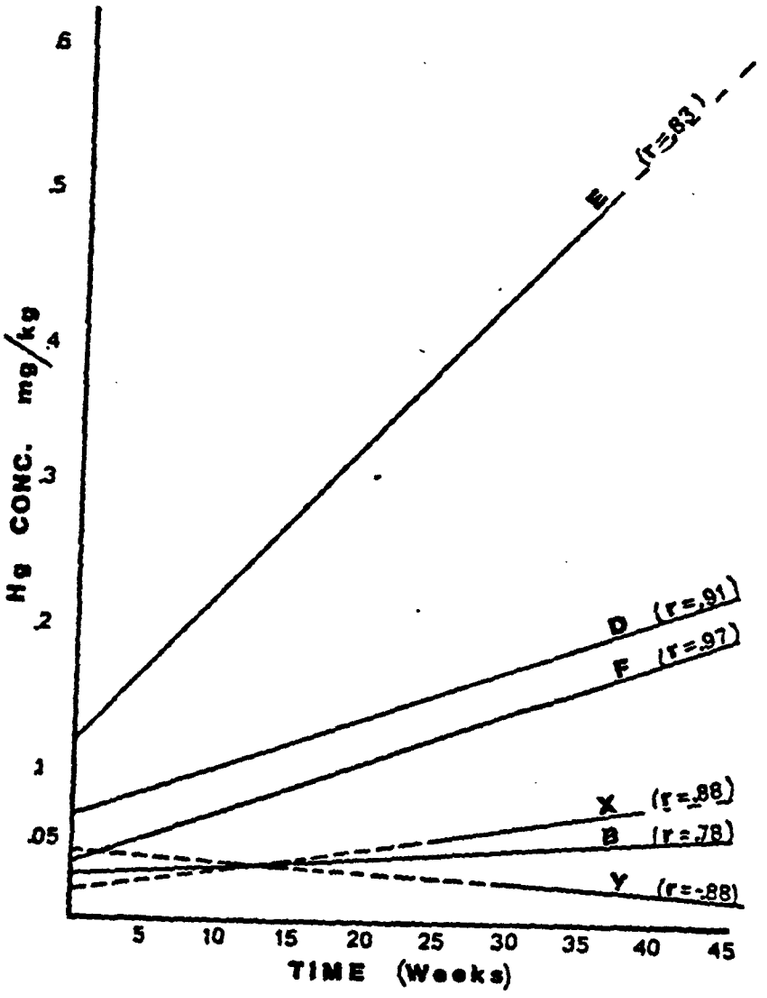


FIGURE 10 POLYCHLORINATED BYPHENYL UPTAKE OVER TIME

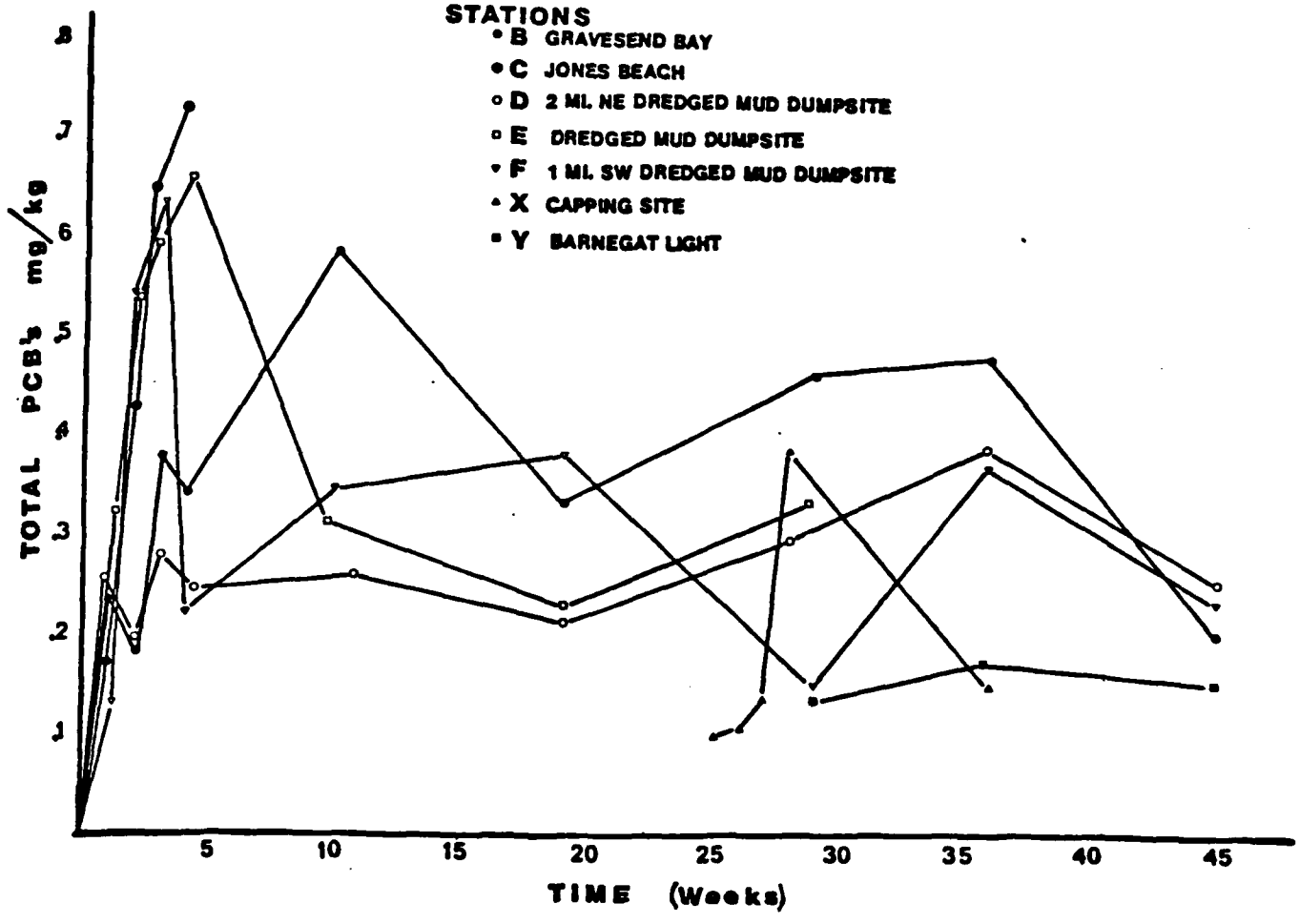
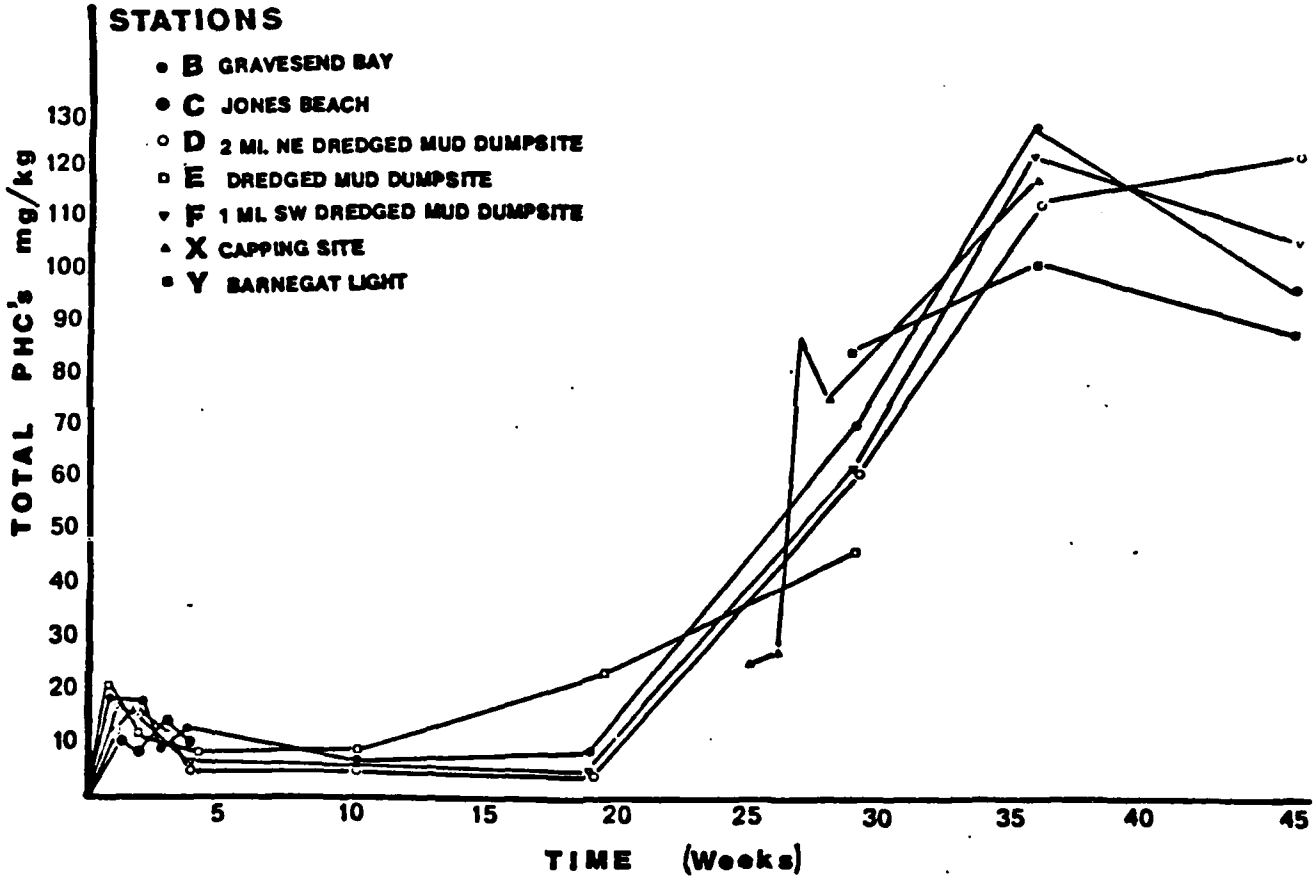


FIGURE 11 FUEL OIL # 2 UPTAKE OVER TIME



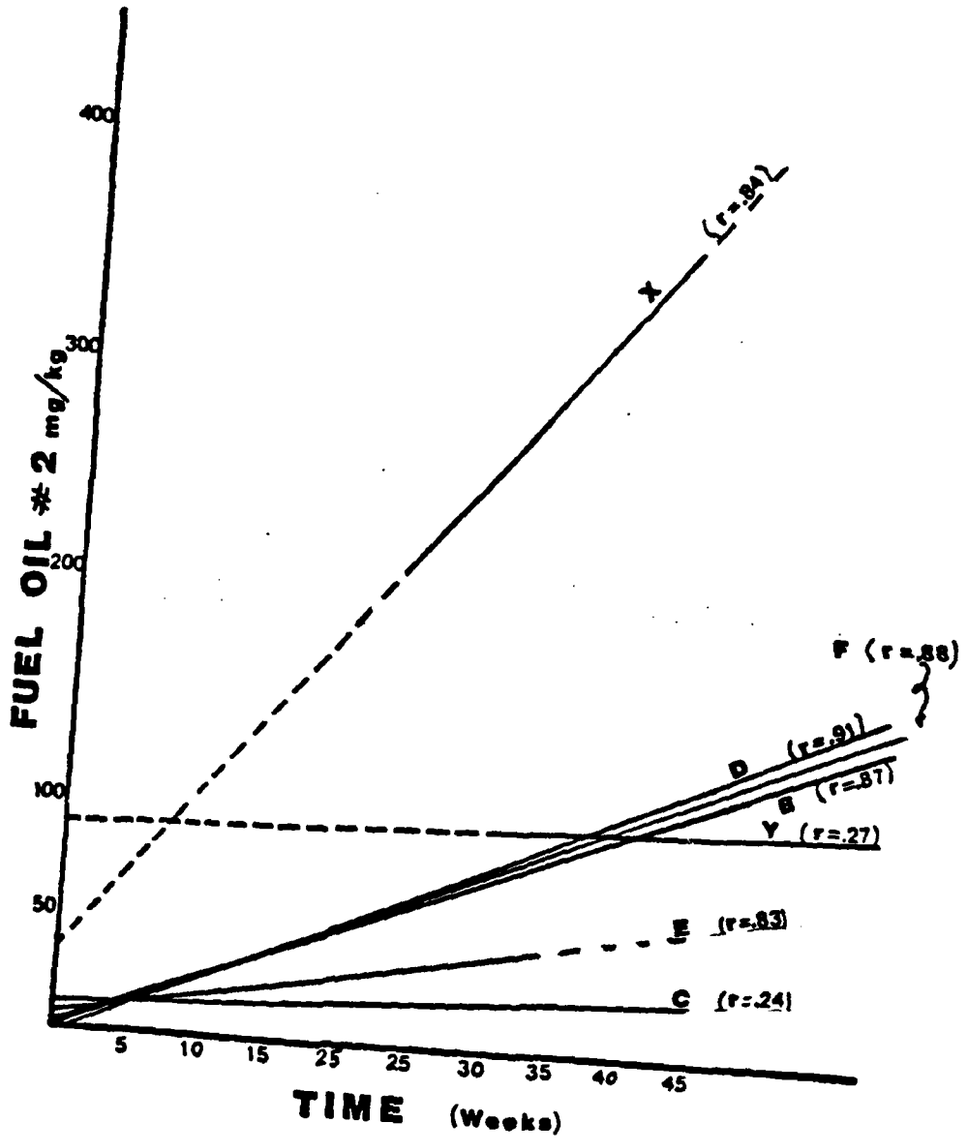


FIGURE 12 FUEL OIL # 2 REGRESSION

APPENDIX C

METAL ANALYSIS

Introduction

The following procedure was used in the digestion and analysis of mussel tissues in this study. The same procedure was used for intercalibration with other laboratories.

General Procedure

The shucked and frozen samples were received at Rider College and frozen until homogenized. Homogenized samples were split into aliquots that were digested separately. In addition, every fifth sample was spiked with a 0.5 ppm spike to evaluate recovery in the analytical system. Analysis for Cd and Pb was by atomic absorption and Hg analysis by flameless atomic absorption.

Sample Preparation and Extraction

The soft tissues of mussels were homogenized by placing the contents of one collection jar into a blender equipped with stainless steel blades and prepared by washing in distilled water, acetone, and methylene chloride. The blender is run for five minutes, stopping at frequent intervals to ensure thorough mixing. The homogenate is then subjected to sonification for three minutes and then returned to the original storage container. Aliquots for analysis of metals are then separated, as is a split sufficient for analysis by New Jersey Institute of Technology where appropriate. Each separated aliquot is subjected to the above homogenization procedure a second time to ensure that separation of the homogenate is minimized.

For mercury analysis, each homogenized aliquot is placed into a prepared BOB bottle and 20 milliliters of mercury-free sulfuric acid along with 5 milliliters of mercury-free nitric acid is added. The bottle is then placed into a water bath maintained at 38°C until dissolved. Bottles are then removed from the bath and cooled to approximately 4°C. Potassium permanganate is then added gradually until a permanent blue color is maintained, which indicates oxidizing conditions. The digested samples are then allowed to stand overnight at room temperature to ensure complete digestion and maintenance of oxidizing conditions.

A second digestion is necessary for Cd and Pb analysis. Ten grams are carefully weighed into a Pyrex beaker. Twenty-five milliliters of 20% sulfuric acid is added to the sample homogenate and the sample is then placed into an oven at 100°C until only a charred residue remains. After approximately 12 hours in the oven the sample is transferred to a cold, clean muffle furnace, making sure that the sample remains covered during the transfer. The furnace temperature is incrementally increased to 275°C (50° per hour) and held for three hours. The temperature is then elevated to 450°C and maintained overnight. Following ashing, the sample is washed with nitric acid to remove residual carbon and evaporated to dryness on a warm hotplate. It is then returned to the muffle furnace and held at 300°C for 30 minutes, after which it is again cooled. This procedure is repeated until the residue is white in color. Digestion is completed by suspending the sample in a warm aqueous nitric acid solution and quantitatively diluted in a volumetric flask and held for analysis.

Analytical Instrumentation

The analytical method used for mercury is the flameless atomic absorption technique described by Hatch and Ott (1968). Mercury in the sample is reduced to its elemental form and the vapor circulated into an absorption cell placed in the path of a mercury lamp and the absorption recorded. The system operates by treating samples with stannous chloride. An aerator is placed in the solution to agitate and circulate the vapor. The instrument used in mercury analysis is a Coleman MAS-50 mercury analysis system.

Prepared solutions are analysed by atomic absorption for Cd and Pb. Direct aspiration techniques were used. Sufficiently high concentrations of both metals were detected to eliminate the need for secondary concentration techniques. As was the case in mercury analysis, both methods of addition standards and discrete standards were used. The instrument used was a Perkin-Elmer 303 atomic absorption spectrophotometer equipped with a strip chart readout system.

Detection Limits

Detection limits for mercury, cadmium, and lead are 0.01, 0.1, and 0.1 ppm, respectively. Precision and recovery are determined by added spikes, replicate runs, and blanks.

APPENDIX D

SEDIMENT ANALYSIS

Introduction

Sediments collected by divers were frozen and transported to the laboratory. Each sample was dried, disaggregated, split and digested, after which it was analyzed for grain size distribution, water loss by heating, and percentage organic material.

Sample Preparation and Extraction

Sediment samples are placed into prepared beakers. One split is weighed and heated to 100°C for several hours to determine water content. The remaining sample is dried and then disaggregated using a clean glass rod to break clumps, and then placed in a cleaned mortar and gently ground. The sediment is then placed between two glass plates and ground, to complete disaggregation. Splits of the sediment samples are digested as previously discussed, and analyzed for Hg, Cd, and Pb as described above.

The volatile solids or percentage of organic materials present are determined by placing a split sample into a crucible and placing it into a muffle furnace at 500°C for one hour. The percentage weight loss after cooling is the volatile organic fraction. This temperature is high enough to ensure combustion and low enough to preclude destruction of carbonate materials (Griffiths, 1967).

APPENDIX E

ORGANIC ANALYSIS

Introduction

Procedure for Lipid Analysis of Mussel Tissue: Ten grams of ground mussel tissue are mixed with 40g of anhydrous sodium sulfate. The glass column is packed with the aforementioned mixture so that it rests against the anhydrous sodium sulfate next to the glass wool plug. Then another 1-2 cm layer of anhydrous sodium sulfate is placed on top of the mussel tissue-sodium sulfate layer.

Two hundred milliliters of methylene chloride are poured onto the column in order to extract the lipids. The solvent flow rate is adjusted for 3 to 5 ml/min by means of the column stopcock. The eluate is collected in a clean preweighed 400 ml beaker. The solvent is allowed to evaporate at room temperature. (Care is taken to prevent extraneous material from entering the beaker.) The beaker is then reweighed and the lipid content calculated: % lipid = (wt. of beaker with 10g lipid - wt. of empty beaker) x 100.

Procedure for Analysis of Pesticides, PCBs, and Fuel Oil No. 2 in Mussel Tissue: Distillation and Separation of Pesticides, PCB Compounds, and No. 2 Fuel Oil from Mussel Tissue: By exhaustive steam distillation in a special apparatus the three desired classes of compounds are transferred from the mussel tissue to a small volume of iso-octane.

The Wheaton exhaustive distillation apparatus is used in this procedure. Five grams of ground mussel tissue and six grams of anhydrous sodium sulfate are mixed and transferred to the 250 ml flask of the distilling apparatus. A total of 70 ml of distilled water is used to help transfer the mixture. The final 10 ml of water is used to wash down the sides of the flask. A boiling rod is placed in the flask and the flask is connected to the column. Two milliliters of iso-octane are added to the column of the distilling apparatus. The flask is heated so that gentle boiling occurs. Care must be taken to prevent foaming due to excess heat. Boil for two hours.

At the end of two hours, the iso-octane is removed from the column via the stopcock and placed in a reaction vessel. The solution is brought up to a volume of 2.0 ml with iso-octane. The reaction vessel

is sealed with the septum, teflon (shiny) side toward the contents using the aluminum seals and the crimper. The reaction vessel is labeled and stored in the freezer for subsequent gas chromatographic analysis.

Gas Chromatographic Analysis of Mussel Tissue Distillate for Pesticides and PCB Compounds: The 6-foot glass column of SP-2250 and SP-2401 is installed in the gas chromatograph. The electron capture (EC) detector is used. Nitrogen gas at a flow rate of 70 ml/min is allowed to flow through the column. The temperature settings are as follows:

Injection part - 280°C
Column - 200°C
EC detector - 300°C

From the 2.0 ml iso-octane solutions of sample distillates (see Section 2, C, (i)), a 5 ul sample is removed using a 10 ul Hamilton syringe and injected into the gas chromatograph. If the Reporting Integrator is used to determine retention times and peak areas, the start button is depressed at the time of sample injection.

Standards are used to determine retention times in minutes and response factors in nanograms (ng) of substance/area of chromatogram for the substance. The amount of pesticide standard injected into the gas chromatograph varied from 2 to 10 ng. The following standards were used: p,p'-DDT; o,p'-DDT; o,p'-DDD; p,p'-DDD and p,p'-DDE.

PCB standards were made to contain 2 ng/ul by proper dilution of the PCB kit A-21 solutions by a factor of 1 to 500 ml using iso-octane as the diluent. The areas and the retention times for respective samples were measured using the Reporting Integrator.

Gas Chromatographic Analysis of Mussel Tissue Distillate for No. 2 Fuel Oil: The 20 inch, 10% UCW-982 on 80-100 mesh WAW-DMCS-B-39 column is installed in the gas chromatograph connecting it to the flame ionizatoin detector (FID). The following conditions are used to operate the column and FID: Column Nitrogen Flow Rate - 25 ml/min (15 on Bendix Chromatograph Flow Meter)

Time (minutes)	0	2.5	12.0*
Temperature (°C)	65	65	225

The chromatogram is recorded from 0 to 12.0 minutes; however, the column is temperature programmed to a final temperature of 225°C to remove high boiling components from the column. The area of the chromatogram is integrated from retention times of 3 to 11 minutes, representing the compounds constituting No. 2 fuel oil.

Five microliter (5 ul) samples are removed from the 2.0 ml iso-octane solutions of sample distillates (see Section 2, C), and injected into the gas chromatograph for No. 2 fuel oil analysis. On injection of the sample, the temperature programming module is activated. In addition, the Reporting Integrator is activated at the moment of sample injection in order to record the chromatogram.

The standard for the No. 2 fuel oil determination is commercial No. 2 fuel oil. A solution containing 100 ug of No. 2 fuel oil in 5 ul is prepared as follows: Place 200 mg of No. 2 fuel oil in a 10.0 ml volumetric flask and dilute to volume with iso-octane. Then 5 ul of this solution (100 ug of No. 2 fuel oil) is injected into a sealed reaction vessel containing 2.0 ml of iso-octane. The solution is shaken. A 5 ul sample of this solution contains 0.25 ug of No. 2 fuel oil and yields an area which is used to calculate the response factor.

Calculations for Analysis of Pesticides, PCBs, and No. 2 Fuel Oil In Mussel Tissue: REAGENT CHEMICALS FOR ORGANIC CONTAMINANT ANALYSIS.

The calculation will be in parts per billion (ppb). The procedure schematically is as follows:

5g of tissue -- 2.0 ml of iso-octane -- 5 ul for gas chromatographic analysis.

Let: A = area for sample chromatographic peak
RF = response factor, ng/unit area
80 = dilution factor

Then:

$$A \times RF \times 80 = ppb$$

CHEMICALS FOR ANALYSIS OF PESTICIDES, PCBs, AND NO. 2 FUEL OIL IN MUSSEL TISSUES:

2,2,4 - Trimethyl pentane (iso-octane), pesticide grade

Sodium sulfate anhydrous, (12-60 mesh) suitable for pesticide residue

DDT COMPOUND STANDARDS, SUPELCO INC.

o,p'-DDT	4ng/ul	4-8979
o,p'-DDT	2ng/ul	4-8975
p,p'-DDD	2ng/ul	4-8971
p,p'-DDT	4ng/ul	4-8981
p,p'-DDE	2ng/ul	4-8969

PCB KIT A-21 (containing separately 1ug/ul of aroclor 1232, 1242, 1248, 1254, 1260) 4-4803

PCB 1016 - Monsanto Chemical Co.

Air, compressed, dry grade

Nitrogen, compressed, ultra high purity grade

Hydrogen, compressed

No. 2 fuel oil - any commercial source of diesel fuel

Analytical Instrumentation for Lipid Analysis of Mussel Tissue

Glass column: 30 cm x 2.2 cm diamater with a stopcock on one end. A pledget of glass wool is placed in the end next to the stopcock, then a 1-2 cm layer of anhydrous sodium sulfate is placed above the pledget before use.

Analytical Instrumentation for Analysis of Pesticides, PCBs, and No. 2 Fuel Oil in Mussel Tissue:

Wheaton Exhaustive Steam Distillation Apparatus, Wheaton Scientific, Catalogue No. 990810

Wheaton Boiling Rod, Catalogue No. 207770

Reaction Vessel, 1 ml, Stock No. 3-3123
Supelco, Inc., Bellafonte, Pa.

Seals, Standard, 1 ml, Stock No. 3-3294
Supelco, Inc., Bellafonte, Pa.

Septa, T/R, 1 ml, Stock No. 3-3194
Supelco, Inc.

Crimper, 1 ml, Stock No. 3-3195
Supelco, Inc.

Suitable Gas Chromatograph with flame ionization detector and electron capture detector (N63) and temperature programmer

Syringe, Hamilton, 701, 10 ul
Supelco, Inc.

Chromatographic column for pesticides and PCB compounds
1.5% SP-2250 and 1.95% SP-2401 on 100/200 mesh
6 ft. x 4 mm 1D glass column, Supelcoport

Chromatographic column for No. 2 fuel oil - 20 inch
10% UCW-982 on 80-100 mesh WAW-DMCS-B-39

Septa for use in injection port for No. 2 fuel oil samples

Thermogreen, LB-1 (Disc), 2-0659
Supelco, Inc.

Optional Hewlett Packard Reporting Integrator 3390A

APPENDIX F

NATURAL OCCURRENCE OF CONTAMINANTS

Mercury enters the marine environment from various sources including paper mills, electrical industries, fossil fuel combustion, chlorine production, fungicide and pesticide use, and sewage (Cassidy, 1978). Although most mercury released into the environment is of the inorganic form, sediment bacteria can convert this into the more toxic methyl mercury form (Jensen and Jernelov, 1969; Holm and Cox, 1975). Human exposure to organic mercurials occurs primarily through consumption of fish which act as bioaccumulators. Chronic methylmercurialism, which causes irreversible brain damage, was reported in the late 1950's among local inhabitants of Minamata Bay, Japan. The disease was traced to long-term consumption of contaminated seafood (Fribers and Vostal, 1972). Effects of mercury on aquatic organisms are well documented (O'Connor and Stanford, 1979). The average concentration of the metal among marine organisms of the New York Bight was 0.5 ppm.

Cadmium contamination of the marine environment can be traced to a wide range of industrial sources, including photography, lithography, electroplating and phosphor use (Merck and Co., Inc., 1976). The metal has been implicated in the painful osseous Itai-itai disease in Japan as well as in various renal, liver, and cardiovascular disorders (Kjellstrom, et al., 1977; Pinkerton, et al., 1972). Concentrations of 80 ppb reduced growth of veliger larvae of the mussel Mytilus (Pavicic and Jaervenpaece, 1974). The bioaccumulation factor for cadmium is about 100 in fish muscle (Lowmar, et al., 1971), 130 in mussels, and 600 in shrimp (Fowler and Benayoun, 1974). Average concentration of cadmium in fish and shellfish of the New York Bight generally is less than 0.1 ppm (O'Connor and Stanford, 1979).

Lead in the marine environment can be chiefly attributed to automobile combustion, paint production and use, battery production and use of various alloys. Lead exerts its principal effects on the nervous system, kidney, and hematopoietic system (Bouldin, et al., 1975; Russel, 1978). A 50-pct. reduction of mussel byssal thread production was caused by the presence of 2.4 ppm (Martin, et al., 1975). The bioaccumulation potential of lead is relatively strong. Phytoplankton concentrate it by

by a factor of 40,000x; zooplankton, by 3,000x; benthic organisms, by 40x; and predators by a factor of 10x (Lowman, et al., 1971). Average concentrations for New York Bight biota were less than 1.0 ppm (O'Connor and Stanford, 1979).

DDT, or 2,2-bi (p-dichlorophenyl)-1,1,1-trichloroethane, is a synthetic organochlorine insecticide used extensively between 1940 and 1960 to combat various arthropod pests. DDT and its metabolites have been shown to cause cancer in mammals as well as mutagenesis and enzyme induction. Since 1972 its use has been restricted in favor of the degradable organophosphorus pesticides; nevertheless, its persistence and potential toxicity to a wide range of marine life are causes for concern. DDT and its isomers are lipophilic, resulting in a relatively high level of accumulation in body lipids (Whittle, et al., 1977). The latter property leads to concentration of these residues in selected finfish, in some cases as high as five orders of magnitude over the surrounding water. Higher predators such as birds or seals show even greater rates of accumulation. DDT accumulation is relatively low in mussels. Accumulation of DDE, a metabolite of DDT, in birds interferes with calcium metabolism and results in thin egg shells, thereby increasing mortality among unhatched birds.

Butler (1972) compared concentrations of chlorinated pesticides in estuarine mollusks collected throughout the United States during the period between 1965 and 1972. New York Bight-collected samples ranked fifth among coastal states surveyed in incidence and sixth in magnitude of DDT residues. Foehrenbach (1972) reported average DDT residues of 0.1 ppm for shellfish collected in Long Island Sound between 1968 and 1970. Significantly higher levels of this pesticide were detected in finfish collected in the New York Bight.

Polychlorinated biphenyls (PCBs) enter the marine environment in conjunction with the manufacture of dielectrics, plasticizers, flame retardants, hydraulic fluids and paint and printing inks. PCBs represent over 200 separate compounds containing from one to ten chlorine atoms in the parent molecule. Commercial mixtures are classified according to the degree of chlorination, with the lower chlorinated forms generally thought to be less significant as environmental residues. PCBs have been implicated in a number of mammalian disorders involving skin, liver, and reproductive

complications (Wasserman, et al, 1970; Vox, 1972; Epstein, 1974). Effects on marine organisms have also been documented (Risegrough, et al., 1968; Duke, et al., 1970; Hansen, 1976). PCBs are of particular interest in the New York Bight since they have been detected among several edible finfish species at concentrations in excess of the 5.0 ppm FDA guideline (NJDEP, 1977).

Petroleum hydrocarbons (PHC) are a diverse group of compounds ranging in chemical structure from the low-molecular-weight alkanes to the condensed aromatic ring forms. Approximately 55 percent of all contaminant petroleum hydrocarbons in the marine environment can be traced to localized release associated with highly industrialized port centers (Whittle, et al., 1977). An additional 21 percent enters along the world's tanker routes. Petroleum hydrocarbons have been shown to accumulate in marine sediments and surface water of the New York Bight (Farrington, 1974; Monaghan, et al., 1974; Searl, et al., 1976). The water-soluble fraction of petroleum oils are known to be toxic (Whittle, et al., 1977). Acute toxicity has been attributed to the polynuclear aromatic hydrocarbon fraction (Neff, et al., 1976).

No. 2 fuel oil is a complex mixture of alkane, isoprenoid, aromatic napthenes and heterocyclic compounds representing one of many crude oil fractions. It is released into the marine environment through a number of routes, most particularly in conjunction with tanker oil spills.

Marine animals differ as to their propensity for accumulating petroleum hydrocarbons. Available data suggest that fish and crustacea selectively regulate hydrocarbon levels in their tissues, whereas mollusks regulate poorly (GESAMP, 1977). Accordingly, the latter tend to bioaccumulate petroleum residues to a far greater degree. In particular, petroleum hydrocarbons have been shown to increase in Mytilus edulis collected in areas subjected to both chronic and single-spill contamination (Whittle, et al., 1977).

APPENDIX G

FILTER-FEEDING IN THE BLUE MUSSEL

The edible blue mussel, Mytilus edulis, is a member of a group of bivalve molluscs, the heteromyarians, known for having uneven adductor muscles and living attached by byssal threads to hard substrata such as rocks or dock pilings. Mytilus is widely distributed in the temperate zones of most oceans and is very hardy. The filter-feeding mechanism of the mussel (Figure 2) is similar to that described for other lamellibranch molluscs (Russell-Hunter, 1969). Lateral cilia of the gill produce the water current between adjacent filaments. This water passes ventrally into the inhalent portion of the mantle-cavity, and then through the gills to the exhalent chamber above and within them. All food organisms and suspended material are accumulated on the inhalent faces of the gill lamellae. These materials are then transported by the frontal cilia toward the ventral edges of the gills and concentrated in the food grooves along with mucus. Cilia associated with the food grooves convey food material along the ventral edges of the gills to between the labial palps. Here again, sorting is carried out on a size basis. Fine material is carried by cilia into the mouth and ultimately into the esophagus and stomach where further sorting occurs. Coarser particles accumulate along the edges of the palps, and periodically are deposited onto the mantle through muscular action. Ultimately, this material is expelled from the mantle cavity as pseudofeces.

APPENDIX H

LITERATURE REVIEW OF THE BLUE MUSSEL AS A BIOMONITORING TOOL

Since many coastal areas throughout the world are receiving increasing amounts of anthropogenic wastes of questionable quality, attempts have been made to develop efficient and economical methods to monitor these waste discharges and assess their effect on marine ecosystems. One method which has been gaining popularity employs sentinel organisms to monitor water quality (Goldberg, et al, 1978). Biomonitors, such as Mytilus edulis, have proven to be effective instruments in measuring contaminant levels, variations and subsequent ecological changes. Use of these organisms has enabled officials to continuously assess the extent of contamination so that remedial action can be taken to minimize loss of marine resources.

The use of blue mussels for biomonitoring studies has gained worldwide approval. The United Nations Environmental Program (UNEP) proposes to use these organisms to monitor organic and inorganic mercury and DDT accumulation, while scientists from Chili, Turkey, Europe, and the United States have already initiated such studies. In addition, the National Research Council has coordinated an international mussel watch (NAS, 1980) using bivalves throughout the world as recorders of environmental change.

At a workshop held in Barcelona, Spain (NAS, 1980), objectives for this international mussel watch were outlined as follows:

1. advance the state of knowledge and understanding of environmental processes;
2. support the processes of environmental regulation, standard setting, and enforcement;
3. determine and assess the level of contamination of coastal areas and warn of potentially dangerous conditions;
4. develop methods and instrumentation; and
5. train scientists.

Scientists present at the Barcelona conference and others throughout the world have attempted to adopt standards for biomonitoring studies. The scientific community is in general agreement regarding selection of sentinel organisms. These should be ubiquitous, sedentary, and be clearly defined as to their culture, pathology, and physiology. Lowman (1979) further points out that effective biomonitors should be capable of

predictably concentrating pollutants from seawater at levels which can be analyzed by available methods. M. edulis has been shown to concentrate hydrocarbons as much as 1000 times above ambient concentrations (Fossatu and Canzonier, 1976) and metal concentrations can be 3×10^6 times in excess of those of the surrounding medium (Phillips, 1976).

In addition to being effective concentrators of pollutants, mussels are able to withstand significant environmental stress. This fact enables them to be transplanted into polluted waters of varying physical and chemical characteristics. Bruce (1926) reported that mussels could withstand unusually high temperatures, and Montwani (1955) found that they could exist in salinities of up to 51 parts per thousand. Thus, mussels seem capable of withstanding the shock of transplantation; however, excessive shock due to extreme variances in salinity or temperature may affect the rate of contaminant accumulation (NAS, 1980).

Although mussels can withstand considerable environmental stress, the rate of contaminant uptake may vary between individuals of any given population due to body weight and sex (NAS, 1980). Scientists associated with the International Mussel Watch suggested use of mussels of relatively uniform size (50-80 mm). Since body weight will vary over the course of one year as a result of spawning and food availability, it has also been suggested that samples should be collected at all test and control sites at similar times.

Even if great care is taken to ensure simultaneous sampling, contaminant concentrations within an individual may change due to improper pre-analytical handling and storage (NAS, 1980). Freshly shucked tissue or whole mussels should be stored at the lowest temperature possible to retard biodegradation of contaminants.

According to NAS (1980), biomonitors such as mussels will retain and discharge contaminants naturally, depending upon factors such as contaminant concentration in the surrounding seawater. It is believed that mussels will accumulate contaminants until their tissues become saturated or reach a concentration equilibrium with surrounding water. Complete equilibration of hydrocarbons is said to take approximately 90 days (NAS, 1980).

After a thorough literature review, it appears that there are limitations to the use of organisms such as the blue mussel (Mytilus edulis) as environmental monitors. Rates of contaminant uptakes and retention differ with body weight, sex, and season, and in most cases it is not possible (and may not be necessary) to accurately identify the source of pollution. However, if these limitations and others are well understood by investigators, there is no disputing the organism's ability to detect and indicate gross pollution levels.

APPENDIX I

ANALYTICAL QUALITY CONTROL PROTOCOLS

Recoveries

Recoveries permit the measurement of systematic error in any portion of the analytical procedure which results in a consistent loss of a contaminant fraction from the sample. Accordingly, spikes of representative contaminants were placed into the sample at various points. For metal analysis a 0.5 ppm spike of each metal was routinely added to every fourth sample analyzed. A 1000 ppm spike was used for both DDT and PCB analyses, while a 20.0 ppm spike was employed for petroleum hydrocarbons (expressed as No. 2 fuel oil). In addition, both tissue and gas chromatographic spikes were added for 10 percent of organic analyses so as to estimate pre- and post-extraction efficiencies.

The recovery of both inorganic and organic analyses is represented by the percentage of the original concentratoin recovered in addition to the spike, and is calculated as follows:

$$\% \text{ Recovery} = \frac{\text{Value by analysis}}{\text{Theoretical value by calculation}} \times 100$$

Extraction Efficiency

The extraction efficiency is used to determine if any recoverable quantity of contaminant remains after analysis. For organic analyses this is separated into pre- and post-extraction efficiency and is determined by:

$$\% \text{ Efficiency} = \frac{\text{Value from initial extraction}}{\text{Initial extraction + 2nd extraction}} \times 100$$

However, a high recovery still does not reflect the actual tissue concentration due to inexorable binding and/or incomplete tissumizing.

Duplicates

Replicate analyses were employed since each retrieved mussel bag (primary sample) was separated during pre-analytical operations into three subsamples. Duplicate ratios are calculated as the higher value of three trials divided by the lower value which generates a number equal to or greater than 1.0.

Intercalibration/Reference Samples

Regular interlaboratory calibration exercises were performed for all contaminants evaluated in this study. In the case of metals (Hg, Cd and Pb), split mussel samples were analyzed by both the Rider College and New Jersey Institute of Technology laboratories. Split sample homogenates for organic analyses were concurrently analyzed by Ramapo College, New York Testing Service and Rutgers University. The initial organic analysis profile of stock mussels used in the August deployment was performed by a contract laboratory (EC-TEST, Inc., Farmingdale, NY).

Miscellaneous

Sets of PCB, DDT, No. 2 fuel oil and metal standards were analyzed during the start-up period of this research. Standard curves representing the results of these analyses are presented in the Appendix.

Criteria for Acceptance

1. Blanks - PCBs, DDTs and No. 2 fuel oil must not contain concentrations greater than 10% of the highest concentration in any sample.
2. Recoveries - generally must be a minimum of 60% of the spiked contaminant concentration. Pesticide recoveries must be above 80%.
3. Acceptable recoveries for cold spikes of representative pesticides and PCBs should be 25% of the theoretical value.
4. Duplicate ratios - must be less than 3.0 for all analyses.

Any sample analysis failing to meet the above criteria was rejected and the analysis repeated.

APPENDIX B

AD-A138 435 DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM 3/6
EVALUATION OF THE 1980 CAPP..(U) NEW YORK UNIV MEDICAL
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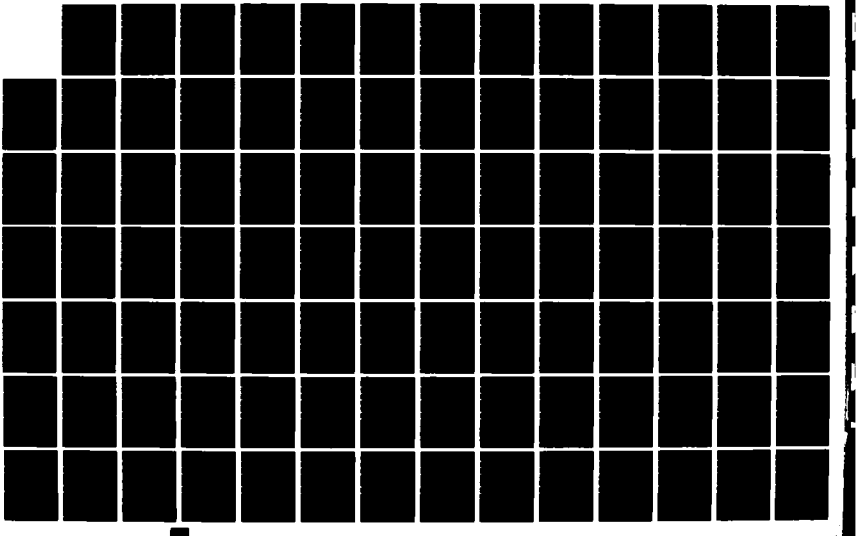

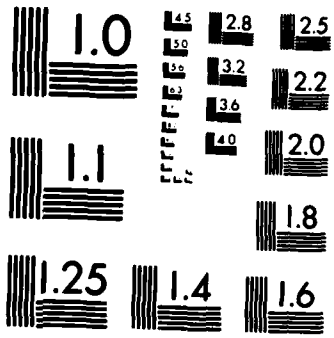

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NATIONAL BUREAU OF STANDARDS-1963-A

IDENTIFYING CHEMICAL SIGNATURES FOR DISPOSED DREDGED MATERIAL

FINAL REPORT

to

U.S. ARMY ENGINEERS
NEW YORK DISTRICT

from

New York University Medical Center
Institute of Environmental Medicine
Lanza Laboratory
Tuxedo, New York 10987

June 16, 1982

Contract No.
DACW51-80-R-0002

EXECUTIVE SUMMARY

Design

1. Physical and chemical characteristics of sediments from 10 dredging projects and 11 cores from the Mud Dump were analyzed.

2. The objective of the analysis was to determine: 1) unique chemical signatures in sediments from various projects; 2) whether a clean sand cap could be placed over contaminated sediments at dump sites in the N.Y. Bight; and 3) if individual projects could be identified at the Mud Dump after disposal.

3. Additional data relative to the extent and depth of sand at the surface of the Mud Dump site were obtained from vibracore samples taken at the dump site.

Results

1. Chemical characteristics and physical characteristics were determined.

2. Levels of chemical contamination were greatest for metals, especially zinc; PCB levels were roughly similar throughout projects.

3. Unique chemical signatures were determinable for a single project - Staten Island - due primarily to very high levels of metals, especially zinc.

4. Chemical and physical analyses of core samples showed the presence of a sand cap of varying thickness.

5. X-ray analysis of vibracore samples taken at the Mud Dump site also demonstrated the presence of a sand cap; the depth of the cap was variable and ranged from a few centimeters to more than 1 meter.

6. The use of contaminated sediment for capping may have confounded the results of the project to a measurable degree.

Conclusions

1. Dredged material from the N.Y. Harbor region varies considerably in physical and chemical characteristics. The wide variability in the parameters chosen for analysis precluded detection of statistically significant differences.

2. Some regions (e.g., Port Newark, Staten Island) are unique in their high levels of chemical contamination.

3. No samples from dredging projects were found to contain unique chemicals; discrimination of projects must rely upon levels of "typical" contaminants, especially heavy metals.

4. Levels of organic and inorganic contaminants at the Mud Dump site are equivalent to levels detected in the analysis of samples from individual dredging projects.

5. Gravity core samples taken in December, 1980 and August, 1981 showed a sand cap containing low levels of contaminants, covering fine-grained, highly contaminated material at some of the dump site sampling locations.

6. The use of contaminated sediments for capping made difficult any conclusion regarding the extent to which successful capping occurred throughout the region under study.

7. The presence of a sand cap at the experimental Mud Dump site was confirmed by additional core samples (vibracores) taken in March, 1982. The depth of the sand cap was variable, but averaged 1.08 m.

8. Where the sand cap was found to be in place, contaminant levels in the sand, and thus in contact with the water column, were greatly reduced.

9. Although studies of contaminant flux between sediments and water at the Mud Dump have not been conducted, we hypothesize that the presence of a clean sand layer between contaminated fine materials and the water column should effectively isolate contaminants by reducing diffusional transport of most contaminants.

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IDENTIFYING CHEMICAL SIGNATURES FOR DISPOSED DREDGED MATERIALS

INTRODUCTION

The dredged materials removed from slips, channels and lightering areas in the Port of New York and New Jersey are contaminated with a variety of compounds considered actually or potentially inimical to marine life. The sources of this contamination have been described (Mueller et al., 1976; O'Connor et al., 1982) as industrial and domestic waste discharges, stormwater runoff and combined sewer overflows, riverine transport, spills and, perhaps, illegal dumping. These varied sources contribute to the sediments a bewildering array of organic and inorganic contaminants (Klein et al., 1974; Mueller et al., 1976; MacLeod et al., 1981); contaminants of prime ecological and human health interest have been discussed in detail by various authors in O'Connor and Stanford (1979).

The indirect result of having comtaminated sediments in the port facilities of metropolitan New York is the removal of some portion of the harbor pollution problem to ocean dumpsites used for disposal of dredged harbor material (Conner et al., 1979). When navigational or construction purposes require, these sediments are removed by dredging. Some portion not used for fill is placed in barges and transported directly to the Dredged Material Dump Site in the New York Bight Apex (Figure 1). The disposal of estuarine and harbor sediments in the marine environment imposes upon them a series of factors quite unlike those at their site of origin; decreased temperature, increased salinity, increased turbulence and vastly different populations of benthic

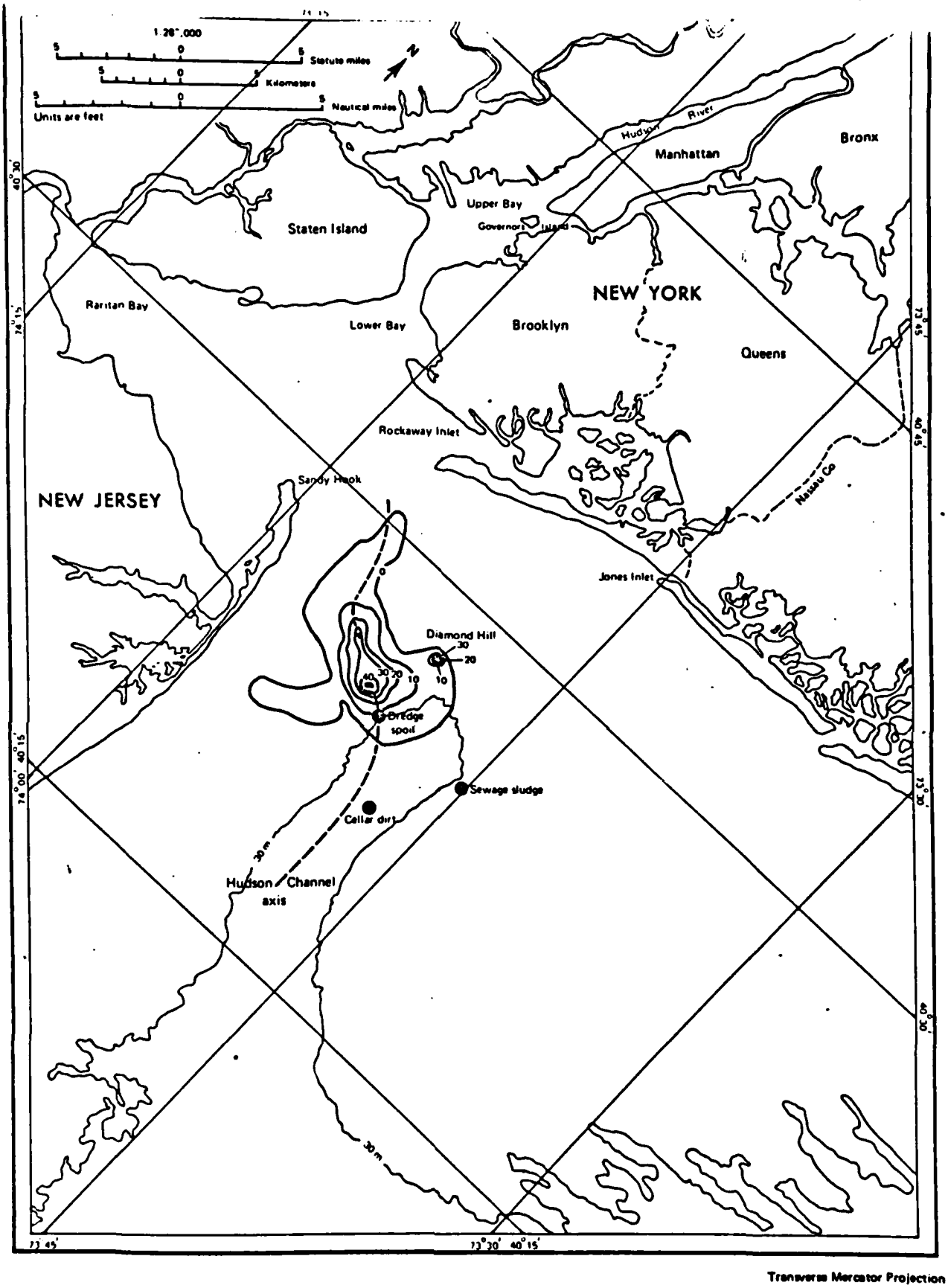


Figure 1. Map of the New York Bight Apex, showing the locations of dump sites for dredged material, sewage sludge, and cellar dirt.

and epibenthic organisms for potential colonization. Perhaps most important, however, is the disruption of the physical integrity of harbor sediments by dredging and dumping operations. From a relatively stable environment of rapid sediment deposition with organically enriched, reducing conditions, dredged sediments are mixed, oxidized and subsequently resuspended in the marine system, where contaminants may become available to marine biota.

In a geophysical sense, contaminants which deposit in estuaries with particulate matter are unlikely to undergo transport to coastal waters, even in a geologic time frame. The more likely fate in the estuary is burial under newly deposited material as natural sedimentation processes gradually fill the estuary (Panuzio, 1965; Gross, 1976).

For many years it had been assumed that dumping of waste materials at sea would have no ecological impact other than the physical disruption of a small area of shelf bottom (Redfield and Welford, 1951). The immense diluting capacity of the ocean, coupled with natural dispersive processes, were presumed sufficient to reduce concentrations of waste materials and contaminants to nondetectable levels. Following dispersion and dilution, any contaminants in waste materials would most likely be reduced to levels unlikely to cause ecological impact on marine biota and marine fisheries. Within the past 20 years, however, this has apparently not proved to be the case. Wholly apart from the question of whether waste disposal has an adverse effect on ecosystems and the environment, one can find much data showing that contaminant levels in sea water, marine sediments and marine organisms are easily detectable (NAS, 1975). The waste assimilative capacity of the oceans, therefore,

is not unlimited (Goldberg (ed.), 1979).

A considerable amount of research has been conducted, and is currently underway to determine the distribution of chemical contaminants in marine organisms, the sources and sinks of these contaminants, and the acute and chronic effects of the contaminants on marine biota. Although it is generally agreed that coastal marine ecosystems adjacent to virtually any industrialized region will contain contaminants (see, e.g., Lake et al., 1979; Wasserman et al., 1979), much disagreement persists as to the long term environmental impact of contaminants on marine ecosystems (Lunz, U.S. Army Engineers, unpublished report summary). On the one hand, it has been proposed that the mere presence of potential contaminants in marine organisms is, in itself, evidence of existing or incipient impact at the organism on population level. Contaminant input should thus be eliminated, if possible, and the system monitored closely to detect effects (Sindermann, 1976; Goldberg et al., 1978; Atwood et al., 1979).

On the other hand, many data exist showing that contaminants in organisms do not, necessarily, reflect actual or potential ecological impact (O'Connor and Rachlin, 1982). Further, data are rapidly accumulating which show that bioaccumulative processes for a variety of contaminants are not directly related to levels present in the environment (Grieg et al., 1977; Neff et al., 1978; Califano et al., 1982; Peters and O'Connor, 1982; Rubinstein and Lores, 1982). Whether contaminant levels or contaminant loading in an environment can be used to predict impact cannot be decided. Complex questions of contaminant bioavailability still need to be evaluated and applied on a situational basis.

Contaminant loading in the marine environment has many interpretations. It can be interpreted rigorously as the placement of contaminants into any system where they are unlikely to have access due to natural processes. Alternatively, the interpretation may relate specifically to life processes which can be affected by the contaminant. That is, since contaminants can only interfere with biological processes, then only those contaminants which are biologically available should be considered with regard to biological or ecological effects. The "mass balance" or "budget" approach to contaminant loading considers only the specific tonnage of material deposited in the system, as evidenced by the approach of Mueller et al. (1976), Bopp et al. (1981) and O'Connor et al. (1982). Contamination, in the sense of the estimates made by these authors, is directly equivalent to how much material is placed in the habitat. West and Hatcher (1980), Bopp et al. (1981) and O'Connor et al. (1982) each evaluated different wastes by this method and pronounced the dumping of dredged material to be the larger "problem" in the New York Bight Apex with regard to PCBs, pesticides and other organic contaminants. Mueller et al. (1976) did the same for metals.

The "bioavailability" criterion for ascertaining potential harm has only recently been applied to ocean disposal practices. Fulk et al. (1975), Neff et al. (1978), and NACOA (1981) discussed the obvious differences in evaluating the potential bioavailability of contaminants to organisms influenced by disposed dredge materials and those exposed to the disposal of sewage sludge. Based upon data from a variety of sources, O'Connor (manuscript in review) concluded for the New York Bight that, although dredged material may contain the greater mass of contaminants, differences in dispersion and settling characteristics of

sewage sludge and dredged materials resulted in the relative bioavailability of contaminants from the two sources being about the same. Relative bioavailability was assessed by the author as being the quantity of materials entering solution in sea water, from which direct uptake may take place (O'Connor, manuscript in review; Pavlou and Dexter, 1977, 1979; Clayton et al., 1977; Nau-Ritter, 1980; Califano et al., 1980, 1982).

Loss of contaminants to the water column from dispersed dredged material represents only part of the bioavailability question, however. Contaminant uptake directly from the sediments may also represent a significant source to marine biota, particularly benthic infauna (Elder et al. 1978; Rubinstein and Lores, 1982). Contaminants in benthos may well represent a significant source of contamination to other organisms via food chain transport (Thomann, 1978, 1981; Pierce et al., 1981; Califano, 1981; Califano et al., 1982; Pizza and O'Connor, in press). While ongoing research demonstrates clearly that direct uptake from sediment of some organochlorine contaminants by fishes and polychaete worms represents about a 1:1 partitioning from sediment to organisms (Califano et al., 1982; Pizza and O'Connor, in press; Rubinstein and Lores, 1982), the apparently efficient process of food chain transport (Thomann, 1981) keeps the contaminants cycling within the biota. Thus, every effort to reduce the magnitude of the interface between ocean-disposed dredged materials and the biota appears justified.

Several plans for reducing the bioavailability of contaminants in dredged materials have been proposed. These include: 1) upland disposal in secure landfills; 2) disposal of dredged materials in abyssal waters

beyond the continental shelf; 3) capping disposed materials with clean (i.e., uncontaminated) material; and 4) disposal of material in submarine pits and subsequent capping with clean material. Economic considerations aside, all four plans have merit; most effective would be upland disposal, followed by the marine disposal plans. In fact, upland disposal of dredged material from the marine district is probably not feasible on a large scale, and various marine disposal plans are being evaluated for their efficacy. Using both economic and ecological criteria, one might tend also to minimize consideration of dredged material disposal beyond the shelf break. Disposal activity beyond the continental shelf may require more and larger vessels to traverse the longer distances and more severe conditions of weather and sea. Ecologically, removal of the disposal site to open ocean waters would not reduce bioavailabiltiy of contaminants to any degree. Bioavailability may, in fact, be increased; only the presumed quantity of biota present to react to the contaminants may decrease.

Two practicable disposal considerations remain: 1) capping disposal sites on the near-coastal continental shelf; and 2) burial of contaminated sediments in subaqueous pits. The project reported on in this report deals specifically with aspects of contaminants dumped at sea on the continental shelf within the confines of the designated Dredged Material Dumpsite. The data herein relate indirectly to subaqueous burial of dredged material as well, since part of the study deals directly with emplacement of a "cap" of clean sand atop "contaminated" fine material, comprising silt, fine silt and clay.

The study was executed between October, 1980 and December, 1981 utilizing primarily samples of dredged material obtained on site, at dredging projects, by personnel from the U.S. Army Engineers and the employees of dredging contractors. Sediment cores were taken from the Mud Dump in December, 1980 and again in August, 1981 from the R/V Onrust operated by the S.U.N.Y. Stony Brook Marine Sciences Research Center. Additional data from the dump site were obtained from a series of vibracore samples taken in March, 1982.

MATERIALS AND METHODS

The samples used for analysis came from two discrete sources, designated as "project samples" and "core samples". Project samples were collected during dredging at each of ten project sites (Table 1; Figure 2) distributed from the transect region of the Lower Bay-N.Y. Bay interface throughout the harbor facilities of the Port of New York and New Jersey, north to Haverstraw, N.Y. Project samples were collected in one-quart glass or plastic jars from barges filled with material from each project site. Separate samples were taken from each barge and, for the most part, labeled to show date of collection, barge number, and the location of the cut within the scope of each project.

The sample jars were transported to the N.Y. District C.O.E. Laboratory, Caven Point, Jersey City, N.J. and frozen until transferred to the NYUMC; Ambrose Channel sand samples were not frozen.

Representative project samples were transported frozen from Caven Point to the NYUMC Laboratory. For projects with large numbers of samples, up to 15 were chosen in order to cover the full geographic extent

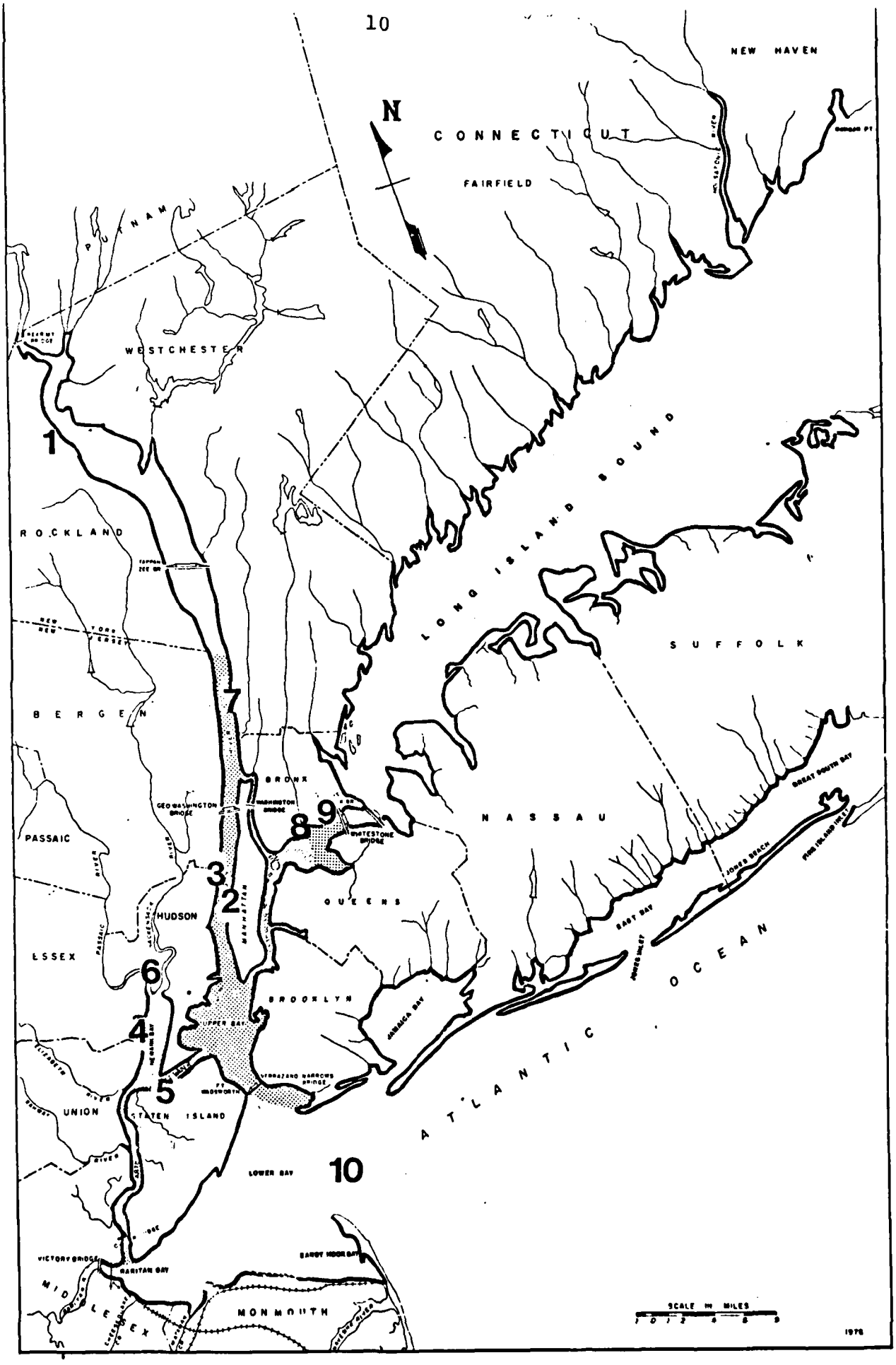
Table 1. Dredging projects and sample numbers available for analysis of chemical signatures. Information from N.Y. District, U.S. Army Engineers.

Project No.	Waterway	Facility[a]	Location	No. Samples Available	No. Samples Run
1	Hudson River	U.S. Gypsum	Stony Pt., N.Y.	54	11
2	Hudson River	Port Authority Term.	Manhattan	76	14
3	Hudson River	Sea Train Terminal	Weekhawken, N.J.	22	10
4	Newark Bay	Port of NEwark	Newark, N.J.	29	15
5	Kill Van Kull	Jackson Engineering	Staten Island, N.Y.	41	11
6	Passaic River	Monsanto Corporation		2	2
7	Hudson River	Westchester Cty STP	Yonkers, N.Y.	2	2
8	Bronx River	Hunt's Pt. Terminal	Bronx, N.Y.	73[b]	10
9	Westchester Creek	--	Bronx, N.Y.	41[b]	10
10	Ambrose Channel	--	--	250[b]	5

[a] If no facility specified, project was general approach channel.

[b] Number of samples represents estimate.

Figure 2. Locations of dredging projects analysed in the Chemical Signature Study. The numbers of the projects correspond to the listing in Table 1.


NEW HAVEN
N
CONNECTICUT
FAIRFIELD
PUTNAM
WESTCHESTER
1
ROCKLAND
LONG ISLAND SOUND
SUFFOLK
BERGEN
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BRONX
GEO WASHINGTON BRIDGE
WHITESTONE BRIDGE
8
9
NASSAU
PASSAIC
3
2
QUEENS
HUDSON
ESSEX
6
4
BROOKLYN
UPPER BAY
5
VERRAZANO NARROWS BRIDGE
UNION
STATEN ISLAND
LOWER BAY
10
ATLANTIC OCEAN
VICTORY BRIDGE
RARITAN BAY
SANDY HOOK BAY
MIDDLESEX
MONMOUTH
SCALE IN MILES
1 0 1 2 4 6 8
1976

of the project. In the case of the Passaic River and Hudson River at Yonkers, only two samples were available; both were analyzed.

Sediment core samples were taken at the designated Mud Dump site (Figure 3) on December 11, 1980 and on August 22, 1981. The December, 1980 samples were obtained shortly after the completion of capping activities on the dump site, and were located so as to cover a transect line through part of the capped area (Figure 3). Capping was completed during the latter part of November, 1980; no significant storms occurred in the interval between completion of capping and obtaining core samples. A second series of cores was taken on August 22, 1981, representing the Mud Dump site after the biological, chemical and hydrological events common to the dump site during winter, spring and summer. The August, 1981 cores were taken in several transects across the capped area (Figure 3).

All cores were taken with 2-meter (m) gravity coring devices having a 5-cm plexiglass sleeve within a stainless steel barrel, and a core-catcher tip on the cutting head. Each core was extruded on board immediately after collection, and sectioned to remove samples. Any samples taken were placed in hexane-rinsed glass jars, capped, and held at ambient deck temperature (-1 C in December, 1980 and 23 C in August, 1981) during the cruise. They were then transported to the NYUMC Laboratory and frozen (-20 C) until analysis.

Selection of core samples for analysis was based on several criteria. For cores of uniform appearance, sections ~ 15 cm in length were cut from the upper, middle and bottom of the core and placed in sample jars. Any cores with unique features, such as distinct layering, were

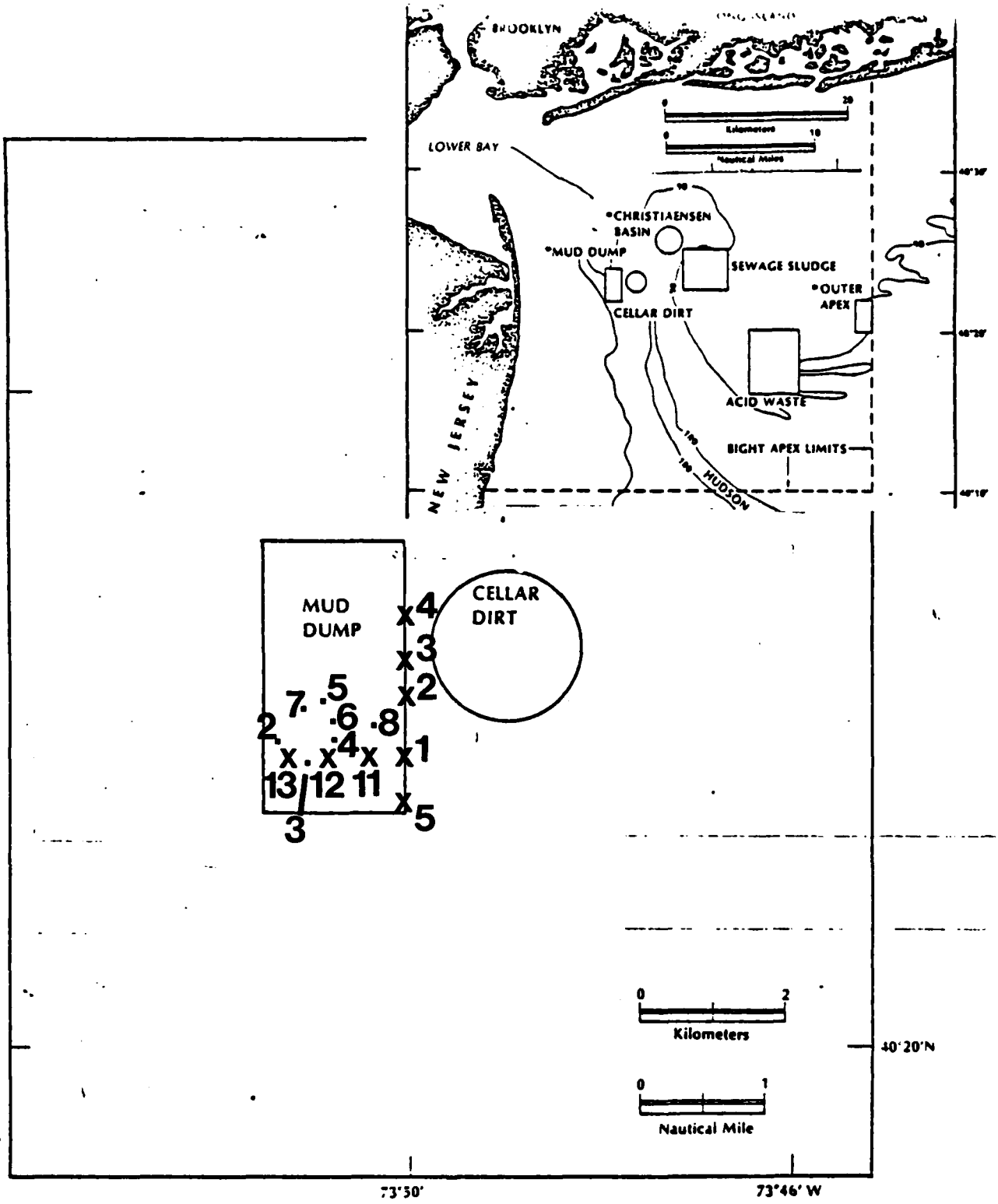

Figure 3. Location of core samples taken in December, 1980 (X) and August, 1981 (rectangles) at the New York Bight Mud Dump Site.

cut so that the layers were sampled, as well as interfaces between layers.

Eleven vibracore samples were taken in March, 1982, under the auspices of the COA-N.Y. District. The vibracore samples, up to 10 m in length, were X-rayed by Dr. Henry Bokuniewicz, Marine Sciences Research Center, State University of New York at Stony Brook, to determine the relative composition of deposited material in the top 2 to 3 m. The sites of the vibracore samples are presented on Figure 3, along with locations of the gravity cores.

A specific sequence of analysis was applied to aliquots of each sample. A flow chart of analyses is shown in Figure 4. Sample portions for analyses were, in all cases, prepared by a single individual, catalogued and distributed for physical analysis, metals analysis, organic analysis, and radionuclide detection.

Not all analyses were carried out on each project or core subsample. Each sample chosen was analyzed for grain size distribution, water content, percent organic matter, Cd, Cu, Pb, Zn and PCB's. Based upon the results of these analyses, decisions were made to composite remaining material for pesticide scans (lindane, aldrin, endrin, p,p'TDE, o,p DDT and p,p' DDT) mercury (Hg) analysis, and analysis for selected polycyclic aromatic hydrocarbons (PAH). A limited number of subsamples were subjected to analysis for selected radionuclides; ^{40}K, ^{226}Ra, ^{232}Th, ^{137}Cs, ^{134}Cs, ^{54}Mg and ^{60}Co. The reader should note that, in this report, percent organic matter represents weight loss from a sample on ignition (550 C). The analytical procedures for analyses are provided as appendices.

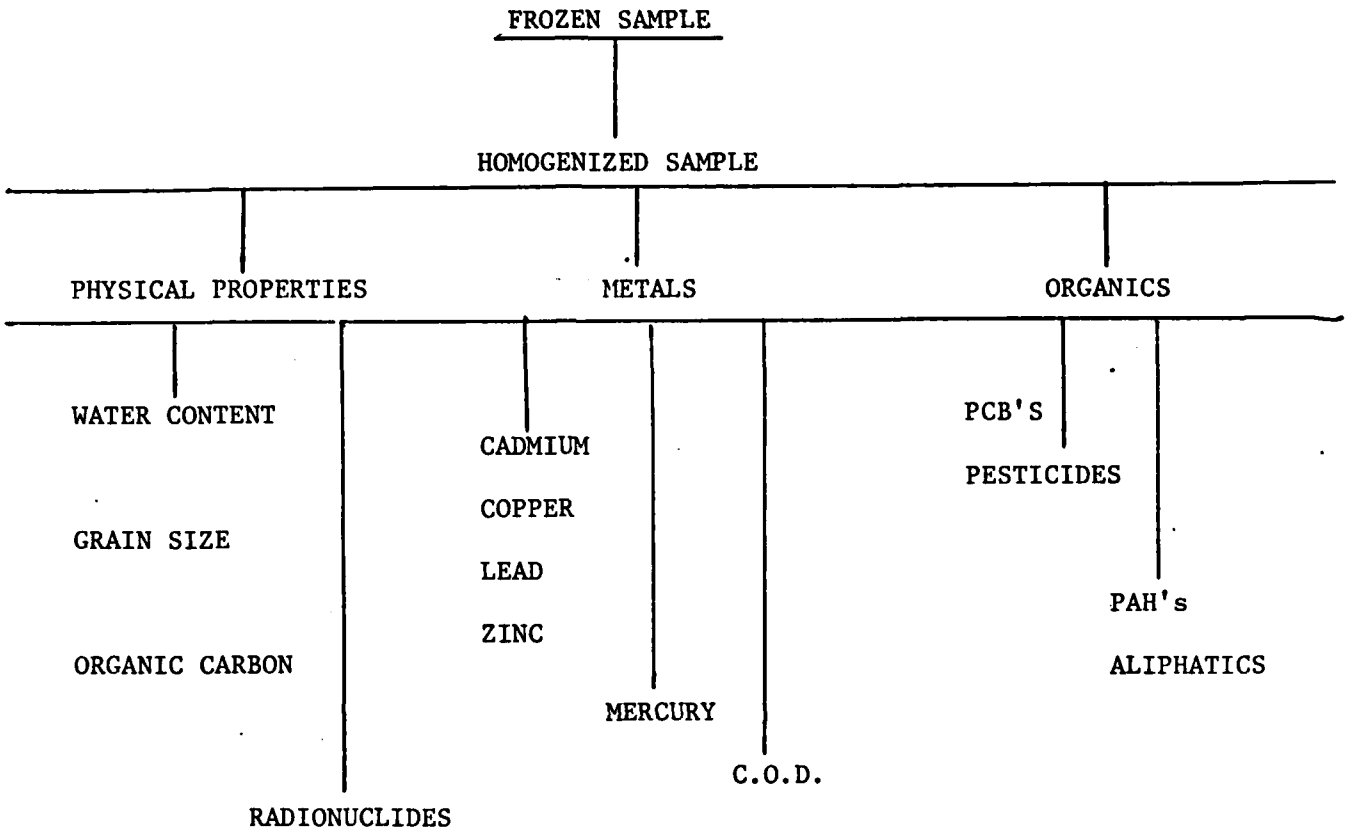

Figure 4. Flow sequence for analysis of samples for Chemical Signature Study.

RESULTS

A. Individual Projects

1. Stony Point

Physical Characteristics: The Stony Point dredge samples were comprised primarily of silts (58.8%) and clays (35.6%) of high water content (47.5%) and a moderate percentage of organic matter (OM = 8.1% of dry weight). As can be seen from the raw data table (Table 2A) the project included distinctly different sediment regimes, one (nearshore; Samples 1-7) consisting of silty clay with almost no sand (0.4 to 4.9%) and the other, nearer the River channel (Samples 8-10), comprising a sandy silt with low clay composition and a reduced organic component (4.9 to 6.4%).

These differences were reflected in standard deviations for the project components; calculated relative standard deviation (RSD) for particle sizes of sand (105%) and clay (43%) were the major varying components. Silt proportions were fairly uniform (RSD = 17%) despite the different zones comprising the project.

Chemical Characteristics: Moderate levels of Cd, Cu, Pb, Zn and PCBs were present in the samples from the Stony Point project. Mean Cd values (2.6 $\pm$ 1.0 ug/g dry weight) had an RSD of 38%; Samples 8, 9 and 10, those with low clay and high sand, had significantly less Cd, Cu, Zn, and Pb than the nearshore stations (Samples 1-7; $p < 0.01$). Composite Hg values for nearshore (1.4 ug/g dry wt) and nearchannel (0.7 ug/g) differed.

Table 2.A. Measured values for grain size,metals and PCB at the Stony Point project.

Component	Sample No.												
	1	2	3	4	5	6	7	8	9	10	n	$\bar{X}$	±S
Sand (%)	2.2	2.4	0.4	0.8	2.5	4.9	1.5	15.9	14.0	11.5	10	5.6	5.9
Silt "	47.8	51.5	53.7	61.4	61.2	49.7	50.5	80.3	68.3	63.2	10	58.8	10.2
Clay "	49.9	46.1	45.8	37.8	36.3	45.4	48.0	3.8	17.9	25.3	10	35.6	15.2
Water "	46.0	60.0	53.0	57.0	59.0	44.0	50.0	29.0	37.0	53.0	10	47.5	9.8
TOC "	9.2	9.6	9.4	9.7	9.8	8.0	8.9	5.4	4.9	6.4	10	8.1	1.9
Cd µg/g dry	3.1	3.3	3.2	3.2	3.1	3.2	3.2	0.7	0.8	2.3	10	2.6	1.0
Cu "	101.0	99.0	110.6	96.1	86.2	82.3	99.0	34.5	28.3	66.0	10	80.3	28.6
Zn "	370.9	575.9	444.8	287.2	241.4	255.2	290.7	99.4	92.4	308.2	10	296.6	145.7
Pb "	149.2	110.6	152.2	143.2	150.4	158.6	137.0	42.5	39.8	109.9	10	119.3	44.4
Hg "	(composites: 1 = 1.4; 2 = 0.7)												
A-1016 "	0.87	0.89	0.75	0.14	0.92	0.92	0.79	0.20	0.13	0.57	10	0.62	0.34
A-1254 "	0.46	0.46	0.45	0.14	0.42	0.26	0.39	0.09	0.08	0.30	10	0.31	0.15
ΣPCB "	1.33	1.35	1.20	0.28	1.34	1.18	1.18	0.29	0.21	0.87	10	0.92	0.48

As with metals, the PCBs were relatively low, with a mean value of 0.92 ± 0.48 ug/g dry weight. PCBs were strongly correlated with organic carbon. As with the metals, the PCB's showed significantly lower concentrations in Samples 8, 9, and 10 than in the nearshore samples ($p < 0.01$; $t = 24.5$ df = 8). Aroclor 1016 was found to be present at higher levels (0.62 ug/g) than Aroclor 1254 (0.31 ug/g; $t = 83.15$ df = 18).

The only detectable chlorinated pesticide from the Stony Point project was p,p' DDT at concentrations of 0.06 ug/g dry weight of the individual samples measured (Table 2B).

Values detected for various PAH compounds in the Stony Point composite samples showed measurable levels of phenanthrene, fluoranthene and chrysene. Except for phenanthrene, which was found in one composite at 660 ng/g (wet weight), PAH values were extremely low, ranging from 10 ng/g to 50 ng/g wet weight (Table 2B).

Radionuclide concentrations (Table 2B) for two composite samples from Stony Point were in close agreement with a "Stony Point reference" sampling station maintained by our Institute (NYUMC). Except for ^{40}K, ^{232}Th, and ^{137}Cs, all radionuclide values were less than 1 pCi/g (dry weight). Radionuclide data through this report are given as picocuries (pCi) per gram dry weight. One curie is a unit of radioactivity defined as the quantity of any nuclide in which the number of disintegrations per second is 3.700×10^{10}. Thus, one picocurie (pCi = 10^{-12} Ci) = $(3.7 \times 10^{10}) \times (10^{12}) = 3.7 \times 10^{-2}$ disintegrations per second, or 2.2 DPM.

Table 2B. Concentrations of chlorinated pesticides, polycyclic aromatic hydrocarbons and radionuclides detected in sediment samples from the Stony Point dredging project.

Compound	Concentration
p,p' DDT	0.06 µg/g dry weight
Phenanthrene	0.2 µg/g wet weight
Fluoranthene	TR
Chrysene	TR
^{40}K	15.9 pCi/g dry weight
^{226}Ra	0.8 " "
^{232}Th	1.2 " "
^{134}Cs	0.2 " "
^{137}Cs	1.1 " "
^{60}Co	0.15 " "

2. Weehawken

Physical Characteristics: Ten samples from barges filled at the Weehawken Seatrain Terminal showed the sediment to consist primarily of clayey silt (clay = 42.1%, silt = 51.6%) with a minor (5.4%) proportion of sand. The most variable component was sand (RSD = 48%). Water content of the various samples averaged 56.7% and was quite uniform, ranging from 55% to 59%. Similarly, organic content was quite uniform, ranging from 10.4% to 11.1%. Relative standard deviations for the water and organic matter components were 3% and 2%, respectively (Table 3A).

Chemical Characteristics: Metals concentrations in the Weehawken project were near the lower end of the range seen in the total of 9 projects analyzed, and were uniform throughout the 10 samples taken. Cadmium ($\bar{x}$ = 4.7 ± 1.2 ug/g) ranged only from 4.1 to 7.4 ug/g. Average values for Cu (237.7 ± 51.1 ug/g) did not vary significantly between samples. Mercury concentration (3.70 ug/g) was determined as a composite, since values for other metals and for physical characteristics showed no between-sample differences.

Aroclor 1016 and 1254 were present in about equal quantities (0.33 and 0.32 ug/g, respectively). The 1016 and 1254 components were similar in most of the samples. Of the chlorinated pesticides tested, aldrin, endrin and DDT were detected; aldrin and endrin values were detectable only as "trace" values (i.e., at or slightly below the detection limit of 0.02 ug/g dry weight). Residual total DDT (ΣDDT) measured was low, 0.04 ug/g dry weight (Table 3B).

Only three PAH compounds were detected in the Weehawken composites;

Table 3A. Measured values for grain size, TOC, metals and PCB at the Weehawken project.

Component	Sample No. (Barge No.)												
	1 (12)	2 (13)	3 (14)	4 (18)	5 (17)	6 (16)	7 (15)	8 (19)	9 (21)	10 (20)	n	$\bar{X}$	±S
Sand (%)	7.3	9.4	6.6	5.6	6.5	0.8	7.3	4.0	2.2	4.1	10	5.4	2.6
Silt "	54.5	57.4	56.8	43.2	57.1	27.3	44.3	60.6	65.1	49.5	10	51.6	10.9
Clay "	38.2	33.2	36.6	51.2	36.4	71.8	48.4	35.4	32.8	46.3	10	43.1	12.1
Water "	59.0	55.0	56.0	58.0	58.0	56.0	57.0	55.0	58.0	55.0	10	56.7	1.5
TOC "	10.4	10.8	10.7	10.8	10.6	10.8	11.1	10.7	10.6	10.5	10	10.7	0.2
Cd µg/g dry	3.8	7.4	5.7	4.8	4.0	3.5	5.5	4.1	4.4	4.1	10	4.7	1.2
Cu "	192.6	279.9	201.4	272.2	189.1	218.1	258.8	256.2	239.0	269.4	10	237.7	34.7
Zn "	424.9	539.7	252.7	420.2	421.4	448.7	450.3	340.8	357.2	414.1	10	407.0	76.5
Pb "	226.9	380.3	285.4	246.1	223.1	214.1	288.5	221.4	250.0	222.4	10	255.8	51.1
Hg "	(composite = 3.70)												
A-1016 "	0.26	0.51	0.39	0.26	0.34	0.27	0.40	0.30	0.29	0.27	10	0.33	0.08
A-1254 "	0.28	0.55	0.46	0.19	0.49	0.24	0.29	0.22	0.22	0.22	10	0.32	0.13
ΣPCB "	0.54	1.06	0.85	0.45	0.83	0.51	0.69	0.52	0.51	0.49	10	0.65	0.20

Table 3B. Measured concentrations of chlorinated pesticides, PAH and radionuclides in composite samples from the Weehawken Project location. Values presented are for those compounds present at trace levels (TR) or above detection limits.

Compound	Concentration
Aldrin	TR
Endrin	TR
Total DDT	0.04 µg/g dry weight
Phenanthrene	TR
Fluoranthene	TR
Pyrene	TR
^{40}K	16.4 pCi/g dry weight
^{226}Ra	0.8 " "
^{232}Th	1.0 " "
^{134}Cs	0.03 " "
^{137}Cs	0.8 " "
^{60}Co	0.2 " "

Table 4A. Measured values for grain size, TOC, metals and PCB at the Yonkers and Passaic dredging projects.

Component	Sample No. (Barge No.)					
	Yonkers			Passaic River		
	1	2	$\bar{x}$	1	2	$\bar{x}$
Sand (%)	30.9	58.2	44.5	23.8	22.8	23.3
Silt "	39.2	23.2	31.2	27.6	42.2	34.9
Clay "	29.8	18.7	24.2	48.5	35.0	41.7
Water "	55.0	68.0	61.5	62.0	70.0	66.0
TOC "	12.8	46.2	29.5	17.1	13.0	15.0
Cd µg/g dry	6.9	21.2	14.1	16.7	6.9	11.8
Cu "	574.4	2241.2	-	807.1	578.5	692.8
Zn "	441.5	2164.6	1303.1	3027.6	935.5	1981.6
Pb "	285.3	832.3	558.8	1938.0	533.1	1235.6
Hg "	1.22			4.27		
A-1016 "	0.46	1.43	0.92	0.41	1.89	1.15
A-1254 "	0.86	1.30	1.08	1.72	1.25	1.49
ΣPCB "	1.32	2.73	2.03	2.13	3.14	2.64

phenanthrene, fluoranthene, and pyrene. Concentrations for these compounds, which ranged from 0.02 to 0.04 ug/g dry weight, were essentially at detection limits (Table 3B). Likewise, the composited Weehawken samples showed very low levels of radionuclides (Table 3B).

There existed essentially no correlation between chemical contaminants at the Weehawken site and either the organic or clay component of the samples analyzed (e.g., coefficients of determination (r^2) for the regression of Cd on OM = 0.22; Zn on OM = 0.06; Cd on clay = 0.14; PCB on OM = 0.06; PCB on clay = 0.19).

3. Passaic River

Physical Characteristics: Only two samples were available from the dredging project carried out at the Monsanto dock in the Passaic River, N.J. These samples were similar in physical characteristics, having an average composition best described as a silty clay with a relatively high percentage of sand (23.3%; Table 4A). Only the Yonkers and Staten Island projects had a higher percentage of sand than the Passaic River project. The water content (66%) and percent organic matter (15%) of the Passaic project were rather high, consistent with the large proportion of clay in the sediment, and the location of the site adjacent to an industry discharging organics.

Chemical Characteristics: All the chemical contaminant values for the Passaic project were high; however, large differences existed between the two samples. Cadmium ($\bar{x}$ = 11.8 ug/g) ranged from 6.9 to 16.7 ug/g, for example, and zinc from 935.5 to 3027.6 ug/g, factors of 2.4 and 3.2, respectively. Similarly, Aroclor 1016 varied by a factor of 4.6

Table 4B. Concentrations of chlorinated pesticides and polycyclic aromatic hydrocarbons in sediment samples from the Passaic River and Yonkers dredging projects. Compounds listed are those for which trace (TR) values or quantifiable levels were detected.

Compound	Concentration		
	Yonkers	Passaic River	
Aldrin	-	0.02 µg/g	dry weight
Endrin	-	0.24 "	"
ΣDDT	-	0.68 "	"
Naphthalene	5.8	0.5 µg/g	wet weight
Phenanthrene	5.0	6.9 "	"
Anthracene	0.1	0.9 "	"
Fluoranthene	2.2	1.5 "	"
Pyrene	12.3	2.6 "	"
Chrysene	0.5	0.5 "	"
Benzo(a)pyrene	2.5	0.4 "	"

between samples, from 0.41 to 1.89 ug/g; total PCBs differed by a factor of only 1.5, accounted for by the uniformity in Aroclor 1254 values between samples (1.72 and 1.25 ug/g). Concentrations of Hg were 2.8 ug/g dry weight, based upon a composite sample.

In the case of all chemical contaminants except Aroclor 1016 and Hg, the highest values occurred in the sample (No. 1; Table 4A) with the higher clay, higher organics and lower water content.

Chlorinated pesticide concentrations from the Passaic Sample No. 1 were quite high, exceeded by none for total DDT and endrin. Endrin values were ~ 0.4 ug/g, and total DDT was 1.04 ug/g dry weight. More samples would be required, however, to use pesticide components as a diagnostic for these sediments (Table 4B).

The PAH concentrations in composite samples from the Passaic River project were among the highest of the 10 project samples analyzed (Table 4B). The full suite of seven PAH compounds was detected in the Passaic project composite, ranging in concentration from 0.39 ug/g (chrysene) to 6.94 ug/g (phenanthrene). Of major significance in the PAH data is the presence of 0.40 ug/g benzo(a)pyrene in the samples, and total PAH values well in excess of 10.0 ug/g (wet weight).

4. Yonkers

Physical Characteristics: As with the Passaic River project, only two barge samples were available from the dredging project carried out at the Westchester County Sewage Treatment plant in Yonkers. The differences in two samples are apparent in Table 4A; they in no way represent replicates. Sand content ranged from 31 to 58%, water from 55

to 68%, and percent organics from 13 to 46%. The true picture of chemical and physical characteristics for the Yonkers site requires resampling and reanalysis.

For Sample 1, it was noted that much vegetative material was present: Sample 2 was described as a "sandy sludge".

Chemical Characteristics: All the chemical contaminants determined in the Yonkers samples showed higher values for the "sandy sludge" (Sample 2; Table 4A) by factors of from 1.5 to 4.5 over Sample 1. Copper (2241.2 ug/g), Zn (2164.6 ug/g) and Pb (832.3 ug/g) were the second highest concentrations measured in any project samples; Cd (21.2 ug/g) concentrations in Yonkers Sample 2 were greater than the means for any other projects tested, exceeding the Port Newark mean (14.1 ug/g Cd) by ~ 30%, and the Staten Island mean Cd value (11.5 ug/g) by 46%. Only one other individual Cd determination (Sample 1, Port Newark) exceeded the Yonkers No. 2 value reported here. Mercury concentrations (1.22 ug/g dry weight), by contrast, were lower than in any other project samples except Ambrose sand.

Concentrations of PCB's and PAH in the Yonkers project samples showed variability between Sample 1 and 2 (Tables 4A and 4B). The magnitude of differences seen in PCB's was less than that seen among the metals; total PCB's varied by a factor of 2.1 between samples, from 1.32 to 2.73 ug/g (dry). However, it is interesting to note that there occurs a difference in isomer distribution between the two samples. In Sample 1 (Table 4A), higher chlorinated isomers (Aroclor 1254) dominate, whereas in Sample 2, the distribution of isomers is essentially the same.

High concentrations of PAH were apparent in Yonkers Sample 2 (Table 4B), but not in Sample 1. Concentrations of naphthalene, phenanthrene, fluoranthene, pyrene and benzo(a)pyrene were present at concentrations greater than 1.0 ug/g (wet weight). High concentrations of naphthalene and phenanthrene (5.77 and 5.04 ug/g wet weight, respectively) were suggestive of fuel oil contamination, as was the very high phenanthrene-anthracene ratio of ~ 44 (Table 4B). Of particular concern were the very high values for pyrene (12.28 ug/g) and benzo(a)pyrene (2.50 ug/g) found in the Yonkers samples (Table 4B).

5. Port of Newark

Physical Characteristics: Port Newark samples representing three docking areas were chosen for analysis. These are separated in Table 5A by vertical lines; Samples 1-4 are Port Newark "A", 5-12 Port Newark "B", and 13-15 Port Newark "C". ANOVA tests of physical characteristics showed no significant differences for distribution of the sand component, but the percentage clay and silt differed among docks ($p < 0.05$). Water content and organic matter did not differ among A, B, and C.

In general, the Port Newark project consisted of clayey silt with a moderate (13.4%) sand component. Dock A had the greater concentration of silt (63.3%), and the least clay, while Dock B had the least silt (38.3%) and the higher proportion of clay. Organic content varied little; the mean (12.2%) varied by only 1.3% over all samples (Table 5A).

Chemical Characteristics: Metals values in the Port of Newark project averaged among the highest seen in any project. Cadmium ($\bar{x}$ = 14.0

± 3.8 ug/g), was the highest project value detected; Dock A at the Newark Port Facility was greater ($p < 0.05$) in Cd concentration than Docks B or C (17.7 ug/g vs 12.9 and 12.3 ug/g). While concentrations for Cu, Zn and Pb were high (465.1, 806.9 and 439.1, respectively), there existed no significant difference among docks. The mean values for Cu, Zn and Pb were greater than all other projects except Staten Island, Yonkers and Passaic River. Yonkers and Passaic, however, were represented by too few data to draw firm comparisons. Composite Hg data for Newark Docks A and C were 27.2 and 8.9 ug/g (dry), respectively.

Total PCB values in the Port Newark project ranged from 0.97 to 2.89 ug/g, with a project mean of 1.59 ± 0.62 ug/g (Table 5A). Dock A had significantly higher PCB concentrations than Docks B or C (2.43 vs. 1.29 and 1.29 ug/g, respectively; $p << 0.01$). The major PCB component overall for the Port Newark project was Aroclor 1254 (1.00 ± 0.39 ug/g) rather than Aroclor 1016 (0.59 ± 0.28 ug/g; $p << 0.01$).

Relationships between physical and chemical parameters, and among various chemical parameters, were examined using regression and correlation analysis. Cadmium, Cu, Pb and Zn showed strong correlations with organic matter in the sediments (r^2 = 0.59, 0.49, 0.45 and 0.73, respectively). For the entire project the correlation between organic matter and PCB's was weak (r^2 = 0.20 for total PCB). However, the relationship of organic matter to PCB at Dock A (Samples 1 to 4; Table 8) was strong (r^2 = 0.99). At Docks B and C the coefficient of determination between organic matter and total PCB was r^2 = 0.003.

The results of correlation analysis suggest a common source for Cd, Cu and Zn; however, lead concentrations did not correlate well with

Table 5A. Measured concentrations of particle size, TOC, metals and PCB at the Port Newark Project.

Component	Sample No.																
	1	2	3*	4	5	6	7	8	9	10	11	12	13	14	15	$\bar{X}$	±S
Sand (%)	14.5	4.6	9.4	7.6	18.8	17.8	22.4	20.9	3.7	11.8	11.0	14.8	21.4	10.5	12.0	13.4	5.9
Silt "	72.8	61.6	67.4	51.9	33.5	42.4	33.6	48.2	36.7	49.4	53.2	9.4	47.4	54.4	49.8	47.4	15.4
Clay "	12.6	33.8	23.1	40.4	47.6	39.8	44.0	30.8	59.5	38.7	35.8	75.7	31.2	35.1	38.2	39.1	14.6
Water "	58.0	62.0	59.0	60.0	55.0	60.0	47.0	52.0	56.0	64.0	58.0	58.0	57.0	57.0	57.0	57.3	4.0
TOC "	13.7	-	12.6	13.5	10.8	11.9	9.5	10.2	12.8	13.7	12.8	12.3	12.9	12.3	11.4	12.2	1.3
Cd µg/g dry	21.3	13.8	17.4	18.2	9.4	11.7	9.6	9.9	20.1	16.0	12.9	13.4	11.1	14.0	11.7	14.0	3.8
Cu "	725.0	481.0	600.6	673.0	326.9	418.2	320.7	341.8	594.0	459.8	382.5	422.5	407.7	435.6	386.5	465.1	126.0
Zn "	1140.3	740.7	934.4	1053.9	558.2	650.4	591.7	588.2	947.8	1003.8	837.6	844.5	682.5	820.2	710.1	806.9	181.1
Pb "	445.1	423.4	407.1	438.8	341.0	380.5	349.3	359.0	417.9	614.0	493.5	512.0	446.0	534.1	425.2	439.1	74.4
Hg "	(comp.= 27.2)												(comp.= 8.9)				
A-1016 "	1.41	0.41	0.89	0.87	0.43	0.73	0.55	0.44	0.51	0.39	0.35	0.37	0.59	0.39	0.59	0.59	0.28
A-1254 "	1.48	1.27	1.37	2.01	0.96	1.19	0.60	0.76	0.88	0.74	0.62	0.78	0.76	0.79	0.75	1.00	0.39
ΣPCB "	2.89	1.68	2.26	2.88	1.39	1.92	1.15	1.20	1.39	1.13	0.97	1.15	1.35	1.18	1.34	1.59	0.62

these metals (e.g., Pb/Cu coefficient of determination = 0.03). In contrast, the r^2 values for other metals pairs were: Cd/Cu = 0.90; Cd/Zn = 0.88; Zn/Cu = 0.77.

Detectable chlorinated pesticides at Port Newark were aldrin (0.04 ug/g), endrin (0.04 ug/g) and DDT (ΣDDT = 0.48 ug/g dry weight) (Table 5B).

PAH concentrations in the Port of Newark samples varied among regions A, B, and C, but showed different trends than did the metals and PCB's Composited samples for the different regions showed, for every PAH quantified, a higher concentration in Dock C area (Elizabeth Channel) than in areas A and B (Table 5B). Values determined for phenanthrene, fluoranthene and pyrene were in excess of 1.0 ug/g wet weight. All other components were below 1.0 ug/g.

Concentrations of radionuclides from the Port of Newark project region were derived from a single composite of all samples and inter-region comparisons cannot be made. However, the values determined for various radionuclides were slightly lower than in samples from projects located on the mainstream Hudson (Table 5B).

6. New York Port Authority

Physical Characteristics: The dredging project at the N.Y. Port Authority Terminal, Manhattan, covered several piers designated in Table 6A according to samples as follows: Samples 1-3, Pier 92 berth 5; 4-6, Pier 90 berth 3; 7-9, Pier 90 berth 3; 10-12, Pier 88 berth 2; and 13-15, Pier 88 berth 1. Statistical analysis showed that the particle size distribution at the various sites differed significantly. Although the

Table 5B. Concentrations of chlorinated pesticides (µg/g dry), polycyclic, aromatic hydrocarbons (µg/g wet), and radionuclides (pCi/g dry) in composite samples from the Port Newark project locations. Values presented are for those parameters present at trace (TR) levels, and at quantifiable levels above detection limits.

Compound	Concentration		
	A	B	C
Aldrin		0.04	Composite A,B,C
Endrin		0.04	
ΣDDT		0.48	
Naphthalene	TR	TR	0.4
Phenanthrene	1.2	0.4	5.6
Anthracene	0.1	TR	0.3
Fluoranthene	0.2	0.1	3.4
Pyrene	0.4	0.4	3.0
Chrysene	TR	TR	0.5
Benzo(a)pyrene	0.3	0.3	0.9
^{40}K		14.5	Composite A,B,C
^{226}Ra		0.8	
^{232}Th		1.1	
^{137}Cs		0.6	
^{54}Mn		0.3	

sand component varied widely and was not different, the silt and clay fractions differed according to pier and berth number. Pier 88 had less silt and more clay than the other piers. Pier 90 had a greater proportion of silt and less clay than Pier 88 ($p < 0.01$). Pier 92 sediments had more clay than at Pier 90, and less than at Pier 88; silt values for Pier 92 were intermediate.

Sediment from the Port Authority project varied between clayey silt and silty clay, but contained a relatively even proportion of water ($\bar{x}$ = 53.9 $\pm$ 2.2%) and organic matter ($\bar{x}$ = 11.4 $\pm$ 0.4%) (Table 6A).

Chemical Characteristics: The heavy metal components of sediments at the Port Authority terminal were relatively low, and concentrations at the different piers and berths were similar despite the significant inter-pier differences in particle size distribution. Relative standard deviations for metals were 11% (Cd); 8% (Cu); 7% (Zn); and 4% (Pb). Mean values for the various metal components were quite similar to the nearest, and most physically similar, project at Weekhawken (Table 3A). The composite sample for Hg analysis had 1.80 ug/g (dry weight) total mercury.

PCB levels in the Port authority project were moderate, (1.23 $\pm$ 0.69 ug/g $\bar{\Sigma}$PCB), consisting primarily of Aroclor 1016 in all samples other than those at Pier 92 (Table 6A). Although there were no statistical differences in Aroclor 1016 concentrations among piers and berths, total PCB's were significantly lower ($p < 0.05$) at Pier 92 (0.46 $\pm$ 0.04 ug/g) than at all other piers and berths ($\bar{\Sigma}$PCB = 1.43 $\pm$ 0.63 ug/g).

Table 7A. Measured concentrations of particle size, TOC, metals and PCB at the New York Port Authority.

Component	Sample No.																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\bar{X}$	±S
	(92-5)			(90-3)			(90-3)			(90-3)			(88-1)				
Sand (%)	8.9	21.1	12.9	8.9	8.4	12.0	7.1	6.4	11.4	10.2	15.9	12.0	17.3	9.3	18.0	12.0	4.3
Silt "	64.1	47.1	49.3	64.1	73.9	76.3	72.7	68.0	55.1	40.7	38.7	47.7	48.6	48.8	40.6	55.7	12.9
Clay "	27.0	31.9	37.8	27.0	17.7	11.7	20.2	25.6	33.5	49.0	45.4	40.2	34.1	41.9	41.3	32.2	10.7
Water "	53.0	54.0	53.0	53.0	50.0	55.0	53.0	55.0	53.0	51.0	58.0	55.0	55.0	58.0	53.0	53.9	2.2
TOC "	11.6	10.7	11.3	11.6	11.2	11.6	11.2	11.6	11.4	10.7	11.3	11.2	11.6	12.2	11.4	11.4	0.4
Cd µg .g dry	4.0	3.9	4.6	4.0	4.5	4.2	4.4	5.0	4.5	4.6	3.9	4.2	4.0	5.3	5.2	4.4	0.5
Cu "	214.0	196.7	217.7	214.0	208.5	218.0	212.5	227.1	223.3	214.7	223.7	204.6	232.7	273.3	240.8	221.4	18.0
Zn "	327.0	296.9	323.1	327.0	333.5	328.2	332.3	324.4	332.3	322.7	339.3	312.5	330.7	400.3	360.0	332.7	23.0
Pb "	278.8	261.1	266.0	278.8	276.8	274.0	281.5	278.9	289.8	261.2	282.6	255.7	276.9	295.7	281.3	275.9	10.9
Hg "			(composite= 1.8)														
A-1016 "	0.23	0.20	0.18	0.23	1.07	1.55	1.06	0.93	1.70	0.88	2.70	1.10	0.54	0.64	1.22	0.90	0.75
A-1254 "	0.25	0.28	0.23	0.25	0.17	0.13	0.33	0.38	0.13	0.23	0.36	0.39	0.31	0.37	0.27	0.27	0.09
ΣPCB "	0.48	0.48	0.41	0.48	1.24	1.68	1.39	1.31	1.83	1.33	3.06	1.49	0.85	1.01	1.49	1.23	0.69

Table 6B. Concentrations of chlorinated pesticides, polycyclic aromatic hydrocarbons and radionuclides in composite samples from the N.Y. Port Authority passenger ship terminal project. Values presented here are for those parameters detected at trace (TR) levels, and at quantifiable levels above detection limits.

Compound	Concentration		
	A	B	
Aldrin	TR	TR	
Endrin	TR	-	
ΣDDT	TR	TR	
Naphthalene	TR	TR	
Phenanthrene	0.25	0.3	µg/g wet weight
Anthracene	TR	TR	
Fluoranthene	TR	0.1	µg/g wet weight
Pyrene	0.1	0.2	" "
Chrysene	TR	0.1	" "
Benzo(a)pyrene	0.2	0.5	" "
^{40}K	18.6	17.8	pCi/g dry weight
^{226}Ra	0.8	0.9	" "
^{232}Th	1.2	1.1	" "
^{137}Cs	0.6	0.6	" "
^{54}Mn	0.3	-	" "

The pesticide component of a composite sample from the Port Authority project showed traces of aldrin and endrin, and a ΣDDT value of 0.07 ug/g, consisting of p,p' TDE, and p,p' DDT.

Concentrations of selected PAH's at the Port Authority Project location were, with the exception of benzo(a)pyrene, rather low (Table 6B); however, all seven PAH's included in the scan were detectable. The reader should note that the two Port Authority PAH composites analyzed were replicate of the same composite. Thus, these data represent, at low levels, the range of variation in the analytical method used (Table 6B).

Radionuclide concentrations (Table 6B) show essentially the same values as other project areas analyzed, with two exceptions; first, ^{60}Co was not present in the sample, and second, ^{54}Mn was present at the Port Authority project, but at no other site tested except Port of Newark.

7. Staten Island

Physical Characteristics: Two separate piers were dredged in the Staten Island project. The data in Table 7A, Samples 1-6, represent sediments from Pier 2, while Samples 7-11 represent selected samples from Pier 4.

Despite the differences in source of the samples, the particle size distribution was homogeneous throughout for sand, silt and clay. The average percent composition describes silty sand with a moderate (16.9%) clay component. Some samples in the Pier 2 area, however (Nos. 3,4), are silty sand with almost no clay. Water content and organic matter

Table 7A. Measured concentration of particle size, TOC, metals and PCB at Staten Island.

Component	Sample No.												
	1	2	3	4	5	6	7	8	9	10	11	$\bar{X}$	±S
Sand (%)	48.2	58.3	45.2	47.7	39.4	44.5	50.0	42.3	56.8	57.9	43.5	48.5	6.6
Silt "	35.0	25.5	54.8	47.9	40.6	30.6	26.6	33.4	27.6	20.4	37.4	34.5	10.2
Clay "	16.8	16.2	0.0	4.4	19.9	24.9	23.3	24.4	15.6	21.7	19.1	16.9	8.0
Water "	48.0	46.0	45.0	38.0	40.0	47.0	47.0	46.0	47.0	44.0	44.0	44.7	3.1
TOC "	7.2	6.8	8.2	7.1	7.0	7.3	8.9	9.5	8.8	7.4	7.0	7.8	0.9
Cd µg/g dry	9.9	-	11.2	8.7	12.5	10.0	13.7	11.3	13.7	15.0	8.7	11.5	2.2
Cu "	3248.8	-	2890.3	6158.6	2809.3	2115.7	3097.2	6540.4	3217.9	3301.0	2276.5	3565.6	1523.0
Zn "	11606.7	-	10481.1	10168.4	9630.8	7257.1	11425.5	11509.9	10222.8	11157.1	8552.7	10201.2	1909.9
Pb "	3917.6	-	3159.1	3202.8	2785.6	2183.3	3660.7	3413.5	3081.7	3464.8	2813.4	3168.2	494.8
Hg "	(composite = 5.8)												
A-1016 "	0.75	5.83	0.58	0.51	0.47	1.48	1.60	0.90	0.71	0.78	0.75	1.31	1.54
A-1254 "	0.71	0.99	0.82	0.41	0.33	0.73	0.98	0.35	0.51	0.77	0.47	0.69	0.24
ΣPCB "	1.46	6.82	1.40	0.92	0.80	2.21	2.58	1.25	1.22	1.55	1.22	1.94	0.70

content were uniform over the 11 project samples (RSD = 7% and 12%, respectively).

Chemical Characteristics: Metals values at Staten Island were exceedingly high and, due to sample-to-sample variation, homogeneous throughout the project. Cadmium concentrations were 11.5 ± 2.2 ug/g; however, Cu, Zn and Pb were all present in excess of 3,000 ug/g (Table 7A). Zinc was present in all samples in excess of 7,000 ug/g, with a project average of 10,201 ug/g dry weight. The composite Hg concentration was 5.8 ug/g (dry weight).

PCB concentrations varied widely throughout the project, ranging among samples taken at Pier 2 from 0.80 to 6.82 ug/g. The range at Pier 4 was from 1.22 to 1.58 ug/g dry weight. The major project component was Aroclor 1016 ($x = 1.31 \pm 1.54$ ug/g), while Aroclor 1254 comprised about one-third the PCBs measured ($\bar{x} = 0.69$ ug/g dry weight (Table 7A).

The Staten Island samples contained measurable quantities of aldrin (0.20 ug/g) and ΣDDT (~ 0.08 ug/g) (Table 7B).

Sediments from the Staten Island project contained relatively high levels of naphthalene and phenanthrene (Table 7B), whereas other PAH components were present at levels an order of magnitude lower, ranging from 0.08 ug/g (wet) for chrysene to 0.80 ug/g (wet) for pyrene. Radionuclides were not tested for the Staten Island sediments.

8. Westchester Creek

Physical Characteristics: Ten samples from the Westchester Creek project were analyzed, three of which (Sample 1, 2, 3; Table 8A) showed

Table 7B. Concentrations of chlorinated pesticides and polycyclic aromatic hydrocarbons in composited samples from the Staten Island (Kill Van Kull) dredging project. Values presented are for those compounds detected at trace (TR) levels, and at quantifiable levels above detection limits.

Compound	Concentration	
	A	B
Aldrin	0.19	TR µg/g dry weight
Endrin	TR	TR
ΣDDT	0.08	0.09 µg/g dry weight
Naphthalene	-	2.3 µg/g wet weight
Phenanthrene	-	5.2 " "
Anthracene	-	0.2 " "
Fluoranthene	-	0.9 " "
Pyrene	-	0.8 " "
Chrysene	-	TR
Benzo(a)pyrene	-	0.5 µg/g wet weight

significantly different physical characteristics than the remaining seven, including a greater proportion of clay and less sand. The sand component was determined to be highly variable among all samples (RSD = 67%); however, percent silt and percent clay differed among sample groups ($p << 0.01$); Samples 1-3 contained silty clay (clay = 55.1%), whereas Samples 4 through 10 contained sandy silt (silt = 52.8%). Water content and organic matter content were homogeneous throughout (Table 8A) with an average water content of 64.3 $\pm$ 1.2%, and a mean organic content of 12.7 $\pm$ 0.8% (dry weight).

Chemical Characteristics: Concentrations of heavy metals for the Westchester Creek project were homogenous throughout the 10 samples taken. Cadmium concentrations (Table 8A) ranged from 3.2 ug/g (dry) to 8.9 ug/g, with a project mean of 7.1 ug/g. Concentrations of Cu, Zn and Pb were rather uniform, with mean values of 408.6, 454.9 and 381.4 ug/g (dry), respectively. Uniformity among samples analyzed is shown by the relative standard deviation (~ 22% for all three metals). The composite Hg value was 1.71 ug/g dry weight.

Total PCB concentrations averaged 1.71 $\pm$ 0.92 ug/g dry weight. Analysis of variance revealed that Sample 1 through 4 and Samples 5-10 comprised different subgroups with significantly different ΣPCB's ($p << 0.01$); Samples 1-4 had Σ = 0.89 $\pm$ 0.09 ug.g, whereas Samples 5-10 had values of 2.26 $\pm$ 0.78 ug/g. The majority of the PCB in the samples with higher values was Aroclor 1016.

Westchester Creek project had high chlorinated pesticide values (Table 8B). Lindane was detected in two composite samples, although at or near detection limits. Aldrin and endrin were present in composites

Table 8A. Measured values of grain size, TOC, metals and PCB in the Westchester Creek Project

Component	Sample No.											
	1	2	3	4	5	6	7	8	9	10	$\bar{X}$	±S
Sand (%)	7.8	8.4	8.0	12.7	15.7	45.3	20.4	25.4	11.7	15.7	17.1	11.4
Silt "	41.1	34.4	34.8	50.6	57.8	54.7	49.4	44.5	54.9	58.0	48.0	8.9
Clay "	51.1	57.2	57.1	36.7	26.5	0	30.2	30.1	33.4	26.3	34.8	17.2
Water "	63.0	64.0	63.0	65.0	64.0	66.0	66.0	65.0	64.0	63.0	64.3	1.2
TOC "	12.3	13.0	12.9	13.4	13.6	12.9	12.4	12.4	13.4	10.7	12.7	0.8
Cd µg/g dry	5.6	5.8	6.2	7.6	8.5	3.2	7.5	8.6	8.9	8.7	7.1	1.8
Cu "	405.8	414.9	426.3	462.0	443.4	153.0	433.8	441.4	476.4	429.1	408.6	92.2
Zn "	439.6	453.4	467.7	530.1	501.2	186.2	461.9	497.4	521.4	490.6	454.9	98.9
Pb "	364.2	389.4	395.3	427.5	404.0	162.4	399.2	418.2	428.9	425.4	381.4	79.6
Hg "	(composite = 1.71)											
A-1016 "	0.37	0.36	0.37	0.48	1.76	0.88	1.04	2.85	1.27	1.50	1.08	0.80
A-1254 "	0.41	0.48	0.58	0.50	0.64	0.50	0.48	0.61	0.46	0.56	0.52	0.07
ΣPCB "	0.78	0.84	0.95	0.98	2.40	1.38	1.52	3.46	2.73	2.06	1.71	0.92

Table 8B. Concentrations of chlorinated pesticides and polycyclic aromatic hydrocarbons in composited samples from the Westchester Creek dredging project. Values presented are for those compounds detected at trace (TR) levels and at quantifiable levels above detection limits.

Compound	Concentration		
	A	B	
Lindane	TR	TR	
Aldrin	0.12	0.49	µg/g dry weight
Endrin	0.05	0.05	" "
ΣDDT	0.26	0.23	" "
Phenanthrene	TR	-	
Anthracene	TR	-	
Fluoranthene	0.1	-	µg/g wet weight
Pyrene	0.2	-	" "
Chrysene	TR	-	
Benzo(a)pyrene	0.3	-	µg/g wet weight

at levels of ~ 0.22 ug/g and ~ 0.04 ug/g dry weight, respectively. Three DDT components were identified, p,p', TDE, o,p DDT and p,p' DDT, at a total concentration of ~ 0.25 ug/g dry weight.

Metals and PCB's were not correlated closely with either percentage clay or percent organic matter. R-square values ranged from 0.004 to 0.01. However, there were some strong relationships evident within the four metals measured one a sample-by-sample basis. Correlations between metals pairs ranged from 0.86 to 0.83 (r^2 = from 0.74 to 0.69). Most strongly correlated were Cd, Zn, and Pb. PCB values were not strongly related to either organic matter content (r^2 = 0.004) or to the various metals. The maximum coefficient of determination was r^2 = 0.44, between Cd and total PCB's.

Polycyclic aromatics in Westchester Creek samples were among the lowest measured in samples with a high proportion of fine materials. Except for pyrene (0.2 ug/g wet) and benzo(a)pyrene (0.3 ug/g wet), the PAH's detected were essentially at the limit of detection for the methods used (Table 8B).

9. Bronx River

Physical Characteristics: The 10 Bronx River samples varied widely, from silty clay (Sample 10) to silty sand (Sample 1; Table 9A). Average percent composition of sand, silt and clay was 21.7, 45.2 and 33.1, respectively. Average water content (61.5 ± 4.4%) and percent organic matter (13.6 ± 1.6%) were homogeneous throughout the 10 samples.

Chemical Characteristics: Metals concentrations in the Bronx River samples were rather uniform. Cadmium (x = 8.1 ± 2.7 ug/g dry) ranged

from 3.6 to 14.2 ug/g (Table 9A). The highest metals values were for Zn ($\bar{x}$ = 579.3 ± 199.8 ug.g dry) which ranged from 360.2 to 1013.6 ug/g. Mercury concentration was low (0.24 ug/g).

Mean total PCB concentration in Bronx River project samples was 3.16 ± 1.95 ug/g dry weight. On the average (Table 9A) Aroclor 1016 isomers comprised 82% of the PCB's present. In only one sample (Sample 9; Table 9A) were Aroclor 1254 isomers more concentrated than those representative of Aroclor 1016.

The strength of the relationships between physical parameters and chemical parameters varied widely in the Bronx River project. There existed correlations between organic matter and the metals Cd (r^2 = 0.52), Cu (r^2 = 0.49) and Pb (r^2 = 0.48). The relationship between organic matter and PCB's was lower; coefficient of determination for OM vs ΣPCB was 0.33, while the coefficient for the dominant isomer group (Aroclor 1016) was 0.29. No apparent correlation existed between percent clay composition and organics, nor between the clay fraction and any of the chemical parameters for which comparative sample data were available.

Chlorinated pesticide scans were run on a composite Bronx River sample (Table 9B). While no lindane was detected, aldrin occurred at concentrations of 0.11 ug/g dry weight. Endrin was present at trace levels; total DDT averaged 0.41 ug/g dry weight.

A composite of sediments from the Bronx River project contained the full complement of PAH included in the scan, although naphthalene, anthracene, chrysene and benzo(a)pyrene were measured at the limit of

Table 9A. Measured values of grain sixe, TOC, metals and PCB in the Bronx River Project.

Component	Sample No.											
	1	2	3	4	5	6	7	8	9	10	$\bar{X}$	±S
Sand (%)	47.9	26.9	23.5	19.4	23.5	23.0	20.9	16.3	7.7	8.0	21.7	11.3
Silt "	26.5	39.1	49.0	52.5	42.2	42.8	55.7	65.4	47.4	31.6	45.2	11.4
Clay "	25.6	34.0	27.5	28.1	34.3	34.2	23.3	18.3	44.9	60.4	33.1	12.1
Water "	61.0	62.4	63.4	61.1	64.4	49.6	60.9	63.5	63.9	64.7	61.5	4.4
TOC "	13.2	13.9	13.3	15.5	13.3	10.0	12.2	14.4	15.2	14.6	13.6	1.6
Cd µg/g dry	8.2	6.8	7.3	14.2	9.9	3.6	6.8	7.8	7.3	8.9	8.1	2.7
Cu "	326.7	396.7	393.2	529.9	478.9	313.6	316.2	404.1	392.3	434.8	398.6	70.1
Zn "	360.2	424.4	456.4	823.2	557.5	1013.6	447.7	522.6	555.9	631.4	579.3	199.8
Pb "	345.0	403.5	422.7	485.1	469.7	376.3	395.4	487.3	561.7	581.5	452.8	78.2
Hg "	(composite = 0.24)											
A-1016 "	2.50	2.90	2.87	5.41	1.78	0.53	0.96	5.87	0.39	2.64	2.59	1.86
A-1254 "	0.82	0.59	0.49	0.63	0.91	0.14	0.36	0.62	0.54	0.61	0.57	0.22
ΣPCB "	3.32	3.49	3.36	6.04	2.69	0.67	1.32	6.49	0.93	3.25	3.16	1.95

Table 9B. Concentrations of chlorinated pesticides and polycyclic aromatic hydrocarbons in a composite sample of sediment from the Bronx River dredging project. Values presented are for those compounds detected at trace (TR) levels and at quantifiable levels above detection limits.

Compound	Concentration
Aldrin	0.11 µg/g dry weight
Endrin	TR
ΣDDT	0.41 µg/g dry weight
Naphthalene	TR
Phenanthrene	0.4 µg/g wet weight
Anthracene	TR
Fluoranthene	0.7 µg/g wet weight
Pyrene	1.3 " "
Chrysene	TR
Benzo(a)pyrene	TR

detection (Table 9B). Phenanthrene (0.37 ug/g), fluoranthene (0.68 ug/g) and pyrene (1.31 ug/g wet weight) were present at values well in excess of detection limits.

10. Ambrose Channel

Physical Characteristics: Three samples from the Ambrose Channel project were analyzed and found to be uniformly sand, containing ~ 21% water and 0.4% organic matter (Table 10).

Chemical Characteristics: Ambrose Channel sand contained no detectable Cd or Hg and small quantities of Pb, Zn and Cu (Table 10). Total PCB concentrations were 0.12 ug/g (dry weight), and only trace quantities of DDT were present. Likewise, only trace elements of PAH were detected in Ambrose Channel samples, all at or below detection limits.

B. Interproject Comparisons

1. Physical Characteristics

The average distribution of particles, water content and organic matter values for the projects are presented in Table 11A. All projects had less sand, more silt, more clay, more water and more organic matter than Ambrose sand. Among the projects in the Harbor-River region, Port Newark, the Port Authority, Westchester Creek and the Bronx River had statistically higher levels of organic matter than the Stony Point, Weehawken, and Staten Island projects. The Yonkers and Passaic River projects could not be compared due to the presence of only two samples from each location.

Table 10. Measured values of grain size,TOC,metals and PCB in Ambrose Channel

Component	Sample No.				
	1	2	3	$\bar{X}$	$\pm s$
Sand (%)	100.0	100.0	100.0	100.0	-
Silt "	0	0	0		
Clay "	0	0	0		
Water "	19.6	19.3	21.3	20.7	1.1
TOC "	0.4	0.3	0.4	0.4	0.1
Cd µg/g dry	0.0	0.0	0.0	0.0	-
Cu "	2.3	3.7	2.6	2.9	0.7
Zn "	11.3	13.2	13.9	12.8	1.3
Pb "	8.4	9.7	10.6	9.6	1.1
Hg "	(composite= 0.0)				
A-1016 "	0.16	0.09	0.03	0.09	0.07
A-1254 "	0.05	0.03	-	0.04	
ΣPCB "	0.21	0.12	0.03	0.12	0.09

2. Chemical Characteristics

Mean data for chemical characteristics are presented in Table 11B. The assumption was made that the mean data for a project were representative of a project for dumping. This accounts for the physical disruption, resuspension and distribution of the material during dredging, transport, dumping and settling. Treating the means as data, and checking correlation status for components within projects, it was determined that strong correlations exist between Zn and Pb, Cu and Pb, and Cu and Zn, despite the fact that these parameters ranged over more than two orders of magnitude. The linear r^2 values among projects for Zn/Pb, Cu/Pb and Cu/Zn were 1.00, 1.00, and 0.99, respectively. No significant correlations existed for Cd with any other component, including PCB. Nor did any correlation exist among projects for Cd with organic matter, and PCB's with percent organic matter.

Application of ANOVA/Student-Neuman-Keuls procedures to the full data set revealed several distinct groupings of projects based upon chemical characteristics. using Cd as a diagnostic, for example, four subsets were established as being similar. These were as follows:

SP NYPA Whkn WCr BR SI PNwk;

i.e., Stony Point (SP) sediments were lowest in Cd, and independent, whereas similarity can be expected between samples from the Port Authority (NYPA) and Weekhawken (Whkn), and among Westchester Creek (WCr), Weehawken, and the Bronx River (BR) projects. The Staten Island (SI)-Port Newark (PNwk)-Bronx River grouping, containing the highest Cd values, was associated with both Westchester Creek and Weehawken due to

Table 11A. Mean values for physical characteristics measured in the Dredging Projects.

Project	Physical Characteristics				
	Component (%)				
	Sand	Silt	Clay	Water	TOC
Stony Point	5.6	58.8	35.6	45.9	8.14
Weehawken	5.4	51.6	43.0	56.7	10.7
Yonkers	44.5	31.2	24.3	61.5	29.5
Passaic River	23.3	34.9	41.7	66.0	15.1
Port Newark	13.4	47.4	39.1	57.3	12.2
Staten Island	48.5	34.5	18.6	44.7	7.7
NYPA	11.9	55.7	32.3	53.9	11.4
Westchester Cr.	17.1	48.0	34.9	64.3	12.7
Bronx River	21.7	45.2	33.1	61.5	13.6
Ambrose Sand	100.0	0.0	0.0	22.0	1.0

Table 11B. Mean values for chemical characteristics measured in the Dredging Projects.

	Chemical Characteristics				
	Component (µg/g dry)				
Project	Cd	Cu	Zn	Pb	ΣPCB
Stony Point	2.6	80.3	296.6	119.3	0.92
Weehawken	4.7	237.7	407.0	255.8	0.65
Yonkers	14.1	-	1303.1	558.8	2.03
Passaic River	11.8	692.8	1981.6	1235.6	2.64
Port Newark	14.0	465.1	806.9	439.1	1.59
NYPA	4.4	221.4	332.7	275.9	1.23
Staten Island	11.5	3565.6	10201.2	3168.2	1.94
Westchester Cr.	6.3	427.2	472.7	394.1	1.71
Bronx River	8.1	398.6	519.3	452.8	4.05
Ambrose Sand	0.08	2.5	48.4	6.2	0.10

variance overlaps.

Groupings were established for Cu, Zn and Pb as follows:

Copper

SP NYPA Whkn BR WCr PNwk SI

Zinc

SP NYPA Whkn WCr BR PNwk SI

Lead

SP Whkn NYPA WCr PNwk BR SI

Thus, for each metal, four groupings exist, which varied according to the metal in question. Most useful is the statistical isolation of the Staten Island samples for Cu, Zn and Pb. For each of these metals, the Staten Island project contained the highest concentrations analyzed. Using these groupings, metals concentrations may be used for identifying contaminated material from Staten Island due to extremely high levels of copper (> 500 ug/g), zinc (> 850 ug/g) and lead (> 450 ug/g).

PCB diagnostics were poorly defined; for most projects PCB variance overshadowed differences in means. Neither quantities of total PCB nor the presence of specific PCB isomers was found useful for project discrimination - all samples from all stations included not only Aroclor 1016 and Aroclor 1254, but also PCB isomers common to other industrial mixtures.

The presence of little or no chemical contamination in Ambrose sand samples (Table 10) allowed discrimination of Ambrose sand from other

sandy dredged materials, e.g., Staten Island dredged material. Based upon deviations experienced in analyzing project samples, especially the Stony Point samples and Ambrose samples, concentrations of Cd > 1.5 ug/g; Cu > 50 ug/g; Zn > 105 ug/g; or Pb > 75 ug/g may be used to discriminate the presence of dredged material in a sample, even if particle distribution suggests relatively "pure" sand.

While statistical comparisons of Hg contamination were not made, it can be seen from the broad range of data in composite samples (< 0.07 to 26.3 ug/g wet weight) that the greater concentrations were present in samples from the Newark region. We speculate that the high-level Hg contamination seen in the Port Newark samples from Docks A and C represent a local point source of contamination. Other samples from the general vicinity (Passaic River, Staten Island) which might reflect background data for the region were at least a factor of 5 less than Dock A at Port Newark.

Other potential diagnostics for discriminating particular dredging projects derive from polycyclic aromatic hydrocarbon analysis. Among the projects sampled, for example, only the Yonkers project contained naphthalene at levels > 5.0 ug/g (wet weight), readily distinguishing these sediments from all others. However, naphthalene, due to its high volatility, probably is not useful as a viable discriminator. In the same sample, however, our analyses also showed higher concentrations of pyrene (> 12.0 ug/g) and benzo(a)pyrene (> 2.0 ug/g) than in any other project. Certainly more data are needed to assess PAH compounds as "signature" parameters. Overall, PAH may not prove adequate as discriminators since they are subject to rather rapid metabolic breakdown,

solubilization and photolysis. Nonetheless, the subject is deserving of further consideration.

C. Core Sampling

Cores were taken on 11 December 1980 and 22 August 1981. The locations of the various cores are given in Figure 3.

1. December, 1980

Physical Characteristics: Cores 2, 13, and 12 from December, 1980 were in the Mud Dump area. Core 2, which was 1.05 m in length, was analyzed at 5 levels (Table 12) and showed distinct layering. At the surface, and at 46 cm. the core was all sand (100%) with low water (21-22%) and low percent organics content. These parameters were identical with Ambrose sand. At 13 and 69 cm, the core was sandy silt with a moderate clay component, high water (46-52%) and high percent organics (~ 8%).

Core 12 (Table 13) was taken in duplicate and showed over its 95 cm length a layer of slightly silty sand on top (0-15 cm), and silty sand below (50-95 cm). Both water content and organic components were lower at the top of the core than at the bottom (35% water, 3.4% OM at top; 40-50% water and 5-8% OM below).

Core 13 (Table 12) was clayey silt at the top, having high water (56%) and a high percentage of organics (9.0%). With depth, the core showed a change to silty sand (25-40 cm) to nearly all sand (60-75 cm) and a corresponding reduction in water (26-31%) and organic matter (2-3%).

Table 12. December core results.

		Sand %	Silt %	Clay %	Water %	TOC %	Cd (µg/g)	Cu (µg/g)	Zn (µg/g)	Pb (µg/g)	ΣPCB (µg/g)
CORE 13											
TOP	(1)	5.9	61.0	33.0	56.0	9.0	4.3	204.4	411.5	210.8	1.17
	(2)	14.4	73.2	12.4	49.0	6.5	3.6	150.2	516.8	158.7	1.58
MID	(1)	75.2	24.0	0.7	31.0	3.0	0.9	53.3	74.0	89.5	0.67
	(2)	11.7	65.1	23.1	56.0	8.5	4.3	220.5	290.9	186.3	0.93
BOTTOM	(1)	86.4	3.1	10.5	26.0	2.0	0.4	32.8	1.0	42.8	0.20
	(2)	86.2	3.4	10.4	26.0	2.2	0.7	28.7	10.7	40.3	0.19
CORE 2											
TOP		100.0	0.0	0.0	22.0	1.0	0.1	5.7	42.5	10.9	0.12
12.7 cm		42.4	38.6	18.8	52.0	8.5	3.2	586.7	2268.8	516.9	0.65
45.7 cm		100.0	0.0	0.0	21.0	1.1	0.0	0.0	55.6	5.4	0.05
69 cm		37.6	39.8	22.6	46.0	7.8	1.5	111.3	183.1	110 1	1.21
BOTTOM		93.8	3.9	2.3	29.0	2.3	0.7	64.8	355.8	151.9	0.38

Table 13. December core results.

CORES 12-1, 12-2		Sand %	Silt %	Clay %	Water %	TOC %	Cd (µg/g)	Cu (µg/g)	Zn (µg/g)	Pb (µg/g)	ΣPCB (µg/g)
TOP	(1)	84.0	10.3	5.6	35.0	3.4	1.1	52.3	114.5	66.6	0.31
	(2)	86.1	9.3	4.6	32.0	3.1	0.9	48.8	81.3	61.3	0.20
MID	(1)	48.6	35.6	15.8	41.0	4.9	1.1	62.0	842.4	68.5	0.23
	(2)	87.1	12.9	0.0	31.0	4.1	1.3	63.1	275.4	78.4	0.38
BOTTOM	(1)	43.4	30.3	26.3	49.0	8.1	3.4	138.9	345.6	178.9	0.40
	(2)	50.7	34.8	14.5	51.0	8.0	3.4	144.8	2241.4	179.0	0.49

Chemical Characteristics: Layering was evident in Core 2. At the surface, and at 45 cm, the metal and PCB values were similar to Ambrose sand. At 13 cm all the metals were high, with Zn reaching levels of 2268.8 ug/g. Pb was detected at 516.9 ug/g. PCB values, however, were low (0.65 ug/g). Lower in the core (69 cm), where silt and clay values were elevated, contaminant concentrations were significantly above Ambrose sand levels, but far less than in the layer at 13 cm.

In Core 12 replicates, surface values for all chemical constituents analyzed in surface samples were below values detected at any of the project sites. Below that level, zinc values increased dramatically, to values > 2000 ug/g, while PCBs and other metals remained at levels below most projects, but above levels for Ambrose sand.

Values for chemical contaminants in Core 13 surface levels (Table 12) were similar to values from several projects, and decreased with depth to concentrations similar to "clean" Ambrose sand.

2. August, 1981

Physical Characteristics: All the data for August 1981 cores are given in Tables 14 through 17. Cores 4, 5, 6 and 8 were in the capping region. Cores 4 and 5 showed higher percent sand at the surface than at intermediate layers; surface and bottom values in both cases were indicative of slightly silty sand of low water content (30-40%) and, for Core 4, low percentage organic matter. Core 5 had organics of 7.2% at the surface, and 4.0% at the bottom. Intermediate layers had more silt and clay, less sand, more water, and higher organic content in both cores.

Table 14. August core results.

		Sand %	Silt %	Clay %	Water %	TOC %	Cd (µg/g)	Cu (µg/g)	Zn (µg/g)	Pb (µg/g)	ΣPCB (µg/g)
CORE 1	TOP	58.9	32.8	8.3	44.0	7.0	3.26	125.51	216.34	168.55	0.47
	MID	99.6	0.4	0.1	21.0	1.4	0.50	19.88	35.01	22.13	0.62
	BOTTOM	86.8	13.2	0.0	35.0	4.1	1.87	50.50	93.12	69.00	0.61
CORE 2	TOP	91.4	8.6	0.0	42.0	5.7	3.00	95.04	166.79	128.35	0.39
	MID	74.7	18.2	7.1	32.0	3.7	1.75	62.69	108.28	81.43	1.37
	BOTTOM	88.9	9.5	1.6	25.0	3.0	1.25	21.71	64.76	42.68	0.32

Table 15. August core results.

		Sand %	Silt %	Clay %	Water %	TOC %	Cd (µg/g)	Cu (µg/g)	Zn (µg/g)	Pb (µg/g)	ΣPCB (µg/g)
CORE 3	TOP	94.7	5.3	0.0	30.0	2.7	1.00	33.82	62.00	51.60	0.21
	MID	84.0	12.8	3.2	34.0	3.5	1.75	44.25	77.38	82.38	0.44
	BOTTOM	92.6	7.4	0.0	30.0	2.9	1.37	42.71	81.42	64.19	0.73
CORE 4	TOP	86.1	9.4	4.5	33.0	3.5	1.13	42.42	85.71	64.70	0.80
	MID	45.0	31.6	23.4	44.0	5.9	2.75	90.78	165.55	122.91	0.46
	BOTTOM	81.8	16.4	1.8	31.0	3.1	1.62	43.58	97.15	71.17	0.57

Table 16. August core results.

		Sand %	Silt %	Clay %	Water %	TOC %	Cd (µg/g)	Cu (µg/g)	Zn (µg/g)	Pb (µg/g)	ΣPCB (µg/g)
CORE 5	TOP	72.0	23.7	4.3	41.0	7.2	3.00	206.53	843.14	234.44	0.84
	MID	49.4	43.3	7.3	46.0	6.8	3.50	154.95	222.92	166.94	0.94
	BOTTOM	86.5	13.5	0.0	33.0	4.0	0.62	65.84	112.11	27.31	0.94
CORE 6	TOP	25.2	44.3	30.5	56.0	9.3	5.23	217.44	380.22	239.86	1.04
	MID	70.9	28.9	0.2	39.0	4.5	1.87	75.22	138.95	98.09	0.55
	BOTTOM	83.7	13.5	2.7	34.0	4.2	1.13	66.38	125.72	89.89	0.11

Table 17. August core results

		Sand %	Silt %	Clay %	Water %	TOC %	Cd (µg/g)	Cu (µg/g)	Zn (µg/g)	Pb (µg/g)	ΣPCB (µg/g)
CORE 7	TOP	32.5	58.4	9.1	55.0	9.0	4.27	201.45	338.39	221.66	0.33
	MID	61.9	30.3	7.8	43.0	5.9	2.37	111.37	178.87	138.87	0.45
	BOTTOM	75.2	16.7	8.1	34.0	4.6	2.25	88.43	154.50	106.04	0.21
CORE 8	TOP	27.6	47.7	24.7	54.0	7.9	3.89	174.58	301.00	65.47	1.19
	MID	46.0	40.2	13.8	47.0	7.1	3.50	147.86	241.52	167.59	1.07
	BOTTOM	46.1	38.2	15.7	45.0	7.0	2.63	140.98	223.62	164.65	0.42

Cores 6 and 8 from August 1981 were comprised of silty sand at the surface and sandier layers at greater depths; water content also decreased with depth.

Chemical Characteristics: In Cores 4 and 5, metals values showed a "layering", with higher values in the middle of the core than at the surface (Tables 15, 16). For PCBs, values at the surface were greater than at depth.

In Cores 6 and 8, all contaminant values decreased with depth (Tables 16, 17). Values for all metals and the PCBs were greater at the surface than at the bottom by a factor of ~ 3 in Core 6, and for PCB, Cd, Cu and Zn in Core 8, by a factor of ~ 1.5. In Core 8, Pb values increased with depth, from 65 ug/g to ~ 165 ug/g.

DISCUSSION AND CONCLUSIONS

The data from analysis of individual projects demonstrates quite clearly that one can easily differentiate most project dredged material from Ambrose sand based upon any of several criteria. These criteria include percent organic matter, metals, PCB's or PAH's. The presence of large proportions of sand in some of the individual dredging project samples would mitigate against using particle size distribution to discriminate dredged sediments from a limited sampling of either cap material or natural sand.

Several interesting data of relevance to dredged material management arose from this study. First, the extensive analyses of individual barge samples provided insight into the variation of parameters to be expected in a given dredging project. The best example might be Port

Newark samples where, at the individual docks comprising the projects, it was possible to see large differences in concentrations of different contaminants (e.g., Cd, Cu, Hg, PCB, PAH). Of greatest interest, of course, is that not all the trends in differences were in the same direction. From careful analysis of such trends, an investigator may identify point sources of contamination to the sediments and possibly eliminate them. Such action would, of course, reduce the overall mass loading of contaminants to the Bight.

Second, these data contribute to establishing a baseline datum for several "new" contaminants (PCB, PAH) heretofore not analyzed thoroughly, but identified as having high priority due to ecological and environmental health concerns (O'Connor and Stanford, 1979). Unfortunately, very few data on PCB's and PAH in the Harbor region are presently available in either published form, or in the gray literature. At this time we are aware only of PCB and PAH data for harbor sediments published by Bopp (1979; Bopp et al., 1981), and Stainken and Rollwagen (1979). A wide selection of excellent unpublished data, in report form, are available from ERCO (1980), and also in a NOAA Technical Memorandum by MacLeod et al. (1981). None of these studies focussed on dredged materials; none, therefore, provide data applicable to determining potential impacts of marine dumping on Bight organisms.

Third, application of the chemical signature data to the results of bioassays conducted prior to disposal may provide much information relative to the bioavailability of a full range of contaminants (EPA-COE, 1977). This objective could be realized only with a commitment to bulk analysis of dredged material on a regular basis.

The project and core analyses gave results in close agreement, but in greater detail, than the analyses of dredged muds provided by Conner et al. (1979) and the very few sediment samples available from the vicinity of the N.Y. Bight dump sites (MacLeod et al., 1981). It should be pointed out also that the small amount of data provided here on contaminant depth distribution in cores may be used in concert with the significant data bases of Segar and Cantillo (1976). Hatcher and Keister (1976), Freeland (Freeland et al., 1976; Freeland and Swift, 1978; Freeland, 1982) and Dayal et al. (1981) to clarify some important physical aspects of metals and organics transport at the New York Bight Mud Dump site.

The primary applications of the chemical signature study, however, were to determine: first, whether dredged material can readily be discerned from the "sand capping" material; second, whether an individual project can be identified at the Mud Dump site; and third, whether the presence of a "sand cap" on the dump site can be ascertained.

1. In the first case, it is immediately apparent from the data that project material can readily be discerned from Ambrose sand by physical characteristics and by chemical content. Ambrose sand consisted almost entirely of sand-sized particles of low (20-30%) water content and very low (~ 1%) organic content. Chemically, Ambrose sand contained trace levels of PCB and some metals, but at concentrations below that seen in all the projects from which dredged material was taken for dumping. At the dump site, in Cores 4 and 5 from August, 1981 and in Cores 2 and 13 from December, 1980, it was obvious that the material on the surface of the mud dump is more like Ambrose sand in physical and chemi-

cal characteristics than any of the projects considered.

A significant problem arose in discriminating Bronx River and Westchester Creek sediments from other project material. These projects, which were used to "cap" at the dump site, contained more silt and more clay than some of the material which was to be capped (e.g., Staten Island, Yonkers, Passaic River). Chemically, this capping material contained more Cd, Cu, Zn, Pb and PCB than Stony Point, Weehawken and the N.Y. Port Authority. Evaluation of capping at the Mud Dump has been made far more difficult due to the inclusion of Bronx River and Westchester Creek material in the capping operation.

Exemplary of this problem is consideration of Cores 6 and 8 at the dump site, where surface material was sandy silt, with high concentrations of metals, organic matter and PCBs. In Core 8, this surface layer might well represent Westchester Creek sediment "capping" on top of project material from any of several sites, or layered over Ambrose sand. "Capping", and the identification of capping material by chemical signatures, therefore, can only be evaluated over that portion of the dump site where the cap consisted of Ambrose sand.

The gravity cores taken on the dump site were not exclusively within the capping area. Nonetheless, they did show evidence that clean, sandy material several centimeters in thickness was in place atop finely divided and chemically contaminated sediment. In some cases, distinct layering was observed, with relatively clean sand layers interspersed with layers of fine material. This is not necessarily related to the capping operation. As shown by Dayal et al. (1981) such layering of particle sizes is evident in many parts of the designated Mud Dump.

The point must be made that gravity coring is not an ideal technique for sediment collection in pollution studies (Baxter et al., 1981). Gravity coring may cause excessive loss of material while distorting vertical profiles. However, at the Mud Dump site, there have also been collected a substantial number of large-diameter vibracore samples which apparently preserve materials and vertical integrity quite well (Dayal et al., 1981; Bokuniewicz, unpublished). Both sets of samples show distinct layering of sandy and muddy material over different portions of the dump site. This is undoubtedly due to the wide variety of materials dumped in the Bight over the past 40 to 80 years (see Conner et al., 1979) as well as the 1980 sand capping operation. Preliminary X-radiographic data from Bokuniewicz (unpublished; Figure 5) shows that the sediments at the capping site possess a surface layer of sand ranging from 0.24 to 1.58 m in thickness. The average depth of the sand layer was 1.08 meters; in all but three samples the surfaces and layer was > 1 m in thickness. This is in contrast with vibracore samples taken from outside the capping region (Dayal et al., 1981). Surface layers from those samples showed from 0 to 98% sand; the sand was concluded to be dredged material based on textural analysis. Most samples showed that sand or sandy layers were far more shallow than those reported by Bokuniewicz (unpublished) for the capping area. From the data of Dayal et al. (1981) we estimate that the "sand" (i.e., > 75% sand-sized particles) layer had an average depth in the dump site of ~ 20 cm, ranging from 0 to 50 cm.

Where the sand cap layer is thin, we can only speculate that the surficial sediments may have been material from Westchester Creek or the Bronx River, both of which were used in the capping operation. A final

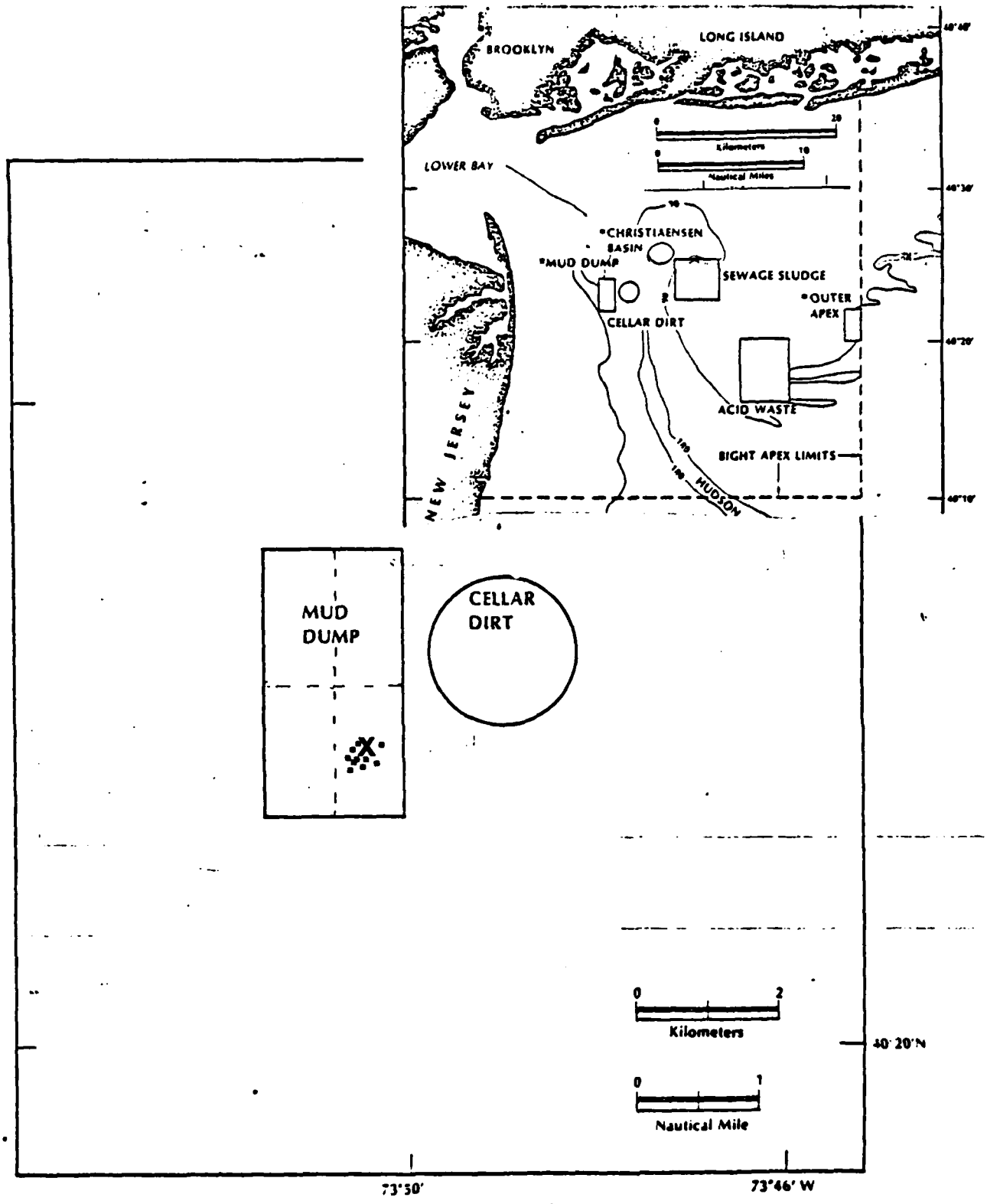

Figure 5. Approximate locations of vibracore samples taken at the Mud Dump Site in March, 1981. The X marks the location of the dumping marker buoy; rectangles are the locations of the core samples.

conclusion must await textural and chemical analysis.

2. The comparison of project data with dump site data shows that individual projects might be positively identified by virtue of their chemical components. In Core 12 from December we noted a unique combination of very high zinc values (800 to 2200 ug/g) combined with low PCBs (~ 0.4 ug/g) and moderate levels of organic matter (~ 5 to 8%). This combination of factors is best reflected in Staten Island samples, leading one to conclude that Core 12 yielded remnants of material dredged from the Staten Island Project (Table 7A). That this material is not from Port Newark is suggested by Port Newark's lower sand content (13% vs 48% at SI), higher percent organics (12% vs 7.8% for SI) and greater proportion of Aroclor 1254, as compared to the equal proportions of Aroclors 1016 and 1254 in the core sample. The Staten Island sample contained a greater proportion of Aroclor 1016. While Aroclor 1016 might be expected to be lost in dumping, a project such as Port Newark would be expected to show enrichment of 1254 over 1016, whereas dumping of Staten Island project material would chemically tend to balance the ratios due to selective solubilization of the Aroclor 1016 components.

3. We can conclude from the available data that is is practical to cover disposed dredged material with a cap of sand, and that the sand cap will persist for periods up to two years. Whether the sand cap can effectively reduce the concentration of chemical contaminants in contact with overlying waters will require both field and laboratory study. Estimates of metals fluxes from deposited sediments to seawater have been made for the Hudson River and for the N.Y. Bight dump site (Lentsch, 1974; Harris, 1976; Williams et al., 1978; Klinkhammer et al.,

1981; Dayal et al., 1981). The general conclusion may be made that each metal species in the sediment is subject to some loss through diagenisis, bioturbation and resuspension. The quantities lost, however, will vary from metal to metal, with iron and manganese being lost most readily. Dayal et al. (1981) have perhaps overstated the fluxes of metals to the water column by stating that "...most metals are lost from the system in varying degrees...during the dumping process or following deposition..." In fact, based on pore water data, only Fe, Mn and Zn were subject to any significant losses; Cd and Hg were not so affected. These data agree with those of Lentsch (1974) and Harris (1976).

Placement of a clean sand cap over metal-contaminated sediments is, in theory, a sound proposal. Carmody et al. (1973) and Segar and Cantillo (1976) suggest that metals in the water column will reflect metals concentrations in the upper 1 cm of deposited sediments. Dayal et al. (1981) show that upward flux of metals in sediments ranged from ~ 2 years to 23 years for migration through 8 cm of sediment. Thus, replenishment of surface layers with high levels of metals would be a slow process. Imposition of a sand cap would make the process slower.

The flux of PCB's, PAH and other organic contaminants from deposited ocean sediments is not well known, but may be estimated from solubility constants and partition coefficients (Hutzinger et al., 1974; Karickhoff et al., 1979). Turk (1980) and Turk and Troutman (1981) estimated PCB flux across the mid-water interface in the Upper Hudson (freshwater) and showed significant releases even from organically enriched sediment. Although PCB solubility is lower in seawater, it must be assumed that release of these contaminants from contaminated

fine materials would occur under two conditions. First, when the bed sediment is at rest, desorption and dissolution would occur at rates dictated by the diffusional constants existing between pore water and seawater. Second, release would occur when resuspension occurs since, in water of low PCB content, desorption may take place rapidly (Nau-Ritter, 1980). Any activity such as capping which would increase the distance between seawater and PCB-contaminated fine materials may be considered effective in reducing losses. Similarly, if capping reduces the potential for resuspension of PCB-contaminated fine particles, it may be presumed efficacious in reducing loss to the water column.

Precisely the same arguments may be applied to PAH contaminants. Based upon available data (Mackay and Shiu, 1977; Karickhoff et al., 1979; Rossi and Thomas, 1981; Banerjee et al., 1981), the potential for PAH transport to seawater from sediments could be virtually eliminated by emplacement of a permanent sand barrier between PAH-contaminated fine material and the water column.

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and was responsible for providing those data to us.

APPENDIX A

PROCEDURES USED FOR THE ANALYSIS OF HEAVY METALS

Analyses for Cd, Cu, Pb, and Zn were carried out using the wet digestion process (with modification) outlined in the EPA-COE manual for analysis of sediment and water samples (Plumb, 1981). Dried samples (~ 2 g) were digested in ~ 50 mL concentrated HNO_3 and brought nearly to dryness. After addition of ~ 20 mL distilled, deionized water, the samples were again brought nearly to dryness and washed through cellulosic fiber filter pads (0.45 um; Millipore Corp.) using 5% v/v HNO_3 in distilled deionized water. The samples were brought to final volume of 25 mL in volumetric flasks and were analyzed using flame atomic absorption techniques (Instrumentation Laboratories Model 257 AA). Values for Cd were, for the most part, determined from undiluted samples; other metals frequently required dilution to 1/10 or 1/100 of the original sample.

Each series of 12 sediment analysis included reagent blanks for correction of background values, and at least one portion of NBS certified "River Standard Sediment" for comparison of extraction efficiencies and accuracy of analysis.

Mercury was analyzed according to the "cold vapor" method. The dried sample was pulverized, weighed and added to a 300 mL BOD bottle; the bottle was cooled on ice. Five mL of concentrated H_2SO_4, 5 mL of concentrated HNO_3 and 15 mL of 5% $KMnO_4$ were added in sequence, and the sample was removed to a water bath (60 C) and heated for two hours, unstoppered. After cooling 5 mL of $K_2S_2O_8$ was added and the sample allowed to sit, stoppered, overnight. For analysis, an excess of

NaCl/[$(NH_2OH_2)H_2SO_4$] was added, followed by ~ 100 mL D.I. water, the sample was reduced with $SnSO_4$ and attached immediately to the cold vapor apparatus on the AA.

APPENDIX B

PROCEDURES USED FOR ANALYSIS OF POLYCHLORINATED BIPHENYLS AND SELECTED CHLORINATED PESTICIDES

Samples for PCB-pesticide analysis were received after being thawed and thoroughly homogenized. A portion of the mixed sample was then placed on a hexane-rinsed watchglass and dried (50 C; ~ 24 hr) to a constant weight. The dried sample was hombgenized in a mortar and pestle and a portion (~ 0.5 g) was weighed on a Cahn Electrobalance (± 0.001 g) and placed in a 125 mL Erlenmeyer flask with 25-50 mL acetonitrile (MCB Omni Solv, Residue Grade) for extraction.

Extraction was carried out three times for each sample in a Bransonic sonication bath (Model B-220). Each extraction used fresh acetonitrile, and was carried out for 20 min, after which the extracting solvent was poured into a separatory funnel with filtration (Eaton-Dikeman Grade 513).

The combined extracts were shaken (3 min) in a separatory funnel with 25 mL hexane (MCB Omni Solv) and 100 mL distilled, deionized water to which a small portion (1-3 mL) of saturated NaCl had been added. The hexane layer was collected, and the shaking process was repeated twice again. The combined hexane extracts were reduced in volume to ~ 20 mL in a Kuderna-Danish apparatus.

The hexane was then portioned through a florisil column using a 15% ethyl ether/hexane eluate (Anhydrous ethyl ether; Baker Resi-analyzed). The mixture collected from the column was reduced in volume to levels compatible with the sensitivity and linear response range of the gas

chromatrograph for PCBs and chlorinated pesticides.

PCB's were quantified using two methods. Both methods were based on analysis on a Varian Model 3700 Gas Chromatograph using a ^{63}Ni electron capture detector. Samples A-1 through A-69 were analyzed using a packed-column procedure with a temperature program imposed to assure complete separation of appropriate quantitation peaks. Conditions of the chromatographic runs on packed column were: Injection temp = 222 C; Detector temp = 350 C; Column = 160 C for 8 min with a 4 C/min increase to a final temperature of 200 C, which was maintained for 10 min. The column was glass, 1.8 m long x 6.4 mm (I.D.) with a packing of 1.5% OV-17 and 1.95% OV-210 on 100-120 mesh chromosorb WHP. Carrier gas flow (nitrogen) = 28 cc/min.

The detector response was recorded at 13 mm/min on a Beckman strip chart recorder; quantitation of PCBs was done directly from the strip chart using peak height response of selected peaks characteristic of Aroclor 1016 and Aroclor 1254 standards (EPA Catalog Nos. 5700, lot 7796 (1016) and 5705, lot 7901 (1254); U.S. EPA Research Triangle Park, N.C.).

Peak heights were measured using the "valley-to-valley" technique (EPA, 1980) and PCB quantitation was by back calculation of peak height response relative to known concentrations of PCB standards within the linear response range of the detector.

The remainder of the samples were analyzed using a glass capillary column which provided a more discrete separation of peaks in PCB mixtures and also allowed for measurement of pesticide residues which are

masked by PCBs on packed-column systems.

The capillary was operated on the same Varian 3700 GC with ^{63}Ni EC detector as the packed column system, and consisted of a Waters SE-54 glass capillary column, 30 m in length by 0.25 mm I.D. Conditions for operation were: Injector temp = 250 C; Detector temp = 350 C; Column temp (program); Initial 200 C for 10 min followed by an increase of 3 C per min to a final temperature of 230 C, which was maintained for 10 min. Column flow was 30 mL/min total made of helium (carrier) and nitrogen as make-up gas.

Quantitation of PCBs and pesticides on the capillary system was automated, using a programmable integrator (Spectra-Physics Model SP4000 central processor) with quantitation peaks identified by retention time of standards and actual quantitation based upon area integration. Component peak identification was based on separation, with a ± 2% retention time "window".

Three peaks from Aroclor 1016 and four from Aroclor 1254 were used for area integration and quantitation; PCB standards from the U.S. EPA Lab at Research Triangle Park were used for establishing quantitation peaks and appropriate response areas within the linear response range of the detector.

Proficiency in detection and quantitation of PCBs was tested by participation in the N.Y. State Dept. of Health Laboratory Certification program. Once appropriate standards for quantitation were obtained, our submitted data were found to be in agreement with "unknowns", based upon a rejection criterion in hexane of ± 25%, and ± 40% in environmental

samples spiked with combinations of Aroclors 1221, 1016 and 1254.

Extraction efficiency of PCBs was tested in a number of matrices and was found to average ~ 86%. Interlaboratory comparison of PCB quantitation from sediments was carried out with the cooperation of the U.S. EPA Gulf Breeze Environmental Research Laboratory and was found to be highly satisfactory, yielding total PCB values ± 10% in samples from Newark Bay, Weehawken and the East River (91st St.).

Pesticide concentrations in sediments were screened using glass-capillary G-C techniques identical to that used for PCBs. Only those pesticides having peak elution times distinctly different from all peaks in the PCB standards were used in quantitation. The identity of chlorinated pesticides was based on elution times of standards (> 85% purity) obtained from City Chemical Corp., New York, N.Y., and from Supelco Corp., Bellafonte, Pa.

APPENDIX C

METHODS APPLIED FOR ANALYSIS OF PHYSICAL CHARACTERISTICS

Frozen samples from each project were thawed, and mixed thoroughly. From each sample, duplicate 15.0 g wet weight aliquots were taken for grain size analysis, one 15 g sample for water loss, and one 20 g sample for total organic carbon. The remainder of each sample was saved for future analyses.

The samples for water loss and organic carbon (weight loss on ignition) were dried in an oven at 55 C for 1-2 days and weighed after equilibrating to room temperature in a desiccator. The organic carbon sample was then ashed in a muffle furnace at 500 C for 30 min, cooled and equilibrated in a desiccator to room temperature and again weighed to obtain weight upon ignition.

Grain size analyses were performed by soaking the duplicate 15.0 g samples in N/100 sodium oxalate solution for one day, and then sonification for 3-5 min before wet sieving through U.S.A. Standard Testing Sieves. The sizes tested for were: 850, 425, 250, 125 and 63 um. Particles retained by each of the above sieves were transferred to pre-dried, pre-weighed Whatman No. 2 filter paper, oven-dried for 1-2 days, transferred to a desiccator to equilibrate, and then weighed. The wash water was collected and evaporated to dryness and weighed for one of the duplicate samples. After wet sieving, the wash water from the other duplicate sample was evaporated to 500 mL and transferred to a graduate cylinder. The volume was adjusted back to 1000 mL, stirred, and after 58 sec a 20 mL pipetted sample was taken at a depth of 20 cm (i.e., 63

um particle size). The sample was re-stirred and allowed to settle for 2 hr and 3 min, at which time a second 20 mL pipetted sample was taken at a depth of 10 cm (i.e., to 0.004 um size). The wash water sample was then evaporated to dryness and weighed. Each 20 mL pipette samples was re-adjusted by multiplying by a common denominator of 50 to obtain the clay and silt weights of each sample according to Krumbein and Pettijohn (1938).

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APPENDIX C

SEDIMENT BUDGET STUDY

FOR CLAMSHELL DREDGING AND DISPOSAL ACTIVITIES

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New York District

ABSTRACT

The 'ediment Budget Study is part of the Dredged Material Disposal Management Plan for the Port of New York and New Jersey. The purpose of this study was to quantify the dry mass of dredged material involved in each stage of typical clamshell dredging and disposal activities in order to identify and quantify "losses" of dredged material. Turbidity plumes generated at dredging sites were also observed. Approximately 2.0% of the dredged material was lost at the dredging site. Of this lost dredged material, 55.7% was due to the dredging itself and 44.3% was due to intentional barge overflow. Approximately 3.7% of the dredged material is lost at the Mud Dump Site, presumably during disposal. Total loss of dredged material during these clamshell dredging and ocean disposal operations was calculated to be 5.6%. Observations revealed that turbidity plumes were local features which traveled along the bottom for several hundred feet. These plumes only persisted while dredging was occurring, and ambient conditions were established within a relatively short time after dredging ceased. Future research should be directed at further description and quantification of suspended sediment conditions during dredging.

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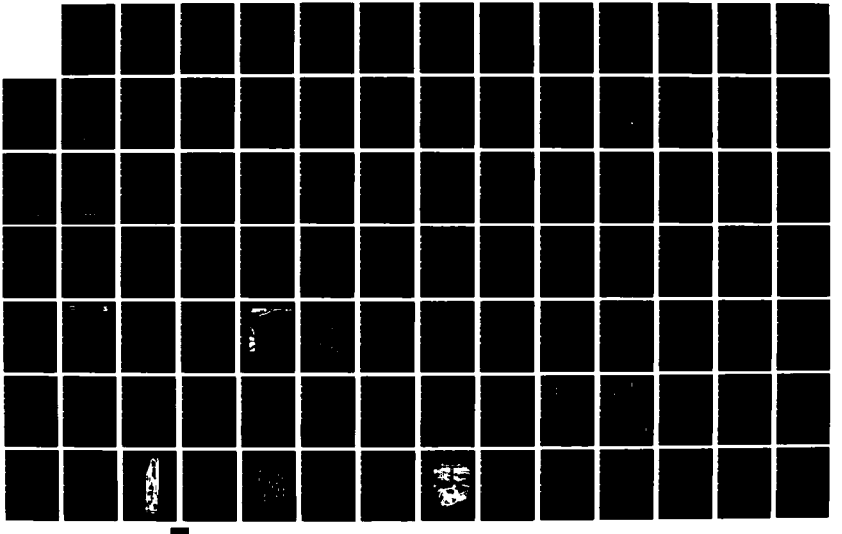

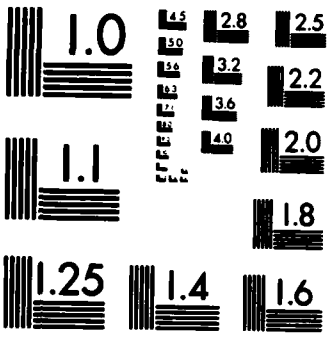

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I. INTRODUCTION

The New York District, Corps of Engineers in coordination with Interagency and Public Committees, is currently involved in a Dredged Material Disposal Management Program for the Port of New York and New Jersey. Various aspects of the ocean disposal of dredged material are being investigated. One of these is the Sediment Budget Study. In the Spring of 1980, approximately one-half million cubic yards of dredged material from six separate locations in the New York Harbor Area were disposed at one previously unused location at the New York Bight Ocean Disposal Site for Dredged Material (Mud Dump Site)., Fig. 1 shows the location and name of each of these dredging projects. The dredged material was covered, or capped, with a layer of 252,000 cubic yards of "clean" fine grained dredged material and 1,533,000 cubic yards of sand from Ambrose Channel.

The purpose of this study is to trace the total quantity of the capped dredged material "from cradle to grave", i.e., from its pre-dredging to its post-depositional stage. Measurements of the dredged material involved in each stage will be compared in order to determine a comprehensive sediment budget. This budget will show if dredged material is being "lost" in the dredging and disposal process. "Lost" will refer to dredged material which is dispersed from the dredging and disposal sites as suspended sediment. This part of the study will determine how much dredged material is lost and the exact point in the process that it is being lost.

The second part of the study will identify how dredged material is lost from the dredging site and to quantify the relative contribution of each mechanism to the total loss. This will also involve a description of the turbidity plumes observed at the dredging sites.

Other authors have performed sediment budget studies at the Mud Dump Site and at other locations, however, the literature is not extensive. Freeland and Merrill (1976) and Freeland et al.,(1976) compared the net accumulation of dredged material at the Mud Dump Site to the total quantity that was transported out to the site for the period 1936 to 1973. They determined that 87% of the volume transported out was accounted for at the dumpsite. Dayal et al.(1981) took this one step further and attempted to calculate the dry mass of dredged material for the period 1936 to 1978 by assuming an average dry density. They determined that 82% of the dry mass of dredged material barged out to the Mud Dump Site was accounted for at the site. The primary source of error in both these reports is the fact that dredging records before 1954 are not very accurate.

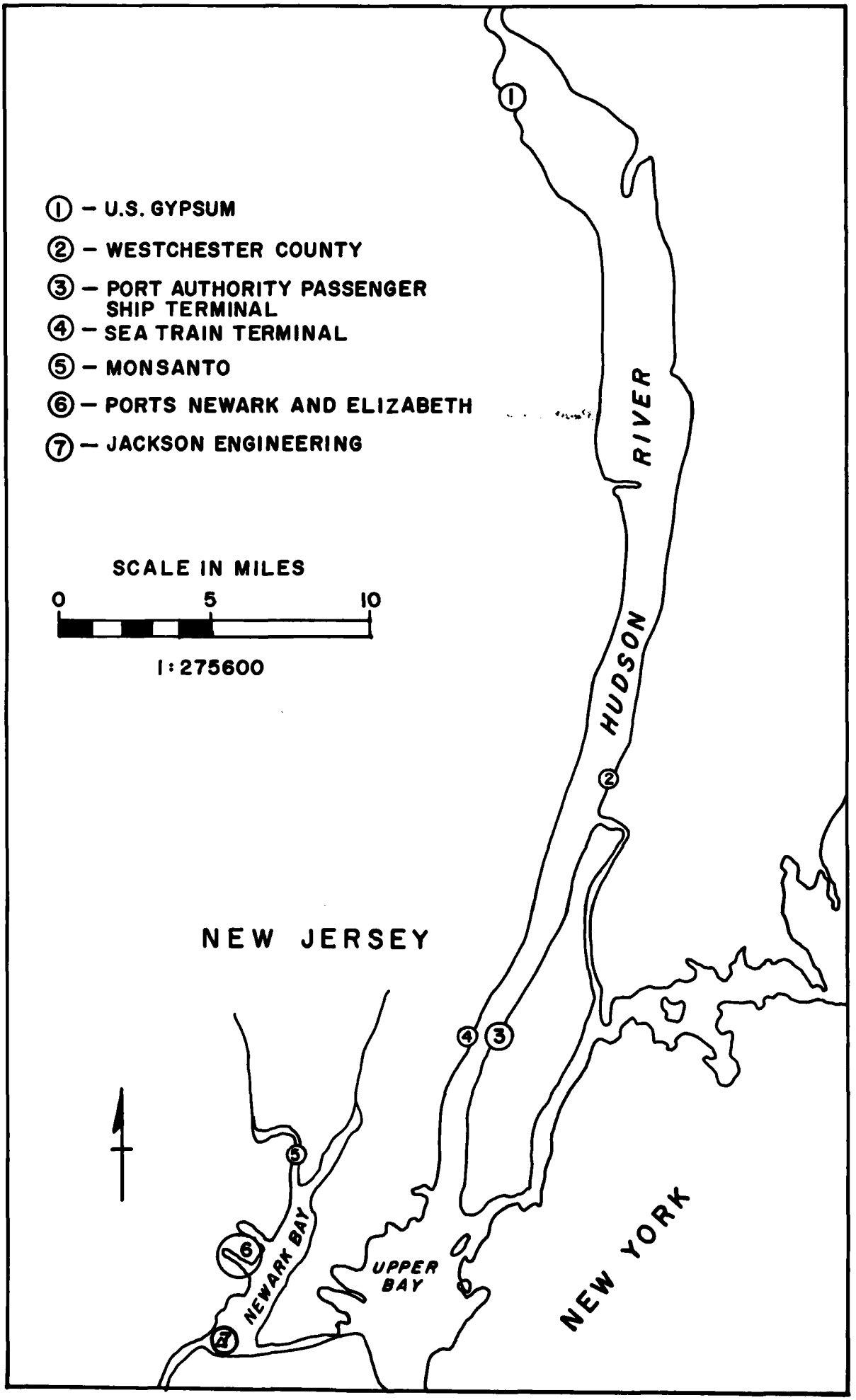


Fig. 1 - Location of Dredging Projects

Morton (1980) observed dredged material disposal at two separate sites in the Long Island Sound. He determined that 90% and 95% respectively of the volume dredged was accounted for.

In this study both the volume and the dry mass of the dredged material will be compared and discussed, but the main emphasis will be on the dry mass. Density changes occur due to the unavoidable addition of water during dredging and to the self-compaction which occurs to the dredged material after it is disposed, depending upon the physical nature of the sediment involved. This will necessarily affect the volume of dredged material seen at each stage. Using dry mass values will eliminate the discrepancies caused by density changes in the dredged material.

Most of this report is the result of many months of original field work and laboratory work, although some draws upon previous field work. Some of the theoretical calculations were drawn from the previous literature. This report is observational in nature. No manipulation of typical dredging and disposal practices was attempted for the purposes of this study. All observations are therefore representative of typical dredging and disposal operations for the New York Harbor area.

II. Clamshell Dredging and Ocean Disposal

All of the dredging projects observed during this study were accomplished by a clamshell dredging operation. In this type of operation a clamshell attached to a barge-mounted derrick is used to excavate sediment. The sediment is lifted through the water column and is placed into a bottom dumping barge which is moored next to the derrick. The barge is loaded with the dredged material in this manner until it is filled. Once the barge is filled, the derrick operator then begins to gently place more dredged material into the barge. This displaces a lower density sediment-water slurry which constitues the upper part of the dredged material in the barge. This slurry is created by the unavoidable addition of water by the clamshell to the barge during dredging. The derrick operator continues to displace lower density dredged material with higher density dredged material until the material which is overflowing is closer in density to the material which is being placed in the barge. At this point dredged material is no longer allowed to overflow and an "economic load" is said to have been achieved (sometimes called an "effective load"). The loaded barge is then transported by tug boat to the dredged material disposal site. At the disposal site the bottom of the barge is opened and the dredged material descends through the water column and is deposited on the bottom.

On various occasions during this process, dredged material is resuspended into the water column. During dredging, sediment is resuspended when the clamshell impacts the bottom and is pulled off the bottom. Since the clamshell is not covered, more sediment is resuspended from the clamshell as it is pulled through the water column. When the clamshell breaks the surface of the water, more sediment is added to the water column as turbid water spills out of the clamshell or leaks through the jaw openings. When dredged material is intentionally overflowed to achieve an economic load, more sediment is resuspended into the water column. Finally during the disposal of the dredged material, some sediment is resuspended as it descends through the water column and impacts the bottom.

Tidal current action will cause some of this resuspended material to be transported away and some will resettle back to the bottom. In addition, oxidation of organic material can occur at many opportunities during the dredging and disposal process. What this study will attempt to do is quantify and identify the losses of dredged material due to tidal dispersion and oxidation. This will be done by quantifying the amount of dredged material present at each stage in this process. The dry mass of the dredged material rather than the volume will be quantified because the volume will change due to the physical nature of the sediment and the addition of water by the clamshell. If no losses occur, the dry mass of dredged material should not change between each stage in the process. Therefore this is the only suitable measure of comparison for a sediment budget.

In this study, the dry mass of dredged material will be quantified:

a) Before it is dredged (in-place measurements)
b) In the barges before it is dumped (barge measurements)
c) After it is dumped (Mud Dump measurements)

Differences in dry mass between successive stages will be considered lost dredged material.

Measurements were also made to determine the means by which material was lost from the dredging sites. The magnitude of loss due to intentional barge overflow and the dredging activity itself was compared. Also, descriptions of the turbidity plumes generated at the dredging sites were made.

III. Previous Research

The literature concerning resuspension of sediment during dredging and disposal operations is not extensive. Most has been written within the last twelve years and most concerned U.S. Army Corps of Engineers projects. A brief summary of the findings of some of these studies follows:

During a channel deepening project at the Alameda Naval Air Station, San Francisco Bay, Wakeman (1976) found that turbidity levels 50 meters downstream from a clamshell dredge averaged 30 mg/l to 90 mg/l with a maximum of 200 mg/l. Background levels were approximately 40 mg/l. The turbidity plume was observed 300 meters downstream on the surface, and 450 meters downstream at 10 meters below the surface. Wakeman (1976) also listed a summary of the previous observations concerning dredging induced turbidity. Five of these are illustrated below:

a. Masch & Espey (1967) studied clamshell dredging in Galveston Bay and found that considerable quantities of dredged sediment were resuspended by the dredging. This resuspended material formed density layers greater than 10 gm/l near the bottom.

b. The U.S. Army Corps of Engineers (1969) found that turbidity levels were raised by 20 Jackson Turbidity Units (J.T.U.) downstream from a clamshell dredging operation in the Calumett River, Ohio.

c. Gordon et al. (1972) concluded that within a few meters of a clamshell dredging site, suspended sediment concentrations were as high as 15 gm/l.

d. Gordon (1973) in his investigation of clamshell generated turbidity in New Haven Harbor, Connecticut showed that 2.5% of the dredged material lifted by the clamshell was lost to the surrounding water.

e. Martin & Yentsch (1973) found that during dredging of the Annisquam Waterway, New England, light transmission decreased from 78% upstream of the dredging site to 53% at the dredging site. Light transmission returned to normal 400 meters downstream.

Barnard (1978) summarized the results of several studies of turbidity plumes induced by dredging. He summarized that depending on the direction and velocity of the current, turbidity plumes downstream of a clamshell dredging operation may extend up to 300 meters on the surface and 500 meters on the bottom. Three of the references which he uses to come to this conclusion are listed below:

a. Cronin et al. (1976) found that levels of suspended sediment near the bottom were 20 mg/l higher than the background levels of 10 mg/l at a distance of 90 meters in the Patapsco River, Maryland.

b. Yagi et al. (1977) found that at a distance of 7 meters from a clamshell dredging operation, suspended solid levels were 150 mg/l to 300 mg/l, compared to background levels of approximately 30 mg/l. These levels decreased by 50% at a distance of 23 m.

c. Bohlen & Tramontano (1977) noted that suspended sediment concentrations ranged from 68 mg/l on the surface to 168 mg/l on the bottom, 100 meters downstream from new work dredging in the lower Thames River, Connecticut. These levels decreased rapidly to background levels of 5 mg/l, 200 meters further downstream.

Gordon (1974), in his observation of Long Island Sound disposal operations, concluded that less than 1% of the sediment remained in suspension long enough to be dispersed by tidal currents.

Sustar and Wakeman (1977) concluded that between 1% and 5% of the dredged material that was discharged remained in suspension two meters above the bottom. This observation was made during disposal operations in San Francisco Bay. They also concluded that very little disturbance occurred to the upper parts of the water column during disposal.

Bokuniewicz et al. (1978) observed dredged material disposal operations in Lake Erie, the Atlantic Coast, the Pacific Coast and the New York Bight. They concluded that more than 95% of the material discharged will be deposited on the sea floor within 200 meters of the discharge point. The material will be spread over this area as a thin, dense bottom surge. They also concluded that the placement of the dredged material on the bottom during disposal occurs as a three phase process: convective descent through the water column, impact with the bottom, and lateral spread of the dredged material as a bottom surge.

Holiday et al. (1978) summarized the field observation of Bokuniewicz et al. (1979) and a computer disposal model developed by Brandsma et al. (1976). The authors modified and calibrated the computer model developed by Brandsma et al. (Tetra Tech model) using the field observation generated by Bokuniewicz, et al., and others. The computermodel was developed as a predictive tool in assessing the behavior of dredged material during disposal.

Connor et al. (1979) using the Tetra-Tech disposal simulation model, determined that in the New York Bight 90% of the suspended clay particles would be deposited within 3 hours of the dumping event. Significant increases in suspended solids are not expected to occur beyond several hundred feet of the dump site.

Bokuniewicz and Gordon (1980) determined that blocks of dredged material may disintegrate upon impact with the bottom, depending on the size and strength of the blocks and the impact resistance of the sea floor. If disintegration does occur, the suspended material would most likely be incorporated into the bottom surge rather than dispersed throughout the water column.

Morton (1980) stated that more than 80% of material dredged by clamshell and dumped from bottom dumping scows descends to the bottom as a cohesive mass and forms a mound. The remaining material forms a dense bottom surge that radiates outward from the disposal point. This observation was made on disposal operations in the Long Island Sound.

Morton and Miller (1980) examined differences in volume between before-dredging surveys and post-dumping surveys for disposal operations in the Long Island Sound. They found a maximum difference of 2.9% which they attributed to compaction of the dredged material under its own weight.

Bokuniewicz et al. (1980) monitored compaction of dredged material in the Long Island Sound for a period of 2.4 years after its initial emplacement. They estimated that the natural fine-grained sediment beneath the dredged material deposit was compacted by 15% due to the additional weight of the dredged material. Field observations showed that the volume of the deposit was reduced by 33% as pore water was expelled. Half of the compaction occurred within the first month after the deposit was completed, while the remaining compaction occurred within one year of the initial emplacement of the dredged material.

Based upon the previous literature, it can generally be stated that dredging causes turbidity plumes to occur downstream from the dredging site with the major part of this plume occurring near the bottom. Concentrations of suspended sediment decreases with distance from the dredging site. The distance that the plume travels is dependent on current velocity. The concentration of suspended solids in the plume depends on a variety of factors such as bulk density and grain size of dredged material, intensity of dredging, clamshell size, quantity of material overflowed, etc. During disposal, the dredged material descends through the water column as a dense mass (convective descent phase), impacts the bottom, and spreads along the bottom for no more than several hundred meters as a dense surge (dynamic collapse phase). Estimates have been made that between 95% and 99% of the dredged material dumped will be deposited within several hundred meters of the discharge point. The remaining 1% to 5% remains in suspension and could potentially be dispersed from the disposal area by tidal currents.

IV. METHODS

A. In-Place Measurements

Before-dredging bathymetry was subtracted from after-dredging bathymetry for all the areas dredged in order to construct "difference maps". These maps show the areal distribution of the thickness of sediment removed from these dredging sites. By contouring and planimetric measurement of these maps, the volume of material dredged was calculated. A one foot contour interval was used, and the volume of material dredged was calculated in one foot thick sections. These sections were later related to dry density measurements in order to determine the dry mass of material dredged from each site.

To physically characterize the material dredged from each site, piston and gravity cores were taken. In cases where it was not possible to take core samples in the exact area to be dredged, cores were taken in adjacent areas. These other areas were chosen based on their hydrologic and sedimentologic similarities to the area that was dredged. Table I shows the areas that were sampled, type and number of core samples taken, and average depth of penetration of the cores. Figs. 2 through 5 show core sample locations.

To physically characterize the material dredged from Monsanto, cores obtained from the relatively nearby Port Newark and Elizabeth area were used. The small volume dredged from Monsanto did not warrant separate core sampling in the immediate area. Jackson Engineering and Westchester County required special treatment which will be discussed later.

For each core, water content and percent loss on ignition were determined at one foot intervals. All loss on ignition values were averaged together to determine an average percent organic content for the in-place material at each site. These averages were later used in the sediment budget determination.

Water content values from each core at a given site were averaged together for each one-foot core interval. In this way an average water content with depth was determined for each site. These averages were converted to dry density values using a conversion graph which was based on previous studies (Suszkowski, 1978, see fig. 6).

These dry density values were plotted against depth, and a best fit curve was drawn. Figs. 7 through 10 show these curves.

In most cases, the cores did not penetrate deep enough to adequately characterize all the material that was dredged. In these instances, the curves were extrapolated to the necessary depths using data supplied by Panuzio (1963). This report listed water content with depth for many very deep cores taken from typical shoaled sediment in Upper New York Bay. All these water content measurements were converted to dry density measurements in the manner described previously and were plotted against depth. From 0 to 3 foot depths, dry density values varied significantly. However, a linear relationship was suggested from 3 to 25 foot depths. A best-fit line was drawn and the slope of this line was used to extrapolate the dry density curves determined for this study to the necessary depths (see fig. 11).

TABLE I - Core Samples

Location	Number of Cores		Average Depth of Penetration	
	Piston	Gravity	Piston	Gravity
Port Authority Passenger Ship Terminal	2*	4	9 ft.	4 ft.
Seatrain Terminal	2*	0	9 ft.	——
Ports Newark and Elizabeth	1*	4*	3 ft.	3 ft.
U.S. Gypsum	0	2	——	3 ft.

*samples obtained from adjacent areas

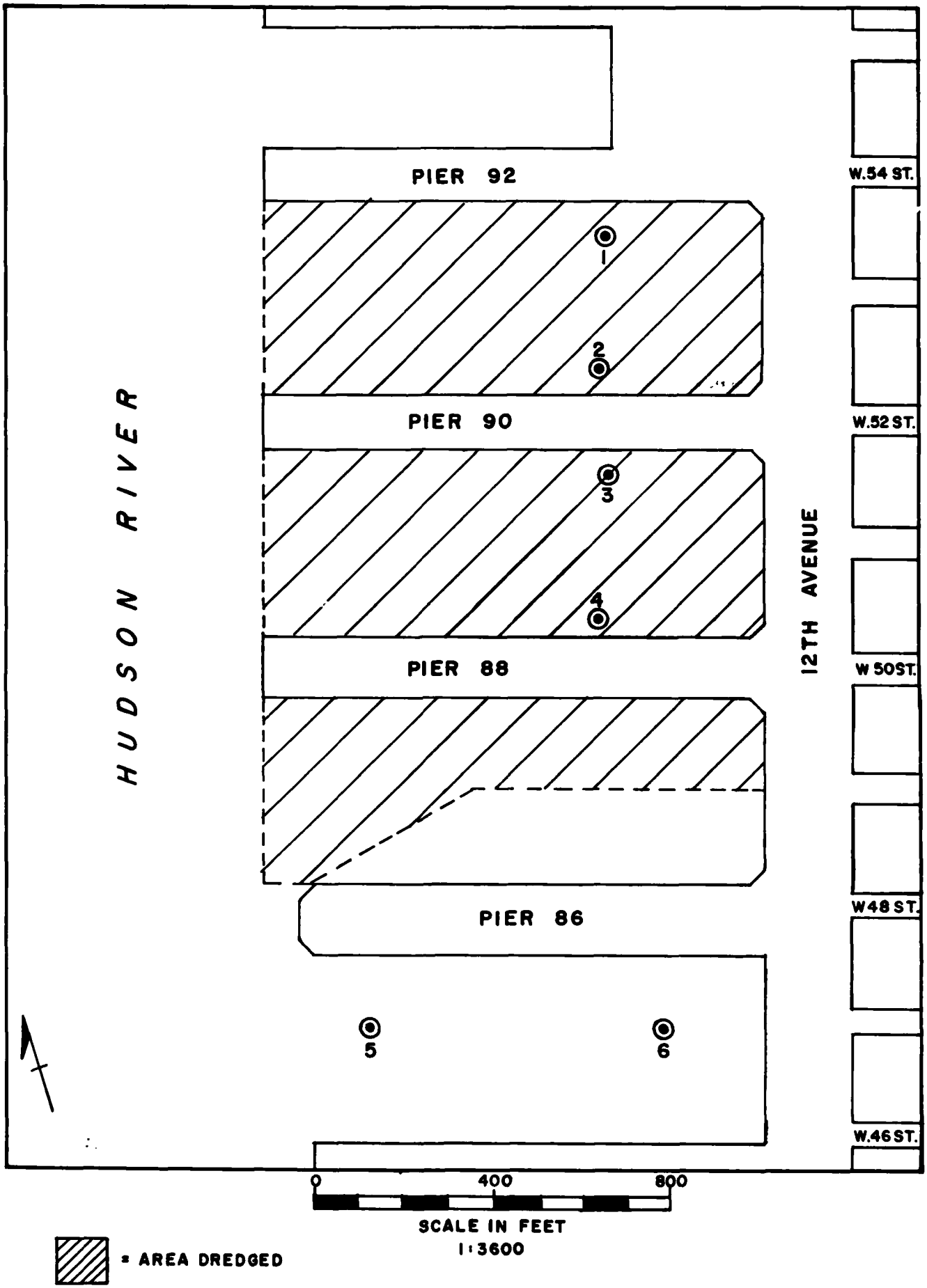


Fig. 2 – Core sample locations at Port Authority Passenger Ship Terminal.

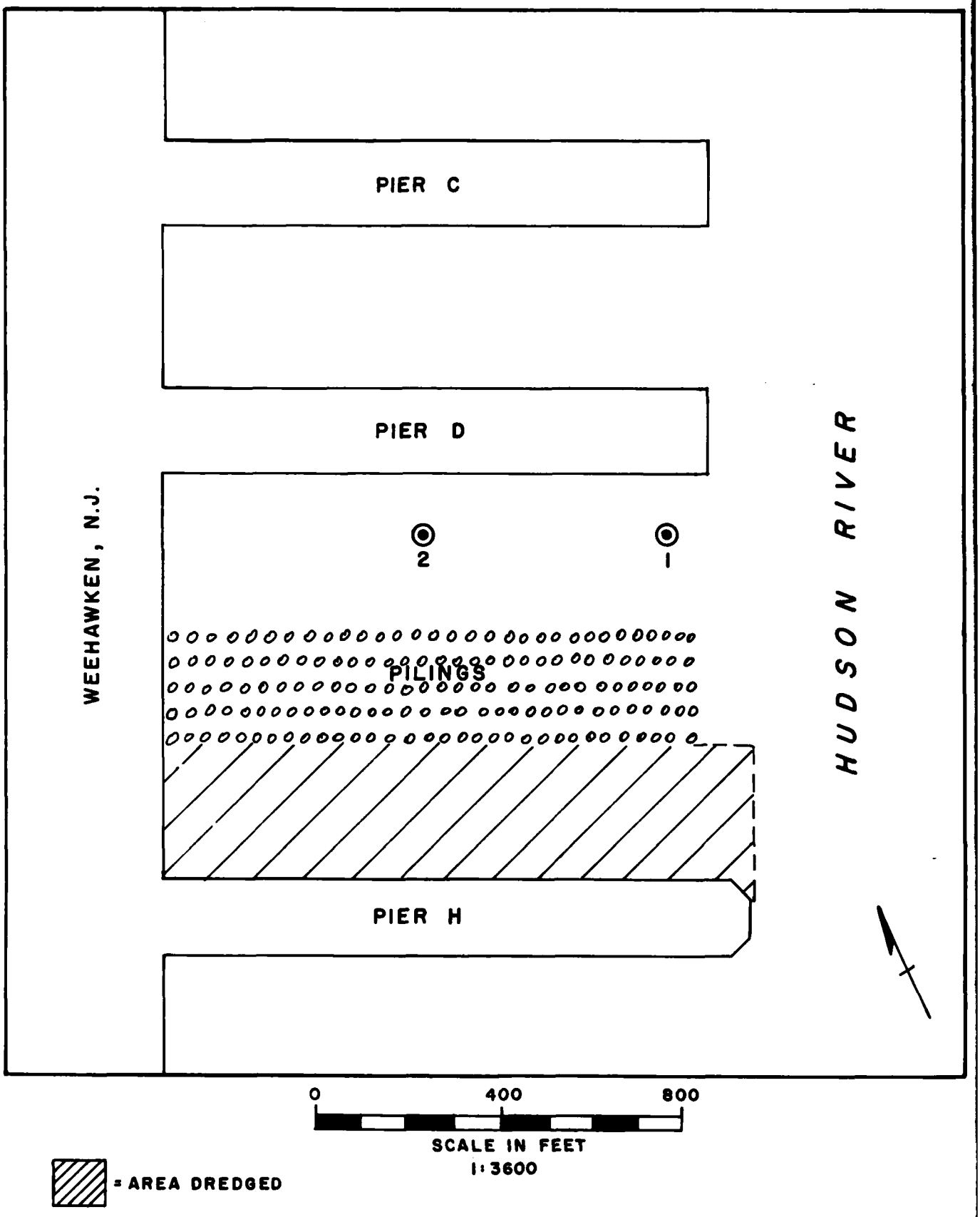


Fig. 3 - Core sample locations at Sea train Terminal.

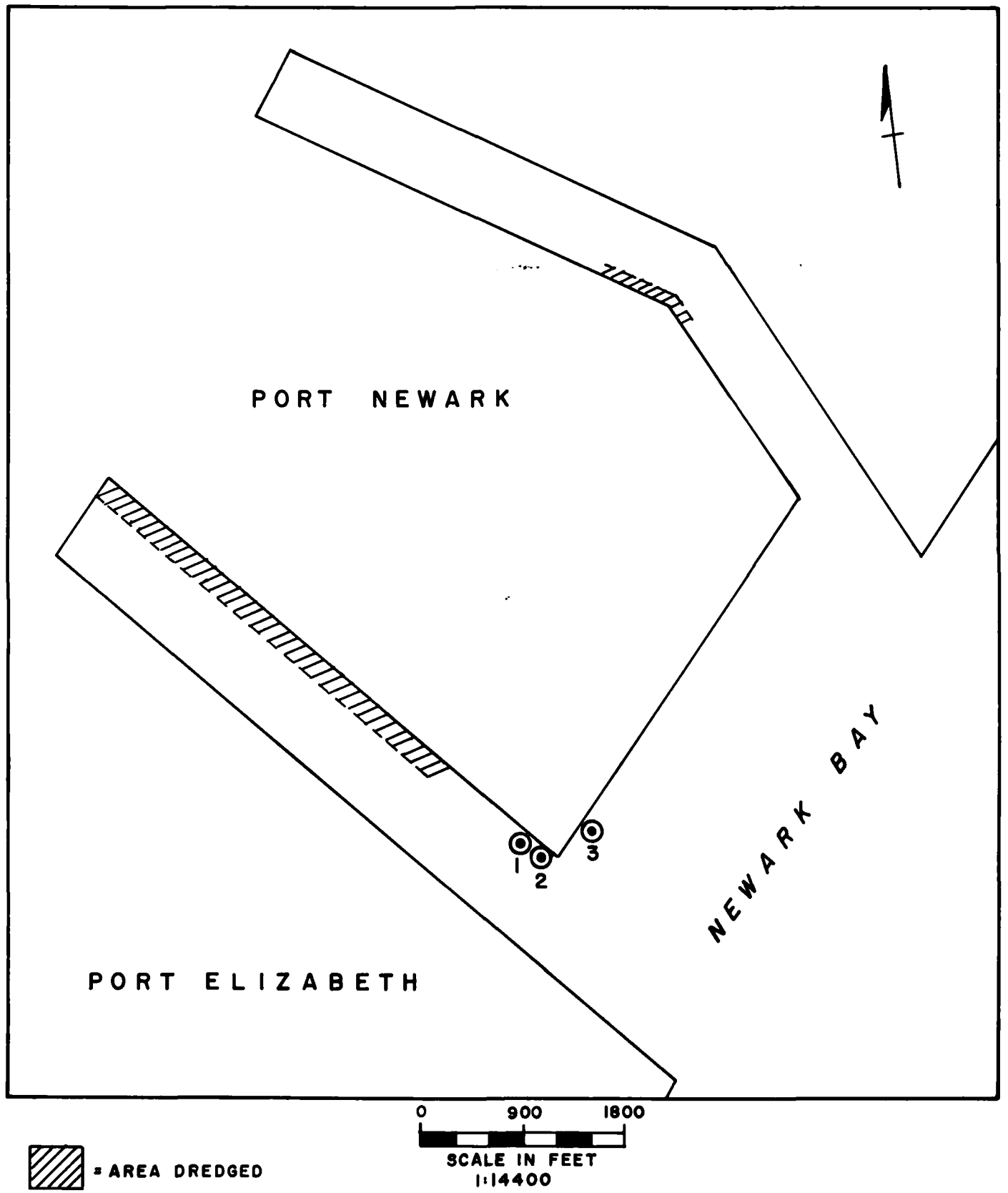


Fig. 4 - Core sample locations at Ports Newark and Elizabeth.

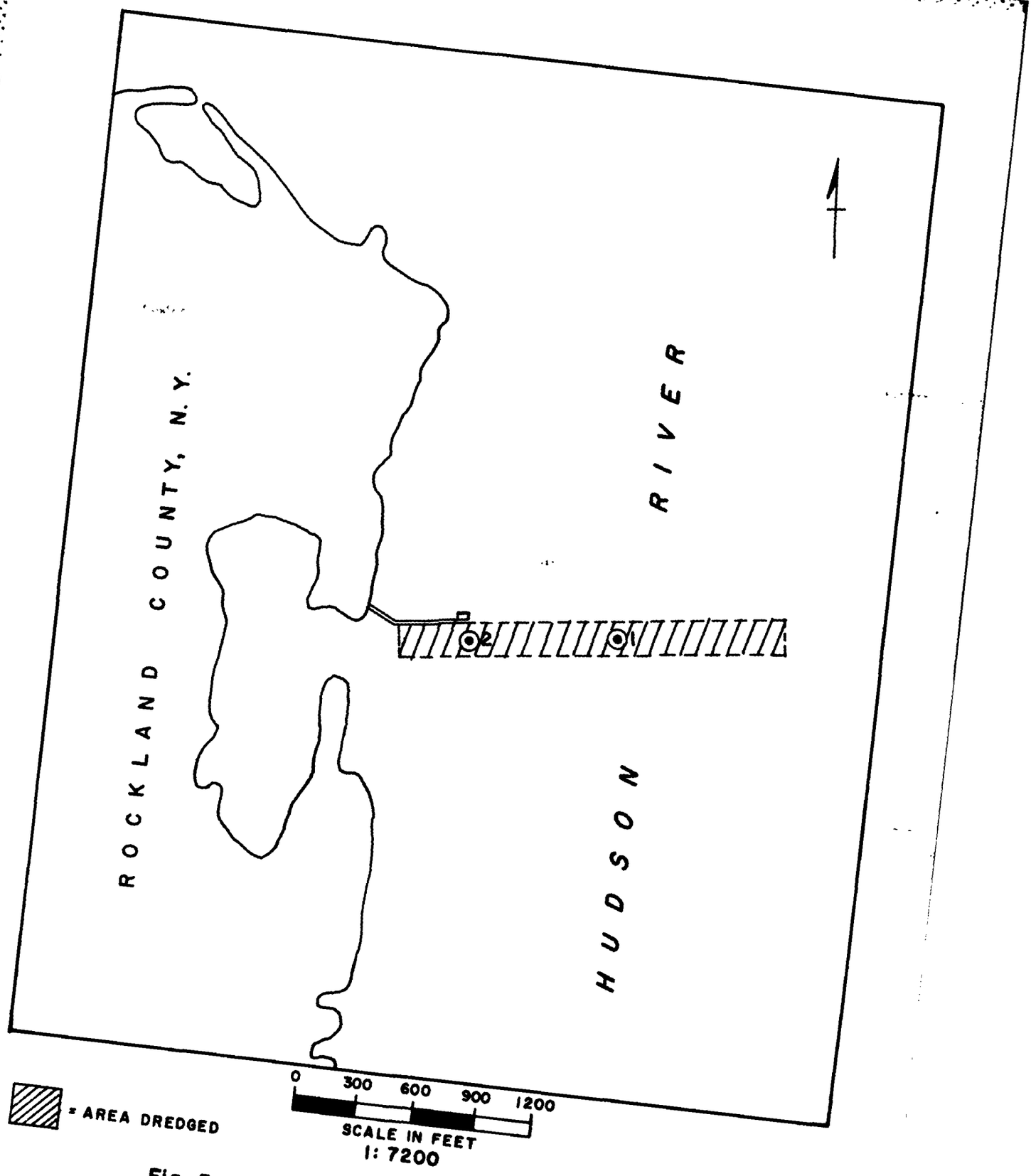
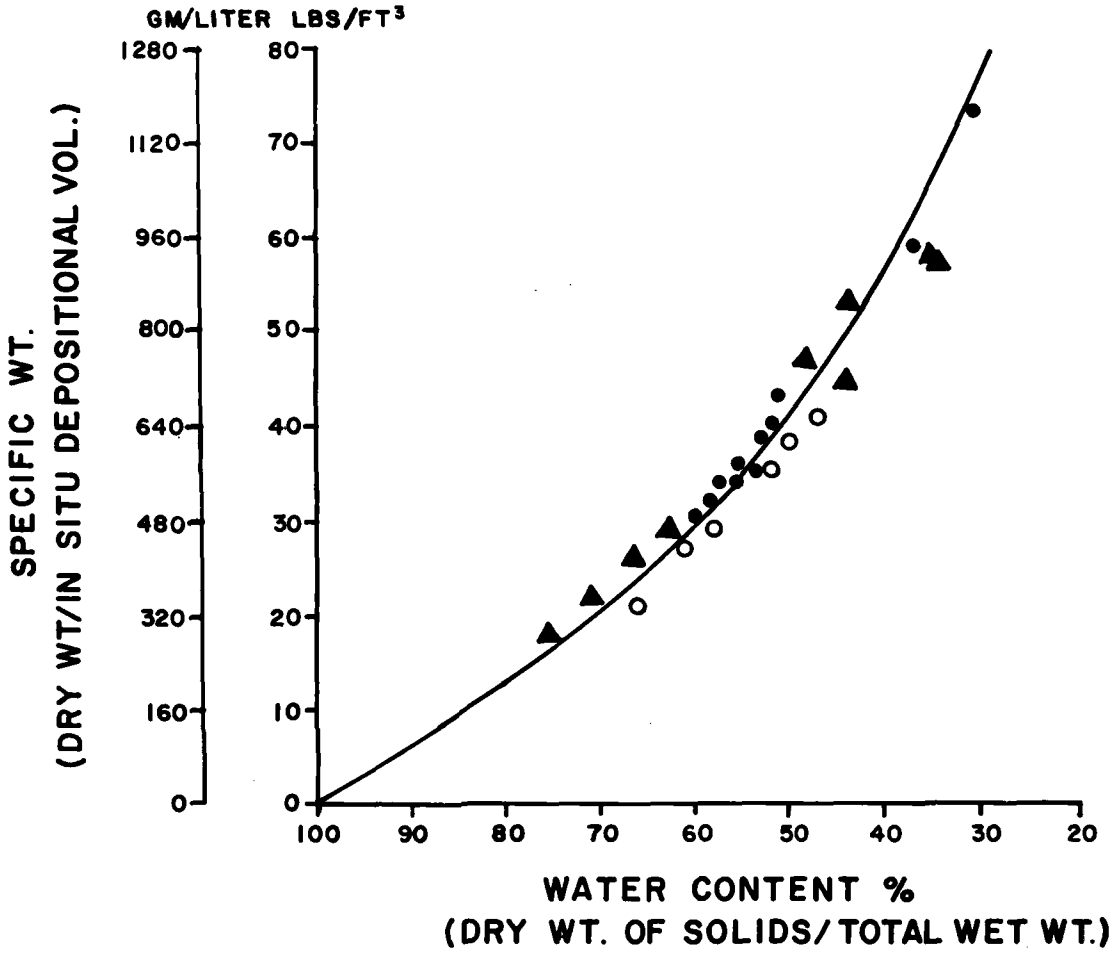


Fig. 5 – Core sample locations at U.S. Gypsum.



- DELAWARE RIVER (NEIHEISEL, 1973)
- ▲ HUDSON RIVER (U.S. ARMY ENGINEER DISTRICT, NEW YORK, 1965)
- ○ NEWARK BAY (SUSZKOWSKI 1978).

Fig. 6 – Water content vs. dry density (Suszkowski 1978).

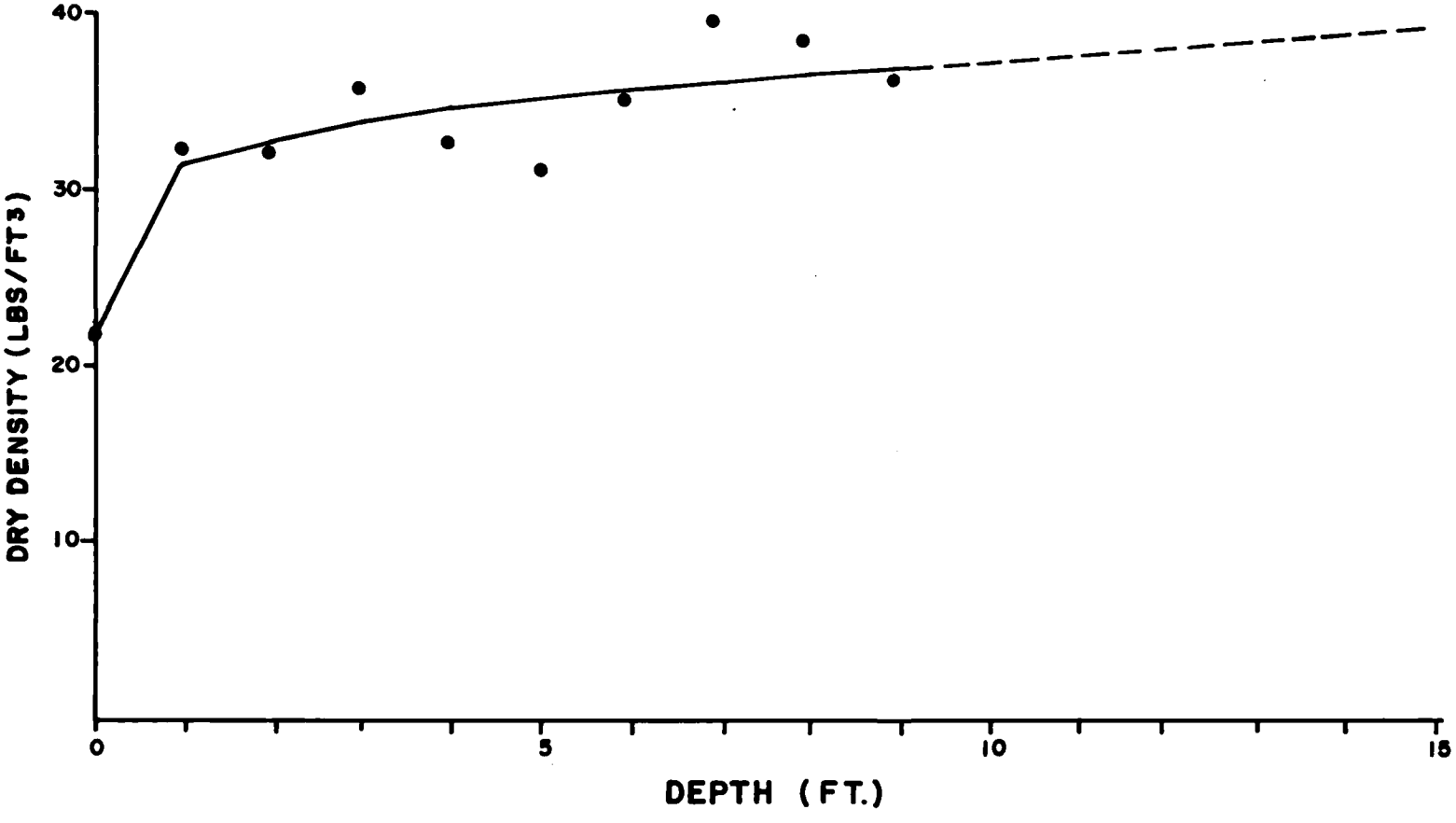


Fig. 7 – Dry density vs. depth for Port Authority Passenger Ship Terminal; dashed line is interpolated from data in Panuzio (1963).

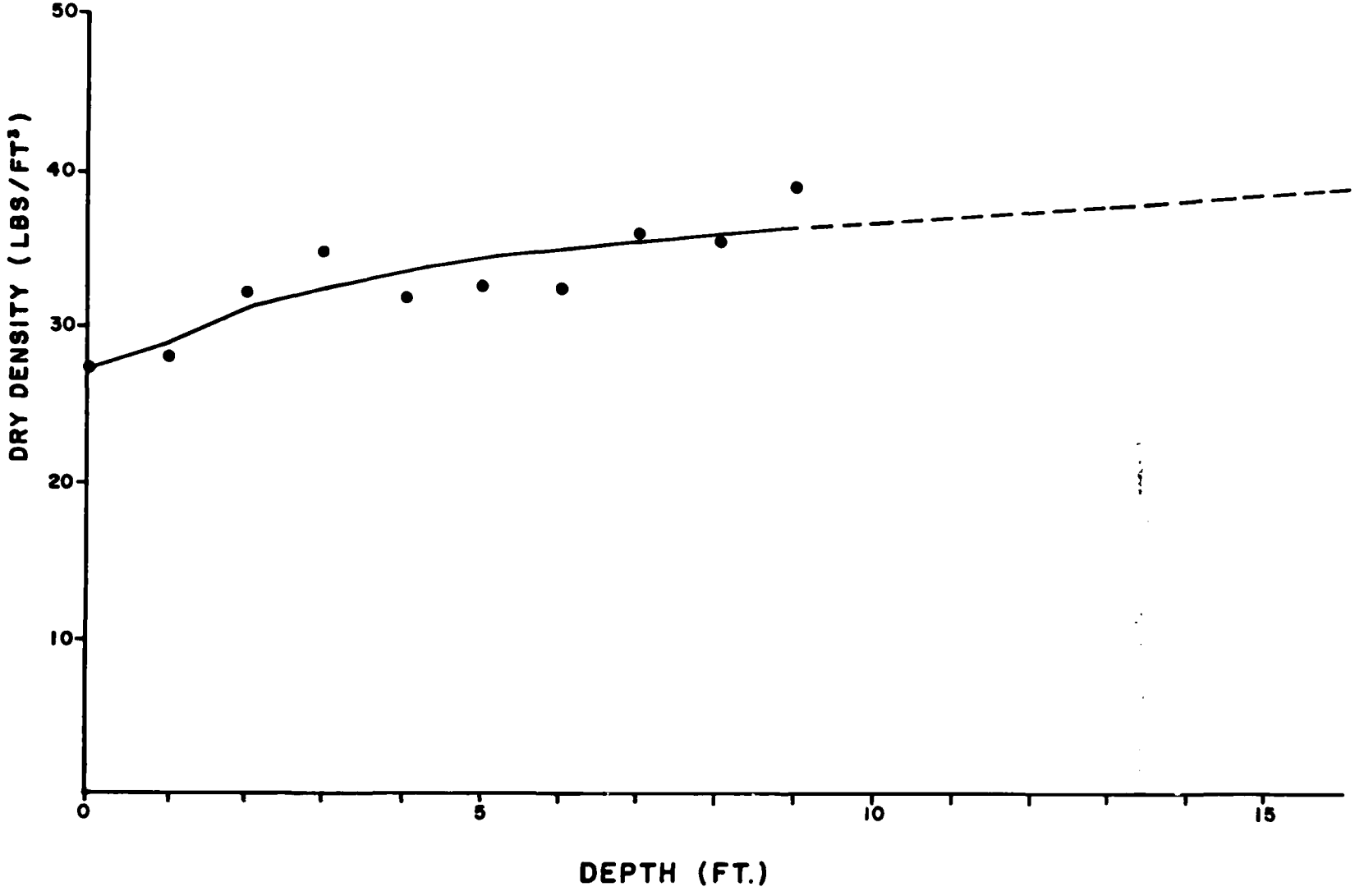


Fig. 8 – Dry density vs. depth for Sea train Terminal; dashed line is interpolated from data in Panuzio (1963)

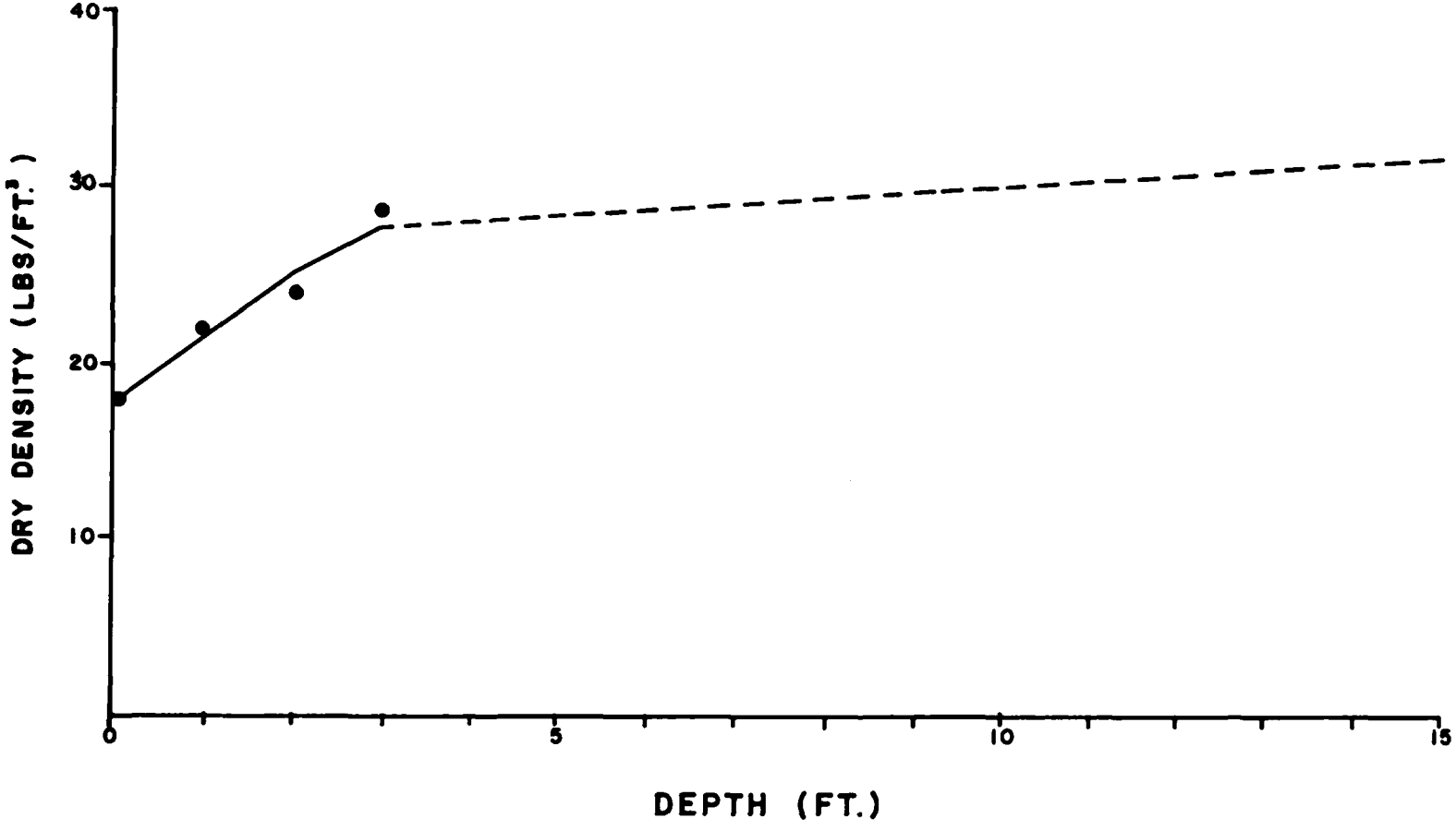


Fig. 9 – Dry density vs. depth for Ports Newark and Elizabeth; dashed line is interpolated from data in Panuzio (1963)

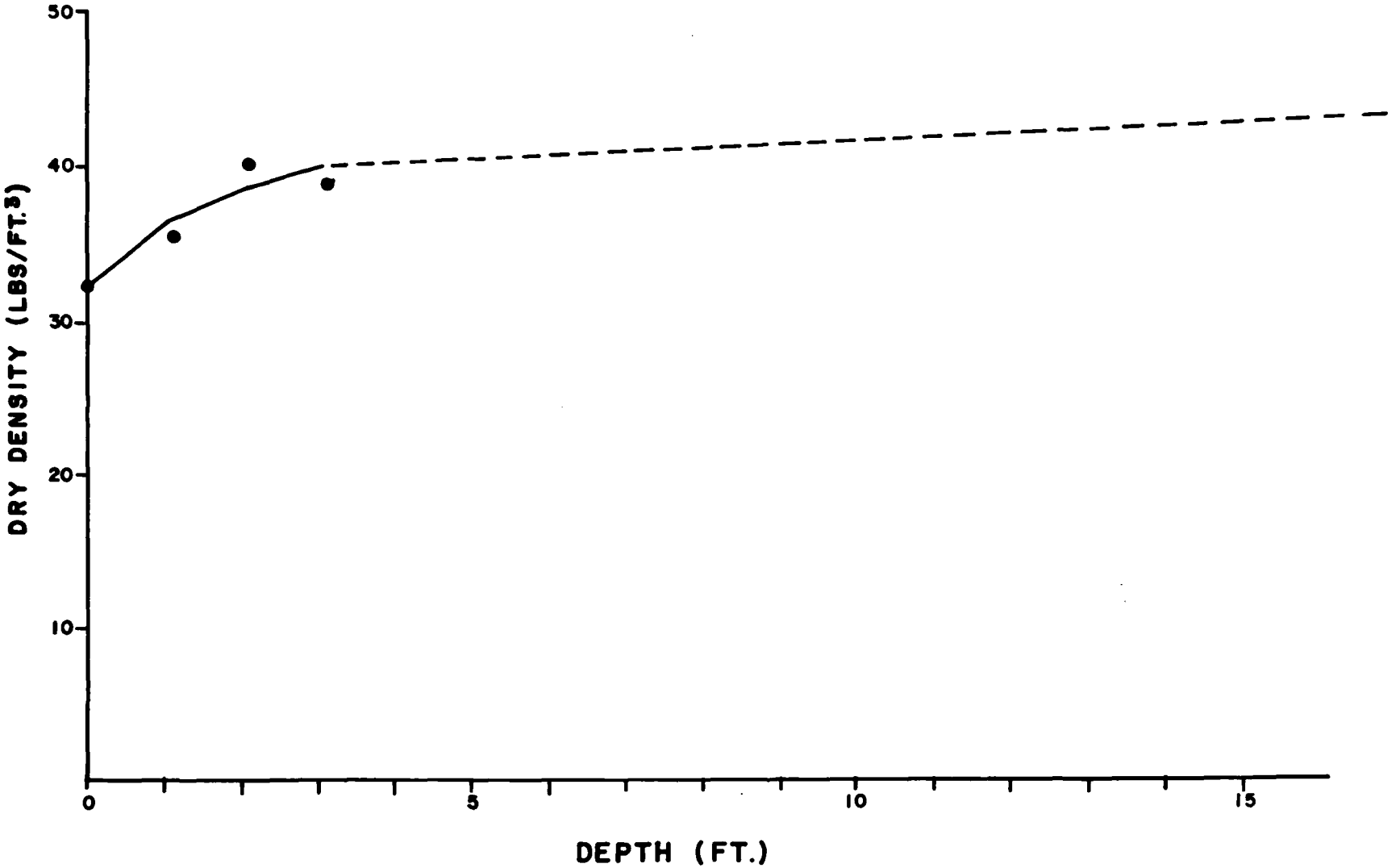


Fig. 10 – Dry density vs. depth for U.S. Gypsum; dashed line is interpolated from data in Panuzio (1963).

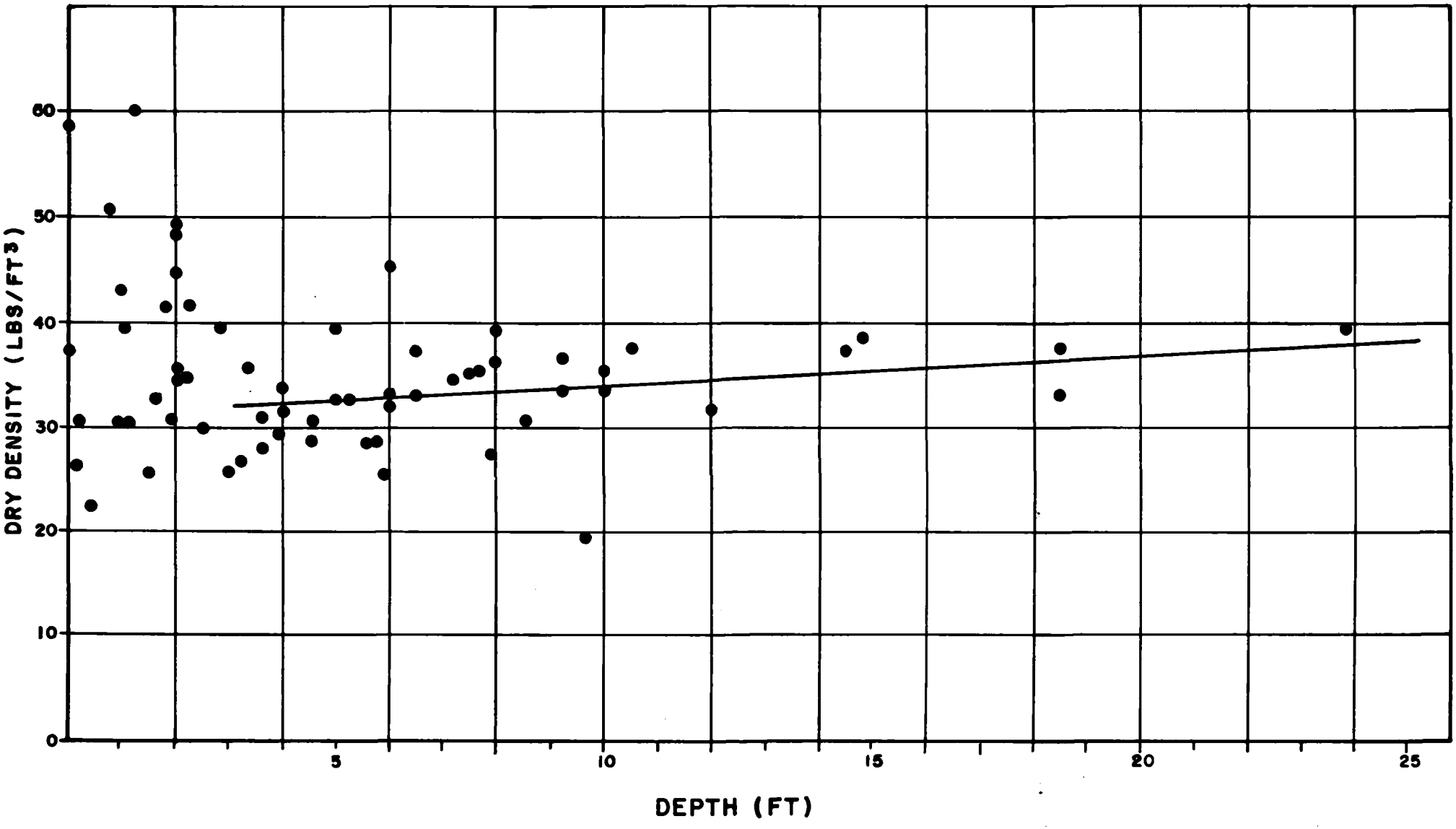


Fig. 11 - Dry density vs. depth from data in Panuzio (1963)

The dry density values determined from these graphs were used to calculate the dry mass of material removed from each dredging site. For each site, the dry density determined for each one-foot core interval was multiplied by the volume of the corresponding one-foot section determined from the difference map. This procedure was repeated for each one-foot interval, and the sum of these values is the total in-place dry mass of dredged material from each site.

B. Barge Measurements

In order to determine the dry mass of dredged material which was transported by barge to the Mud Dump Site, calculations from the earlier work of Bokuniewicz et al. (1978) were used. They determined that the bulk density of dredged material deposited in a given vessel can be calculated by the following formula:

$$\rho = \left[\frac{\bar{A}}{V}(d1 - d2) + 1\right]\rho_w$$

where:
- w = density of the water
- V = volume of the vessel
- $d1$ = draft of vessel when it is filled with dredged material
- $d2$ = draft of vessel when it is filled with water
- $\bar{A}$ = effective cross sectional area of the vessel at the waterline

An assumption is made that, for a given vessel, there exists an effective cross sectional area at the waterline ($\bar{A}$) that is constant over the range of drafts encountered in loading and unloading the vessel with dredged material. This can be calculated by the following formula:

$$\bar{A} = \frac{V}{(d2-d3)}$$

where:
- V = volume of the vessel
- $d2$ = draft of the vessel when it is filled with water
- $d3$ = draft of vessel when it is empty

The variable d1 was determined by taking draft readings at the four corners of each barge load and averaging them. The variables d2 and d3 were determined from a capacity plan of the type of 4,000 cubic yard bottom dumping barge typically used for the majority of the dredging performed during this study. A capacity plan is a graph which shows the range of freeboard on the barge as it is filled with sea water of a given density. With minor adjustments concerning the density of the water involved, the capacity plan can be used to determine d2 and d3 for any body of water. The capacity plan was provided by Great Lakes Dredge and Dock Co., one of the contractors who performed the dredging involved in this study.

The bulk density determined for each barge was converted to dry density values by using a conversion graph shown in fig. 12 (Wicker et al., 1973). The dry density values were multiplied by the volume of the barges to obtain the dry mass per barge. Approximately 52% of the barge loads did not have draft readings taken when they were full. For these barge loads the average barge dry density for that particular dredging site was used to determine the dry mass. The sum of the dry mass determinations for all 229 barge loads is the total dry mass which was transported to the Mud Dump Site.

Five cores were obtained of dredged material in several barges. These cores were obtained to determine an average organic content of the dredged material after it is dredged and before it is dumped. This average organic content will be used later in the sediment budget determination.

C. Mud Dump Measurements

A difference map for the Mud Dump Site was constructed by comparing before dumping and after-dumping bathymetry. Ten vibracores were obtained through the dredged material at the Mud Dump Site so that water content with depth and average organic content could be determined. Figure 13 shows the vibracore locations at the Mud Dump Site. The volume and dry mass of material at the Mud Dump Site was determined in the same manner as previously described for in-place measurements.

D. Turbidity Plume Measurements

At the dredging site, sediment is resuspended into the water column when the clamshell impacts the bottom, as it is pulled through the water column and as it breaks the water surface and spillage from the clamshell occurs. This report will consider all these together as resuspension due to dredging itself.

Sediment is also resuspended into the water column due to the intentional overflow during economic loading. This report will consider this resuspension due to barge overflow.

In order to determine how much dredged material is lost through dredging and how much through barge overflow, a three phase investigation was necessary. Phase I investigated the dry mass of material which overflowed per barge. Phase II investigated the dry mass of sediment which was resuspended due to barge overflow and dredging itself per barge load. Phase III investigated the dry mass of resuspended sediment which can be attributed to the dredging itself per barge load.

For Phase I, six barges were measured for volume of overflow and average dry density of the material overflowed. Three barges were observed at the Port Authority Passenger Ship Terminal (4000 cu.yd. capacity) and three barges were observed at the U.S. Gypsum dredging site (4000 cu.yd., 2200 cu.yd. and 1800 cu.yd. capacities). Quantity of overflow was determined by counting

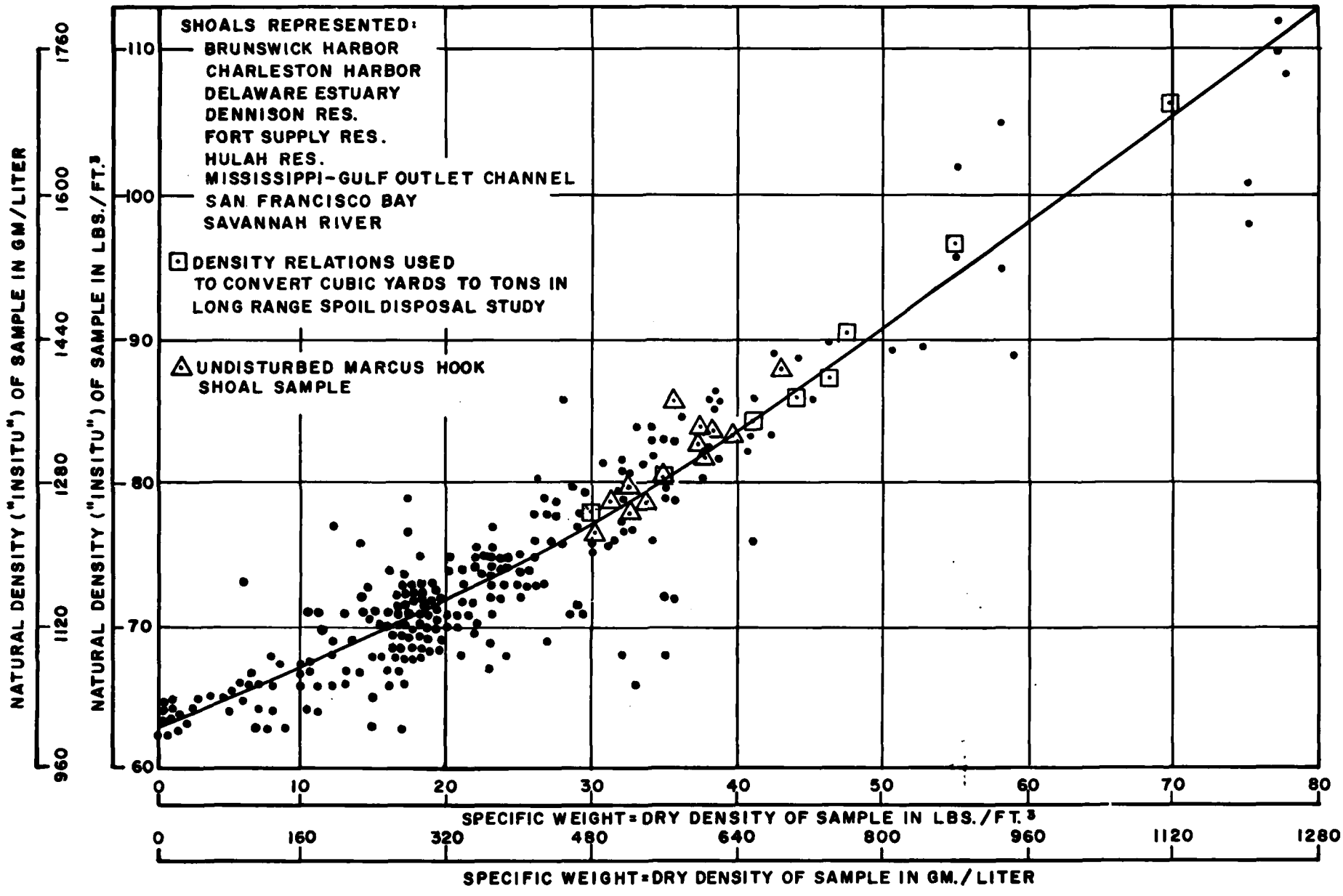


Fig. 12 – Bulk density vs. dry density (Wicker et. al., 1973).

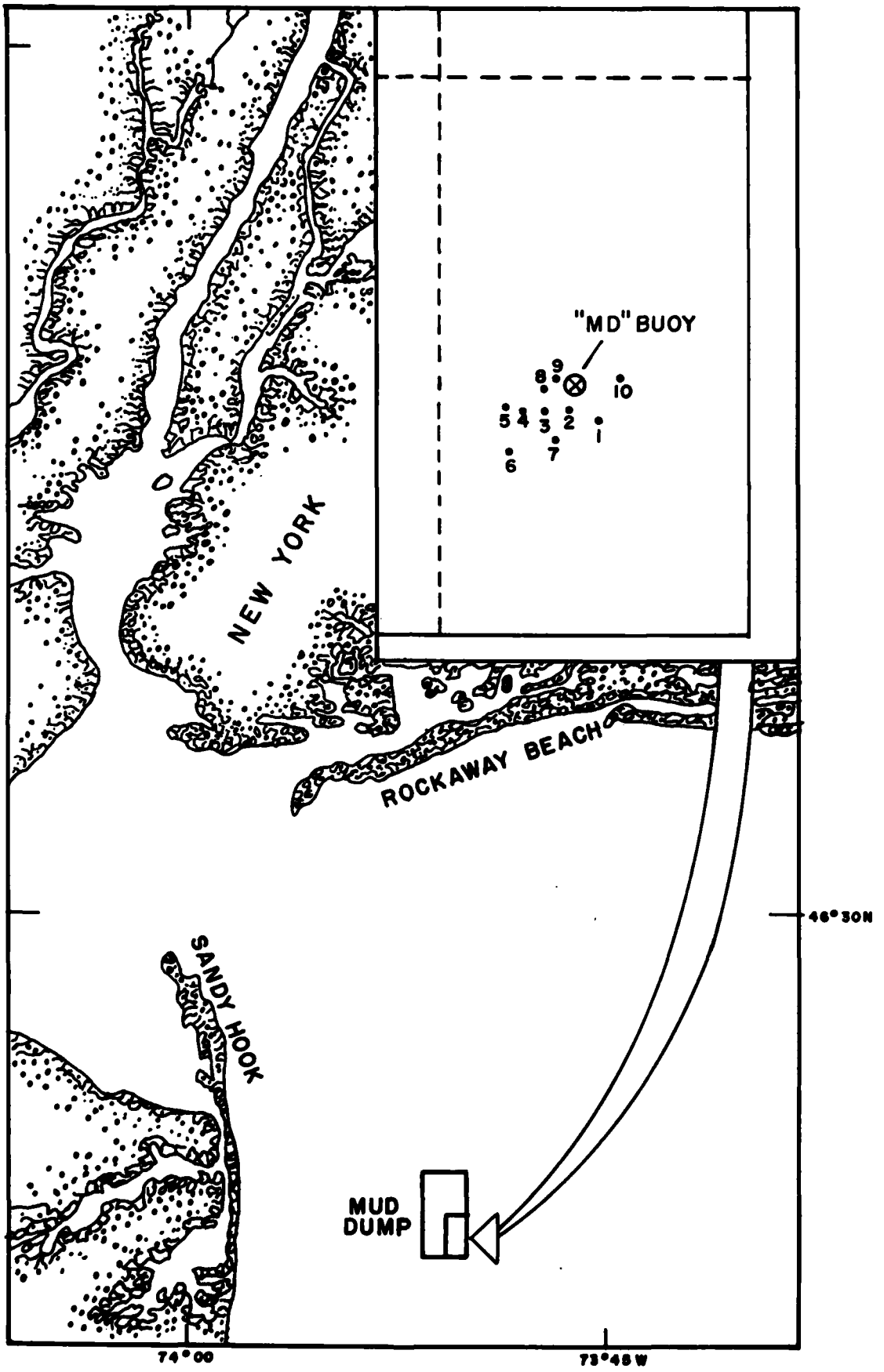


Fig. 13 - Vibracore locations at the Mud Dump.

the number of 13 or 15 cu/yd clamshell loads that were placed into the barge once the overflow was initiated. Dry mass was determined by sampling the overflow slurry at 5 minute intervals, drying and weighing known volumes of the sediment samples, and averaging these dry density values per barge load. Table II shows the average dry density per barge, volume of overflow and length of overflow time.

For Phase II, water samples were taken at 6 locations in an interpier area of the Port Authority Passenger Ship Terminal where dredging was occuring. Sampling was initiated approximately 10-15 minutes after oveflow began in order to allow turbidity plume conditions to establish. Samples were taken at five foot intervals vertically at each location. These were filtered, dried, weighed and averaged to determine an overall average dry density of sediment in the water column due to dredging and overflow for this barge load. Fig. 14 shows the sample locations.

In order to subtract the ambient suspended sediment load from the calculations, sampling of the water column at five foot vertical intervals was performed approximately 24 hours after dredging had entirely ceased at the Port Authority Passenger Ship Terminal. Since this study was not initiated until after dredging had begun, it was not possible to sample the area for ambient suspended sediment beforehand. However 24 hours (two full tidal cycles) is considered an adequate time to allow ambient conditions to reestablish themselves. Fig. 15 shows the sample locations.

The opportunity arose to determine the amount of sediment which is resuspended due to dreding itself when Mamaroneck Harbor Federal Navigation Project was dredged. For this dredging operation, no barge overflow was allowed to occur. For Phase III, water samples were taken prior to dredging during flood tide at five foot vertical intervals. This established ambient suspended sediment characteristics. Fig. 16 shows the sample locations.

During dredging at flood tide, water samples were again taken in the vicinity of the dredging. Two "runs" were performed during the filling of one barge load. In this way an average suspended sediment concentration due to dredging itself was determined. Fig. 17 shows the sample locations.

Once the three phases were completed it was then possible to compare them to determine what percentage of the total loss of resuspended sediment at the dredging site can be attributed to dredging and to barge overflow. This analysis is presented in the discussion section of this report.

TABLE II - Barge Overflow Data

Location	Barge Size	Average Dry Density	Volume Overflowed	Dry Mass Overflowed	Time Of Overflow
Port Authority Passenger Ship Terminal	4000 cu.yd.	3.27 lbs/ft	855 cu.yd.	37.78 short tons	69 min.
	4000 cu.yd.	6.94 lbs/ft	180 cu.yd.	16.86 short tons	35 min.
	4000 cu.yd.	13.68 lbs/ft	360 cu.yd.	66.19 short tons	28 min.
U.S. Gypsum	4000 cu.yd.	3.78 lbs/ft	299 cu.yd.	15.26 short tons	28 min.
	2200 cu.yd.	5.85 lbs/ft	390 cu.yd.	30.82 short tons	41 min.
	1800 cu.yd.	6.91 lbs/ft	182 cu.yd.	16.98 short tons	11 min.

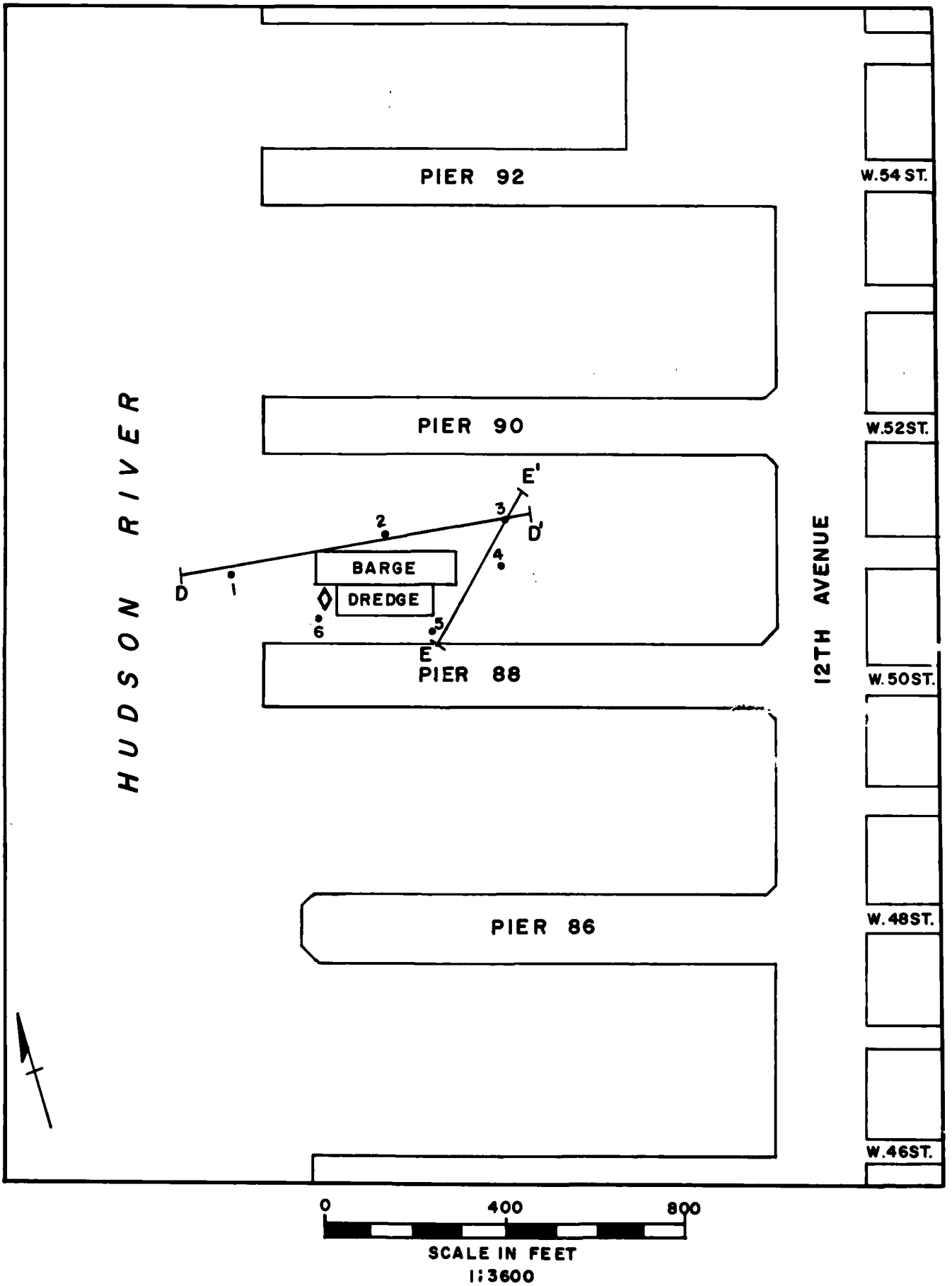


Fig. 14 - Water sample locations during dredging at Port Authority Passenger ship Terminal.

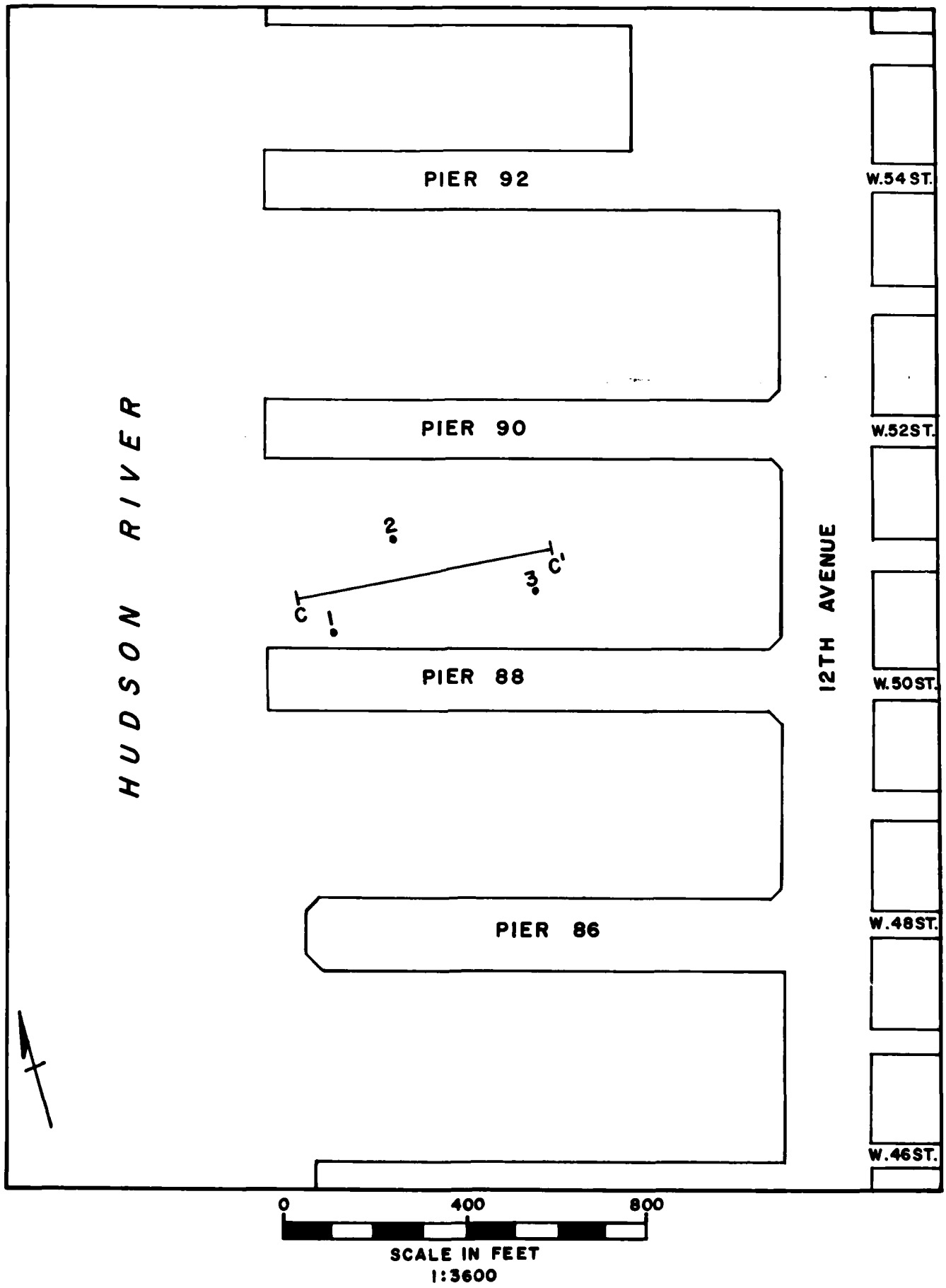


Fig. 15 – Water sample locations for ambient conditions at Port Authority Passenger Ship Terminal.

Fig. 16 - Water sample locations for ambient conditions at Mamaroneck Harbor.

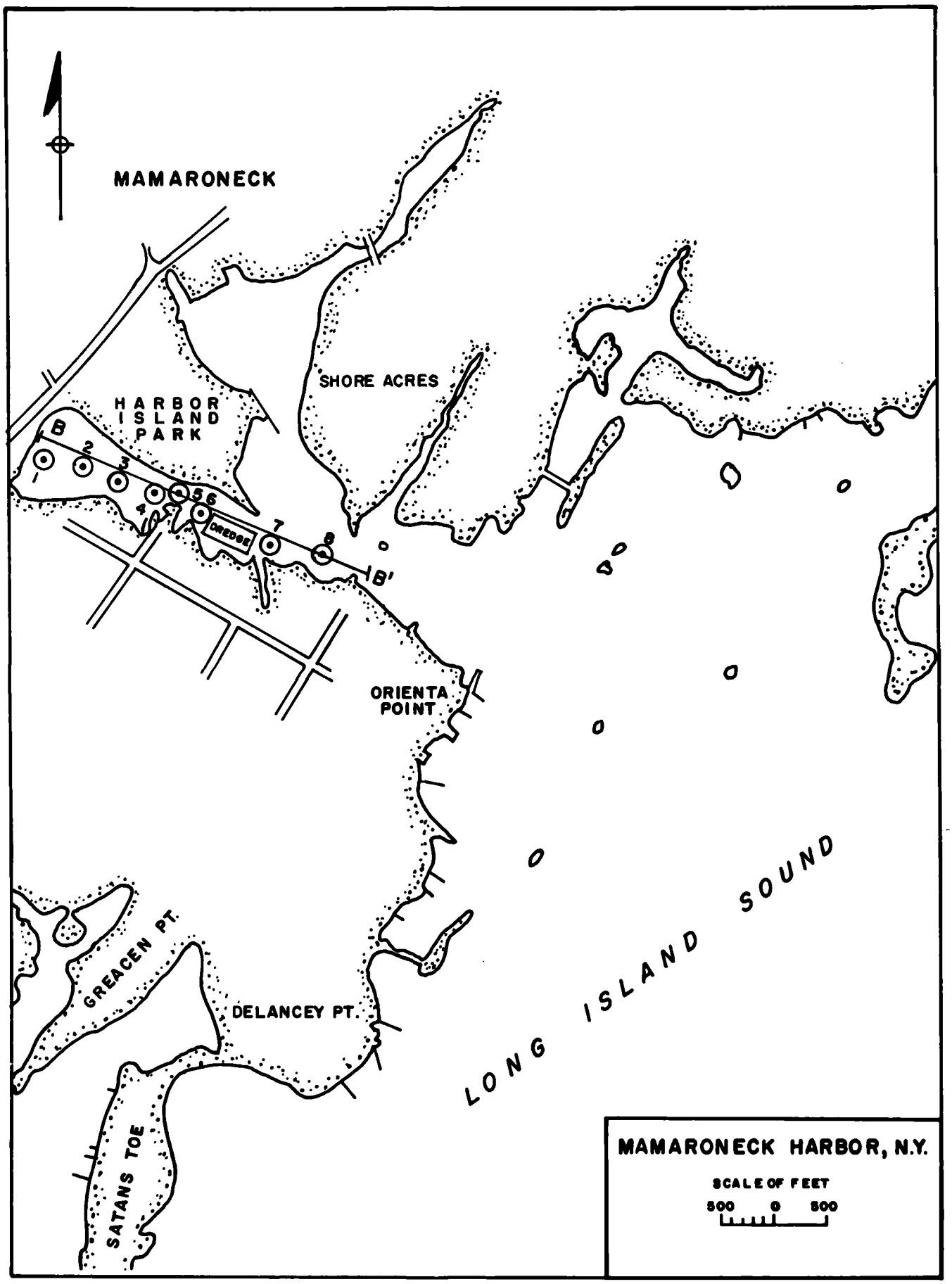


Fig. 17 – Water sample locations during dredging at Mamaroneck Harbor.

V. Mass Balance of Dredged Material

To determine a sediment budget for all of the dredging and disposal operations involved in this project, a mass balance approach will be used. In a mass balance analysis, the mass of the material involved is determined at various stages in the process to determine if there is an overall conservation of mass. This study will compare the total dry mass of dredged material at each stage in the dredging and disposal process.

If conservation of dry mass was demonstrated the following relationship would hold true:

1) $$\sum D = \sum B = \sum I$$

where $\sum D$ = Mud Dump dry mass
$\sum B$ = sum of barge transported dry mass
$\sum I$ = sum of in-place dry mass

Intuitively we know that this is not true. At the very least, oxidation of organics will leave some quantity of dredged material unaccounted for in the budget. If oxidation of organics were considered, then equation (1) would become:

2) $$\sum D\ (1 + ib - id) = \sum B\ (1+ip - ib) = \sum I$$

where $\sum D$, $\sum B$ and $\sum I$ are quantities described above and:
ip = in-place organic content
ib = barged organic content
id = organic content at the Mud Dump
(ip, ib and id are decimal fractions)

Intuitively we also know that some quantity of dredged material is dispersed from the dredging site due to barge overflow and the dredging itself. Also, some quantity of dredged material is dispersed from the disposal site during the disposal operation. Therefore all quantities in equation (2) will not be equal. To determine losses of dredged material due to dispersion from the dredging and disposal sites, equation (2) is broken down into two separate equations:

3) $$\sum I - \sum B\ (1 + ip - ib) = Lt$$

4) $$\sum B\ (1 + ip - ib) - \sum D\ (1 + ib - id) = Ld$$

where Lt = total loss of dredged material at the dredging site
Ld = total loss of dredged material during disposal
and all other variables are as described previously.

Since previous well documented research has been performed on losses of dredged material during disposal (Conner et al.,1979, Bokuniewicz et al.,1978, Holiday et al.,1978, Sustar & Wakeman 1977, etc.), no attempt was made to determine where or how the dredged material was resuspended during its descent through the water column and impact with the bottom. However, an attempt has

been made to determine how much of the barge overflow and sediment resuspension caused by dredging itself is dispersed from the site and what percentage each of these contributes to the total loss at the dredging site.

If we assume that all the dredged material that was overflowed or was resuspended due to the dredging itself is dispersed from the site, then the following relationship would exist:

$$5) \quad \sum B\,(1 + ip - ib) = \sum I - Lo - Lc$$

Where: Lo = total amount of barge overflow (dry mass)
Lc = total amount of resuspension due to dredging itself (dry mass)
and all variables are as described previously

However, some of this dredged material will resettle back to the bottom and not be dispersed from the site. Therefore to determine the mass of dredged material which resettles back to the bottom (St):

$$6) \quad [\sum B\,(1 + ip - ib)] - [\sum I - Lo - Lc] = St$$

Of this material which was resettled back to the bottom, an attempt was made to quantify the respective contributions made by barge overflow and resuspension due to dredging itself. This determination was based on the results of water column sampling during dredging. Once this was known, the respective contribution to the dredged material which was lost from the dredging site could be determined. A detailed explanation of how these determinations were made is presented in the discussion section of this report.

VI. DISCUSSION

Table III shows a comparison of the in-place and barge volumes. The dredged material from Westchester County totalled 2966 cubic yards which only partly filled one barge. The remaining volume in that barge was filled with dredged material from Jackson Engineering, so in all of the following analyses the two were considered together. It should be noted that all other barge loads were full loads, i.e., barges filled at least to the point of intentional overflow.

Table III shows an increase in volume in all cases which varies from 6.7% to 36.0% and averages 18.7% $\pm$ 12.5%. At the Jackson Engineering site a substantial amount of "new work" dredging took place. "New work" dredging is the removal of previously undredged natural sediment deposits, in contrast to "maintenance" dredging which is the dredging of recently accumulated sediment in areas that have been dredged previously. Usually, new work dredged material is denser and more cohesive than the typical black, organic silt and clay which is maintenance dredged. When dredged, new work sediment will behave in a block-like manner and volume is increased because the pore spaces between blocks become filled with water (H. Bokuniewicz, personal communication). If we consider only the projects which required mostly maintenance dredging and exclude Jackson Engineering and Westchester County, the average percent difference is somewhat lower at 14.3% $\pm$ 9.0%.

Monsanto required special treatment in calculating the barge volume. A first barge was filled and the barge draft was recorded, but a second barge was only partially filled and draft readings were not recorded. It was therefore necessary to use the average percent difference between barge and in-place volumes for the other projects observed during this study in order to calculate the barge volume for Monsanto. Since Monsanto involved only maintenance dredging, the average percent difference which excluded the new work of Jackson Engineering and Westchester County was used (14.3% difference). Table III lists the calculated barge volume of 7,292 cubic yards for Monsanto.

Table IV shows a comparison of the in-place and barge dry mass. Except for the Port Authority Passenger Ship Terminal, all dredging projects showed some loss of mass. The average percent of lost mass was 3.0%. It should be noted, however, that this average percent of lost mass does not take into account oxidation of organics. This is taken into account later during the mass budget calculations.

The Port Authority Passenger Ship Terminal shows a very slight increase in mass caused by the dredging. The increase is so slight that it is probably within the margin of error inherent in the calculations.

TABLE III - Volume Comparisons

Project	In Place Cubic Yards	Barge Transported Cubic Yards	Percent Difference
Port Authority Passenger Ship Terminal	217,693	300,000	27.4%
Seatrain Terminal	85,840	92,000	6.7%
Ports Newark and Elizabeth	101,844	116,000	12.2%
U.S. Gypsum	179,915	202,200	11.0%
Monsanto	6,246	7,292	*
Jackson Engineering and Westchester County	92,016	143,800	36.0%
Total Volume	683,554	861,292	20.6%
Average Percent Difference			18.7% ± 12.5%
Average Excluding Jackson Engineering and Westchester County			14.3% ± 9.0%

*special treatment was required; see text for explanation

TABLE IV - Dry Mass Comparison

Project	In Place Dry Mass (short tons)	Barge Transported Dry Mass (short tons)	Percent Difference
Port Authority Passenger Ship Terminal	95,309	95,464	-0.2%
Seatrain Terminal	39,152	38,172	2.5%
Ports Newark and Elizabeth	41,864	39,559	5.5%
U.S. Gypsum	94,888	91,068	4.0%
Monsanto	2,078	*2,008	3.4%
Jackson Engineering and Westchester County	86,473	83,845	*
Total Dry Mass	359,764	350,116	
Average Percent Difference			3.0%

*special treatment was required; see text for explanation.

Jackson Engineering required special treatment in calculating the in-place dry mass due to the significant amount of new work dredging which was performed. The new work dredged material from Jackson Engineering was most likely a brick-red dense clay with many slightly rounded flat or spherical pebbles. The pebbles are a mixture of red sandstone pebbles similar in appearance to the Triassic-Jurassic Stockton Formation and dark igneous pebbles similar in appearance to the Triassic-Jurassic basalt igneous intrusions both of which outcrop nearby. No sedimentary structures were seen. These observations were made on the bottom portions of several of the cores taken at the Ports Newark and Elizabeth site. This red clay also appears to underlie a substantial portion of Newark Bay below the recent estuarine deposits, and some authors believe that this is the lacustrine deposits of ancient Lake Hackensack (Suszkowski 1978). In other core sampling performed by the New York District Corps of Engineers for Federal Navigation Projects, this red clay has been observed from the Arthur Kill entrance in southwestern Newark Bay, as far north as the Passaic River entrance and as far east as the main channel of Newark Bay. Since Jackson Engineering lies within this area it is very likely that the red clay at least in part constituted the new work dredging performed there.

If we assume that this red clay constituted all of the new work dredging, then, based upon the average dry density of typical estuarine muds involved in this study (32.6 lbs/ft), and average dry density of the clay (88.7 lbs/ft), it is estimated that approximately 30% of the Jackson Engineering dredged material was maintenance material and approximately 70% was new work material. These dry density values were compared to the total in-place dry mass for the Jackson Engineering site, as calculated below, to derive these percentages.

In order to calculate the in-place dry mass of dredged material from Jackson Engineering, the average percent difference between in-place and barge dry mass determined for the other projects was used. This percent difference was used with the known barge dry mass to determine the in-place dry mass from Jackson Engineering. The assumption is made that the same factors which affected the sediment during dredging at the other sites also acted at the Jackson Engineering site. Since the dredged material from other sites was less cohesive and dense than the red clay, this assumption will probably somewhat overestimate the loss of dredged material from the Jackson Engineering site. The in-place dry mass calculated in this manner is listed in Table IV as 83,845 short tons.

Employing formula (3) of the mass balance equations will enable the determination of the total dry mass "lost" from the dredging sites. This formula takes into account the losses due to oxidation of organics. Average in-place organic content was determined from the cores obtained at the dredging site and average barge organic content was determined from cores obtained from several barge loads. The average in-place organic content was determined to be 9.4% + 2.3% (based upon 89 samples) and average barge organic content was determined to be 8.7% + 0.7% (based upon 31 samples). Total in-place dry mass of sediment was determined to be 359,764 short tons and total barge dry mass of dredged material was determined to be 350,116 short tons. Inserting all these values into equation (3) gives 7,303 short tons as the total loss of dredged material at the dredging site (Lt). This is 2.0% of the total amount dredged. It should be remembered that the estimate of dredged material lost from the dredging site without taking into account oxidation of organic material was 3.0%.

A comparison was made of the total barge volume and the total volume determined at the Mud Dump. There was an overall loss in volume of 40.7% between these two stages. A large part of this reduction in volume can be attributed to self-compaction of the dredged material after is is dumped. There is a significant amount of interstitial water associated with the dredged material in the barges. During disposal some of the interstitial water is dispersed and, after the dredged material is deposited on the bottom, expulsion of pore water occurs as the deposit self-compacts. This compaction will usually occur fairly rapidly so that 50% of the total compaction will occur within one month and the remaining compaction will occur within one year (Bokuniewicz et.al.,1980). At least two weeks had passed between the dumping of the dredged material and the bathymetric survey of the Mud Dump so some self-compaction had probably already occurred. This at least partly explains the drastic reduction in volume.

If compaction of the natural sediment under the dredged material deposit occurred, it would apparently reduce the calculated volume of the dredged material deposit. The natural sediment under the dredged material deposit is coarse to fine grained sand because the site had not received dredged material before. For all practical purposes, the sand will not compact under the weight of a dredged material mound of this size and need not be considered in the volumetric calculation.

If a comparison is made of the total volume of dredged material at the Mud Dump with the total in-place volume, a volume loss of 25.3% is seen. Of the 40.7% loss of volume noted between the total barge volume and the total volume of dredged material at the Mud Dump, 15.4% can be accounted for as loss of interstitial pore water during disposal and initial self compaction.

Approximately one year had passed between the time the surveys of the Mud Dump were performed and when the vibracores were taken. During this time all measurable self compaction took place (Bokuniewicz et al.,1980). Based on laboratory consolidation tests of New York Harbor muds, it is expected that the compaction will range from 6% to 9% of the total volume with an average compaction of 7% (H. Bokuniewicz, personal communication). In order to determine the total dry mass of the dredged material after it had been deposited on the bottom, we must reduce the volume of each one foot section by 7%.

Employing formula (4) of the mass balance equation will enable the determination of the total dry mass "lost" during disposal. The sum of the barged dry mass is 350,116 short tons and the total dry mass deposited at the Mud Dump is 337,787 short tons. The average organic content of the dredged material in the barges was previously determined to be 8.7% + 0.7%. The average organic content at the Mud Dump is 8.2 %+ 2.17% based upon 34 samples from all the cores. Inserting these values into equation (4) gives a total loss during disposal of 12,918 short tons. This is 3.7% of the total amount transported there by barge and 5.6% of the in place material. Table V is a summary of all the volume and mass comparisons. Fig. 18 is a schematic diagram further illustrating the sediment mass budget.

TABLE V - Summary of Volume and Mass Determinations

Project	In Place Measurements	Barge Measurements	Mud Dump Measurements
Total Volume (cubic yards)	683,554	861,292	510,565
Percent Difference		20.6	40.7
Percent Difference (In Place vs. Mud Dump)			25.3
Total Mass (short tons)	359,764	350,116	337,787
Percent Difference		*2.0	*3.7
Percent Difference (In Place vs. Mud Dump)			*5.6

*takes into account organic content, see text for explanation.

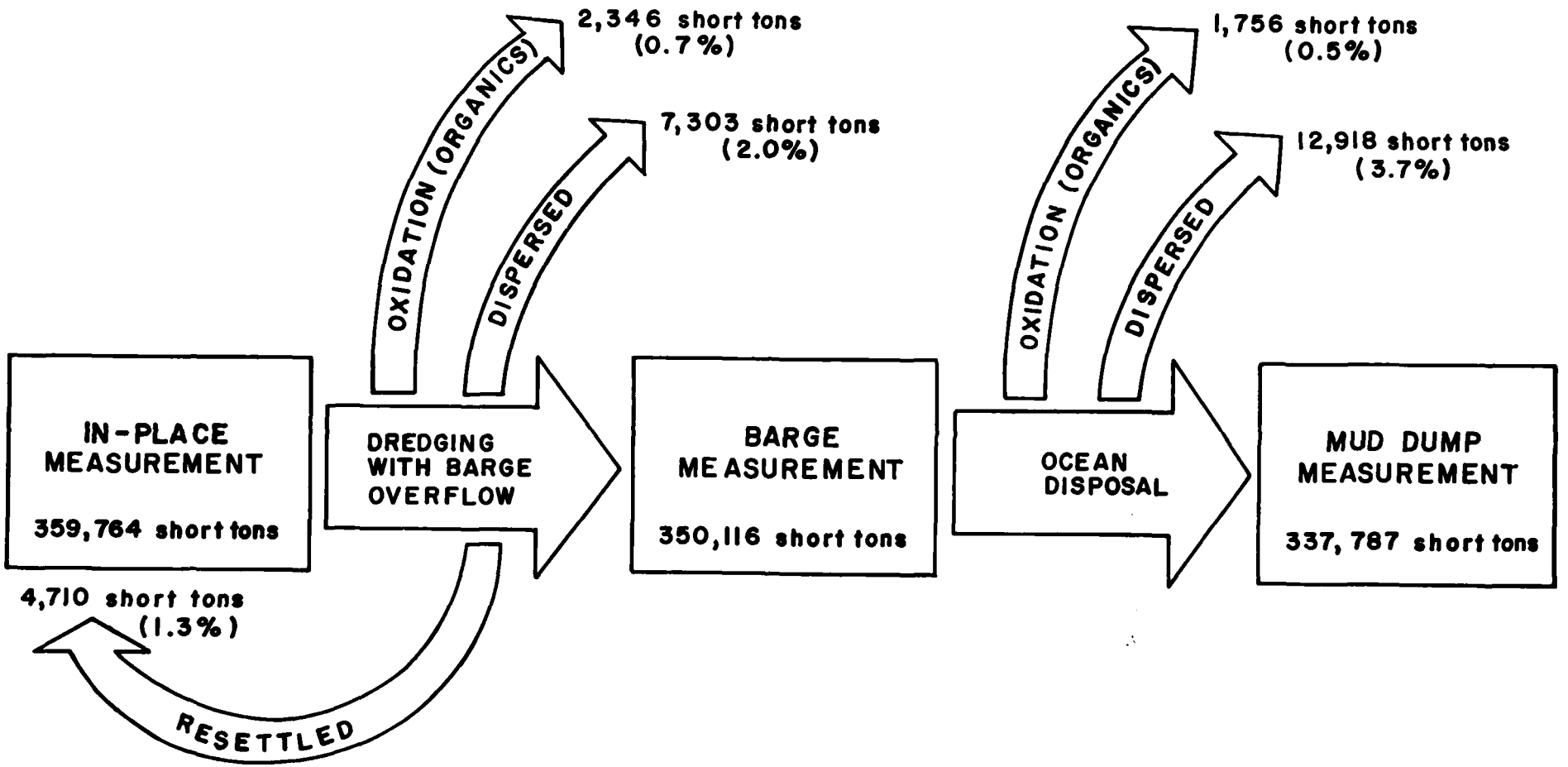


Fig. 18 – Schematic diagram illustrating the mass budget. It should be remembered that oxidation of organic material is also taken into account in the calculations. (see text for details).

It has been determined that the total dry mass of dredged material lost from the dredging sites (Lt) was 7303 short tons. The question arises: how much of this loss was due to the dredged material overflowed during "economic loading" and how much of it was due to the resuspension of sediment during dredging? In order to answer this question, three estimates had to be made:

a) the total quantity of dredged material that is overflowed.

b) the total quantity of the overflowed dredged material which descends down to the bottom possibly to be dredged again (and, conversely, the total quantity of material which remains in suspension long enough to possibly be dispersed).

c) the total quantity of sediment which is resuspended into the water by the dredging alone.

All these estimates were made in terms of dry mass.

To estimate the quantity of dredged material which is overflowed during "economic loading", six barge loads were observed. Four split-hull barge loads of 4,000 cubic yard capacity were observed, three at the Port Authority Passenger Ship Terminal and one at the U.S. Gypsum site. One pocket-barge of 1800 cubic yard capacity and one pocket-barge of 2200 cubic yard capacity was observed, both at the U.S. Gypsum site. Both these dredging operations are fairly typical of maintenance dredging activities.

These observations encompass the range of variation in barge type and volume that were involved in the dredging of all the projects in this study. The largest type of barge used was a 4,000 cubic yard split hull barge. A split-hull barge disposes of dredged material by splitting its hull open approximately 28 degrees along its long axis. The smaller volume barges (2200 and 1800 cubic yard capacity) were pocket-barges. These barges have six or seven open-topped compartments in them. During disposal, "trap doors" beneath each compartment open up to allow the dredged material to leave the barge.

Each barge was observed and sampled in the manner described earlier in this report and the results can be seen in Table II. For the 4,000 cubic yard barges, it is apparent that there is a great amount of variability in the volume, average dry density and dry mass of dredged material which overflows, and the amount of time for the overflow to occur. There also seems to be no direct relationship between these variables. Some of the factors controlling these variables are the intensity of dredging, the amount of water that enters the barge from the clamshell, the length of time that overflow is allowed, and the amount of care that is taken in placing the dredged material into the barge. Since these measurements cover a wide spectrum of possibilities, I believe that an average value derived from these observations will be fairly representative of an average "economic loading" of a 4000 cubic yard split-hull barge.

Observations were made on only one 2200 cubic yard and one 1800 cubic yard barge. The range of variability seen for the 4000 cubic yard barges was not observed for these barge sizes. However, since these two barge sizes constituted a total of only 13% of all the barge loads observed in this study, the amount of error involved in using these dry density values should not be highly significant.

Based on the overflow observations it is determined that an average of 2.0% of the dry mass per 4,000 cubic yard barge will overflow, 2.5% of the dry mass per 2200 cubic yard barge will overflow, and 1.8% of the dry mass per 1800 cubic yard barge will overflow. Using these percentages, the average mass per barge size, and the number of barges of a given size, the total amount of overflowed dredged material (Lo) was determined to be 7561 short tons.

In order to determine what part of the dredged material that overflows is dispersed from the site and what part descends back to the bottom, we must first separate out the amount of suspended sediment which is due to the dredging itself. This opportunity arose during the dredging of Mamaroneck Harbor when no barge overflow was allowed.

On March 25, 1982 during a flooding tide, suspended sediment samples were taken to determine ambient conditions. Fig. 16 shows the sample locations and Fig. 19 shows a longitudinal cross section. The average suspended sediment concentration was 33.0 mg/l ± 7.7 mg/l. Multiplying this by the volume of the basin (7,112,000 cubic feet) gives a suspended sediment load in the basin of 7.3 short tons.

During dredging, suspended sediment samples were taken on two occasions during the filling of one barge load. This occurred during flooding tide on 7 April 1982 which was also the first day that dredging occurred in Mamaroneck Harbor. The first sample run occurred when dredging was at a constant rate of intensity, the second during a lull in the dredging of about 7 to 10 minutes. Together these sample runs gave a wider spectrum of suspended sediment conditions during dredging than one sample run would. Fig. 17 shows the sample locations and Fig. 20 shows a longitudinal cross section of each sample run.

Fig. 20 shows that, for both sample runs, the highest suspended sediment values are located in the lower half of the water column near the point of disturbance and ambient conditions are established within 300 to 400 feet from the point of disturbance. The major difference between the two profiles is that suspended sediment concentrations are as high as 790 mg/l when dredging is at a constant intensity while suspended sediment concentrations are only as high as 63mg/l when dredging intensity slackens. This indicates that significantly raised levels of turbidity do not persist long after the disturbance ceases, perhaps for only a few hours at most. Based on these two sample runs, the average suspended sediment concentration in the basin during dredging was 73.4mg/l ± 126.3 mg/l. The suspended sediment load in the basin during dredging was 16.3 short tons. If we subtract the previously determined ambient suspended sediment load (7.3 short tons), then 9.0 short tons of sediment are in suspension in the basin due to dredging alone during the filling of one barge. The average increase in suspended sediment caused by dredging is therefore 40.5 mg/l.

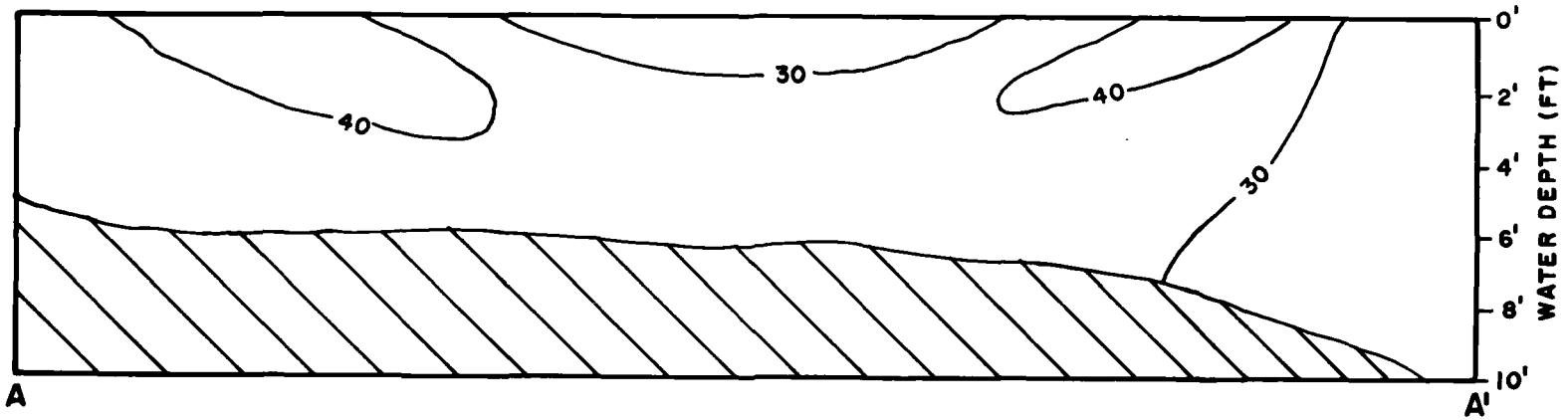


Fig. 19 – Profile of ambient suspended sediment concentrations for Mamaroneck Harbor. Horizontal scale is 1" = 300'. Contours are in mg/l.

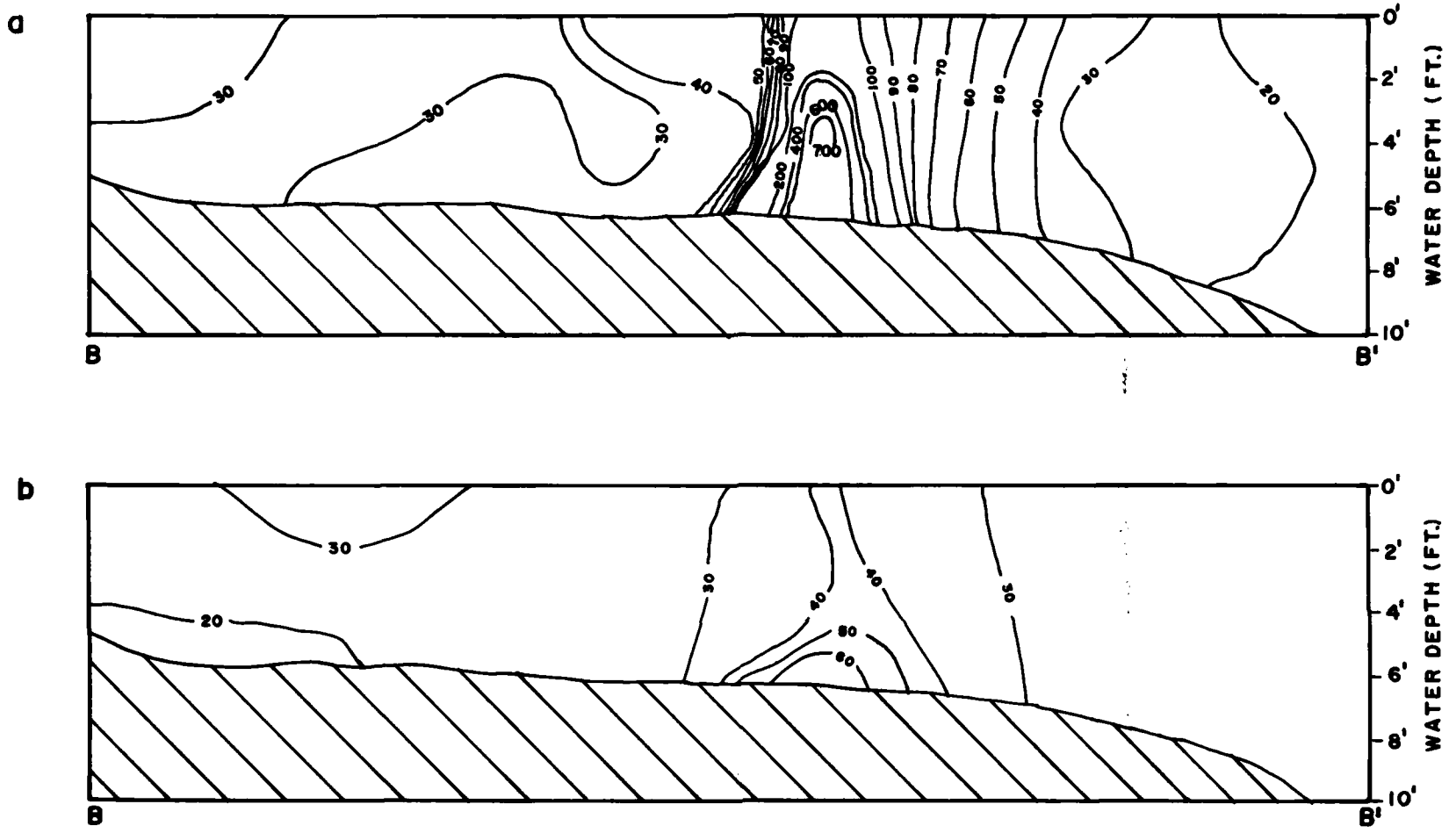


Fig. 20 - Profiles of suspended sediment concentrations during dredging without barge overflow in Mamaroneck Harbor ; a) first sample run, b) second sample run. Horizontal scale is 1" = 300'. Contours are in mg/l.

To determine the amount of suspended sediment that is caused by barge overflow, samples were taken in an interpier basin at the Port Authority Passenger Ship Terminal for ambient conditions and conditions during dredging and barge overflow.

Ambient condtions of suspended sediment were sampled during a flooding tide on April 23, 1980. Fig. 15 shows the sample location and Fig. 21 shows a cross sectional profile of the basin. The average suspended sediment concentration was determined to be 19.0 mg/l ± 5.8 mg/l. Multiplying this by the volume of the basin (15 ,364,694 cubic feet) gives an ambient suspended sediment load in the basin of 9.1 short tons.

Sampling was performed during dredging and barge overflow during a flooding tide on April 22, 1980. Sampling was initiated several minutes after barge overflow began. Fig. 14 show the sample locations and Fig. 22 shows two cross sectional profiles. Fig. 22a shows that the highest concentration of suspended sediment occurs in the immediate vicinity of the activity and affects nearly the entire water column at that point. Suspended sediment concentrations drop off significantly within 300 feet but are still three times higher than ambient conditions near the bottom. At the eastern extremity of fig. 22a, profile D-D', we see an isolated "peak" of 100 mg/l. This was probably caused by the passage of an isolated surge of dredged material. Whether this surge was caused by dredging by barge overflow or both combined is not known. The average suspended sediment concentration was determined to be 88.9 mg/l ± 137.9 mg/l. The suspended sediment load in the basin during dredging was therefore 42.7 short tons. Subtracting the ambient condition (9.1 short tons) gives us 33.6 short tons of suspended sediment caused by dredging and barge overflow per barge.

We must now assume that the average increase in suspended sediment caused by dredging alone 40.5 mg/l determined for Mamaroneck Harbor will be the same in an average sized interpier basin such as at the Port Authority Passenger Ship Terminal. This type of basin was typical of the dredging sites which were observed in this study. An average sized interpier basin contains a larger volume of water but is not as long as Mamaroneck Harbor. Ideally, an interpier basin should have been observed during dredging without barge overflow but this was not possible since that is such a rare dredging practice. Since interpier basins have a longer water column for the clamshell to pass through, there is more of an opportunity for sediment to leave the bucket and more time for the suspended sediment to remain in suspension and possibly be lost from the site. Keeping this in mind, I believe that the calculations that follow should give an overestimate of the impact that barge overflow has on suspended sediment concentrations.

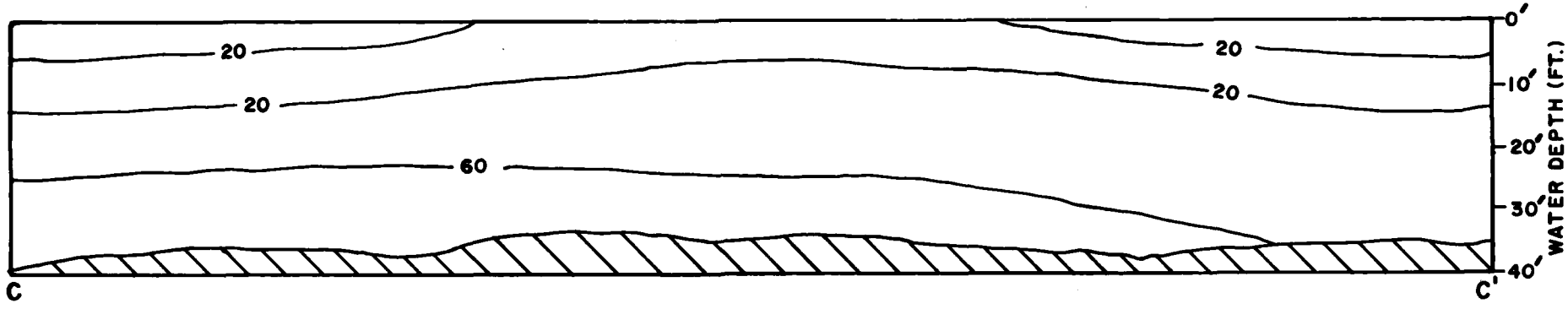


Fig. 21 - Profile of ambient suspended sediment concentrations for Port Authority Passenger Ship Terminal. Horizontal scale is 1" = 50'. Contours are in mg/l.

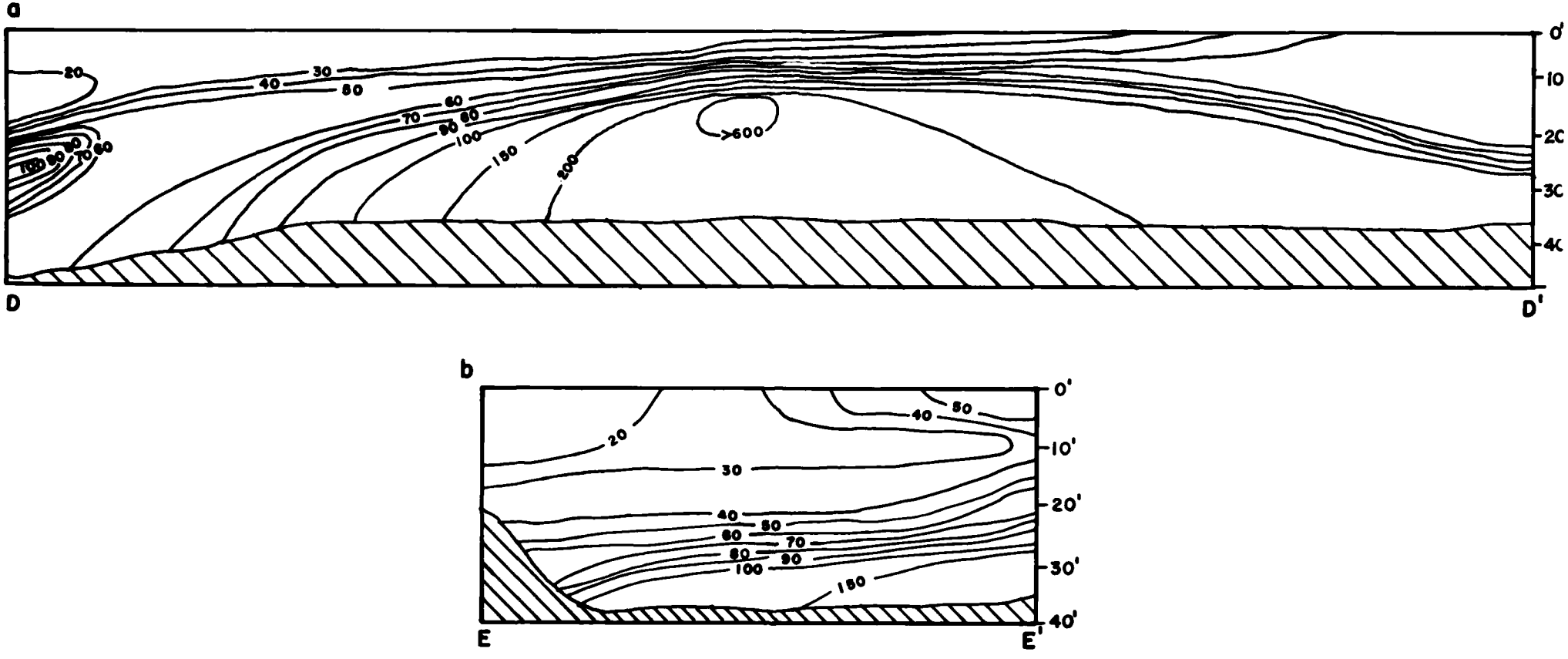


Fig. 22 - Profiles of suspended sediment concentrations during dredging with barge overflow at Port Authority Passenger Ship Terminal; a) east - west cross section, b) north - south cross section. Horizontal scale is 1" = 50'. Contours are in mg/l.

Assuming that 40.5 mg/l are due to dredging alone in a typical interpier area such as the Port Authority Passenger Ship Terminal, then 19.4 short tons of suspended sediment per barge are due to dredging alone. If 33.6 short tons of suspended sediment per barge are due to dredging and barge overflow, then 14.1 short tons of suspended sediment are due to barge overflow alone.

If we assume that these figures apply to all 229 barge loads involved in this project then, in total, 4,452 short tons of sediment are susceptible to dispersion due to dredging itself (Lc) and 3,238 short tons of sediment are susceptible to dispersion due to barge overflow alone. If we subtract the above barge overflow estimate from the total mass of barge overflow previously determined (7,561 short tons), then 4,323 short tons or 57.2% of the total amount of barge overflow descended back to the bottom in a very short time and was not susceptible to dispersion. Conversely 42.8% of the barge overflow is susceptible to dispersion from the dredging site.

We will now determine the total amount of dredged material which was not dispersed from the dredging site, taking into account the total amount of barge overflow (Lo) and the total amount of resuspended sediment caused by dredging alone (Lc). The sum of Lo and Lc is the total amount of dredged material which could possibly be lost from the dredging site. Employing formula (6), it is determined that a total of 4,710 short tons of dredged material that could possibly be lost from the dredging site will not be lost (Sc). This is 39.2% of the sum of Lo and Lc.

Now that we know the total mass of dredged material which is not lost from the dredged site, that is, a combination of barge overflow and dredging induced suspended sediment, we can calculate the contributions that barge overflow and dredging itself made to this quantity. It was previously determined that a total of 4,323 short tons of barge overflow dredged material descended back to the bottom in a short time. If we subtract this from the total amount of dredged material which was not dispersed from the dredging site (St), then only 387 short tons of this total was contributed by dredging itself. It appears as if 91.8% of St originated as barge overflow and 8.2% of St originated as dredging-induced suspended sediment. Subtracting the 387 short tons of dredging induced suspended sediment which descends back to the bottom from the total (Lc) gives us 4,065 short tons of dredging-induced suspended sediment which is dispersed from the dredging site.

To summarize the discussion concerning losses at the dredging site:

4,065 short tons of dredging induced suspended sediment is lost from the dredging site, 3,238 short tons of barge overflow dredged material is lost from the dredging site, and 7,561 short tons in total is lost from the dredging site. Therefore we can say that 55.7% of the total loss of dredged material is caused by dredging itself and 44.3% of the total loss of dredged material is due to barge overflow.

Out of the total amount of dredged material which could possibly be lost from the dredging site (Lo+Lc), 39.2% is not lost from the dredging site and resettles back to the bottom (St). Out of this quantity of resettled dredged material (St), 91.8% appears to have originated from barge overflow of dredged material and 8.2% appears to have originated as dredging-induced suspended sediment. Finally, out of the total amount of dredged material which is allowed to overflow during "economic loading" of the barge (Lo), 57.2% descends back to the bottom in a relatively short time.

VII. CONCLUSIONS

1) A sediment budget study involving dredged material is best performed using a dry mass balance approach. Volume comparisons are unreliable due to the changes in bulk density which occur during dredging and disposal. These changes in bulk density are primarily due to the addition of water during dredging and the loss of water during self compaction of the dredged material after disposal. If the dredged material is disposed on a natural substrate which is susceptible to compaction, volumetric measurements are further affected.

2) Approximately 2.0% of the dry mass measured in-place is unaccounted for in the barges and is assumed to have been "lost" from the dredging site. Approximately 3.7% of the dry mass measured in the barges is unaccounted for at the Mud Dump Site and is assumed to have been "lost" during disposal.

3) Of the dry mass of dredged material which is "lost" from the dredging site, approximately 55.7% is due to dredging itself and 44.3% is due to intentional barge overflow during economic loading. It appears as if dredging itself is the major contributor to the loss of dredged material at the dredging site.

4) The total quantity of dredged material which could possibly be lost from the dredging site is the sum of the barge overflow dredged material and the dredging induced suspended sediment. Approximately 39.2% of this quantity is not lost from the dredging site but instead resettles back to the bottom.

5) Of the dry mass which resettles back to the bottom, approximately 91.8% appears to have originated from barge overflow of dredged material and 8.2% appears to have originated as dredging induced suspended sediment.

6) Of the total quantity of dredged material which is allowed to overflow from the barges, 57.2% settles back to the bottom in a relatively short time.

7) Plumes of suspended sediment during dredging with or without barge overflow appear to be local features. Suspended sediment concentrations are highest near the bottom and plumes of higher than ambient quantities of suspended sediment travel along the bottom for a few hundred feet. These plumes only last as long as the dredging does and a return to ambient conditions occurs within a very short time (a few hours at most). These observations are consistent with the observations of Barnard (1978) and others, however, the distance that the plume was observed to travel in this study is not as far as these other studies have shown, both on the surface and on the bottom.

8. Future research should be directed at further description and quantification of suspended sediment conditions at dredging sites. More work should be done to estimate how such variables as type of equipment used, intensity of dredging, depth of dredging, and shape and hydrodynamics of the basin affect the nature and quantity of sediment which is incorporated into the water column.

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APPENDIX D

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
Atlantic Oceanographic and Meteorological Laboratory

SEDIMENT CAP STABILITY STUDY

NEW YORK DREDGED MATERIAL DUMPSITE

by

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Final Report under Support Agreement No. NYD 80-124(C),
New York District Corps of Engineers

1983

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Introduction

This project was initiated by a proposal dated August 25, 1980, to the Corps of Engineers, New York District, and the NOAA Office of Marine Pollution Assessment. Funds have been provided by both agencies. The project objective is to study the environmental conditions existing at the southeast quadrant of the New York dredged material dumpsite. This site received 510,565 yd^3 of dredged material in 1980, which was considered unsuitable under the ocean dumping pollution criteria. Subsequently, also in 1980, 119,536 yd^3 of fine-grained material and 1,226,737 yd^3 of sand-sized material were dumped at the same site to form an environmentally acceptable sediment cap over the previously dumped material. This study will examine the surface of the cap and related meteorological and oceanographic conditions to attempt to determine the erosive capabilities of bottom currents at the cap site. The results will indicate the relative stability of the cap.

Location

The area examined is in the southeast quadrant of the designated dredged material dumpsite (Figs. 1 and 2). It is about one nautical mile square lying between 40°21.7'N and 40°22.8'N, and 73°39.7'W and 73°51.2'W, approximately 6 n. mi. east of the New Jersey shoreline. Water depths are between 75 and 85 feet (23 to 26 m).

Background

Energy to transport bottom sediment comes from bottom currents. These are in the form of (a) unidirectional currents caused, in this area, by tides and regional continental shelf circulation, and (b) oscillatory currents caused by waves. In order to transport sediment, the bottom current must exceed a threshold which is sensitive to the nature of the sediment: grain

Figure 1. Location of the New York dredged material dumpsite. Bathymetry is in meters from a 1973 COE/NOAA survey. Other dumpsites are for sewage sludge, cellar dirt (construction rubble), and acid waste.

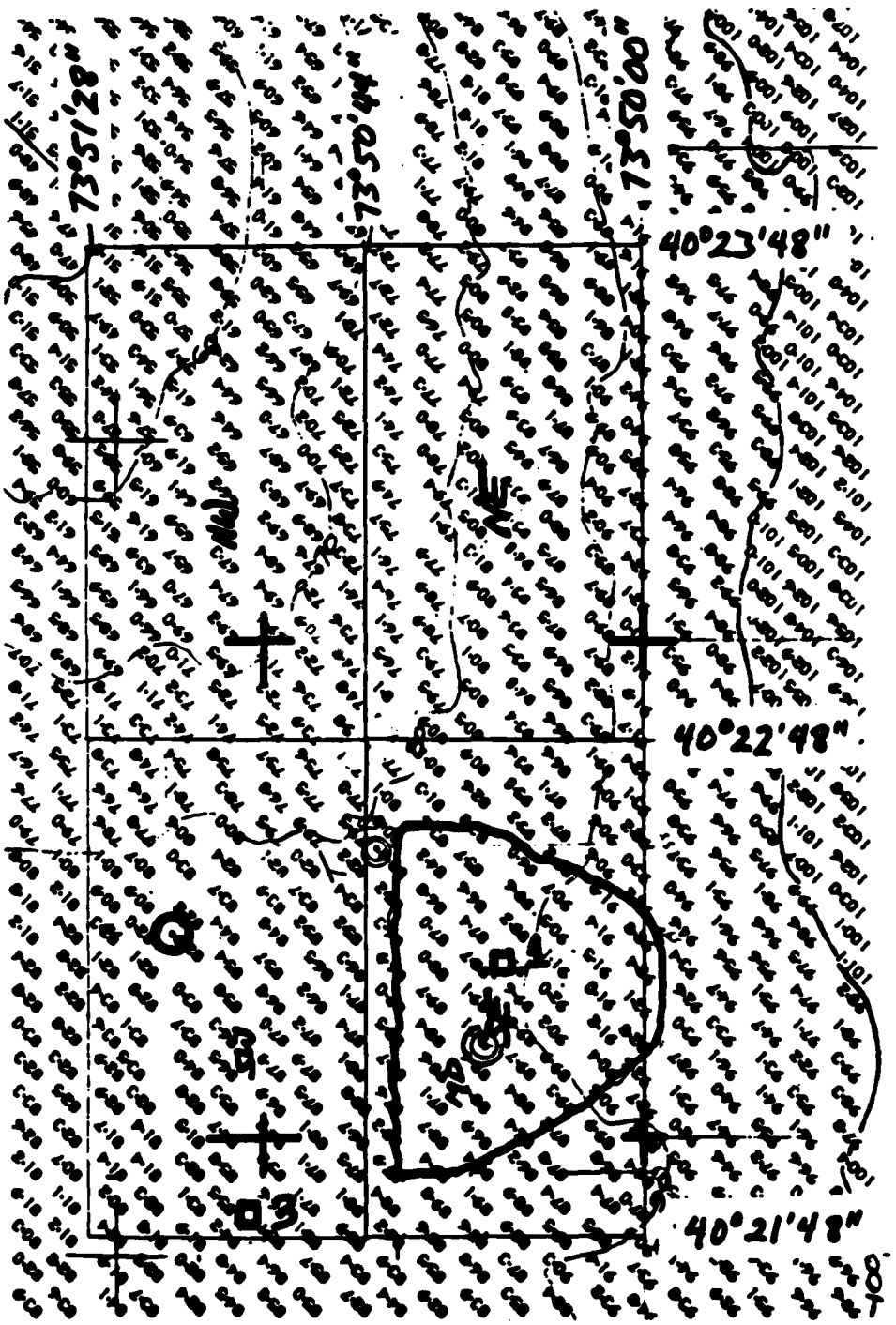

Figure 2. Detail of the dredged material dumpsite. The cap studied is outlined in the southeast quadrant. "MD" is the temporary buoy used to guide dump barges. Depths, in feet and tenths of feet, are from a COE survey completed in October 1978.

size and density, and water and organic content. Normal shelf circulation causes currents usually insufficient to erode bottom sediment, but may transport fine-grained particles once they are in suspension. Tidal currents may be strong enough to erode only the most easily resuspended sediment, fine sand. The strength of wave-generated bottom currents is dependent on water depth and wave height and period; these currents are also too weak to transport sediment during non-storm periods. The result is that bottom transport occurs only when a combination of conditions occur to produce bottom currents exceeding the threshold value for the sediment under study.

There are several site characteristics of the dumpsite which affect the generation of bottom currents. The New York Bight is a broad continental shelf with open fetch from east-northeast to south-southwest. When low-pressure storm cells traverse the eastern U.S. seaboard offshore, their counterclockwise circulation generates east to northeast winds over the Bight resulting in large seas, and a strong unidirection circulation westward along the Long Island shelf and southward along the New Jersey shelf. They occur much less frequently than onshore storms which create westerly winds, but their effect is much more pronounced. There are also seasonal considerations. During summer, the surface water is warmed, creating a two-layer water column with a density interface. This inhibits transfer of surface energy from waves and unidirectional storm-generated current to the bottom. Consequently, winter storms are much more effective as agents of bottom sediment transport. The local bathymetry of the dumpsite area is also important. Water depths to the northeast, east, and southeast drop sharply into the Christiaensen basin and the Hudson Shelf Valley. Therefore, the site is more susceptable to waves and currents from these directions. In addition, the Hudson Shelf Valley, traversing the shelf from the apex to near shelf-edge,

acts as a conduct for cross-shelf water movement during both offshore and onshore storms, the Valley bottom water moving landward during westerly winds, and seaward during easterly winds. Much of the sediment resuspended during storms is transported either towards the harbor mouth or the shelf edge by Valley currents, or settles into the Valley bottom.

The site is close enough to the New York harbor entrance to have tidal currents stronger than on the open shelf, occasionally exceeding threshold values. However, as will be seen in Section D, there does not seem to be a concurrent increase of turbidity when these tidal currents are not coupled with increased wave energy.

Organization

Various environmental factors affecting the site were studied. These are reported as sections herein as follows: (A) The surficial sediments and bottom microtopography of the cap were examined in November 1980 and again in June 1981. (B) Experiments were conducted in both November and June on the cap to determine threshold bottom current velocities necessary to initiate sediment transport. (C) A study was made of long-term meteorological conditions in the Bight apex, how wind-forcing energy is translated into wave energy, and the effect these waves have on the bottom. (D) Estimates were made of the resultant sediment transport from long-term current flow and bottom turbidity measurements. (E) A mathematical study of the combined effects of unidirectional currents and oscillatory waves currents. (F) Summary.

SURFICIAL SEDIMENTS OF A DREDGED MATERIAL CAP IN THE NEW YORK BIGHT APEX

by

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Methods

The initial operations of the study took place on a cruise in November 1980. Bottom grab samples were taken by Shipek sampler on a 1/8 nmi spacing; sidescan sonar recordings (sonographs) of bottom microtopography were taken on east-west tracklines spaced 400 ft apart using a recording range of 250 ft on both sides of the trackline in an attempt to record 100% bottom coverage; and 12 deployments were made with the SEAFLUME, a device emplaced on the bottom which induces a gradually increasing current over the sediment surface to record photographically the threshold of sediment transport (see Section B). In addition, two graduated steel rods were emplaced into the bottom to measure erosion or deposition, and two bottom-mounted concentration-velocity (CV) probes were emplaced to measure currents and suspended-sediment concentration (see Section D). Both rods and probes remained on the bottom until June 1981. The CV probes were serviced in February and April 1981.

The second cruise took place in June 1981 when the sampling, sidescan sonar recordings, and SEAFLUME data collection were repeated. The graduated steel rods could not be found.

Navigation for both cruises was by a Cubic Autotape system supplied by COE with range towers on the New Jersey and Long Island shores. Station locations and tracklines were plotted before each cruise on 1:3000 scale mylar plotting sheets which contained Autotape ranges. These were furnished by the NOAA Atlantic Marine Center, Norfolk, Virginia. Loran C readings were taken of the CV probe sites and used for recovery and replacement operations in February and April.

Sediment Analysis

Sediment samples were stored refrigerated in Whirl-pac plastic bags. An analysis aliquot was freeze-dried, weighed, and seived on a 2 mm screen to

separate gravel, then weighed and washed on a 62.5 um screen to separate fines (mud fraction = silt + clay). The sand fraction was analysed by running a 5 to 7 gm aliquot through an automated rapid sediment analyser (settling tube) which calculated mean grain size for the sand fraction. Data for gravel, sand, and fines percent were mapped for both November 1980 and June 1981 cruises. Sand percentage maps for both cruises were overlain on each other and a map of the differences (net change) between them was drawn. On this map, areas within each contour were measured by planimeter and multiplied by the contour values (in decimal fractions) to calculate a weighted measure of sand change on the sediment surface over the seven months.

Results

Gravel Percentage: Maps for both November and June (Figs. 3 and 4) show mostly less than 5% gravel with the following exceptions: in the northwest corner, a November maximum of 45% was reduced to 1% by June. In the northeast corner, a 64% maximum in November shifted somewhat southeast and increased to 66% in June. In the southeast corner, an 18% maximum in November increased to 35% to 86%. In general, coarser sediment (higher gravel percentage) lie along the eastern edge of the dumpsite where it was about 15% in November and increased only slightly by June. Composition of the gravel fraction is primarily (30-95%) construction rubble consisting of brick, concrete, rock, and slag fragments, with rounded quartz and feldspar fragments and shell particles intermixed. This is the case particularly in the high-gravel areas along the eastern part of the area which border the cellar dirt (construction rubble) dumpsite. To the west, the gravel fraction consists of larger percentages of shell and rounded particles, except the area of over 30% gravel in the northwest corner of the November 1980 cruise which consists of about 60% construction rubble. Although the areas of high gravel content had

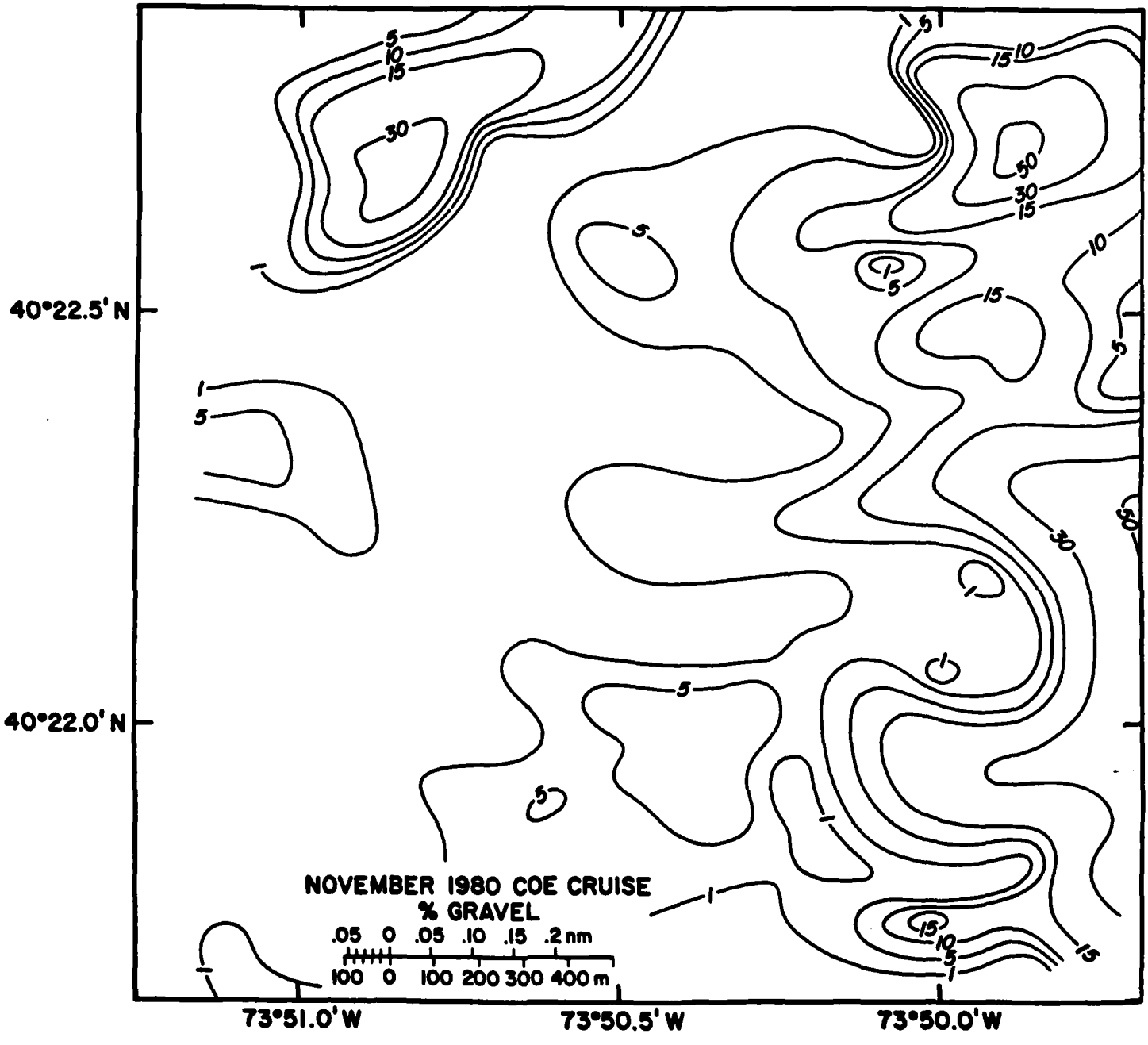

Figure 3. Percent gravel in the surficial sediment, November 1980.

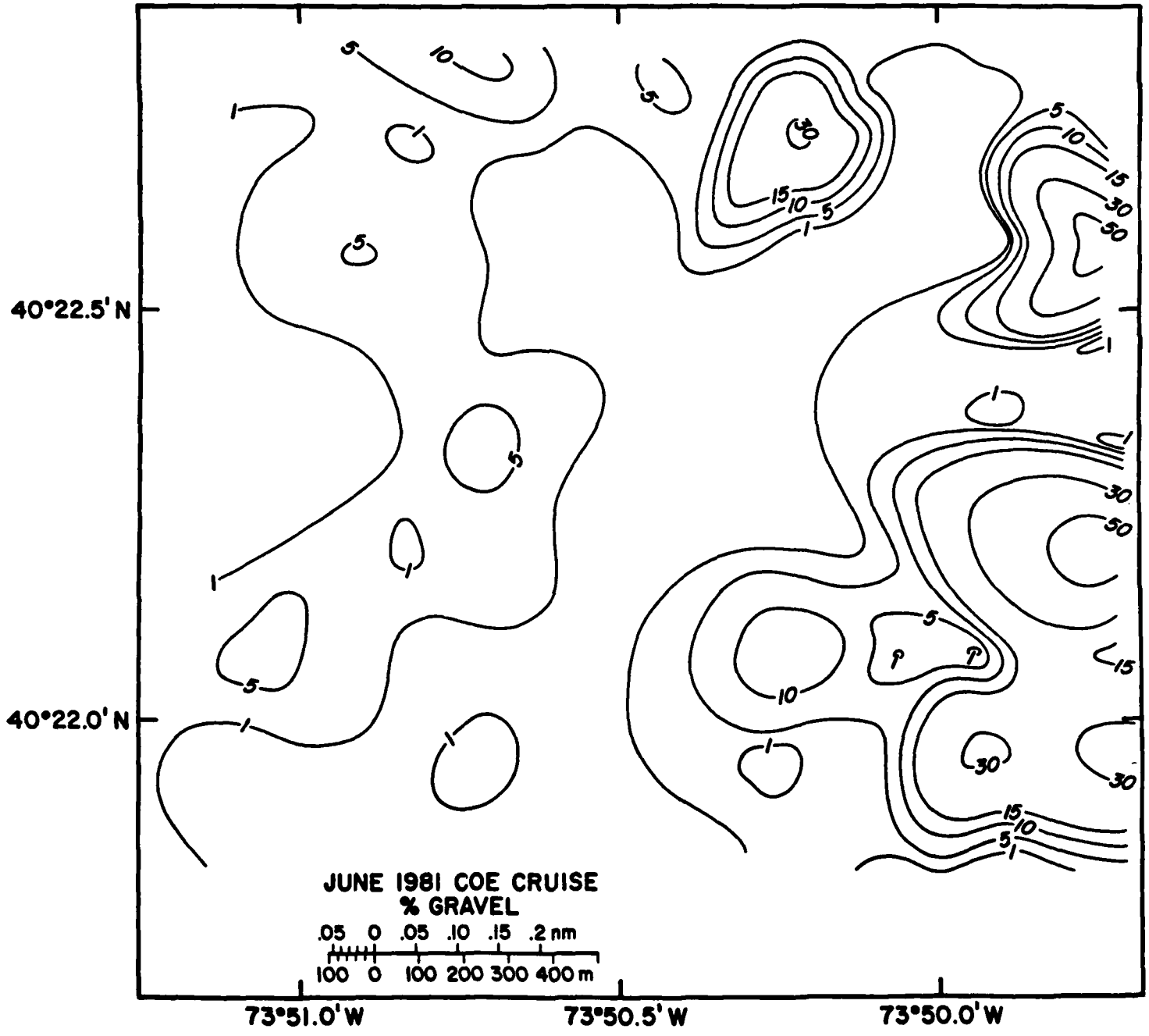

Figure 4. Percent gravel in the surficial sediment, June 1981.

shifted from November to June, the high construction rubble content remains consistently high along the eastern edge of the study site.

Sand Percentage: Both November and June maps (Figs. 5 and 6) show mostly greater than 90% sand (cap material), with areas of less than 50% in the northwest corner, northeast and southeast corners (minimum 32%), and southwest corner (one sample 5%; others 50% - 80%). Along the eastern edge, values varied between 32% and 80%.

Data calculated from the sand percentage net change map (Fig. 7) shows that the northeast quarter of the sampled area lost 6% sand, the southeast quarter gained 2%, and the southwest and northwest quarters each lost 2% and 9% respectively. The total dumpsite lost a weighted average of only 3.1% sand. Most of these changes, however, were around the periphery of the area along the edge of the cap. A large south-central area (the center and highest point of the cap) showed little change. These calculations represent a change in the composition of the surface layer only, and cannot discern whether sand was removed, or was diluted with the addition of fines.

Fines Percentage: The November map (Fig. 8) shows a large central area of less than 5% fines; by June (Fig. 9), this area was somewhat smaller and shifted slightly to the southeast. In the northwest corner, there are several areas on the November map of over 40% fines with one sample of 88%. There, areas had slightly higher fines content in June. Along the northern edge, fines content was about 30% in both November and June. In the northeast corner, fines varied between 5% and 30% in November and increased only slightly in June. In the southeast parts of both maps are areas of between 30% and 60% fines. These values did not change from November to June, but the areas of high and low values shifted. In the southwest corner an area of 30% did not change, but one sample with 99% mud in November was reduced to 67% in June. In general, fines did not change much, but some areas shifted.

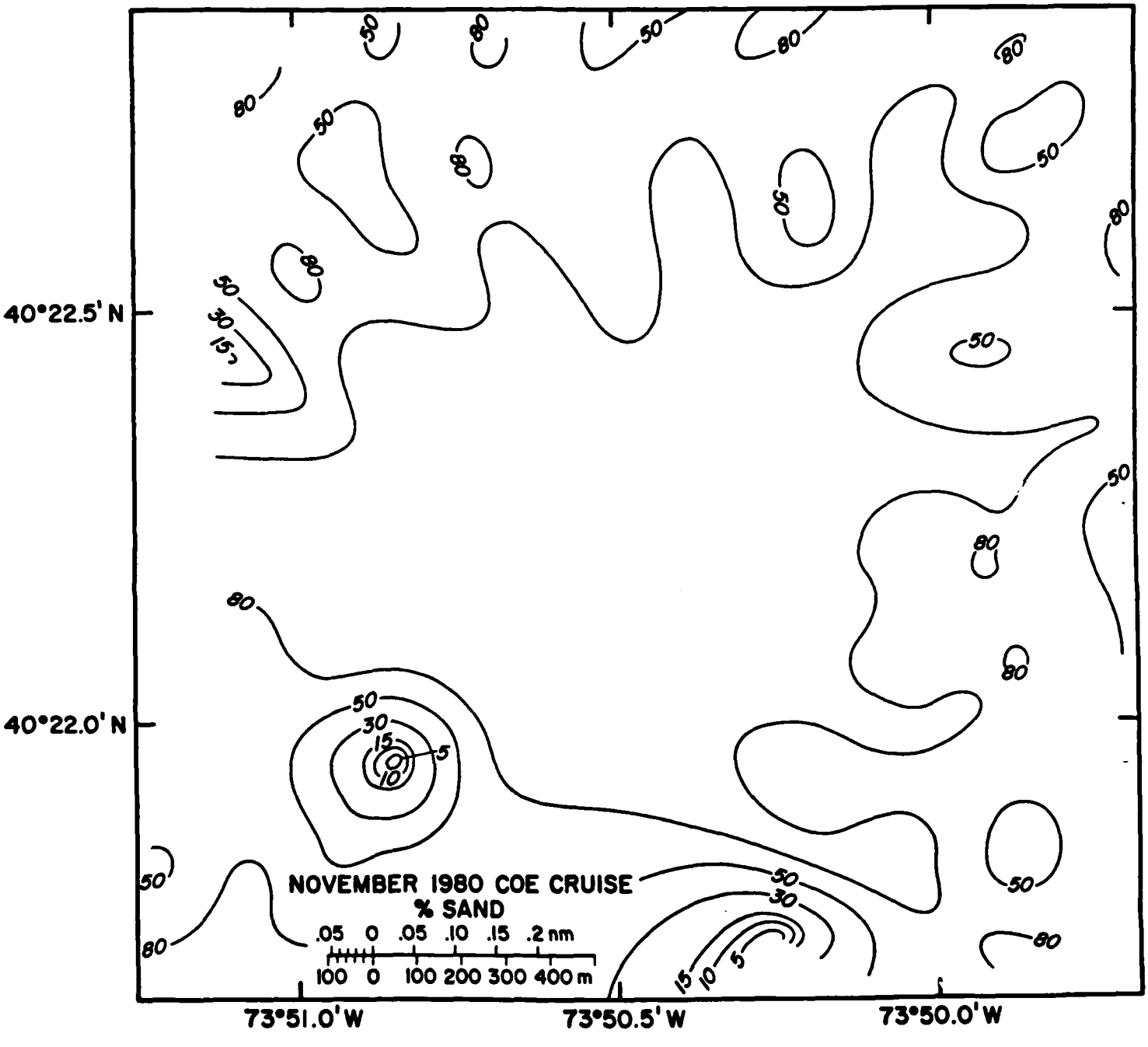

Figure 5. Percent sand in the surficial sediment, November 1980.

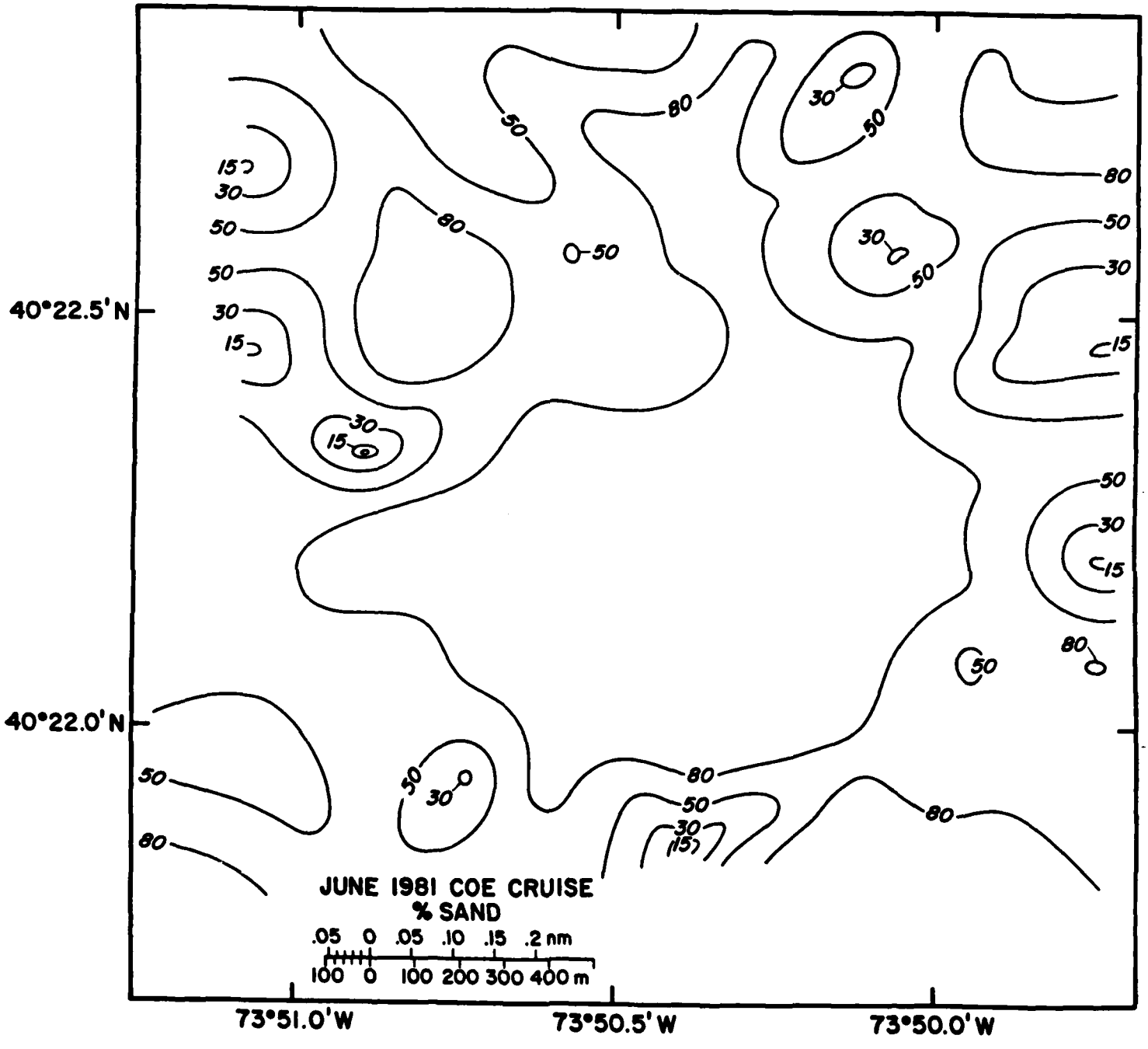

Figure 6. Percent sand in the surficial sediment, June 1981.

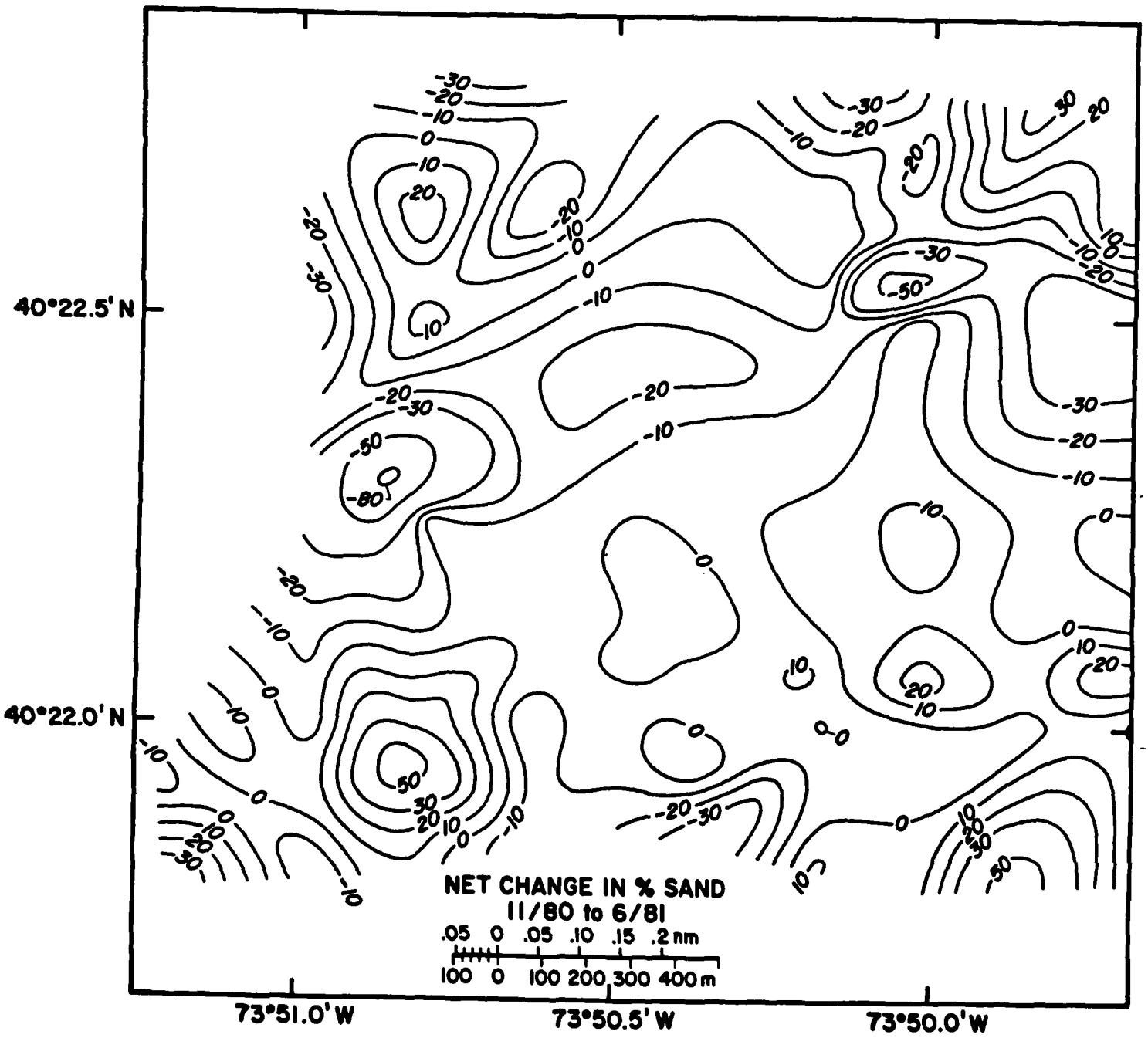

Figure 7. Net change in percent sand, November 1980 to June 1981.

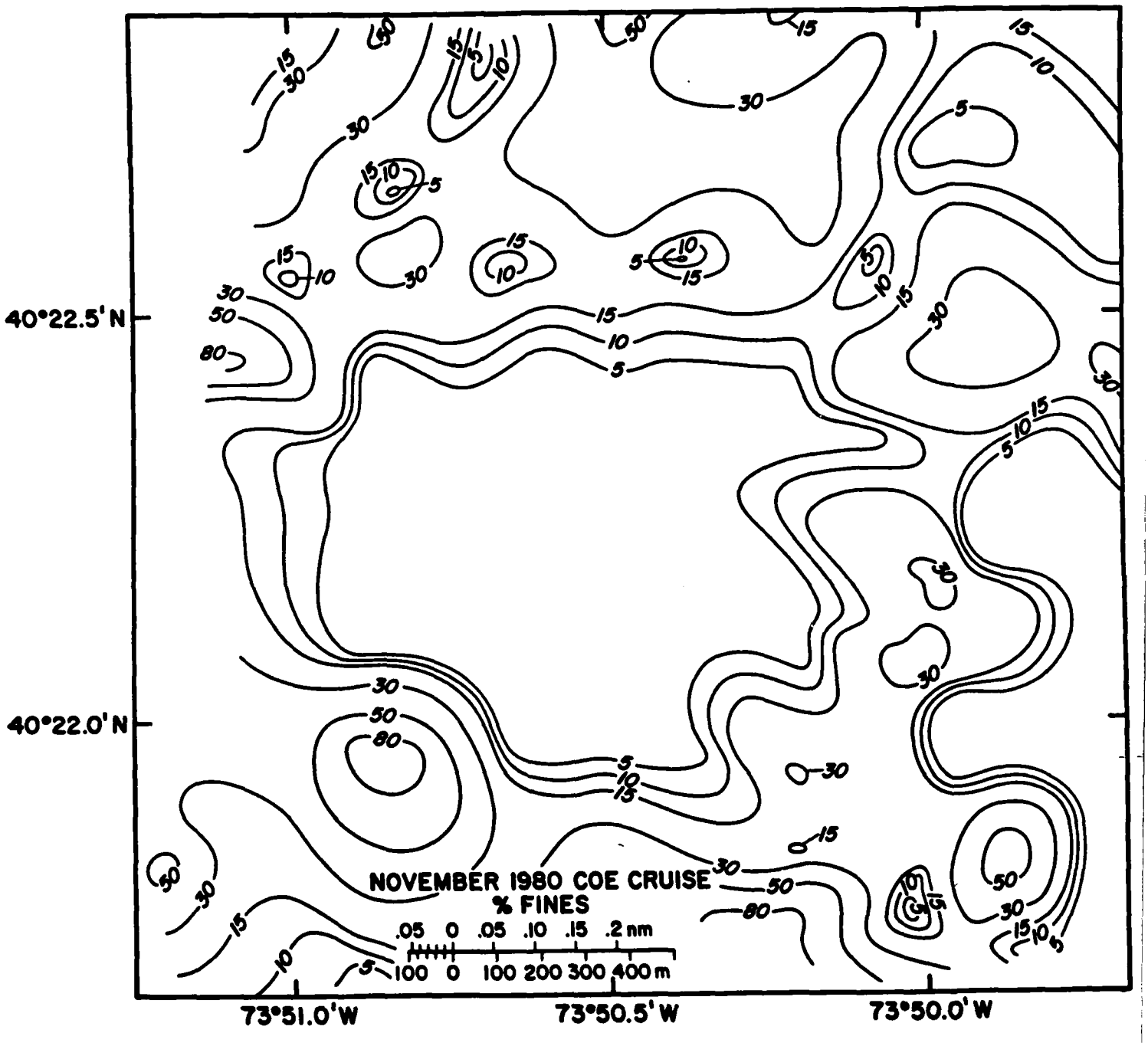

Figure 8. Percent fines (mud) in the surficial sediment, November 1980.

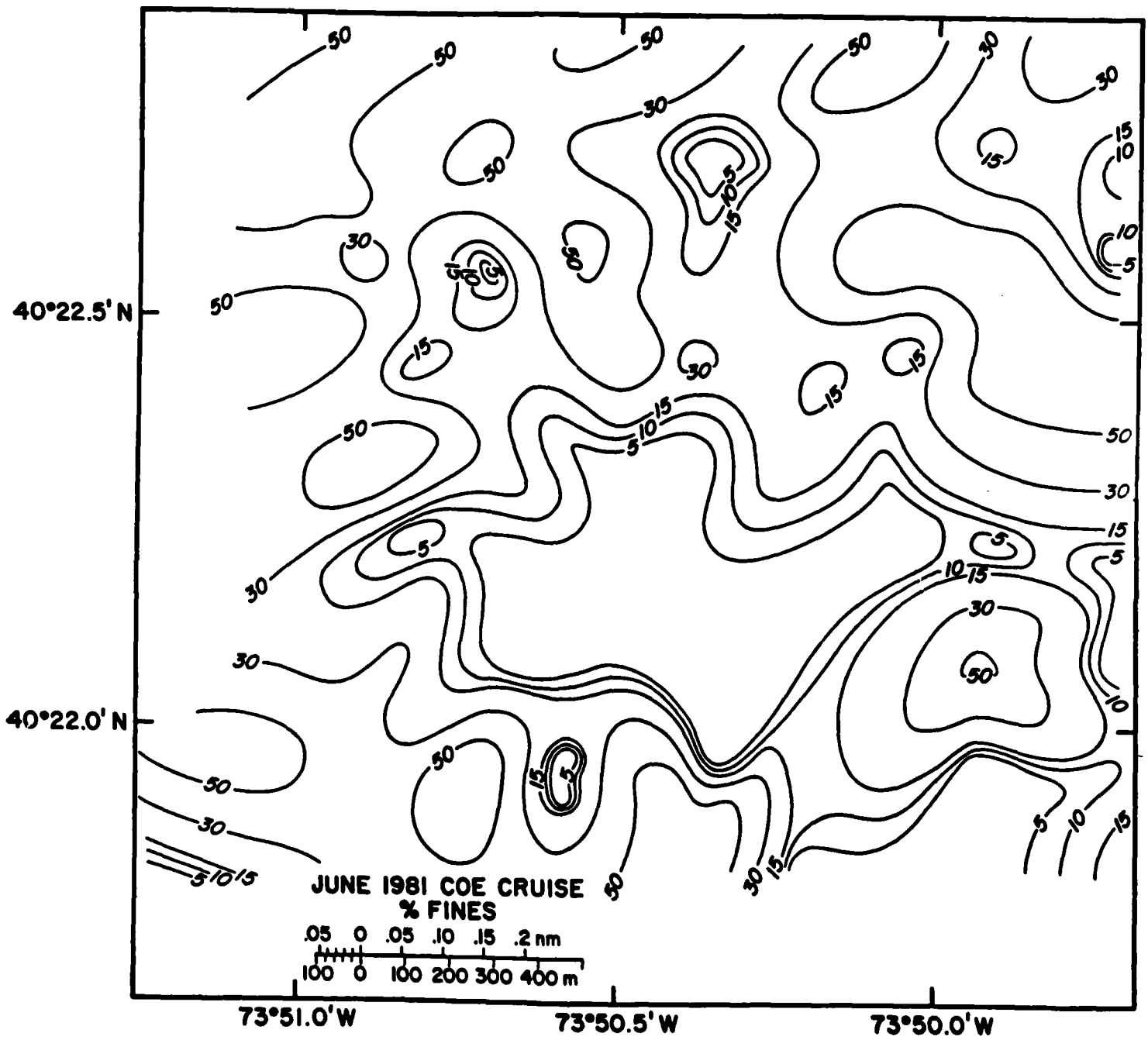

Figure 9. Percent fines (mud) in the surficial sediment, June 1981.

Phi-mean grain size: The mean grain size of the sand-sized fraction is reported in phi units (ϕ = -3.32 log [grain size in mm]) (Figs. 10 and 11). A large central area on both November and June maps is between 2.00 and 2.50 ϕ (fine sand). North of this are samples of 1.25 ϕ (medium sand) to the northwest and northeast, and a sample of 0.00 ϕ (coarse sand) near the north-central edge. Sand in these northern areas became finer by June, varying between 1.75 ϕ (medium sand) and 2.5 ϕ. South of the central area, similar 'fining' occurred: in the southwest one sample with 0.00 ϕ mean in November was 2.57 ϕ in June.

Cap Thickness

The cap proper is defined by the net change (COE 'differences') map drawn by the Corps from the March 1980 and July 1980 surveys (done before and after the cap material was dumped). This area is roughly an isosceles triangle with the base to the west and the apex to the east, covering approximately 6,900,000 ft^2. The cap is mostly 3 to 4 ft thick, with an area 5 to 9 ft thick just west of where the "MD" marker buoy was deployed during the dumping of the cap material. Volumes of material dumped for the cap are reported (by COE) as 119,536 yd^3 of fines [(166,400 + 127,300 bin yardage) x .407 (bin to in-place compaction)], and 1,226,737 yd^3 of sand (1,533,421 bin yardage x .8). This material would average 6 ft thick over the cap area. This discrepancy in thickness between calculated in-place material and survey volumes is likely to be the result of survey errors of up to one foot in each survey.

The COE net change map for the period between July 1980 and March 1982 shows erosion over the two winters of generally less than one foot (maximum of 1.7 ft within the cap area), about the error inherent in the data.

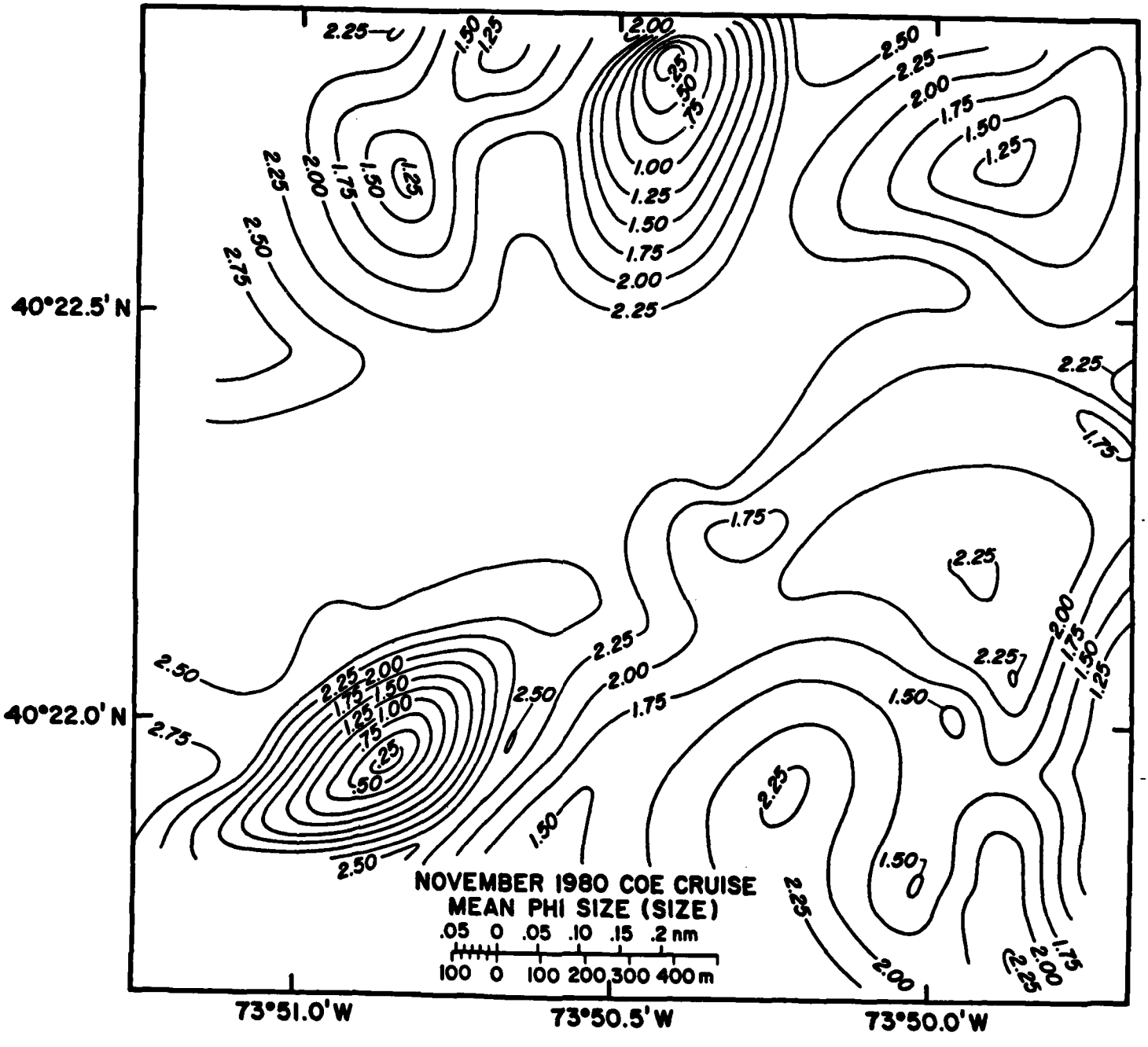

Figure 10. Mean grain size in phi units, sand-sized fraction, November 1980.

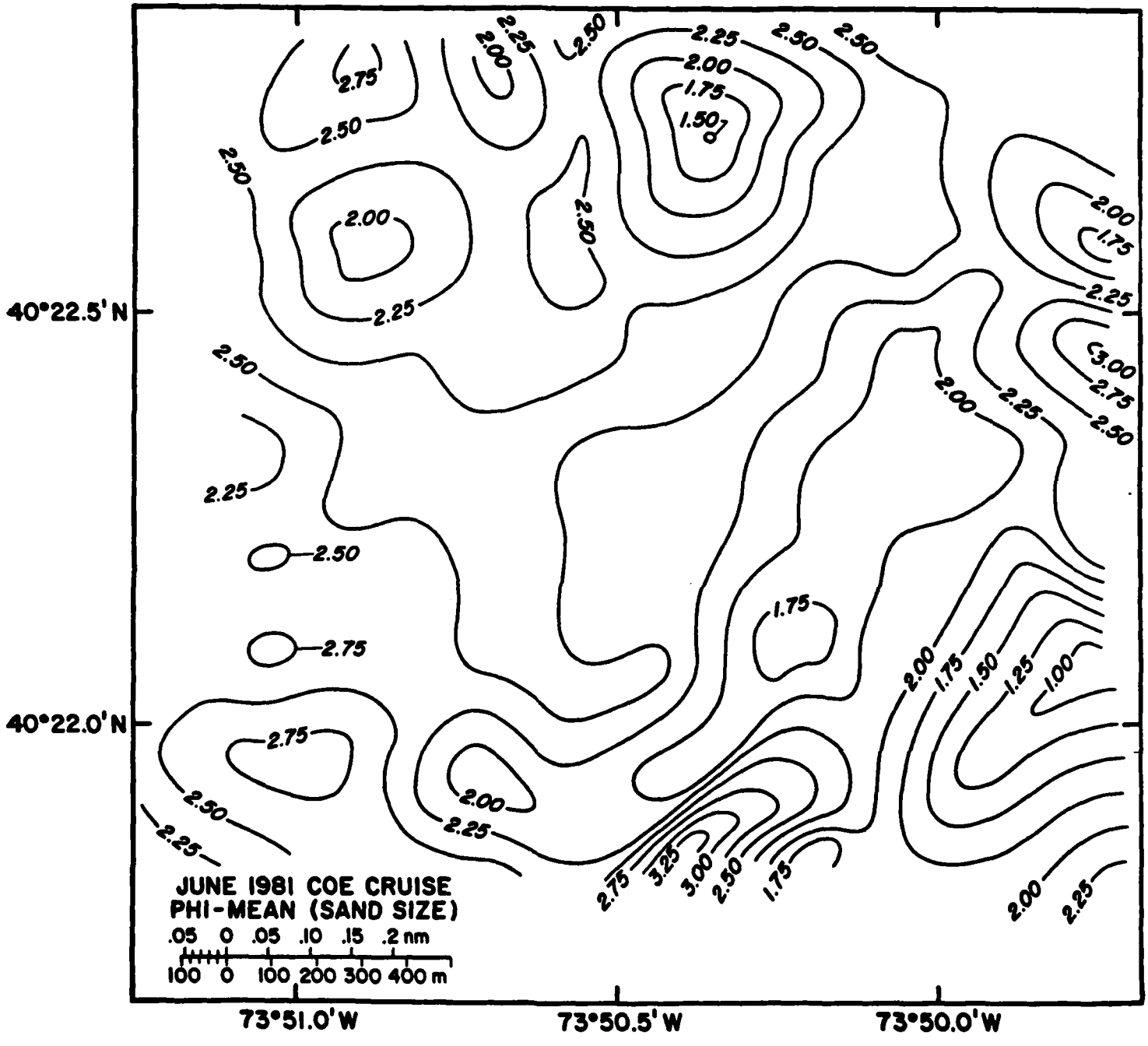

Figure 11. Mean grain size in phi units, sand-sized fraction, June 1981.

Bottom Roughness

A qualitative estimate of bottom roughness was made by examination of sidescan sonar records (sonographs). These were plotted on maps at the same scale as the sediment parameters using nomographs to correct for analog record distortion according to ships' speed (Figs. 12 and 13). The map made for the November 1980 data shows the cap area relatively smooth with occasional dump craters and lineations aligned just west of north. Along the northern edge there is considerably more bottom roughness and lineations with the same orientation. In the eastern third of the area there is irregular roughness probably due to the muddy bottom east of the cap. In the southeast corner several areas of roughness also have ripple marks which indicate relatively high percentages of sand. A total of 29 lineations were measured for azimuth: the mean is 166° (346°) with a standard deviation of 22.5°.

The June 1981 map, compared with the November map, shows the central cap area still relatively smooth. Sonograph images of dump craters and lineations have been modified so that they are smaller but are more numerous. The northern area so disturbed in November is smoother. Areas of intense roughness were smoothed to moderate roughness, but the area of moderate roughness was extended southward (from 1600 ft from the northern edge to 2500 ft). The eastern area of roughness is smaller and has more areas of relative smoothness. The number of measureable lineations was reduced from 29 in November to 10 in June: the latter had a mean direction of 178° (358°) with a standard deviation of 32°.

Conclusion

The sediment sampling data indicates that there was a general decrease in grain size over the winter from November 1980 to June 1981, but most of the

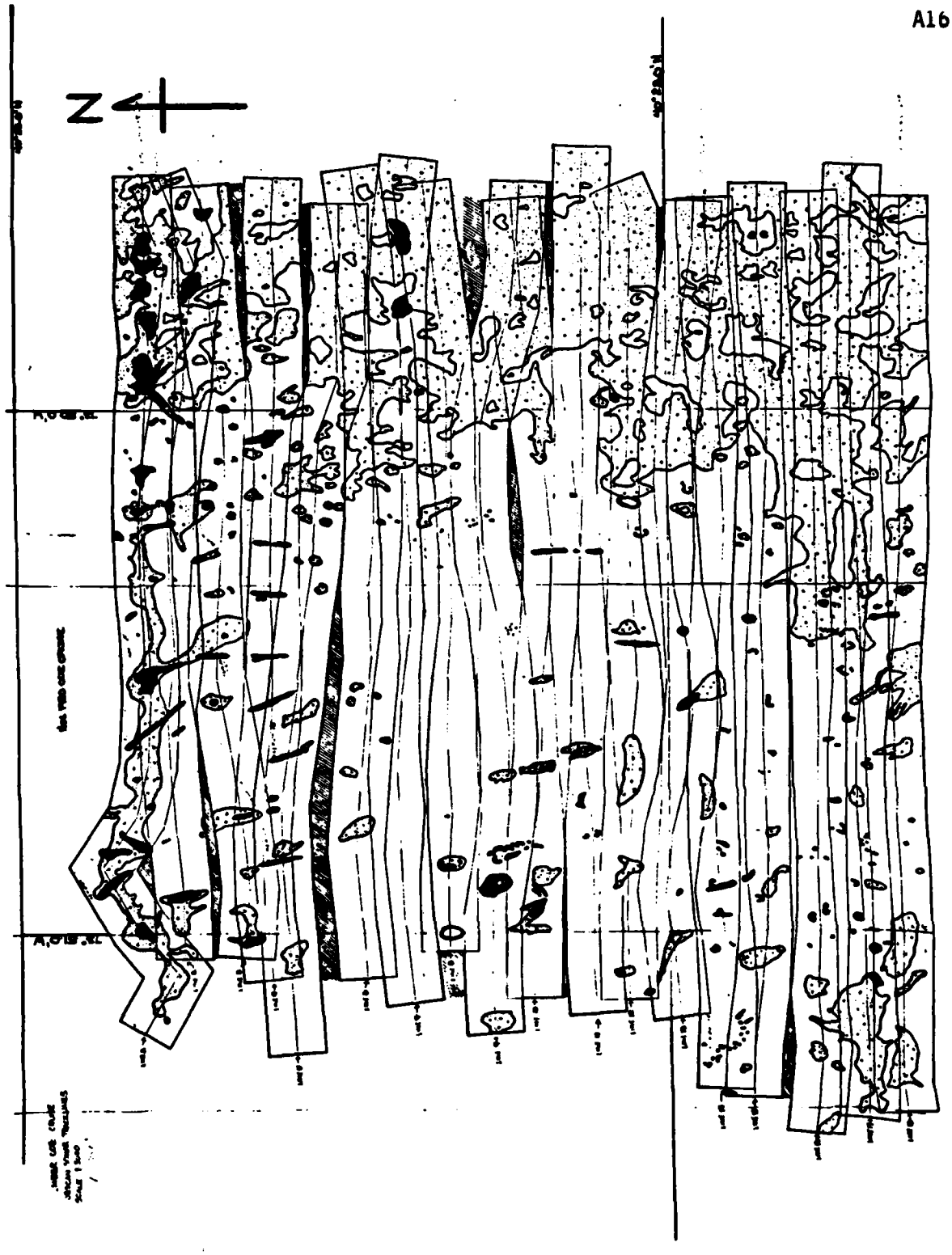

Figure 12. Map of bottom roughness drawn from sidescan sonar analog records, November 1980. Black areas are very rough; dotted areas are moderately rough; clear areas are smooth. Diagonal lines are areas of no bottom coverage.

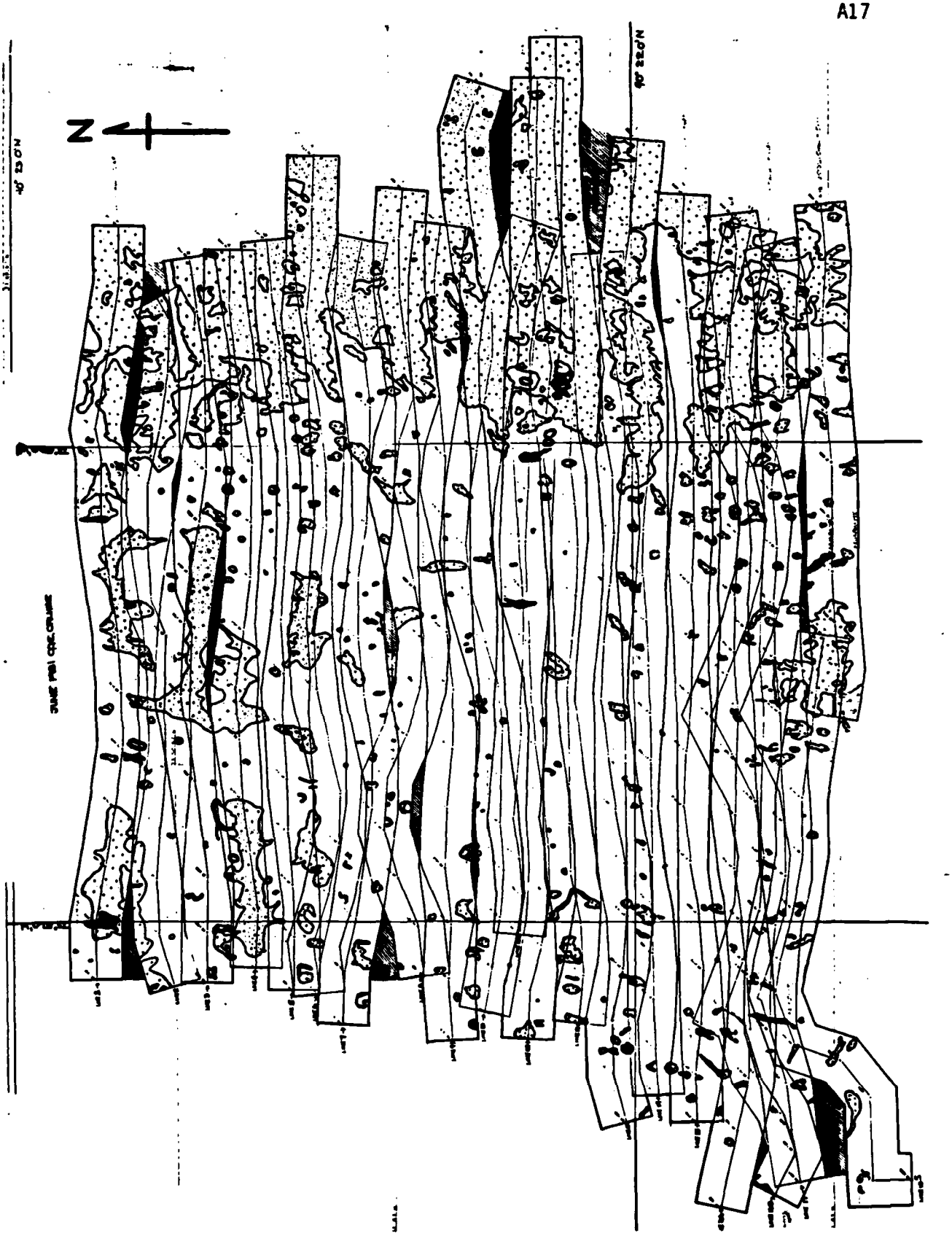

Figure 13. Map of bottom roughness, June 1981. Symbols are the same as in Fig. 12.

changes occurred around the periphery of the cap. The cap itself appears to have undergone little change in grain-size characteristics, with a slight decrease in grain size. Bottom roughness maps drawn from sonograph data support this by showing a smoother bottom in June, indicative of sediment transport which would fill in small-scale depressions. Both the leveling out of bottom roughness and decrease in grain size results in smoother sonographs. It is likely that some of the sand cap was removed, fine sand being the easiest grain size to erode, but silt- and clay-sized sediment eroded from around the cap and muddy bottoms elsewhere was deposited on the cap sand. Thus, there was intermixing of grain sizes resulting in poorer sorting and a reduction of mean size. We would recommend that if additional cap material is desired, the coarsest clean sand available should be used, with an attempt to keep grain size larger than 0.25 mm.

The changes over the seven month winter period reported herein must be viewed as tentative indications of long term phenominon. Most of the changes are within the scope of errors inherent in the data. Longer term analysis will be necessary to reach firm conclusions as to the life of the cap based on this data set.

THRESHOLD EROSION VELOCITIES OF POORLY SORTED SEDIMENTS, DREDGE MATERIAL DUMPSITE, NEW YORK BIGHT APEX

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ABSTRACT

Field studies have been carried out during two cruises to determine the threshold flow conditions for erosion of sediments emplaced over a fine-grained dredge material deposit. The deposits are located in the apex of the New York Bight. A sea-going flume (SEAFLUME) was used to create the erosional currents under experimental control. Sediments ranged in texture from muddy sands to sandy muds. The in-situ measurements indicate that SEAFLUME measurements yield the best possible field measurements of erosion conditions when suitably treated. The data agree reasonably well with the Shields and Yalin threshold curves usually used to predict threshold flow conditions. Some scatter is observed, but is attributed to poor sorting of the sediments and thus to grain size or roughness features of the sediment beds which are not accounted for by existing flow models.

Threshold shear velocity (U_*) values range between 0.6 to 1.4 cm/sec. The estimated erosional velocities at one meter above bottom (U_{100}) corresponding to the U_* values ranged from 14 to 31 cm/sec. Values of U_* and U_{100} averaged for each cruise are 1.04 and 23 cm/sec, respectively, for the November cruise, and 1.00 and 21 cm/sec, respectively, for the June cruise. These values are thought to be reasonable estimates of threshold U_* and U_{100} to be used in calculations of rates of transport and erosion.

1. INTRODUCTION

A field measurement program has been undertaken to determine the threshold erosion velocity for surficial sediments which are the cap material dumped as part of the COE capping project at the New York dredged material dumpsite.

Only the erosion experiments which were part of a more comprehensive field program are reported in this section.

1.1 Definitions and Objectives

The threshold for erosion may be defined by that value of bed shear stress or near-bed velocity just sufficient to cause particles on the bed surface to move. Suspension is not necessary after initial movement; neither is continuous movement.

Objective definitions or measurements of threshold conditions on even the simplest flat, smooth bed of well-sorted spherical sand grains are rare and not universally agreed upon. When one is possible it is only under laboratory conditions (see Yalin, 1972, for a detailed discussion). Seafloor sediments are rarely smooth, level or mono-sized. Therefore, other, perhaps subjective definitions of threshold conditions creep in where more objective ones fear to

tread. This is certainly the case in the present study where close-up photography of the eroding bed, capable of resolving features of .05 cm or larger, was the only measurement of bed conditions during erosion. Since the diameter of the bed sediments was around .01 cm, it is apparent that individual grain movement is not resolved and threshold conditions are defined on the basis of changes in bed microtopography. This may lead to overestimation of the threshold shear stresses, but hopefully not by a significant amount. Field methods used in this study were designed to minimize disturbance of natural bed conditions before erosion. Therefore, we assume that natural currents will erode the seafloor in about the same way and at about the same bed shear stress as we have observed here under experimental control.

Our objective is to measure the critical shear stress necessary to initiate erosion of the sand capping material. To do this requires measurements and observations of both fluid and sediment properties. We compare these measurements to the existing body of laboratory data on the erosional threshold of similar sediments. Finally, we will assess the factors which influenced field measurements of threshold shear stress and determine how they differ from laboratory conditions.

2. METHODS

2.1 Field

The primary tool used in this study was the SEAFLUME II, a device for in-situ studies of threshold erosion velocities and the resulting erosional behavior of undisturbed marine sediment. This instrument is a modified version of the original model described by Young (1977) and Young and Southard (1978) and is shown in Figure 1. The SEAFLUME photographically records bottom

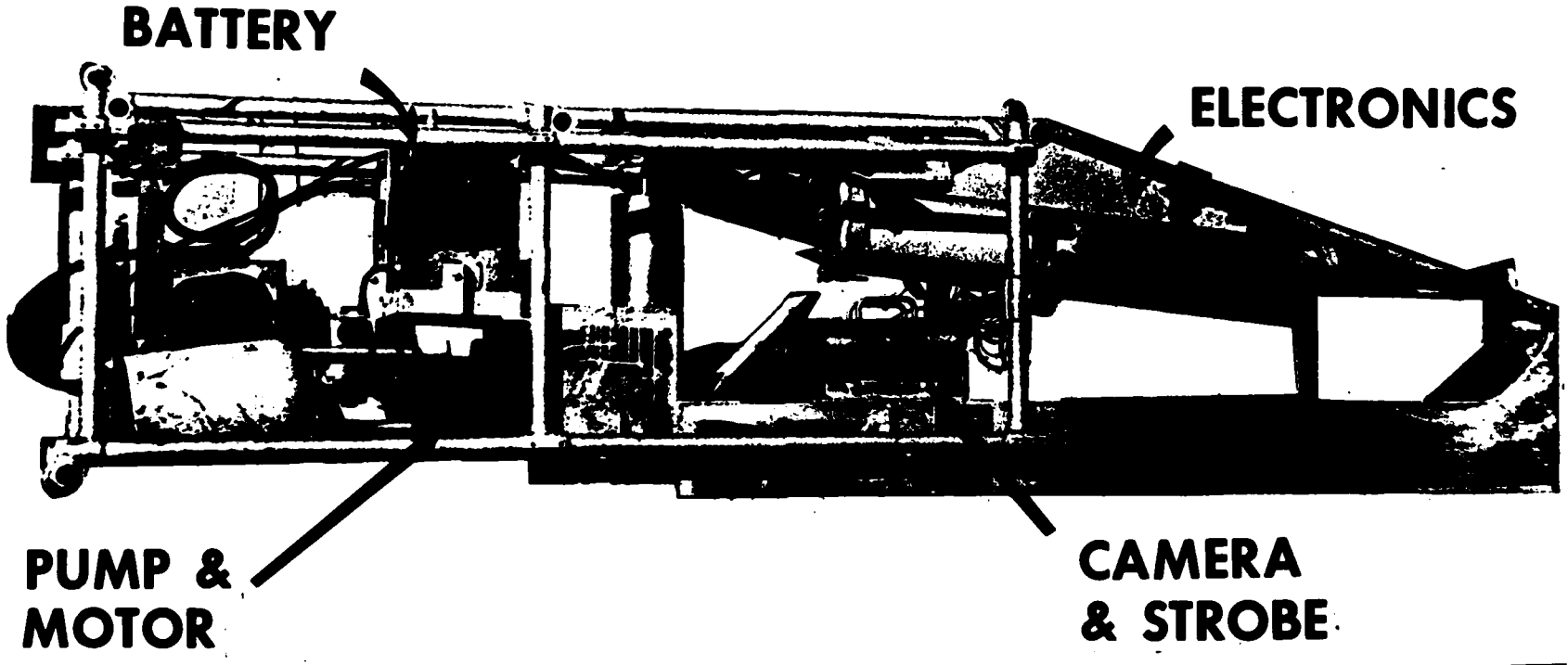

Figure 1: SEAFLUME used in this study. This version is similar to one described by Young (1977) and nearly identical to the one described in Young and Mann (1982).

sediment response to a systematic increase in flow velocity. The 35 mm camera is enclosed in a hood and the optical path includes a 45° mirror (Figure 1). Low angle side-lighting is provided by a synchronized strobe. Photos are taken at the rate of one approximately every three minutes, and about 17 photos were obtained per 45-55 minute flume run. Flow is produced by water being drawn through the three sided, aluminum-walled channel via a submersible pump and motor assembly mounted at the down-stream end. The working part of the flume channel measures about 2.3 m in length, .47 m across and .15 m in height. The bottom of the channel is formed by the seafloor. SEAFLUME is self-contained and can be operated automatically by means of a bottom contact switch. During this study divers accompanied the flume to the bottom to insure that the sediment formed a proper seal around the edges of the channel.

SEAFLUME sites were selected at current-meter deployment sites and other sites on the sandcap and dredge material dump areas shown in Figure 2. Three sites (SF8, SF9, and SF10) were chosen at other locations on the dumpsite just outside of the sandcap for comparison. Sampling took place during two separate cruises from 14 November to 20 November 1980, and 26 June to 30 June 1981, on the NOAA ship GEORGE B. KELEZ. Sea and weather conditions were good during both cruises.

Flow velocity in the channel of SEAFLUME was measured by several different sensors. A propellor flow meter mounted along the flow axis (General Oceanics, Model 2031) measured the mean flow through the channel core at the measurement section about 1.8 m from the entrance. A frequency-to-voltage converter changes the switch closure frequency, induced by propellor rotation, to a voltage which is recorded on a strip chart. An event marker on the strip chart recorded the times when photos were taken. The flow-meter signal is converted to flow velocity by the equation:

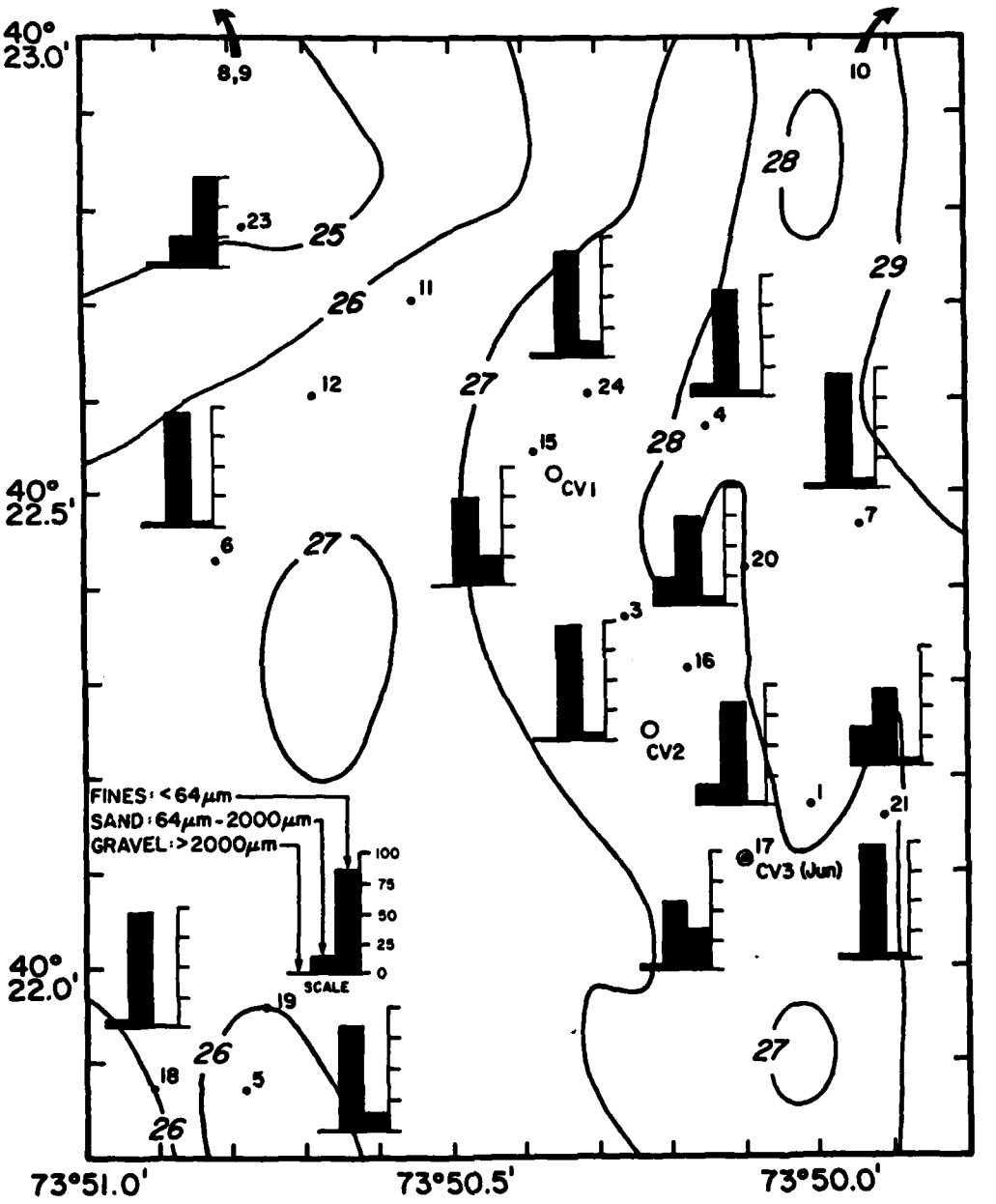

Figure 2: Location map for SEAFLUME sites on the sand cap area. Numbered dots are stations. Circles are sites of long-term current meter/transimissometer deployments. Histograms are explained in text (section 3).

$$V = 5.3 + .156\ (mv) \qquad (1)$$

where V is velocity of current in the channel in cm/sec, and mv the recorded millivolts from the strip chart (Figure 3). Because of propellor size (10 cm) and temporal filtering of the propellor output, propellor velocities are considered to have a 10 sec time constant. The values 5.3 and .156 are constants derived from laboratory calibration of the flow meter in a circular tow tank. This calibration plot is shown in Figure 3. It is estimated that V values calculated from the strip chart records are within ± 10% of actual values.

For the second (June 1981) cruise, an additional group of velocity sensors were added. Three small hot-wire velocity probes mounted on a vertical axis and a hot-film sensor (Gust and Patrick, 1981; Gust, 1982) mounted on an articulated plate below the lowest hot-wire probe were attached to a movable cage assembly (Figure 4). The cage was released after the flume contacted the bottom and was lowered by gravity along guide rails such that when the hot-film plate contacted the bed surface, downward movement ceased. This arrangement was only partially successful due to the unexpectedly low bearing strength of the sediment which allowed the hot-film sensor plate to bury itself in the mud in most deployments. In addition, hot-film sensors were installed inside the channel, on the top and on one side wall (Figure 4). Comparisons between wall stress calculated from the propellor flow meter and observed by the stress sensors are described later in the RESULTS section. Data from all hot-film and wire sensors were sampled and recorded digitally at 1 Hz on magnetic cassette tapes in a pressure housing mounted on the flume frame. Start and stop times on this recorder were electronically synchronized with the propellor flow meter recorder.

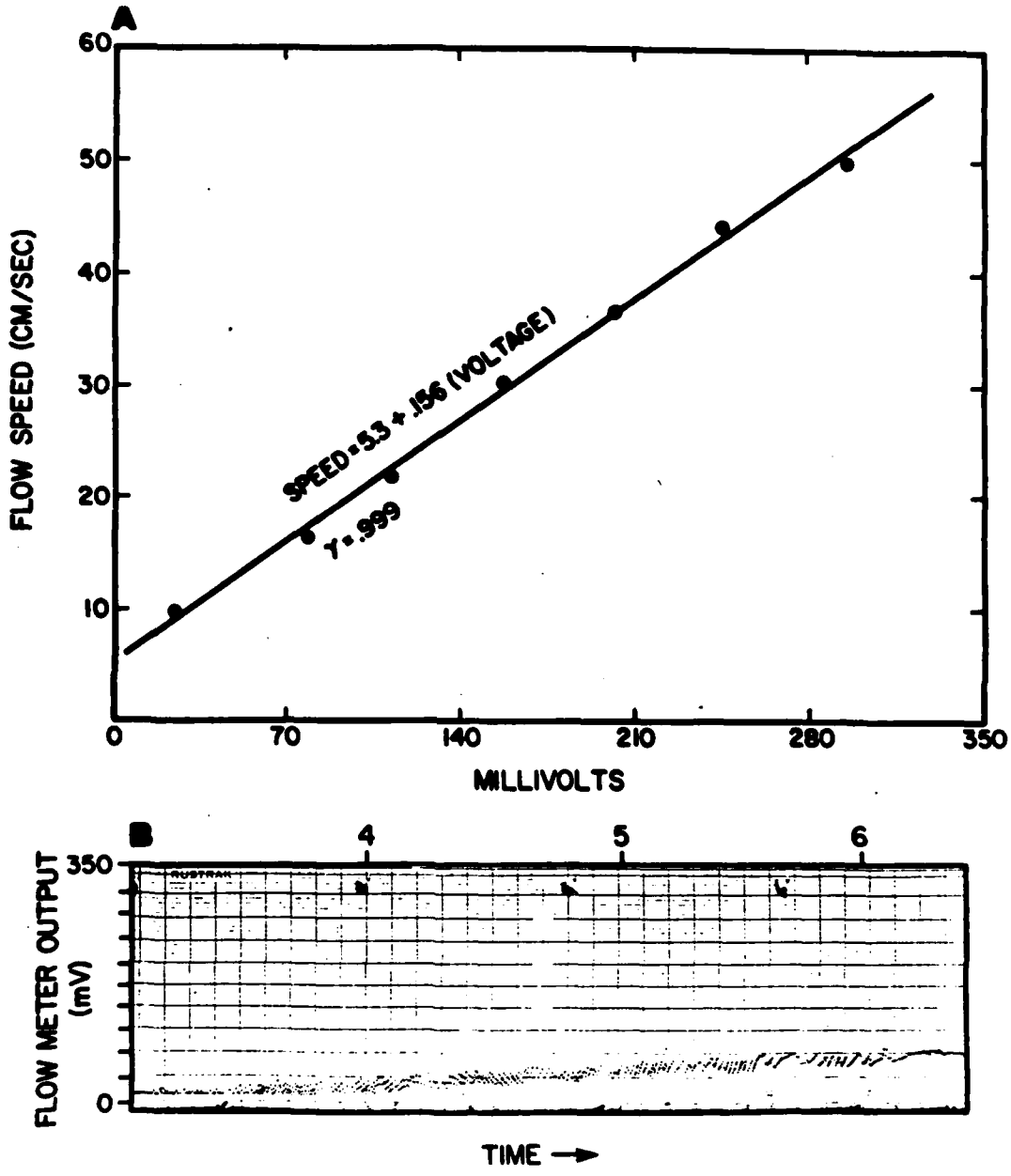

Figure 3: Calibration of propellor flow meter (lower) and example of propellor output to chart recorder (upper).

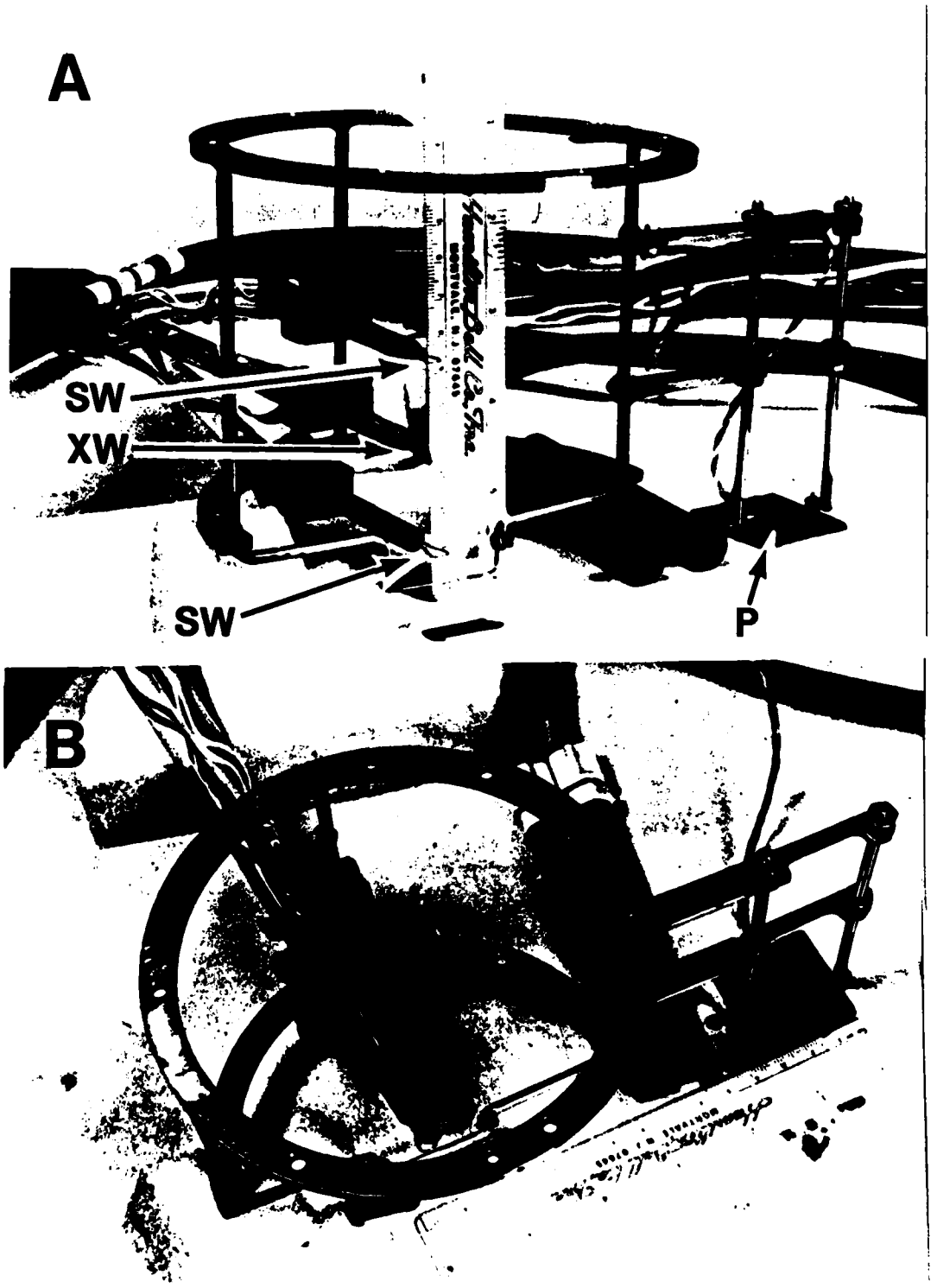

Figure 4: Support system for hot film drag plate and hot-wire flow sensors. SW: single hot-wire probes. XW: crossed-wire probe. P: hot-film plate.

A total of 25 SEAFLUME runs were attempted for this study. Bottom core samples were taken next to the SEAFLUME at each site by SCUBA divers. Cores were taken by shoving PVC pipe 6.25 cm in diameter vertically 12 to 38 cm into the sediment. Both ends of the pipe were then capped and the retrieved cores frozen until analysis could be performed at the laboratory.

2.2 Experimental Conditions

Bottom conditions were highly variable in the sand cap study area. While some sites were fairly smooth, many were covered with irregular mounds and pits ranging in size from centimeters to meters in horizontal or vertical scale. This was also observed on side-scan records, described elsewhere. During several deployments divers found the flume had been placed over large gullies or on dumped debris. The flume was retrieved and relocated by the ship in those instances. Later it will be shown that the seafloor enclosed by the flume was often irregular, certainly not the flat, smooth conditions desired for maximum confidence in the measurement of critical erosion velocity.

Visibility at the bottom was 0.-1.0 meters and the water was usually turbid. This prevented photography of bed features of scales between flume-size and those resolved by side-scan. We are, therefore, unable to comment on the exact nature of bed roughness outside the flume, except to cite divers' reports that no ripples were encountered at any flume site.

2.3 Laboratory Analysis

Positive prints were made for each run and examined in sequence for changes in the bedforms and features. Evidence of movement could be detected, for example, by appearance or disappearance of embedded shell material,

changes in the shape of mounds or ridges, filling of depressions, and in some cases the changes of appearance to shadows. The photo which indicated incipient motion of the bed was correlated with velocities from flow meter, hot-film and hot-wire recordings. Notes for each run indicating features chosen to characterize threshold are given in Appendix A.

Runs for which partial or no propellor flow meter data was obtained (due to malfunction of the recorder or the flow meter) required extrapolation or interpolation from known data. For such cases, flow velocities were taken from the hot film sensors, or flow meter records from several other runs were averaged and a linear first-order curve was fitted to the average velocity and elapsed time data (See RESULTS).

Grain size analysis of core samples from SEAFLUME sites were perfomed to relate the estimated threshold velocity for each run with the particular type of sediment present. Cores were first examined visually for evidence of vertical size fractionation and the length of the core sample was recorded. The cores were then prepared for a standard sieve analysis. When more than one core had been taken from the same site, the samples were combined and homogenized to produce one representative sample. SF1, SF3, SF4, SF6, and SF7 were dried in an oven at 100°C. The remainder of the samples were freeze dried. The sieve analysis yielded percent by weight of fines (< 64 μm), sand (64-2000 μm), and gravel (> 2000 μm) in the sample. When the fine fraction was relatively large, pipette analysis was performed to separate the fines into < 4 μm, 4-16 μm, 16-32 μm and > 64 μm fractions. Further analysis of the sand fractions were performed for all samples by using an automated settling tube (Nelsen, 1976).

2.4 Threshold Calculations

Several velocity profile equations were tested and evaluated for determination of threshold values of shear stress at initiation of erosion. The rough-walled form of the law-of-the-wall equation describing velocity profiles in turbulent boundary layers is given by

$$\frac{U}{U_*} = \frac{2.3}{k} \log \left(\frac{Z}{Z_0}\right) + C. \qquad (2)$$

Here $U_* = (\tau_T/\rho)^{1/2}$ is the friction or shear velocity, U is velocity at height Z above bottom. k is Von Karman's Constant ($\simeq 0.4$), C is a constant dependent on from the nature of the channel, and Z_0 is a measure of bed roughness often taken to be the representative grain diameter/30 for uniform sediments.

To apply law-of-the-wall equations, the flume boundary layer must be fully developed at the measurement point, and the flow steady and uniform. Changes in velocity develop slowly during the experiment (dU/dt $\simeq$ 0.89 cm/sec/min) so that the flow is considered quasi-steady. In the center of the channel the side-wall boundary layers are assumed to have little affect on the vertical velocity distribution because of the 4:1 width to height aspect of the channel, and the channel water properties (ρ, ν) are assumed unchanged from the ambient exterior conditions; hence, the flow is assumed to be uniform.

To determine if the velocity profile is fully developed at the measurement section, we use the equation given by Schlichting (1968, Chap. 2) for estimating turbulent boundary layer thickness δ at distance x along a flat smooth plate. This gives, for velocity V = 15 cm/sec and distance x = 200 cm, $\delta = 0.37\ (Vx/\nu)^{1/5} \simeq 6.0$ cm, assuming that development of the boundary layer begins at the entrance.

Since smooth flow conditions were assumed, the thickness estimated for δ is conservative, because rough walls cause more rapid growth and greater thickness of the boundary layer, all other factors being equal. This assumption is critical to developments which follow and will be evaluated in light of the experimental results later in this work.

The Shields curve, derived through dimensional analysis, is probably the best recognized of all threshold curves. The ordinate of the curve represents the Reynold's number (Re_*) and is given by:

$$Re_* = \frac{U_* d}{\nu} \tag{3}$$

and the abscissa represents the Shields threshold criterion given by:

$$\theta_t = \frac{\tau_T}{(\rho_s - \rho)\, gd} = \frac{\rho\, U_*^2}{(\rho_s - \rho)\, gd} \tag{4}$$

where d is a representative mean diameter of the bed sediment, ν is the kinematic viscosity, τ is bed shear stress, ρ is the fluid density, ρ_s is sediment density, and g the gravitational constant.

The Yalin curve is very similar to Shields' (cf., Figure 10). The abscissa remains exactly the same. The ordinate in Yalin's curve, $\sqrt{\Xi} = Re_*/\sqrt{\theta_t}$, differs from Shields' in that it combines θ_t and Re_* in such a manner as to eliminate dependence on shear velocity. For this reason the Yalin curve is probably the most useful one available for determination of sediment incipient motion (Miller et al., 1980). Yalin also claims that his curve is more sensitive for grain sizes at small values of Re_*.

3. RESULTS

Figure 6 presents a key to aid in identification of the features seen in the SEAFLUME photos. Photographs in Figure 6 a-t show the initial condition of the seabed and the threshold for motion for each SEAFLUME run. Comments are included in Appendix A to aid the reader in understanding the criteria used for the selection of a given threshold photograph.

Determining the threshold for some runs, as in run SF1 (Figure 6a) was straightforward in that initial changes to the bed were easily seen. Other runs, such as SF6, (Figure 6f) were difficult to judge and required a more subjective approach. During the November experiments (SF1-7) the camera-mirror system was not well sealed and particles often settled out onto the window on the flume top, partially obscuring the bed. A new mirror-window assembly, sealed and filled with clear water was installed for the June cruise and picture clarity was much improved.

For SF17 and SF24 the photographs showing incipient motion could not be identified. This was due to poor picture quality as a result of insufficient lighting (SF17) and the presence of suspended material between the camera lens and the bottom (SF24). Also, flow during SF24 was altered due to a foreign object becoming lodged in the channel. This affected the results of this run and hence no threshold photograph was selected. Where photographs from a SEAFLUME deployment are missing in whole or in part, either an aborted run occurred or mechanical difficulties prematurely terminated the run.

When flow meter data were incomplete or missing but sediment and photographic data were of good quality, velocities were interpolated from other runs or from partial data. Examples are shown in Figures 7 and 8 of curves for SF5 and SF20 from which the threshold velocities were picked.

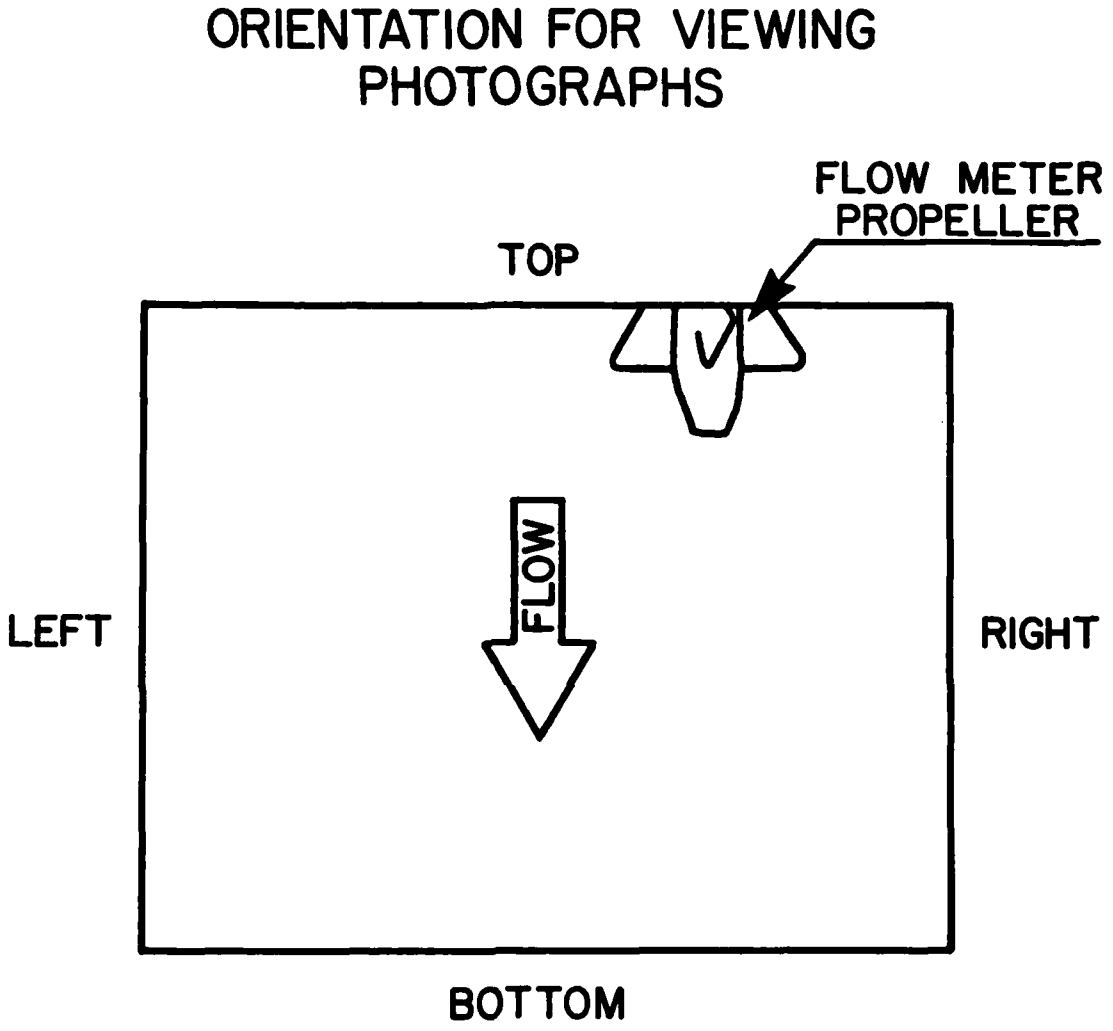

Figure 5: Schematic drawing of a typical seafloor photo taken by the SEAFLUME camera. The directions left and right, and flow direction, are referred to in Appendix A in descriptions of the bed surface during erosion.

AD-A138 435 DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM 5/6
EVALUATION OF THE 1980 CAPP.. (U) NEW YORK UNIV MEDICAL
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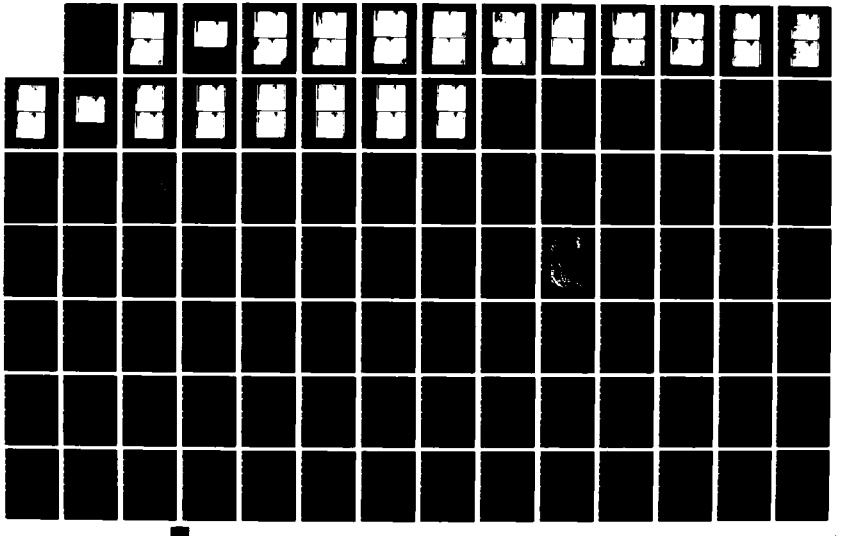
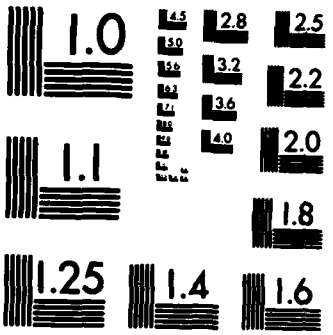
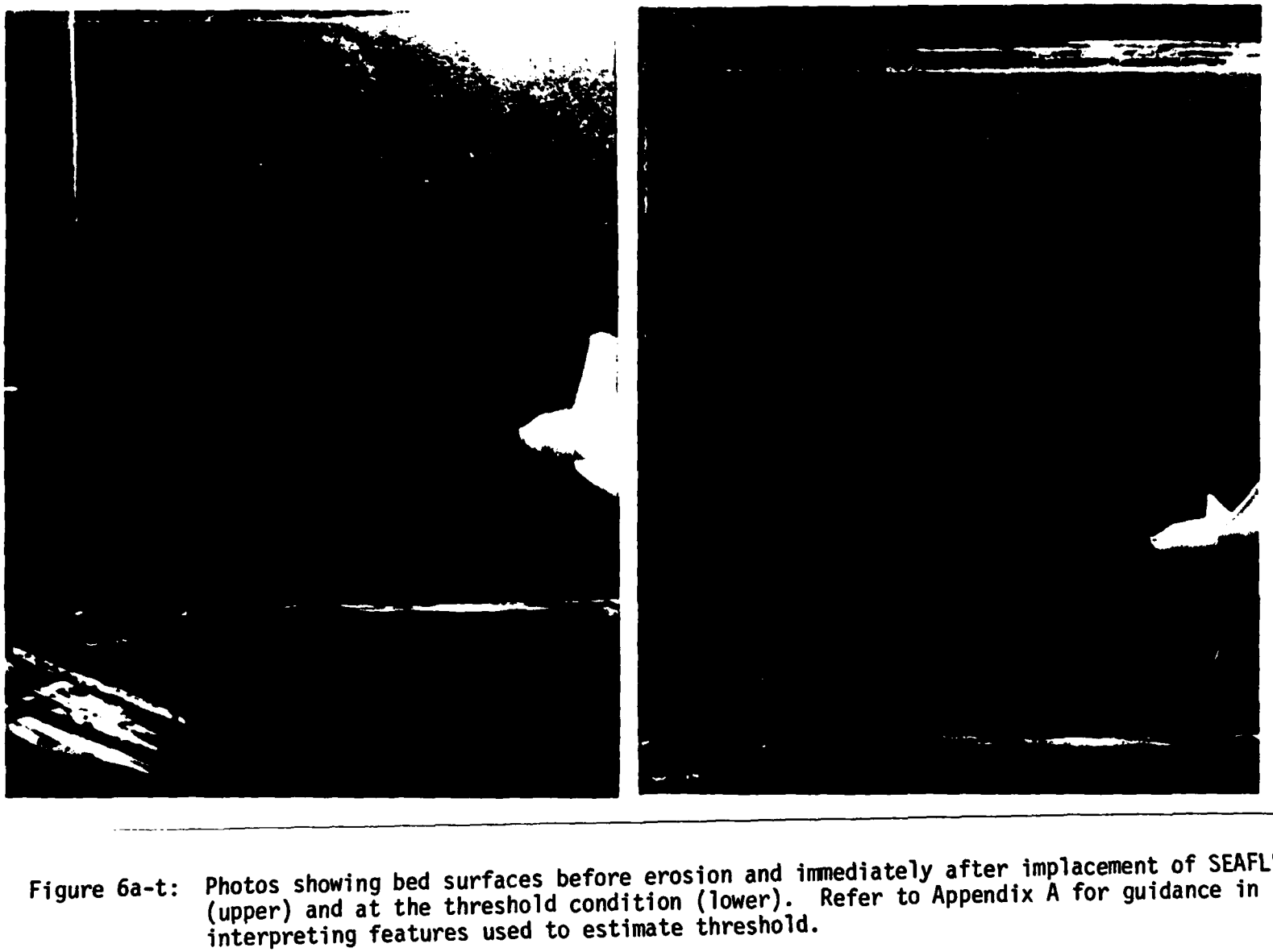
UNCLASSIFIED WES-TR-D-83-3 DACW39-82-M-2544 F/G 13/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



SF-1

Figure 6a-t: Photos showing bed surfaces before erosion and immediately after implacement of SEAFLUME (upper) and at the threshold condition (lower). Refer to Appendix A for guidance in interpreting features used to estimate threshold.

SF-2

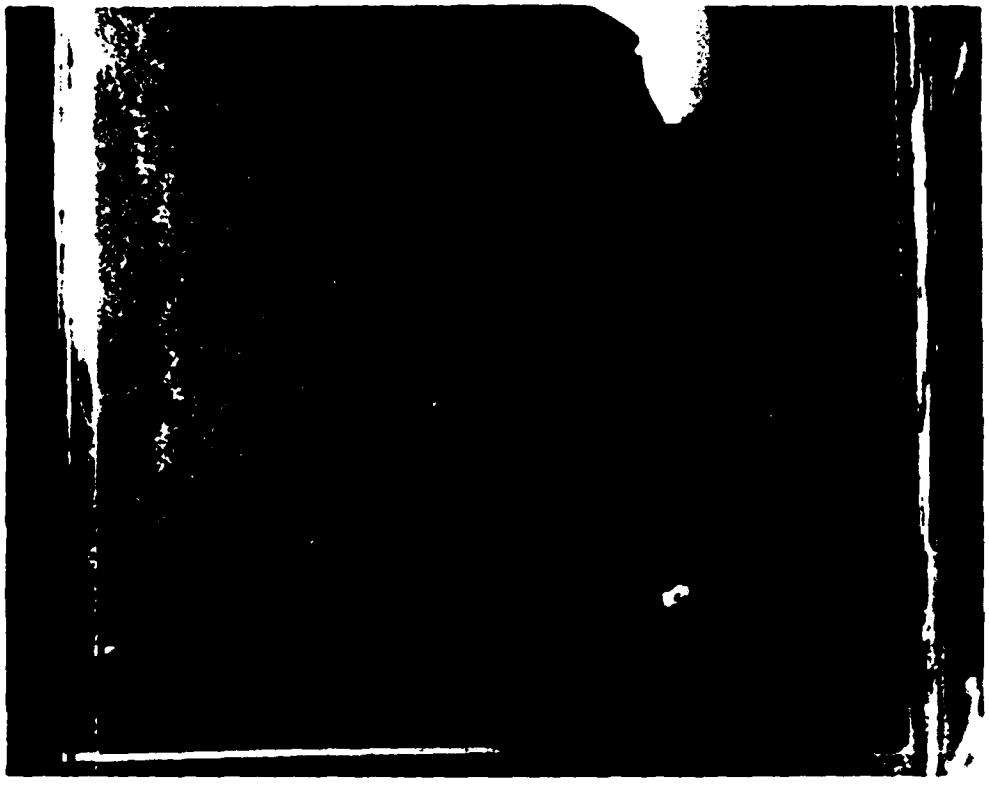


Figure 6b

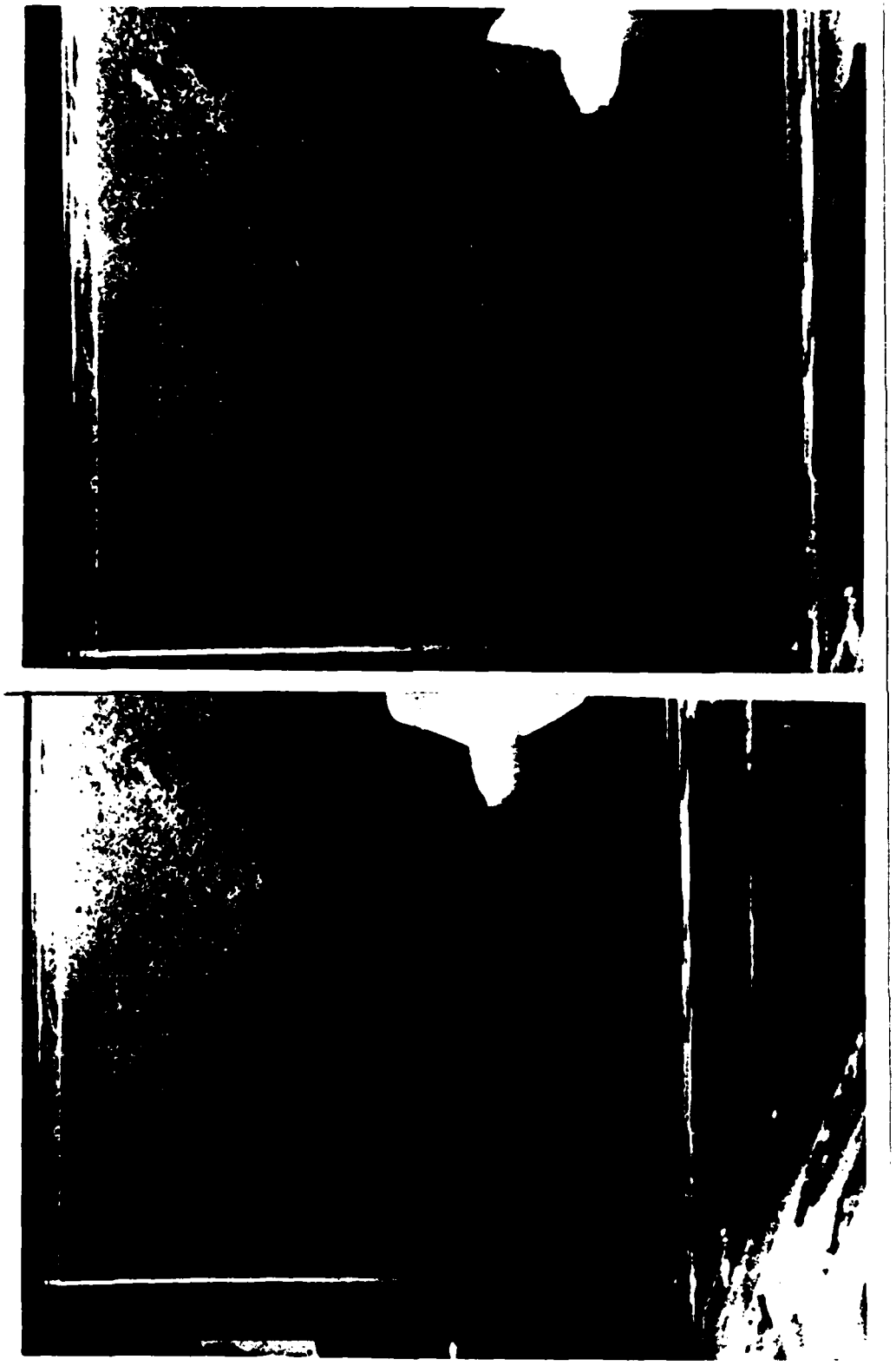


Figure 6c

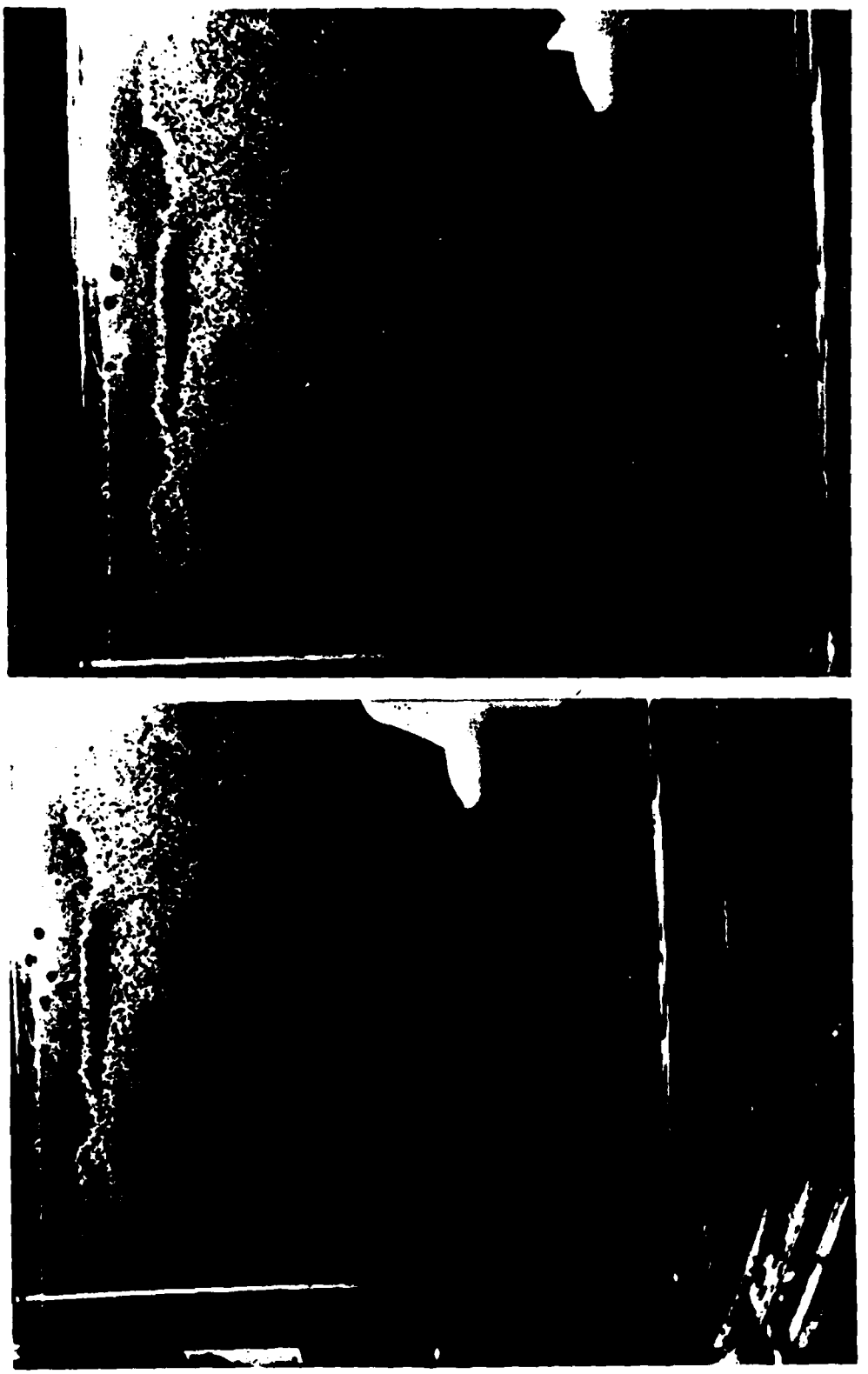


Figure 6d

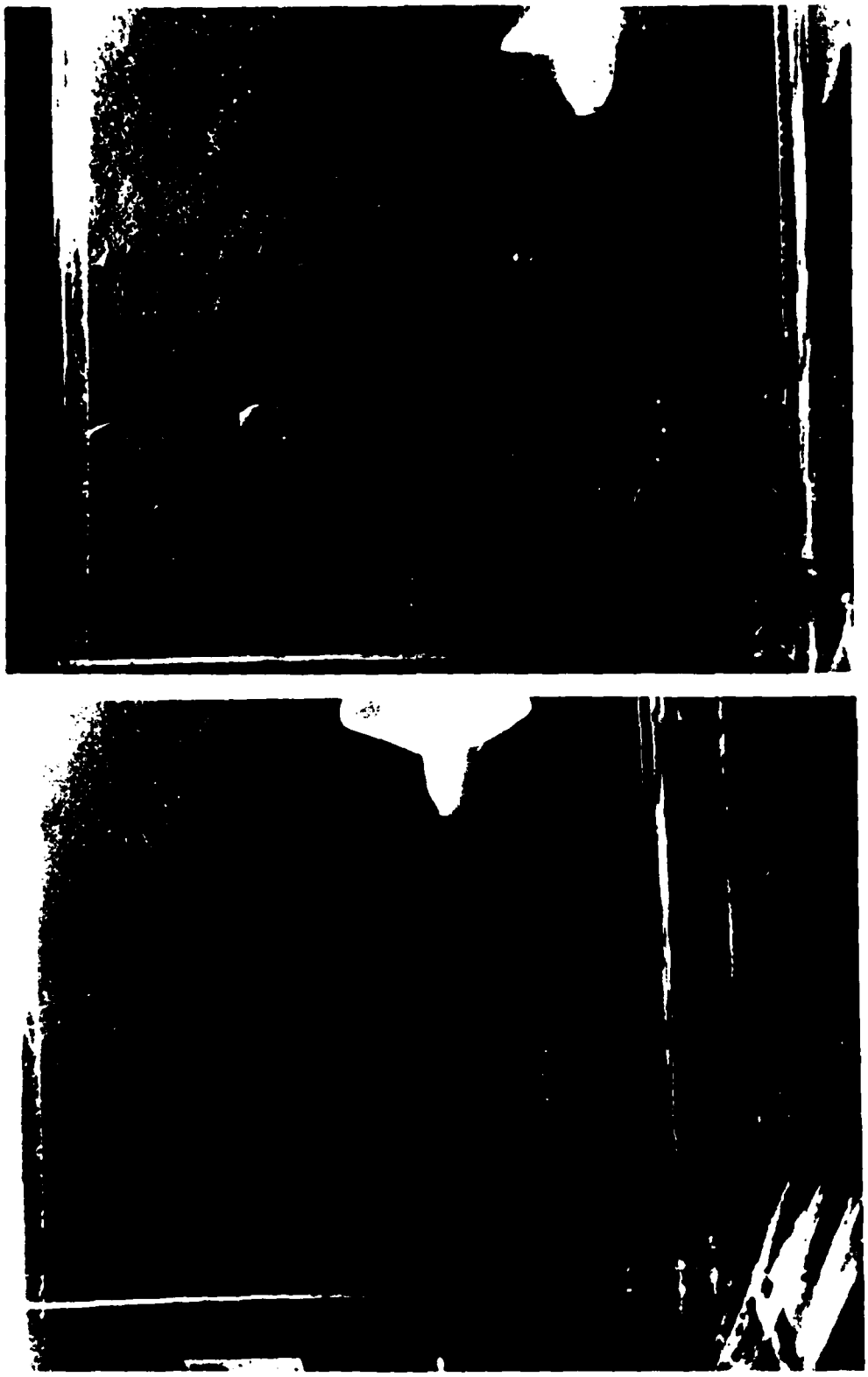


Figure 6e

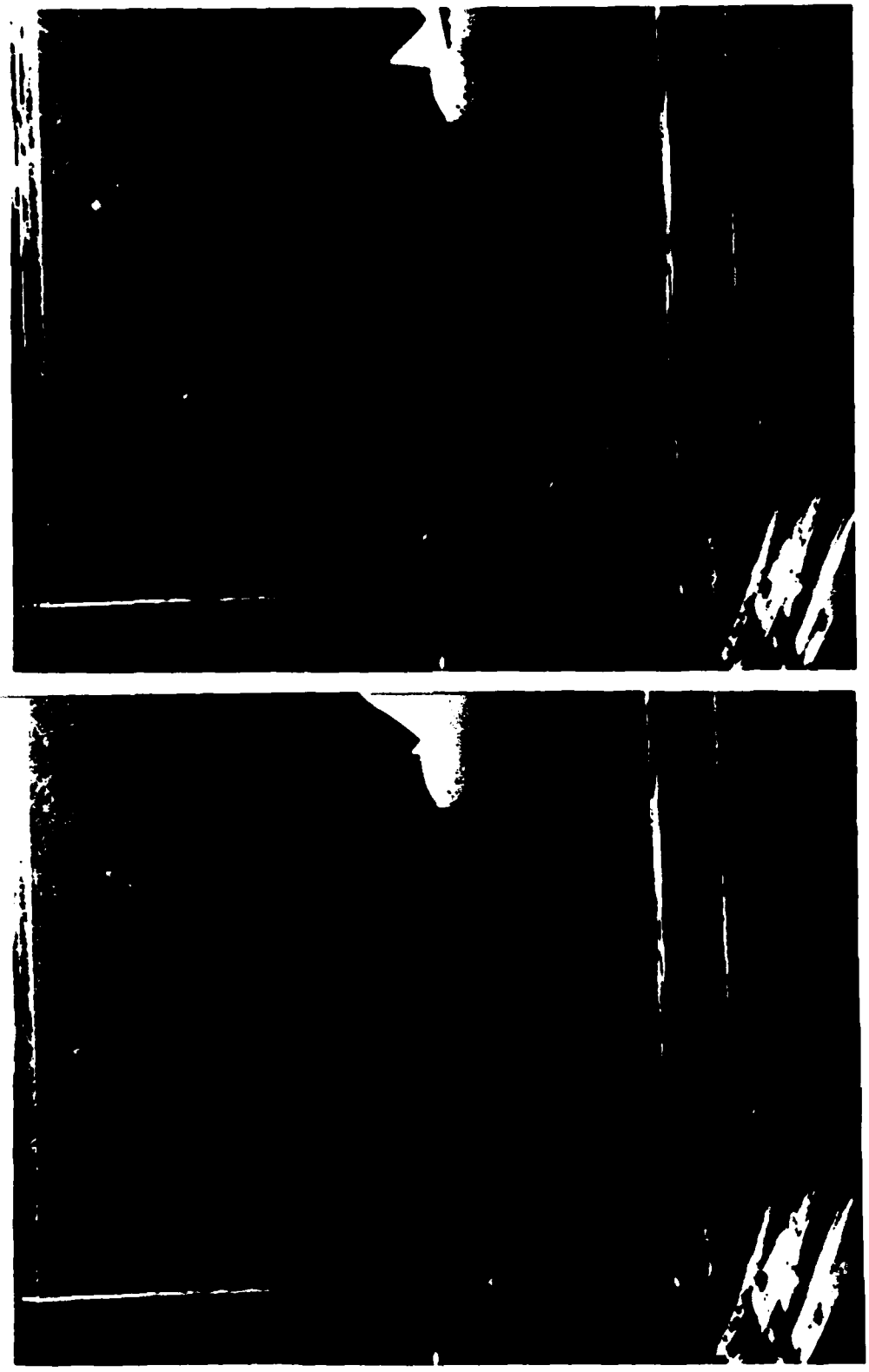


Figure 6f

Figure 6g

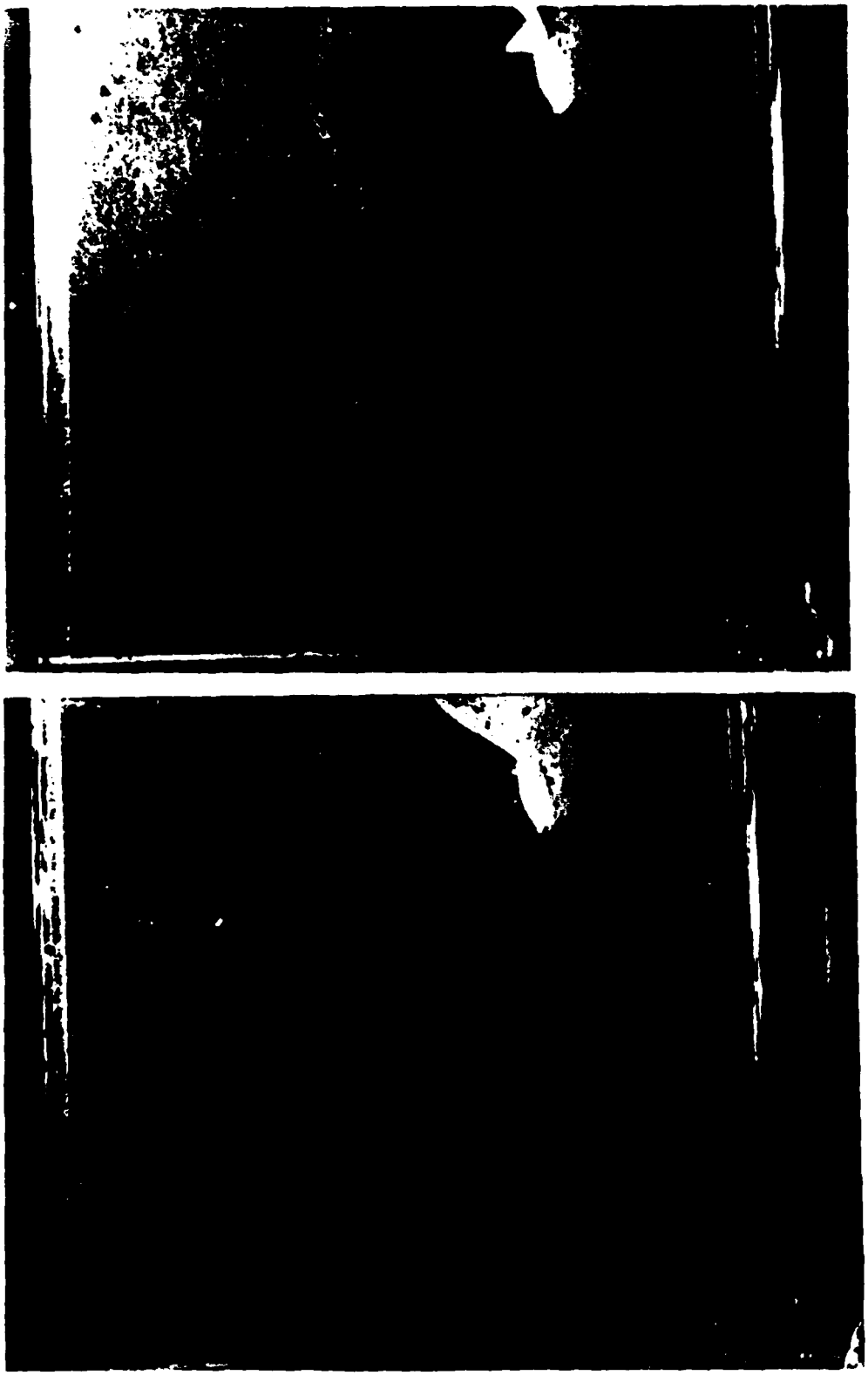


Figure 6h

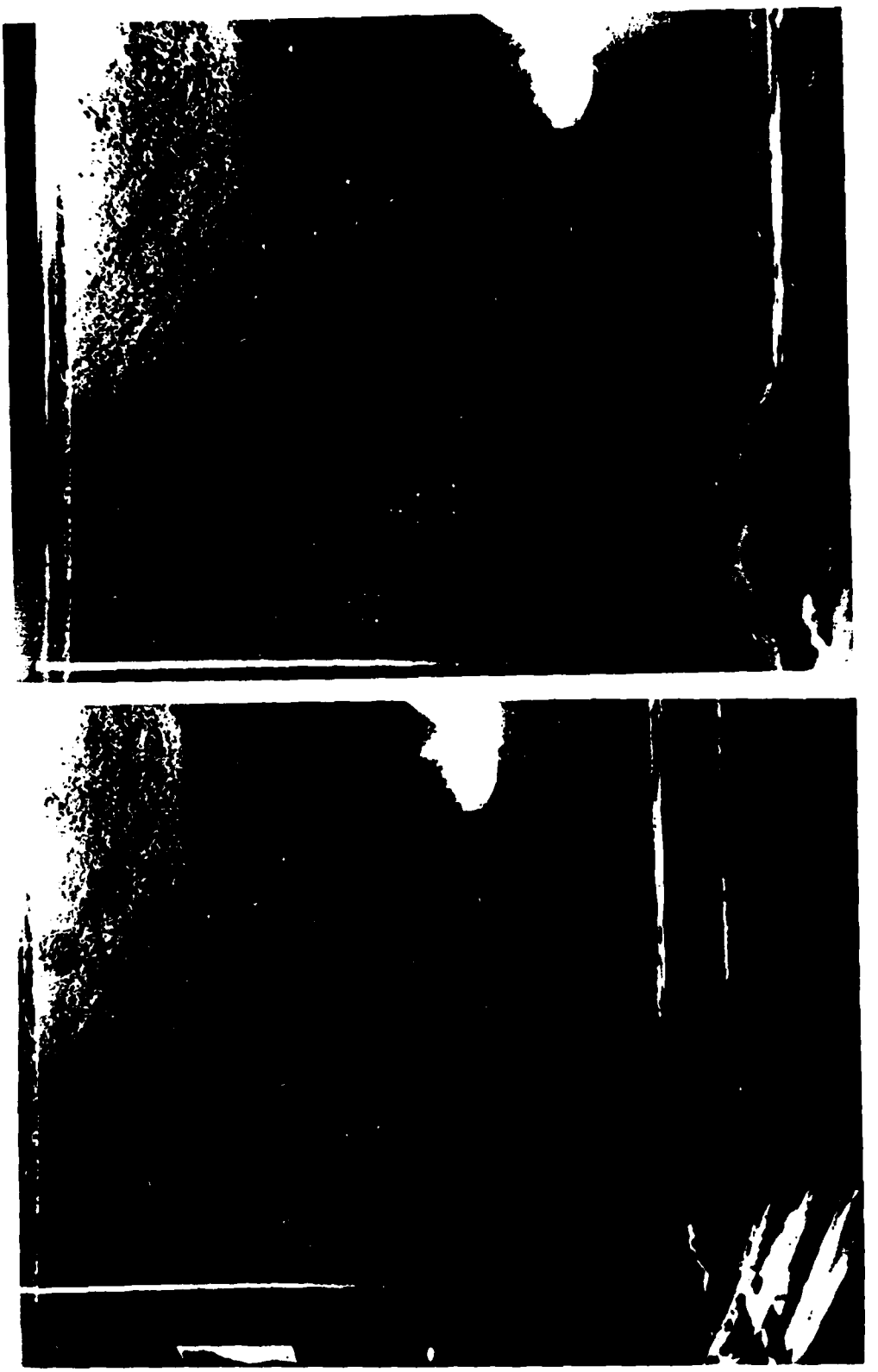


Figure 6i

Figure 6j

SF-15

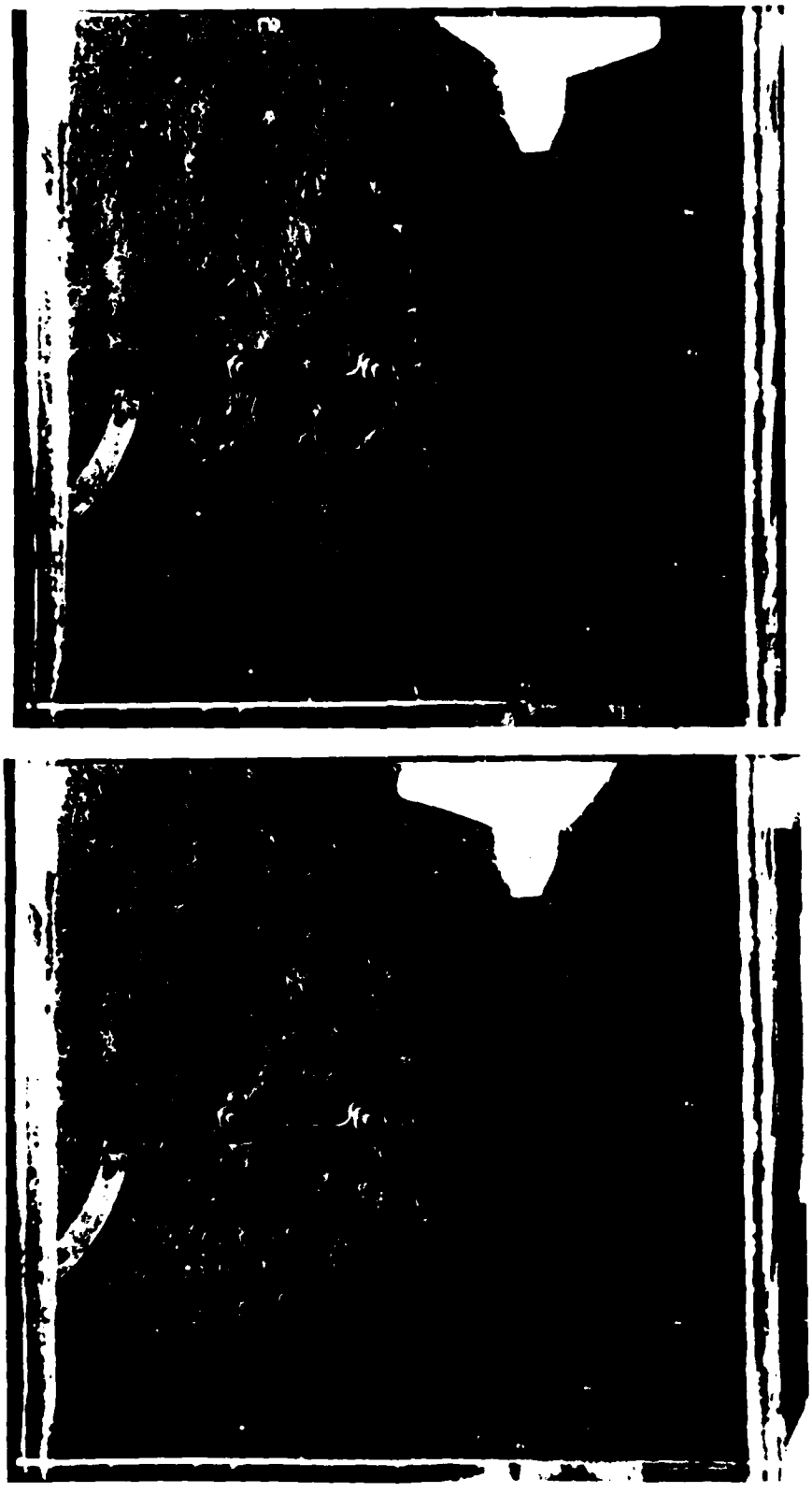


Figure 6k

Figure 61

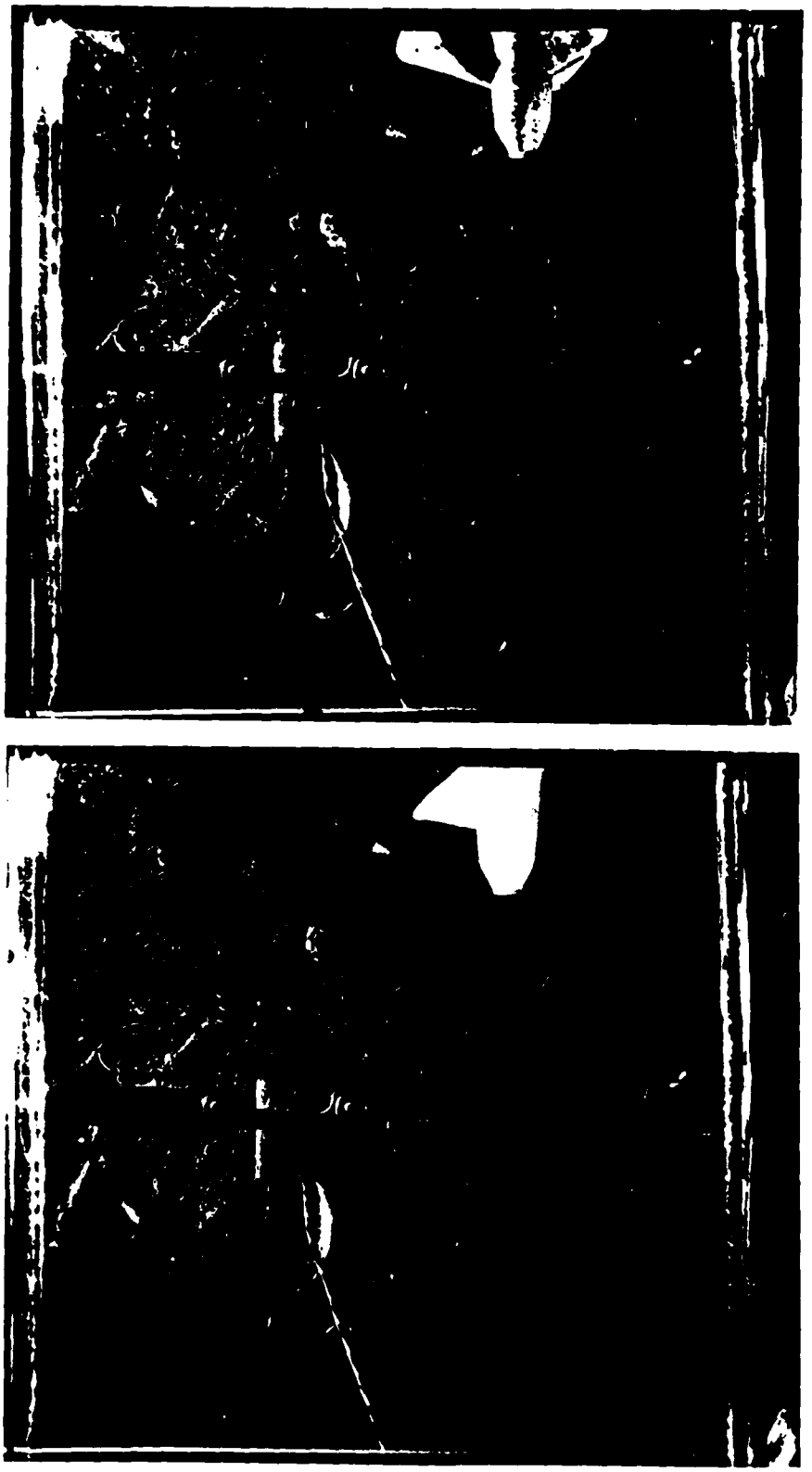


Figure 6m

SF-18A

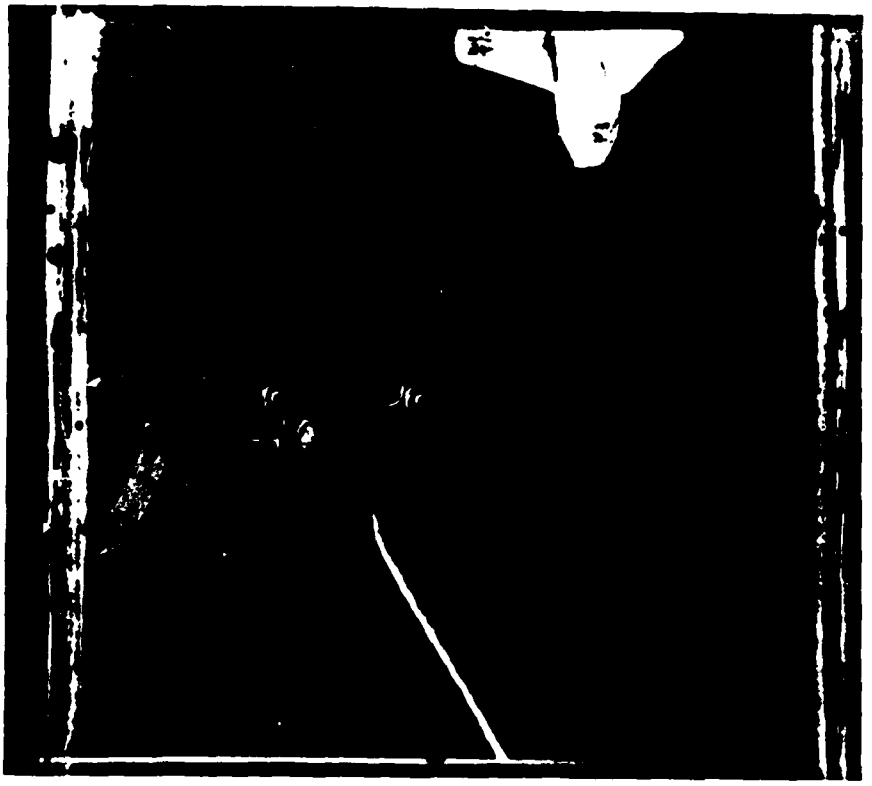


Figure 6n

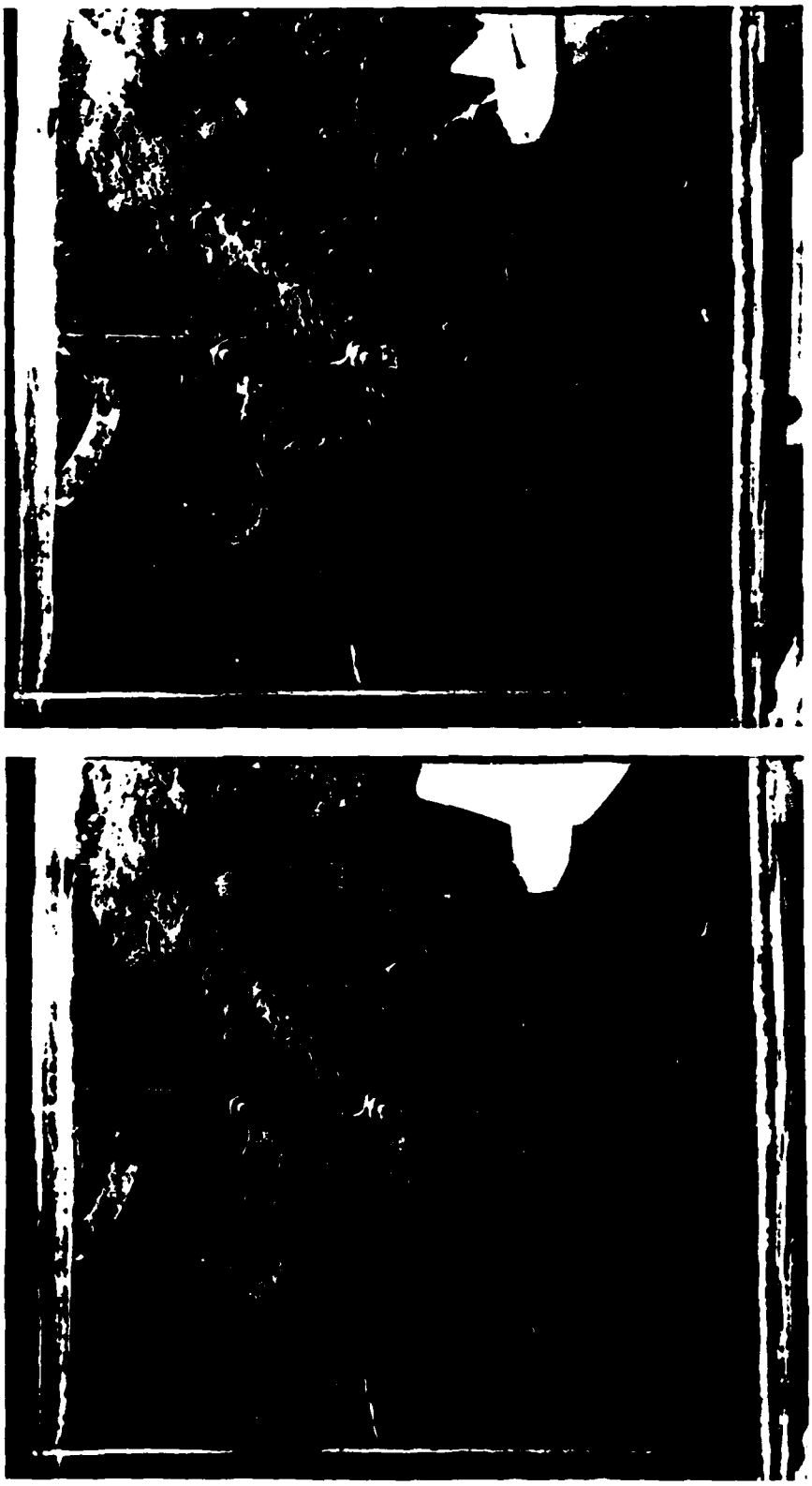


Figure 6o

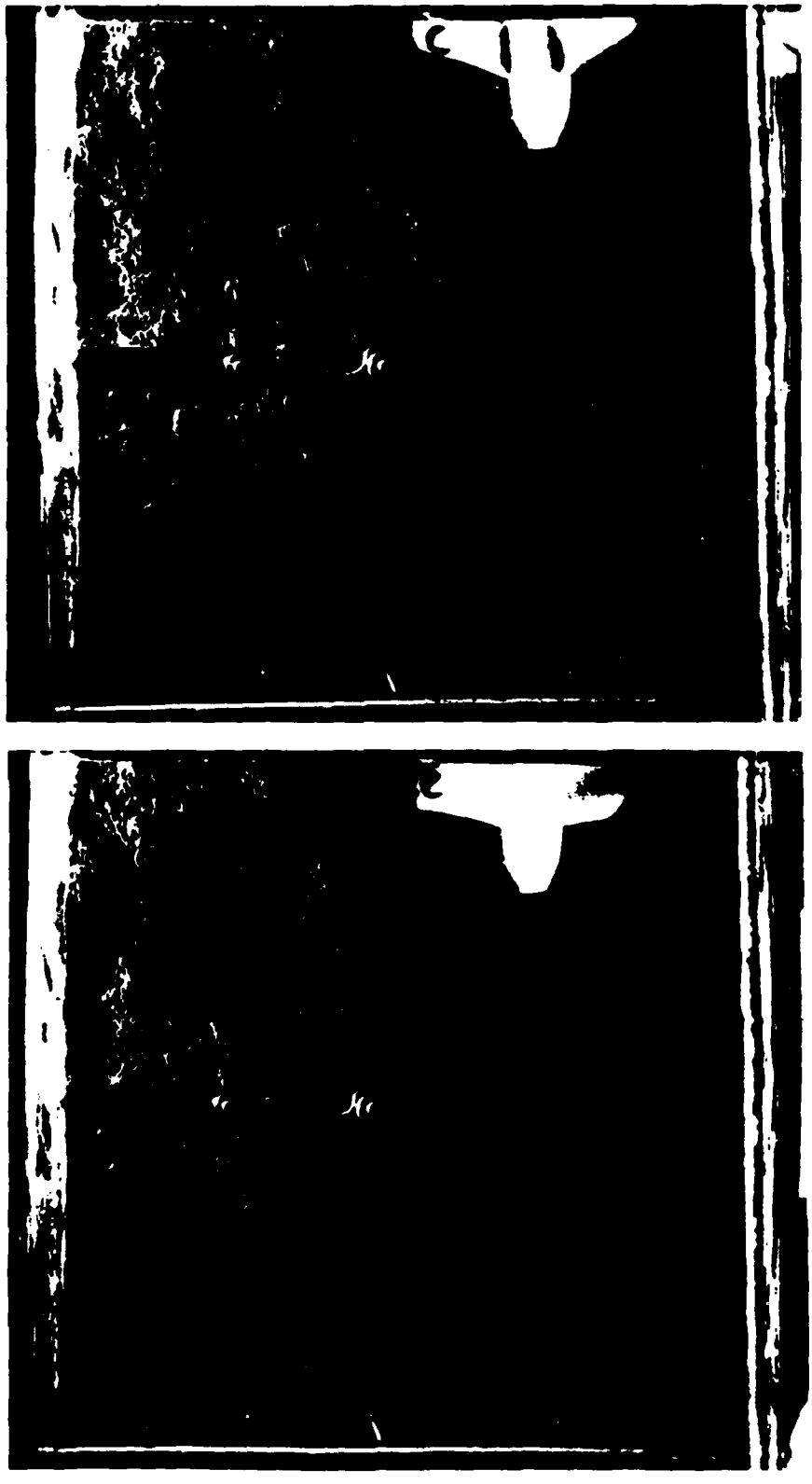


Figure 6p

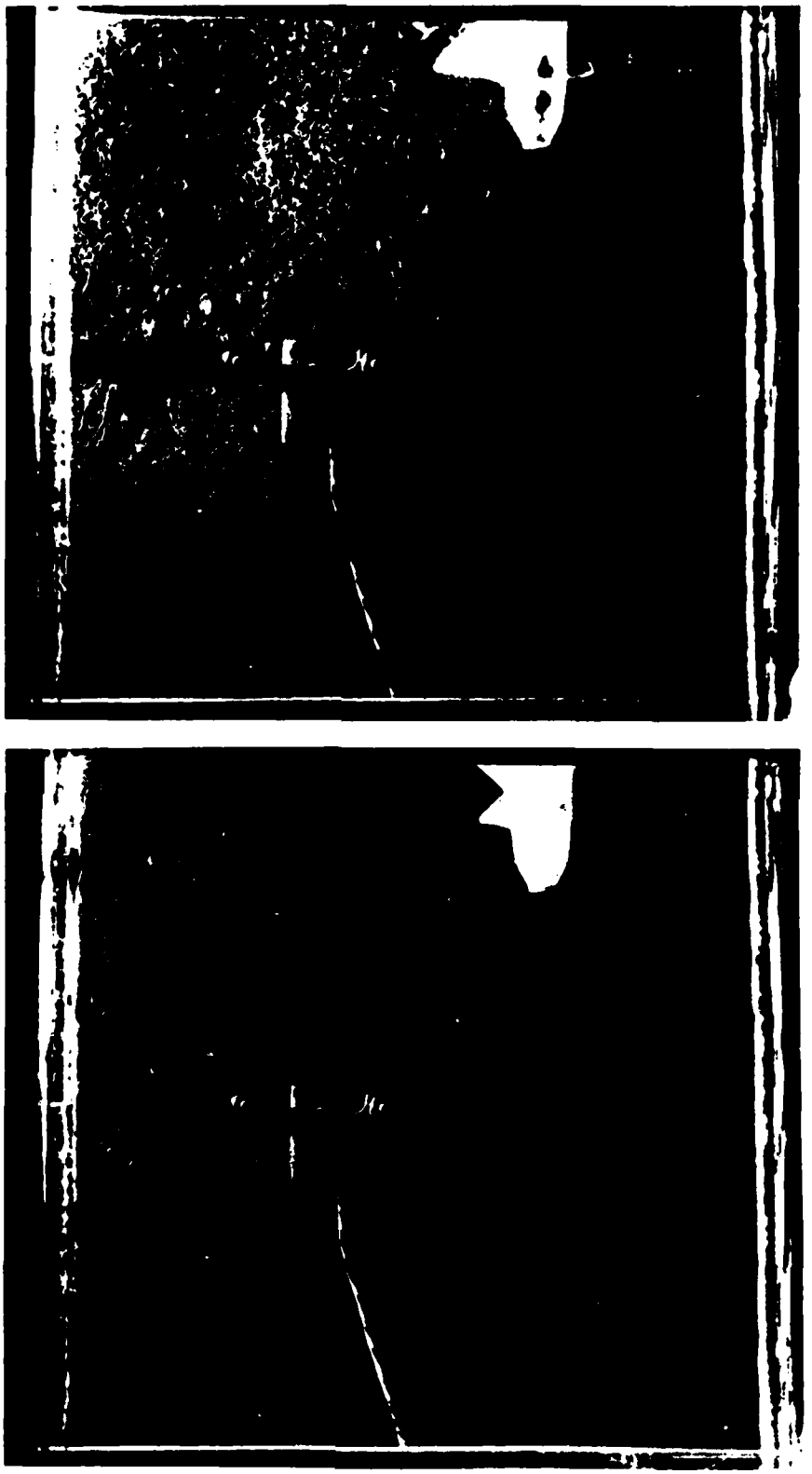


Figure 6q

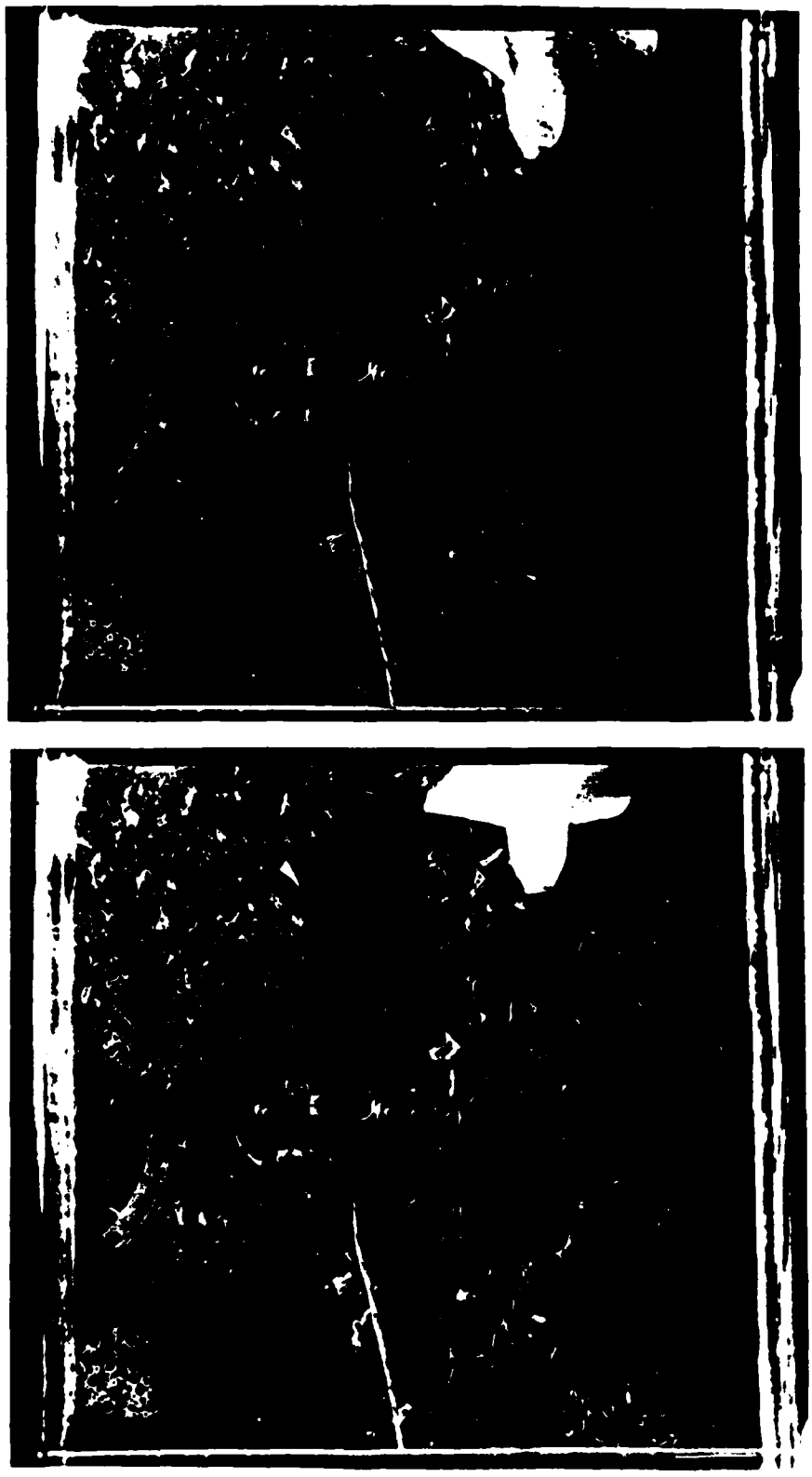


Figure 6r

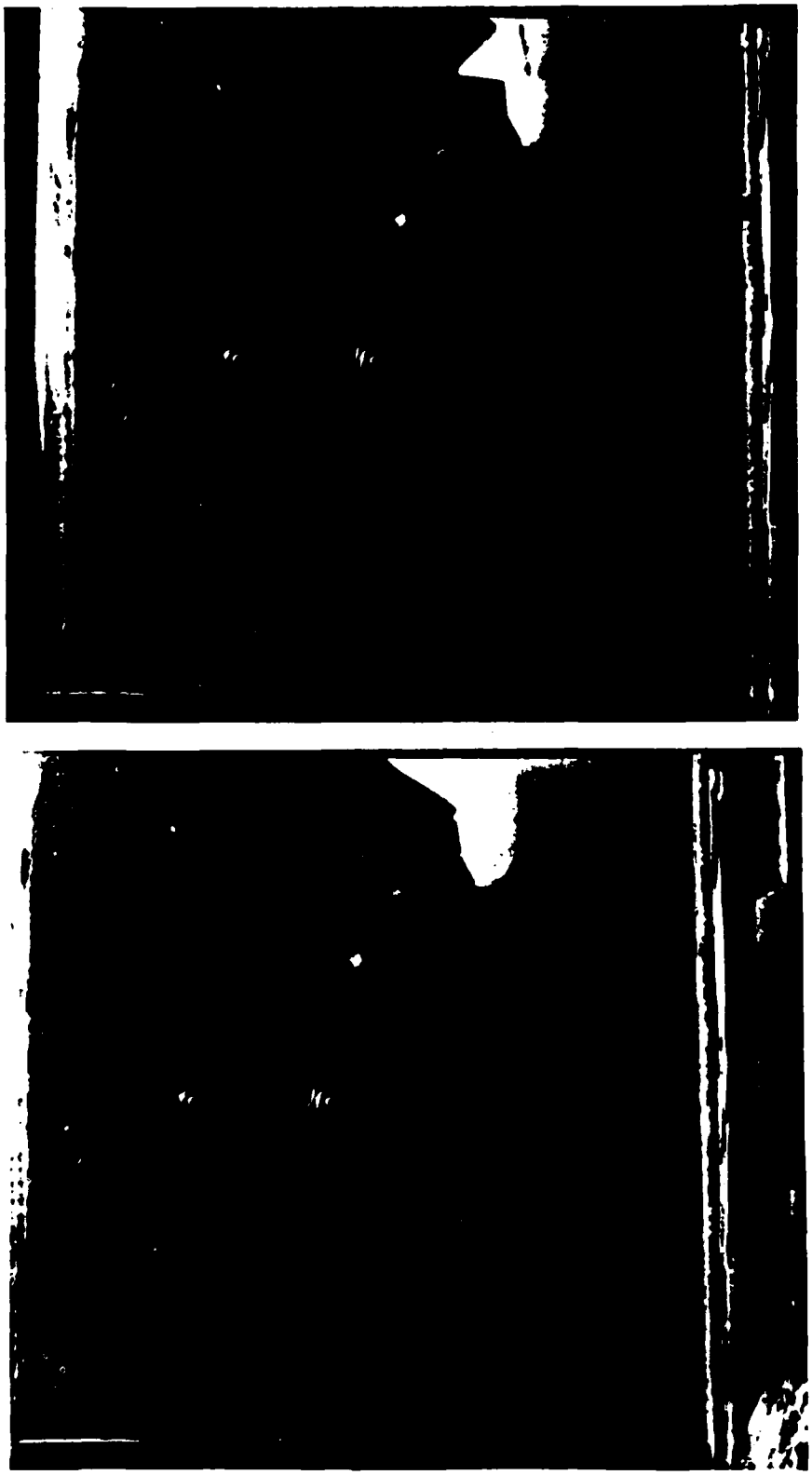


Figure 6s

Figure 6t

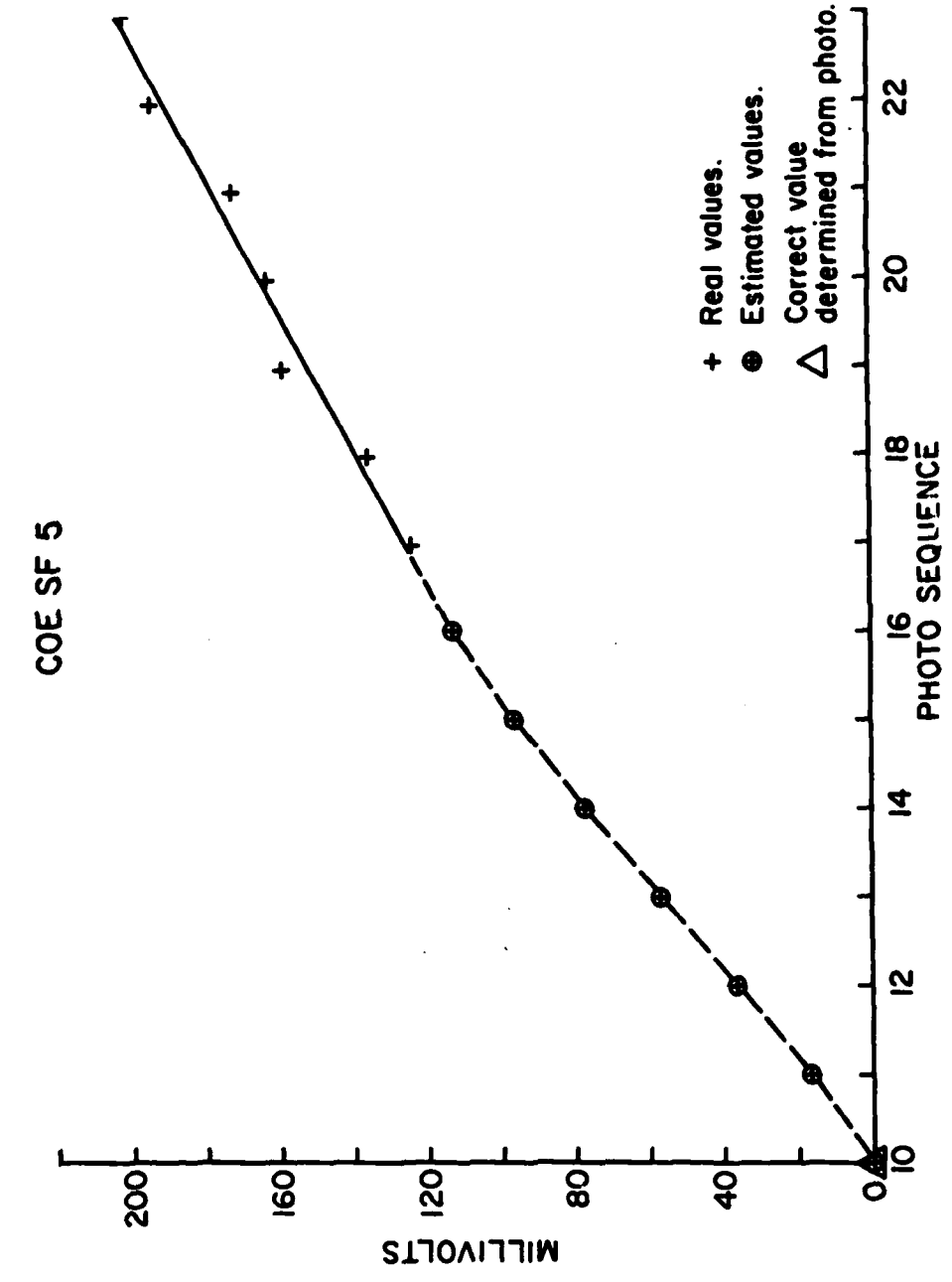


Figure 7: Plot showing velocity versus time curve developed to estimate threshold velocity for SF5.

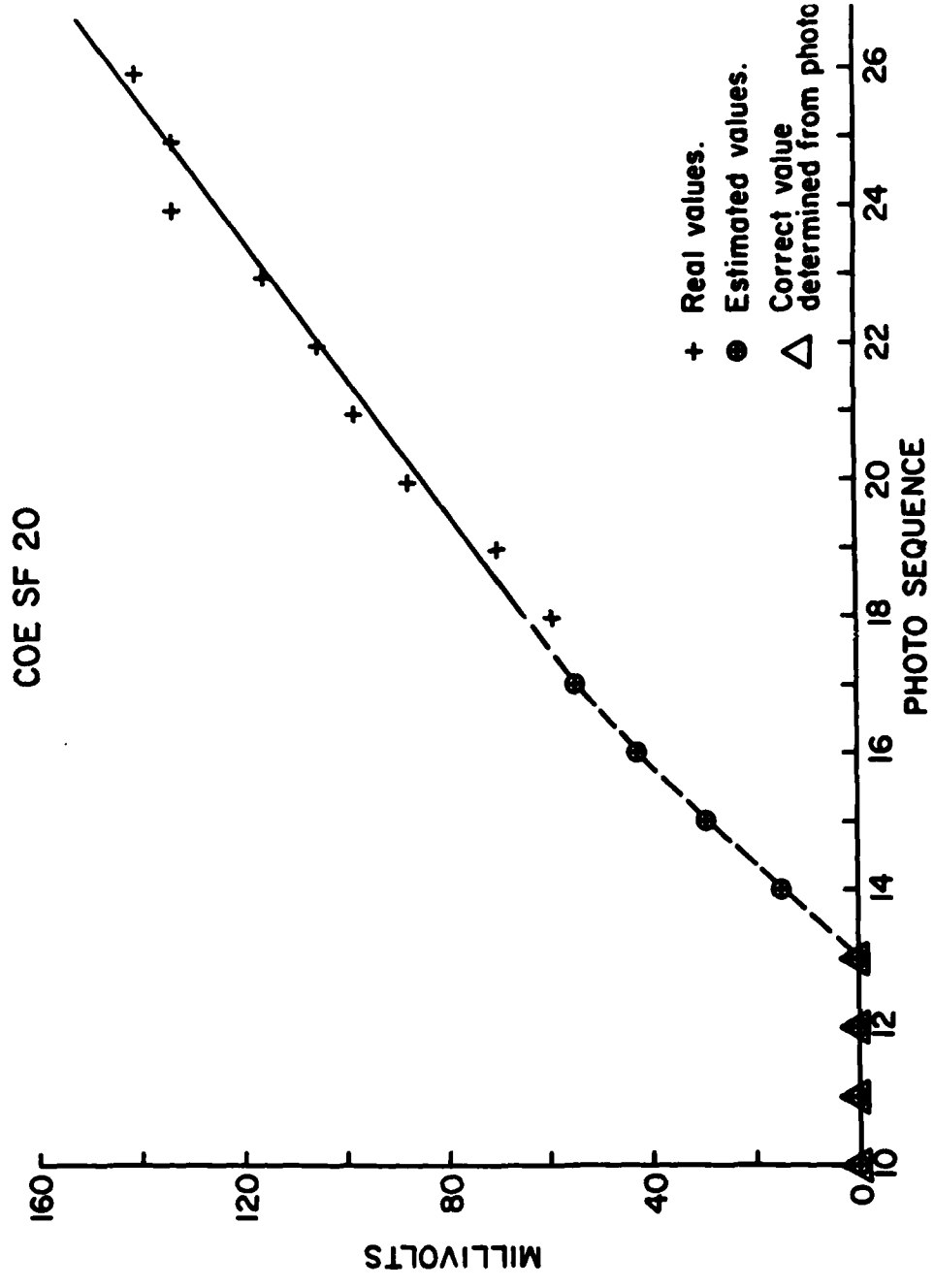


Figure 8: Plot showing velocity versus time curve developed to estimate threshold velocity for SF20.

Benthic animal trails which developed during one run (SF9; Figure 6i), were regarded as pertaining to a separate threshold criteria than for the undisturbed surrounding areas, since fresh bioturbation disturbs the sediment and affects natural erosional characteristics.

All SEAFLUME deployment positions are given in Table 1. Figure 2 shows the site of each run that provided data. Next to each site is a histogram showing percent by weight of the gravel, sand, and fine fractions of the sediment from the diver core samples. Note that SF8, SF9, and SF10 are not on this map, as they were deployed outside the perimeter of the sandcap. Also on this map are the nominal positions of the concentration-velocity (CV) probes (probes were retrieved and re-deployed at these stations about every two months for servicing). Results of CV deployments are presented in a companion report (Young, 1982, this report).

Table 2 summarizes grain size and flow data for each SEAFLUME run. SEAFLUME runs SF11, SF12, SF18(A), SF22, SF25, and SF26 were aborted runs. During SF2, the panel which regulates the flow speed became inoperative. As previously noted, threshold velocity could not be determined for SF8, SF17, and SF24. Core samples for SF8, SF9, and SF10 were lost at sea, eliminating grain size data from those runs. There were no SF13 or SF14 runs. In all, a total of 25 SEAFLUME runs were attempted. Six runs from the first cruise (SF1-SF12) and seven of the twelve runs from the second cruise (SF15-SF26) provided complete flow and sediment data.

Table 2 gives the results of the grain size analysis for each core sample taken. Included in this table are percent by weight of the gravel, sand and fines, results of the pipette analysis of the fines, and the mean phi (θ) size of the sand fraction from ARSA analysis. Phi (θ) is defined as $[(-\log_2(d)]$ where d is the diameter of the grain in millimeters. From the grain size data

Table 1: SEAFLUME deployment locations.

SEAFLUME Run Number	Latitude	Longitude
SF1	40°22.18'	73°50.01'
SF2	40°22.38'	73°50.26'
SF3	40°22.38'	73°50.26'
SF4	40°22.59'	73°50.15'
SF5	40°21.85'	73°50.79'
SF6	40°22.45'	73°50.83'
SF7	40°22.49'	73°49.93'
SF8	40°24.38'	73°51.59'
SF9	40°24.15'	73°51.80'
SF10	40°24.30'	73°48.10'
SF11	40°22.73'	73°50.56'
SF12	40°22.63'	73°50.69'
SF15	40°22.56'	73°50.39'
SF16	40°22.32'	73°50.17'
SF17	40°22.12'	73°50.09'
SF18(A)	40°21.85'	73°50.92'
SF18(B)	40°21.85'	73°50.92'
SF19	40°21.94'	73°50.77'
SF20	40°22.44'	73°50.09'
SF21	40°22.17'	73°49.90'
SF22	40°22.06'	73°50.08'
SF23	40°22.81'	73°50.79'
SF24	40°22.63'	73°50.31'
SF25	40°22.28'	73°50.91'
SF26	40°22.33'	73°50.17'

Table 2: Grain size analyses from samples taken at SEAFLUME sites.

SEAFLUME Run	% by Weight Gravel >2.0 mm	% by Weight Sand 2.0-.064 mm	% by Weight Fines < .064 mm	Pippete Analysis of Fines*				Mean Sand Diameter (ϕ/cm)
				.064-.032 mm	.032-.016 mm	.016-.004 mm	<.004 mm	
SF1	2.4	94.8	2.8	--	--	--	--	2.3/.0203
SF3	0.6	95.0	4.4	--	--	--	--	2.5/.0177
SF4	9.9	87.7	2.4	--	--	--	--	2.2/.0218
SF5	0.4	87.0	12.6	--	--	--	--	2.5/.0177
SF6	2.0	95.2	2.8	--	--	--	--	2.6/.0165
SF7	1.5	92.5	6.0	--	--	--	--	2.4/.0189
SF15	1.0	73.8	25.2	2.6	5.5	5.2	11.9	2.4/.0189
SF16	14.9	83.4	1.7	--	--	--	--	2.1/.0233
SF18(B)	4.3	94.4	1.3	--	--	--	--	1.9/.0268
SF19	.2	13.9	85.9	8.5	17.1	25.2	35.1	3.6/.0082
SF20	21.1	72.9	6.0	--	--	--	--	2.8/.0144
SF21	31.4	64.3	4.3	--	--	--	--	2.2/.0218
SF23	2.8	24.5	72.7	6.8	7.5	20.0	38.4	2.2/.0218

*(% by weight)

it is observed that the percentage of sand was generally greater for samples taken during the first cruise. Except for SF18B, sediments from the second cruise contained more fine material. Pipette analysis for the four samples (SF15, SF17, SF19, and SF23) that had relatively high percentages of fines show that most of the fines had a diameter less than .004 mm. Also noted is the generally higher percentage of gravel (> 2 mm) present in samples taken during the second cruise. Sediment samples from the second cruise also had a greater variance (1.9-3.5ϕ) than those from the first cruise (2.2-2.6ϕ).

3.1 Comparison of Hot Film and Propellor Velocities

Recalling that the hot film velocity measurements were made along the top and side walls of the flume, and at the bed surface via the drag plate, we use these measured wall velocities as estimates of U_* along these surfaces. These values are compared with U_* calculated from propellor measurements and law-of-the-wall equation (2) in Table 3.

Due to the deployment procedures and the soft "fluffy" layer of fine sediments at the bed surface, a cloud of loose surficial suspended matter was stirred up and subsequently settled on the hot wire probes. Also, in many deployments the hot film plate sank completely through the sediment-water interface despite efforts during the cruise to modify the elevator mechanism. In other cases, the hot film plate became contaminated by the resuspended matter during deployment and was only swept clear by flows exceeding threshold conditions. Particles remained attached to the velocity probes even when flow was above threshold and no data was obtained from these sensors. However, the bottom hot film sensor plate was swept clean of sediments during several runs, and no particles adhered to the hot film sensor on the flume top wall. In those cases, velocities from top and bottom plates

Table 3: Comparison between U_* measured determined by the hot film sensor on flume top wall and U_* calculated from law-of-the-wall equation (2) using propellor velocities.

SEAFLUME Run #	U_* Equation (1)	U_* Wall Sensor
15	0.68	0.89
16	0.50	0.81
18B	0.83	1.10
19	0.40	1.05
20	0.48	0.93
21	0.54	0.82
23	0.54	1.17

agreed to within ± 10%. This infers that the roughness of the flume top wall and the sediments comprising the lower flow boundary were of about the same magnitude. If their roughness had differed significantly, the flow profile would have been assymetrical and top and bottom wall velocities would not have agreed so well. The measurements show that the threshold U_*, determined by the top wall sensor, is higher than the U_* derived from the propellor flow meter under the wall law assumption.

We suspect several factors contribute to this inconsistency between hot film and propellor U_*. The first is the reasonableness of the assumption, discussed earlier, that the flume boundary layer is fully developed at the measurement section. It was estimated that the boundary layer thickness was about 6 cm. If this was not the case, and the thickness much less than 6 cm, the wall law equations used to calculate U_* do not apply, even approximately.

Turbulence spectra for SF19 using data from the top wall sensor for a six-minute interval encompassing the onset of erosion were calculated to see how far the flow in the flume might deviate from that of a fully developed turbulent flow. The results (Figure 9) are compared with a hot film velocity spectrum from a fully developed turbulent flow in a laboratory flume. Energy levels of the SEAFLUME spectra are lower at almost all frequencies than the levels in the laboratory flume, again suggesting incomplete development of the SEAFLUME boundary layer.

Other factors, discussed elsewhere, including choices of bed roughness (Z_0), and the constant in equation (2), can also lead to variation in U_* from propellor velocities. However, after checking the effect on U_* (equation (2)) of reasonable but extreme variations in these factors, it was determined that U_* values were changed by factors of only 1.05 to 1.30, not enough to explain all differences observed in Table 3.

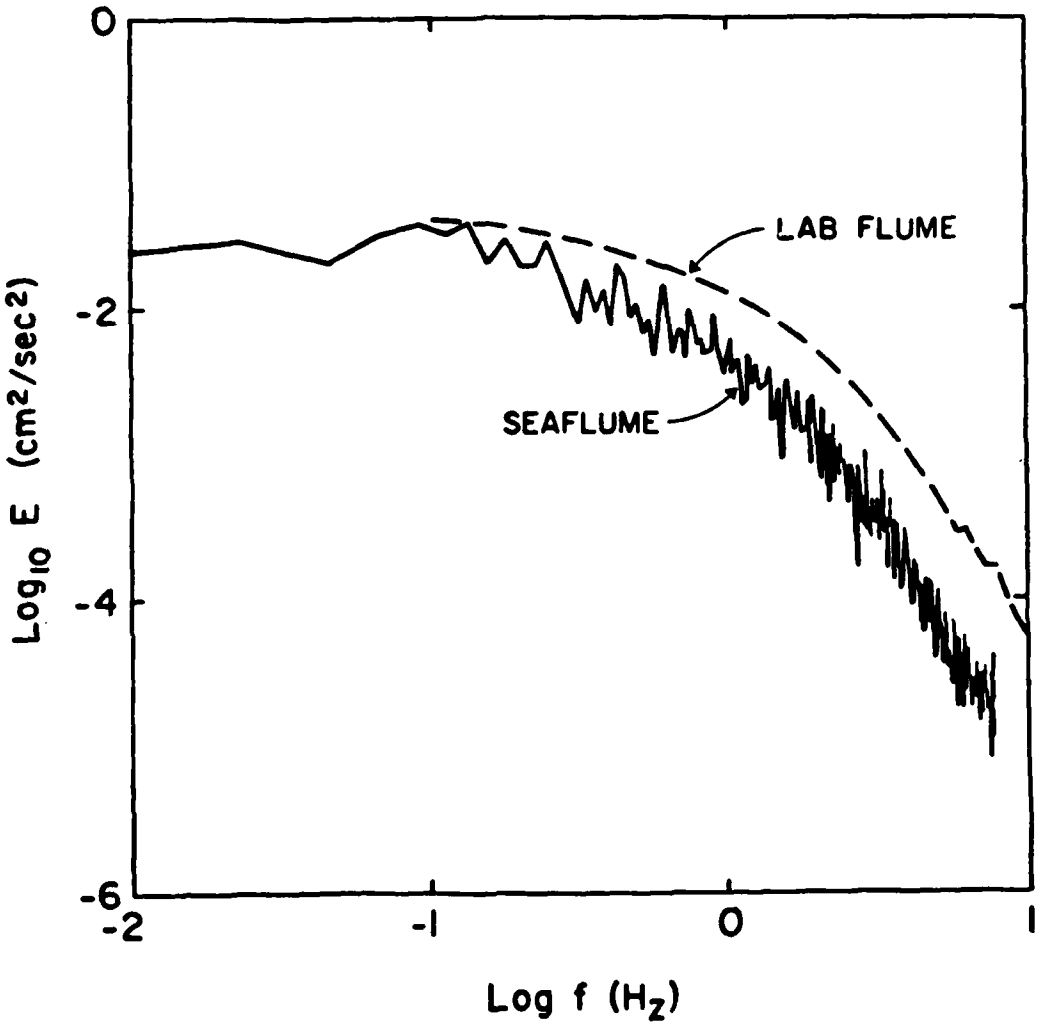


Figure 9: Turbulence spectra from run SF19 top sensor (solid line) and from a fully developed smooth turbulent boundary layer in a laboratory flume (dashed line).

We conclude that U_* from propellor measurements underestimate values of U_* from wall measurements because of incomplete boundary layer development. The November experiments (SF1-SF7) did not include hot film measurements. We, therefore, increase the calculated values of U_* for SF1-SF7 by a factor of 1.7, the average value of the ratio of hot film U_* to propellor U_* during the June experiments (SF15-23). It is felt that this procedure, although approximate, is better than accepting uncorrected data strongly suspected of containing a systematic bias.

3.2 Summary of Results

Flow velocity and threshold parameters calculated from the velocity and grain size data are summarized in Table 4. The value of U_* was found by using equation (2) for SF1-7 and multiplying by 1.7, and the hot film data from the flume top wall for SF15-23. The constants $Z_o = d_{65}/30$ and $C = 6.1$ were used in equation (2). The diameter d_{65} represents the grain size of the 65th percentile in the cumulative frequency distribution for the bed sediment, which is suggested as the most appropriate roughness parameter in poorly-sorted sediments (Einstein, 1950). The constant C is from laboratory studies of flow over regular corrugated roughness elements (Daily and Harleman, 1966), a first approximation to the bed conditions encountered here.

Also presented in Table 4 is an estimate of U_{100}, the mean-flow threshold velocity at 100 cm above bottom. U_{100} was calculated from equation (2) using an arbitrary value of $Z_o = 5.0$ cm and $C = 6.1$. The value of U_{100} is not particularly sensitive to the choice of Z_o, but is strongly affected by C. The values of $Z_o = 5.0$ cm was thought to represent the roughness felt by a geophysical scale boundary layer flow better than the grain roughness d_{65}.

Table 4: Flow velocity and threshold parameters determined by SEAFLUME measurements for various sediment types.

Run	U (cm/sec)	U_* (cm/sec)	U_{100} (cm/sec)	d_{65} (cm)	θ_T	Re_*	$\sqrt{\Xi}$
1	11	.64	13.8	.0238	.01101	1.159	11.05
3	18	1.03	22.4	.0209	.03284	1.647	9.09
4	16	.94	20.3	.0268	.02112	1.919	13.20
5	23	1.32	28.6	.0209	.05362	2.105	9.09
6	25	1.43	30.9	.0198	.06625	2.158	8.38
7	15	.87	18.8	.0230	.02107	1.523	10.50
15	15	.89	19.3	.0202	.02524	1.798	11.32
16	10	.81	17.5	.0270	.01564	2.187	17.49
18B	18	1.10	23.8	.0334	.02332	3.674	24.06
19	8	1.05	22.7	.0082	.08654	.861	2.93
20	10	.93	20.1	.0170	.03275	1.581	8.74
21	11	.82	17.8	.0209	.02071	1.714	11.91
23	16	1.30	28.2	.0259	.04200	3.367	16.43

Data plotted on Shields and Yalin diagrams (Figure 10) are in reasonable agreement with the threshold curves, considering experimental conditions and the approximations needed to derive the values of U_*, θ_T, Re, and Ξ. Data scatter seems greater on the Yalin diagram only because the Yalin curve is presented as a single-valued function. In fact, uncertainty in the Yalin curve is of the same order as expressed by the shaded area on the Shields diagram, because the Yalin curve (from Miller et al., 1980) was derived from the averaged Shields curve.

4. DISCUSSION

Sediments encountered during the SEAFLUME experiments ranged from gravelly sands, to sands, to sandy muds. Beds were sometimes smooth, but more often deformed by irregular bedforms. Consequently, the assumptions made in comparing the field results to laboratory threshold values for smooth monosized sediments were not often met. It is, therefore, not surprising that some of the data fall off the accepted threshold curves (Figure 10).

The presence of about 5% or more of mud (diameter < .0065 cm) in the sediments suggests that cohesion should be considered as an additional force resisting erosion. Data in Table 2 show that 7 of the 13 flume runs had > 5% muds; two (SF19 and SF23) had > 70% mud.

The muddy sediments plot on or reasonably close to the Shields curve (Figure 9), indicating that the sandy-muds and muddy sands behaved as noncohesive sediments characterized by the mean diameter of the sand fraction. We speculate that the muds (even for SF19 which had 86% mud) were unconsolidated and only slightly cohesive. Further, the mud fraction may have been located mostly in the sediment pore spaces between sand grains or below the sediment water interface. The diver sampling procedures tended to

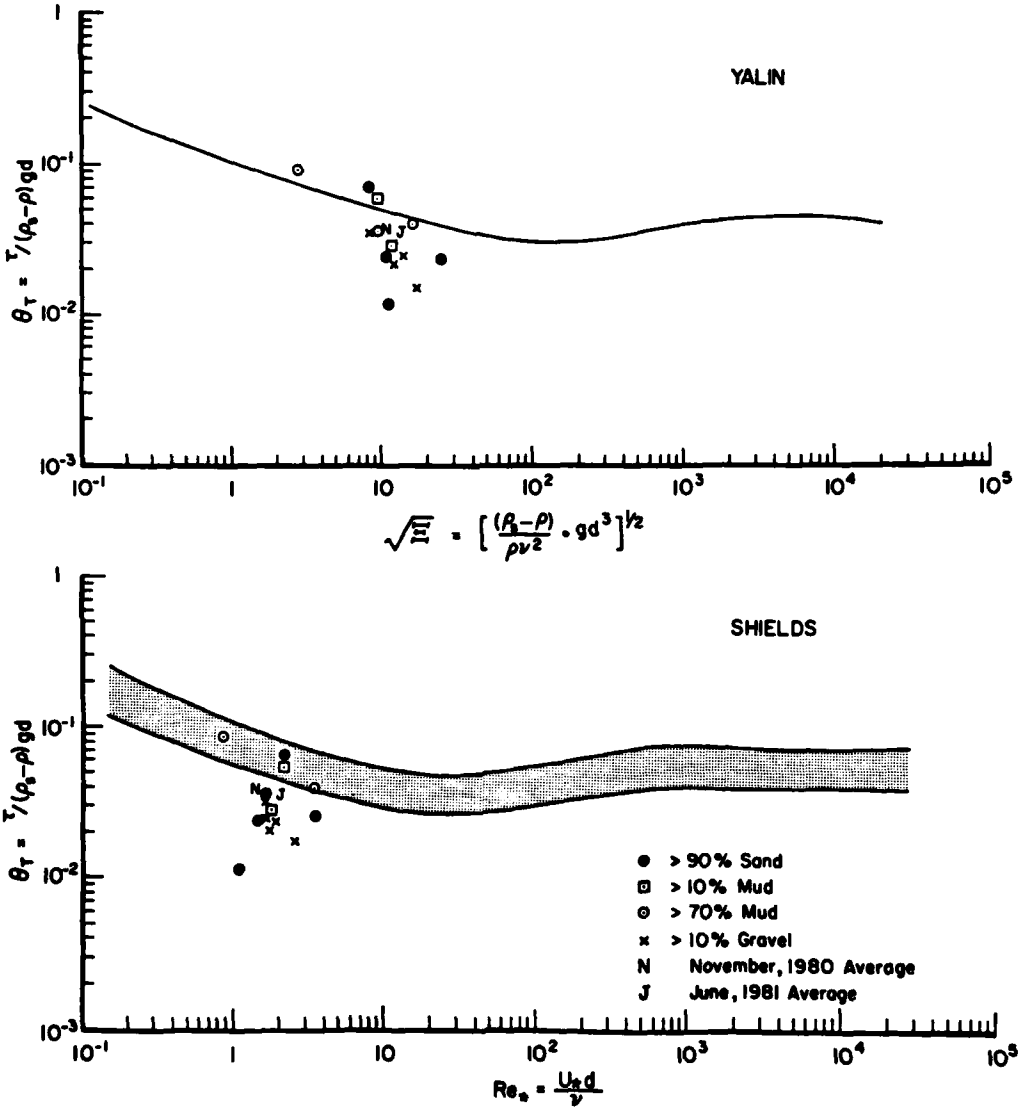


Figure 10 : Shields and Yalin diagrams with SEAFLUME data plotted for comparison with threshold curves for erosion. Curves are from Miller et al. (1977). Symbols are explained on the figure and are meant to show association of data points on the basis of sediment texture.

Table 5: Cruise averaged values of U_*, U_{100}, and threshold parameters.

Cruise	U_* (cm/sec)	U_{100} (cm/sec)	Re_*	θ_T	$\sqrt{\Xi}$
November 1980	1.04	22.5	1.75	.0034	10.2
June 1981	0.99	21.3	2.17	.0035	13.3

homogenize any layering or other stratigraphy so that the position of the mud fraction with respect to the sediment surface is not known. In any case, the muddy sediments behaved more like sands and cohesion seems to be negligible.

Gravelly sediments plot mainly below the threshold curve (Figure 10), suggesting either a lower U_* value than calculated, or a larger effective diameter. In this case, we interpret the results as indicating larger effective diameters. Evidently, the representative diameter d_{65} used to calculate θ_T, Re_* and Ξ does not adequately characterize the bed roughness. The choice of a diameter weighted by the sand plus gravel fractions would no doubt bring the data into closer agreement with the threshold curve.

For the cases where the sediments were sands with only traces of gravel and sand (Figure 10), the data exhibit reasonable scatter and so can be said to agree with the Shields and Yalin criterion for erosion.

Finally, cruise-averaged values of the threshold parameters are given in Table 5 and are also plotted on Figure 10. They are seen to plot very close to their expected positions, in very close agreement with the threshold criterion. Considering the approximations necessary to arrive at these values, the averaged values of U_* and the other parameters can be considered to adequately represent the average threshold conditions necessary to erode the sediments encountered at the sand cap site.

5. CONCLUSIONS

Erosion experiments carried out using a sea-going flume to determine threshold U_* and U_{100} for the sediments capping the Corps of Engineers dumpsite are compared with expected values of U_* derived from the threshold shields and Yalin curves. Reasonable agreement is found between the observed and expected values lending support to the assumption that the threshold U_*

values found here can be used in other calculations of transport and erosion rates. Such calculations are the subject of a separate part of this study (Young, 1982, this report).

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APPENDIX A:

SEAFLUME 1-24

INCIPIENT MOTION NOTES

SF1 (14 NOV 1980)

Initial Bed Description:

The bed is fairly flat and smooth. Some depressed areas are present near the left portion of the photograph. A small amount of shell hash is present and some organic material or "fluff" covers most of the bed surface. Note the small dark area located ten centimeters from the down-stream edge and five centimeters from the left side of the photograph.

Bed Description at Threshold:

The depression noted in the initial photograph appears deeper and more defined. Shell hash is slightly more exposed and the "fluff" material is arranged in a linear pattern in the direction of flow. The small dark are noted previously is larger and has changed shape. Threshold velocity for this run is 11 cm/s.

SF2 (14 NOV 1980)

Initial Bed Description:

A large round depression is located near the left side of the photograph. The left side of this depression is bordered by a ridge of mostly shell material. The rest of the bed is flat and smooth and is covered with a small amount of shell hash and some organic "fluff". The panel on the seaflume jammed during this run. The highest velocity reached was 7 cm/s. No motion was detected over the entire sequence.

SF3 (15 NOV 1980)

Initial Bed Description

There is a small area of highly concentrated shell hash in the upper left corner of the photograph. A curving depression is located just to the right

of this shell hash and extends down to the mid-left portion of the photograph. There is a small amount of shell material scattered over the rest of the bed. Some organic "fluff" is also present.

Bed Description at Threshold:

The curving depression has been partially filled. There is a newly formed depression located 5 cm below the left side of the flow meter propeller. Some shell material has been displaced. There is indication of slight lineation patterns forming in the direction of flow. Threshold velocity for this run is 18 cm/s.

SF4 (15 NOV 1980)

Initial Bed Description:

A high concentration of shell hash borders the left side of the photograph. The rest of the bed is flat and smooth.

Bed Description at Threshold:

The shell hash is unchanged. Just to the right of the hash, near the top of the photograph, there are some small, newly-developed depressions. Threshold velocity for this run is 16 cm/s.

SF5 (16 NOV 1980)

Initial Bed Description:

The bed is characterized by several small depressed areas. A small amount of shell material is present in the top left portion of the photograph.

Bed Description at Threshold:

Bed has been smoothed. Most depressions are filled. Slightly more shell hash is present in the upper left corner. Threshold velocity for this run is 23 cm/s.

SF6 (16 NOV 1980)

Initial Bed Description:

Bed is characterized by undulatory ripples. There is a small amount of shell hash present.

Bed Description at Threshold:

The ripples are slightly more oriented in the direction of flow. The are in the upper left corner has been smoothed slightly. Changes in shadows between ripples are evident, indicating movement of surrounding sediments. Threshold velocity for this run is 25 cm/s.

SF7 (16 NOV 1980)

Initial Bed Description:

The bed is fairly flat. There is a curved ridge just to the left of the propellor. A couple of large shell pieces are sticking up out of this ridge. There is an area of relief on the left edge of the photograph about mid-way between the top and bottom. There is a small dark are located about 4 cm from the top and 4 cm from the left side.

Description of Bed at Threshold:

The small dark are noted has changed size and shape. The area of relief on the left has undergone slight change and is less defined. The large shell

piece below the propellor is more exposed and the ridge below it has slumped. Threshold velocity for this run is 15 cm/s.

SF8 (17 NOV 1980)

Initial Bed Description:

Bed is fairly flat and smooth. There is a curved line of shell hash to the left of the propellor. To the left of the lower tip of this hash is some slight relief. No motion was detected over this entire run. First and last photos of the run are presented for comparison. Velocity ranged from 0-36 cm/s.

SF9 (17 NOV 1980)

Initial Bed Description:

Bed is smooth with a large depression to the left of the propellor. A small amount of shell hash is present.

Bed Description at Threshold:

Some erosion has occurred 7.5 cm from the top on the left side of the photograph. Also, a slight ridge has formed about 4 cm down-stream from the propellor. Threshold velocity for this run is 13 cm/s. Evidence of threshold motion is noted earlier in this sequence. Note the last three photos presented for this run. The first two pictures show a trail being made by a gastropod. In the third photo (velocity = 9 cm/s) the trail is partially covered. Since this study is interested in movement of undisturbed sediment, the erosion of this freshly bioturbated sediment is not regarded as representing the threshold.

SF10 (17 NOV 1980)

Initial Bed Description:

There is a curved depression half-way between the propellor and the left edge of the photograph. Some worm tubes are located on the left side of the photograph about 10 cm from the top.

Bed Description at Threshold

There is a slight ridge forming to the left of the propellor: The worm tubes have been displaced. A piece of shell material is now present about 4 cm from the top on the left side. Threshold velocity for this run is 17 c/s.

SF11 (17 NOV 1980)

Run Aborted

SF12 (17 NOV 1980)

Run Aborted

SF15 (26 JUN 1981)

Initial Bed Description:

The bed is characterized by prominent depressions and mounds. There is a fair amount of organic "fluff" on the bottom.

Description of Bed at Threshold:

The depressions and mounds have become smoothed out slightly, especially above the drag plate arm. A slight lineation pattern is developing. Threshold velocity for this run is 15 cm/s.

SF16 (27 JUN 1981)

Initial Bed Description:

Bottom is fairly flat. There is a lot of organic "fluff" present. Several worm tubes are noticed.

Bed Description at Threshold:

Aggregates above the drag plate arm are being swept away. Threshold velocity for this run is 10 cm/s.

SF17 (27 JUN 1981)

Initial Bed Description:

The bed has some large pieces of shell scattered over it. Otherwise, it is fairly flat. This sequence was difficult to analyze. The photograph showing threshold motion could not be identified. The first and last photograph of this run are shown for comparison. Velocity ranged from 0-10 cm/s for this run.

SF18A (28 JUN 1981)

Initial Bed Description:

The bed has many small depressions and mounds. It appears to be fairly muddy. This run was aborted. No flow was ever created in the SEAFLUME.

SF18B (28 JUN 1981)

Initial Bed Description:

The bed has many prominent mounds and depressions. There is a large, deep depression to the left of the drag plate arm. Notice the small mound about 2 cm below the left side of the propellor.

Bed Description at Threshold:

Uncovering of some shell material has occurred. There is a worm tube present 5 cm from the top on the left side of the photograph. The area around the small mound noted in the initial photograph has changed slightly. There are now three small mounds present there. Threshold velocity for this run is 18 cm/s.

SF19 (28 JUNE 1981)

Initial Bed Description:

Bed had some small depressions and mounds present. Organic "fluff" covers the surface.

Description of Bed at Threshold:

Small mounds above and below the drag plate arm are gone. Bed is generally smoother. Threshold velocity for this run is 8 cm/s.

SF20 (29 JUN 1980)

Initial Bed Description:

Bed is fairly flat and smooth. There are some small mounds, probably sediment covered rocks or shell present. There is a worm tube located just above the mid portion of the drag plate arm.

Bed Description at Threshold:

The small mound that was located just above the drag plate is gone. The worm tube has been swept away. The small round mound that is just above the mid portion of the drag plate arm has changed shape slightly and a new smaller mound has formed above it. A trail has been uncovered just below the drag plate. Threshold velocity for this run is 10 cm/s.

SF21 (29 JUN 1981)

Initial Bed Description:

Bottom is covered with many large rocks and shells.

Bed Description at Threshold:

Slight uncovering of rock and shell material has occurred. This is evident in area 2-3 cm to the left of the propellor. Threshold velocity for this run in 11 cm/s.

SF22 (29 JUN 1980)

Run Aborted

SF23 (30 JUN 1981)

Initial Bed Description:

Bed is fairly flat and muddy looking. Organic fluff covers the surface. Many aggregates are present below the drag plate arm. There is a small crescent moon-shaped shadow 5 cm above the mid portion of the drag plate arm.

Bed Description at Threshold:

Aggregates are arranged in a linear pattern in direction of flow. A new shell is present just below the propellor. The cresent moon-shaped shadow has disappeared, indicating sediment motion in that area. Threshold velocity for this run is 16 cm/s.

SF24 (30 JUN 1981)

Initial Bed Description:

Bed is flat smooth and muddy looking. Organic fluff covers the surface. Threshold motion could not be identified for this sequence. The fine, low

density material or fluff, began to be removed as soon as current was induced, (second photo) exposing covered trails and worm tubes, but this probably does not represent true incipient motion. Velocity for this run ranged from 0-32 cm/s. Photos taken after velocity reached 11 c/s were disregarded due to piece of paper entering flume and causing deflection of the normal flow.

SF25 (30 JUN 1981)

Run Aborted

SF26 (30 JUN 1981)

Run Aborted

WAVE HINDCASTING FOR A SEDIMENT TRANSPORT MODEL OF CAPPED MATERIAL AT THE NEW YORK DREDGED MATERIAL DUMPSITE

by

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1. INTRODUCTION

1.1 Wave Hindcasting and Forecasting

Wave hindcasting and forecasting has evolved since World War II from Sverdrup-Munk (1947) Bretschneider (1957) method and the Pierson-Neuman-James (1955) method to the Pierson-Moskowitz (1964) spectral method. More recent developments have resulted from the Joint North Sea Wave Project (JONSWAP, Hasselmann et al., 1973) and experiments by Liu and Ross (1980) in Lake Michigan integrating stable and unstable atmospheric conditions.

Two basic concepts can be used for wave hindcasting: the wave spectral model and the wave parametric model. The first one is based on the integration of the wave energy balance equation and the second one assums an approximate invariance (Hasselmann et al., 1976) of the normalized wave spectral shape with fetch; the latter is easier to use as wave heights and frequencies are calculated directly on the basis of wind intensity, fetch and duration.

1.2 Seasonal and Infrequent Events

As the ultimate objective of this study is to contribute data to evaluate the probability of breaching as well as the ultimate life span of a sediment cap, it is important to consider both the seasonality of the wave climate at the dumpsite site, but also the infrequent events not well represented by monthly-averaged regional wave data.

2. SETTING OF THE NEW YORK BIGHT DUMPSITE

2.1 Location of Depth

The dumpsite for the dredged material (mud) in the New York Bight Apex is located 9.8 km due South of Ambrose Lightship, at a depth of 27 to 30 m (Figure 1).

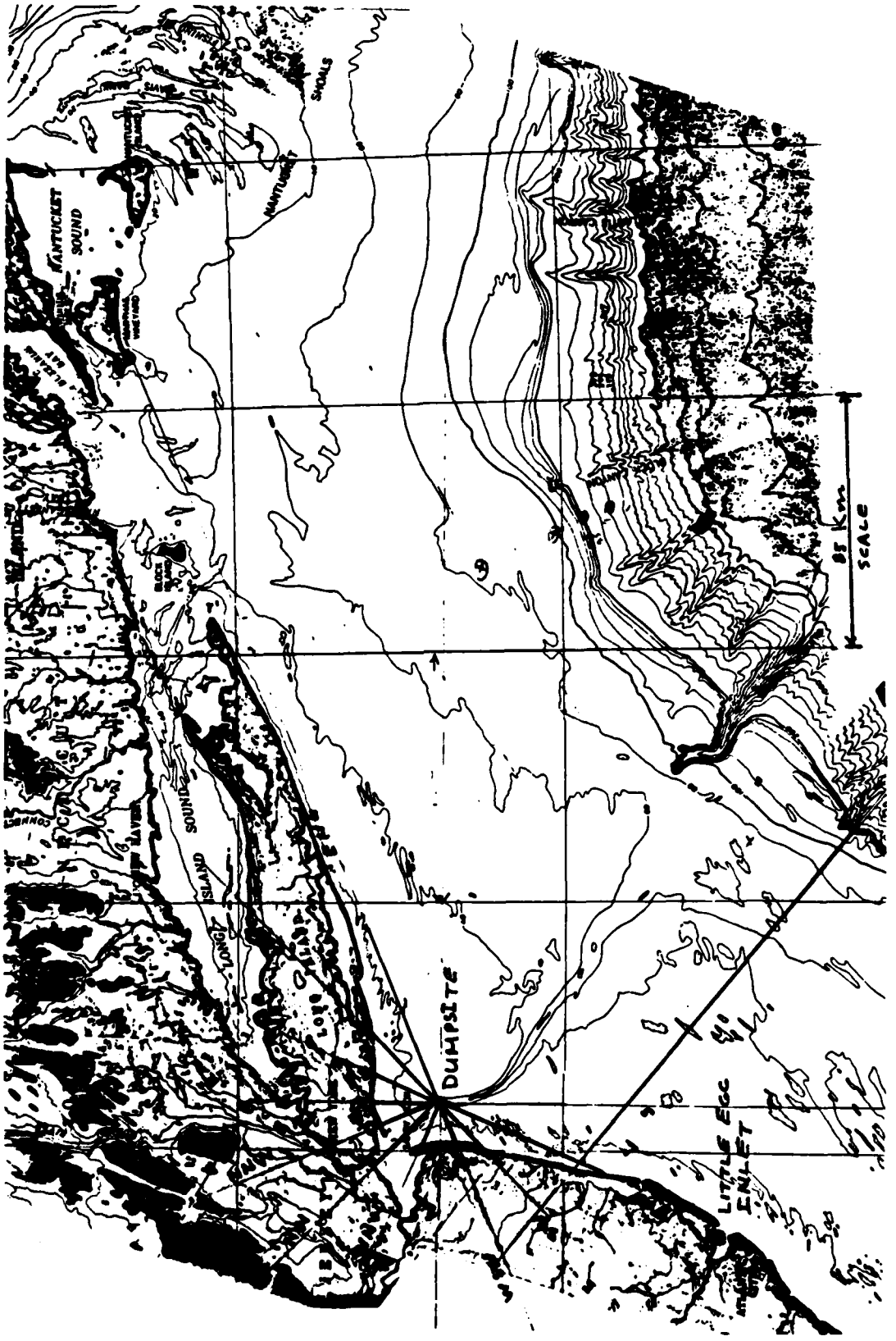

Figure 1. Location map. Fetches from Ambrose Lightship are outlined. The dumpsite is located five nautical miles south of the Ambrose Lightship station. The location of EG&G survey at Little Egg Inlet is also shown on the figure.

2.2 Types of Sediments

Approximately 900,000 cubic yards of muddy sediments that had failed the ocean dumping pollution criteria had to be capped. Approximately 500,000 cubic yards of sediments finer than sand and 1,500,000 cubic yards of sandy sediments were emplaced in two layers between July and November 1980.

3. DATA BASE

3.1 Ambrose Lightship (ALS)

The data available for this study are Ship's Weather Observations log sheets on microfiches. The microfiches available cover the period from November 1956 to December 1980. According to the Index of Surface Weather Records (National Climatic Center) the data were recorded at a height of 18 feet (from a lightship) until 1966 and at a height of 94 feet from a tower since 1967. The data recorded are in accordance with the International Weather Ship Weather Code: date, time, sky condition, present weather, visibility, wind: speed and direction; state of the sea: height and period; sea water temperature, air temperature, and barometric pressure.

3.2 Public Service Electric and Gas Company of New Jersey (PSEG)

The Public Service Electric and Gas Company of New Jersey was engaged in an environmental site assessment off Little Egg Inlet, New Jersey to evaluate the site proposed for the nuclear powered Atlantic Generating Station. EG&G environmental consultants carried out a wave observation program in September, October and November 1974. During the three-month observation period, a Datawell Waverider Wave Measurement System was deployed at the proposed site for the generating station along with three Clinet CI-25 Wind Recorders at a height of 10 m in the vicinity of the station. Air and sea temperatures were also recorded during the same interval. This survey provided an excellent set

of data of four records per day for wave height and period, wind velocity and direction, and air and sea temperatures during these three months. Although these data are recorded 75 km south of the dumpsite, they are useful to analyse waves coming from offshore.

4. OBJECTIVES OF THE STUDY

(1) The immediate objective of this study is to examine the visual wave observations recorded at the Ambrose Lightship to determine how they can be used as input for the sediment transport model.

(2) Winds and waves recorded at Ambrose Lightship are correlated in order to verify existing models and to assess the best relationships for that location.

(3) Winds from the John F. Kennedy Airport are correlated with those of Ambrose Lightship. Wind data from John F. Kennedy Airport can then be used to extend the investigations at the dumpsite.

(4) Generation of waves in the Atlantic Ocean outside the study area is analysed for the period November 1980 to June 1981.

5. DATA ANALYSIS

5.1 Ambrose Lightship (ALS)

5.1.1 Summary of Data

Records from microfiches were transferred to a computer file. Four records per day at 6-hour interval were copied: month, date, hour, wind direction (16 points of compass), wind velocity (knots), state of the sea: height (feet), period (seconds); sea water temperature (°F), air temperature (°F), and barometric pressure (inches Hg) for a total of 1464 records.

Data from ALS for the year 1980 are summarized on Figure 2. The first column on the figure indicates the mid-point value of the corresponding cell on the histogram; the second column, the cell fraction, and the third column the number of observations for each cell of the histogram.

Wind direction: (degrees true north) The histogram shows that the wind is blowing predominantly from the quadrant northwest-northeast and also from the southwest.

Wind velocity: (meters per second) The maximum velocity recorded is 23.2 m/s and the mean value is 5.4 m/s. The histogram shows that the events that reach an intensity of 14 m/s or more are rare; 96.3% of the time the wind intensity is below that level.

Wave height: (meters) The highest wave height recorded is 3.7 m and the mean wave height is 0.60 m. The first row outlines the zero-height records, that is 284 records of calm. The histogram shows a break between 1.66 an 2.00 meter wave heights, as indicated by the number of observations for each cell.

Wave period: (seconds) The maximum wave period recorded is nine seconds and the mean period is 1.91 seconds. In some instances visual observers have a tendency to overestimate wave periods (Schneider and Weggel, 1981) and in other cases to underestimate it (Quayle and Changery, 1982). At the Ambrose Lightship the observations seem to be biased in the latter direction.

5.1.2 Fetches

The fetches for the 16 points of the wind rose from Ambrose Lightship are shown on Figure 1. It shows in particular that the dumpsite location is quite protected and that unlimited fetches are restricted to winds from the quadrant east to south.

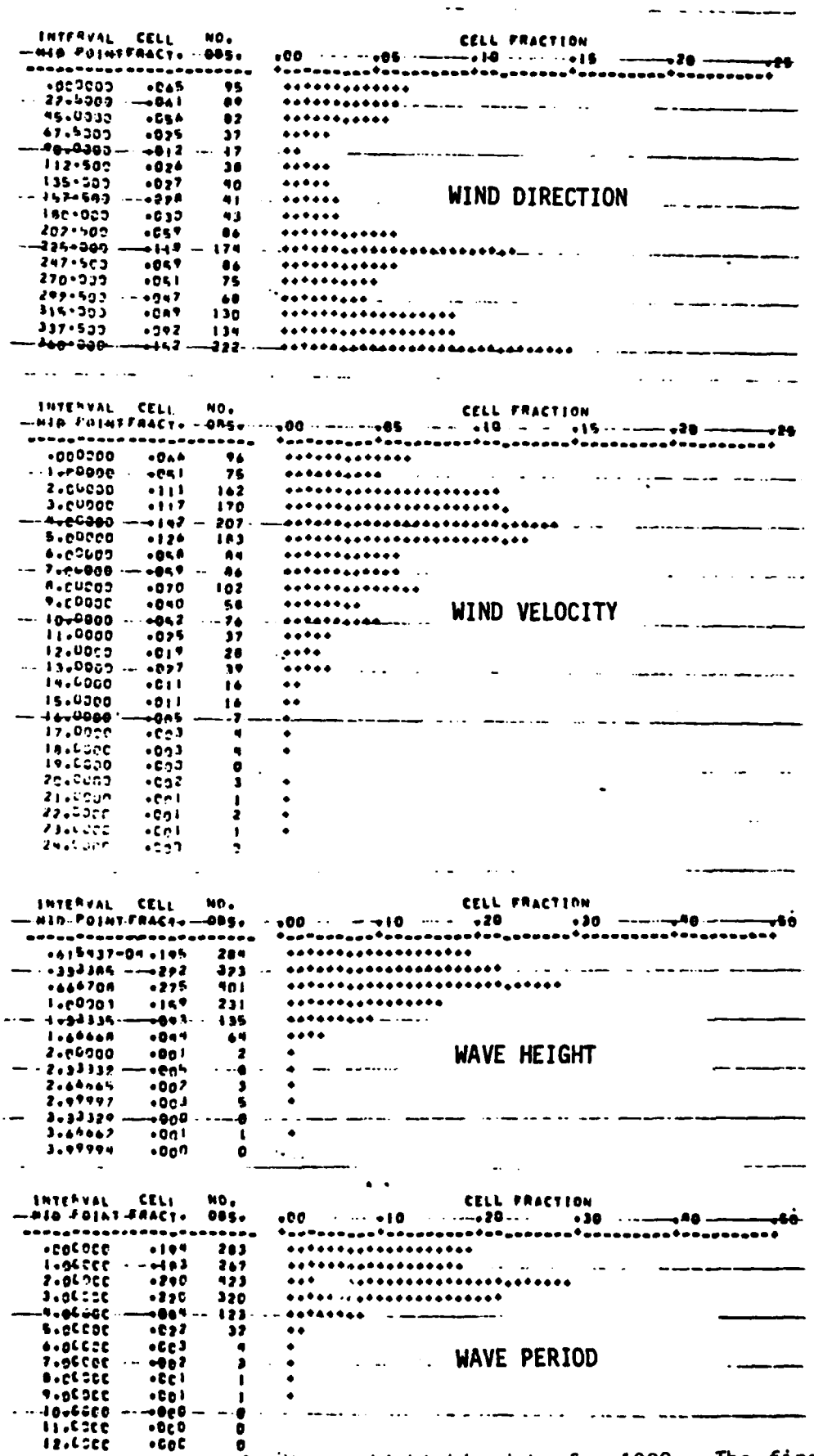

Figure 2. Histograms of Ambrose Lightship data for 1980. The first column on the figure indicates the mid-point value of the corresponding cell (first = zero values); the second column, the cell fraction; and the third column, the number of observations for each cell of the histogram.

5.2 Public Service Electric and Gas Company of New Jersey (PSEG)

The wind data recorded at PSEG were vector averaged from hourly averages of three wind sensors 10 km apart that provided accurate identification of the local wind. Wave records of 20 minutes duration from the wave rider buoy were made four times a day, every six hours. The wave height and period were determined from energy spectrum analyses, the period (peak spectral period T_s) corresponding to the frequency band containing the most energy and the wave height (significant wave height H_s) being four times the standard deviation of a wave record.

6. CORRELATION OF WINDS AND WAVES

The development of generalized concepts related to wind generated waves is summarized by Sylvester (1974). Four dimensionless parameters can relate the energy source to the energy sink all linked by the important variable of wind velocity in a dimensionless form:

Source	Fetch gF/U^2
	Duration gt/U
Sink	Wave height gH/U^2
	Wave period $gT/2\pi U$

g: gravitational acceleration
F: fetch
U: wind velocity
t: wind duration
T: wave period
H: wave weight

6.1 Limited Fetch

It has been pointed out by Kitaigorodskii (1962) that fetch-limited wave parameters, when non-dimensionalized in term of U and g, should be functions only of the single non-dimensional variable $X = gF/U^2$ identified as the non-dimensional fetch parameter. Similarly the non-dimensional peak-energy frequency is defined as $V = U_{10}f_m/g$ and the non-dimensional total energy is defined as $e = Eg^2/U_{10}^4$. These parameters are related, but the functional forms vary among different studies. For instance, Hasselmann et al. (1976) have developed the following equations for the non-dimensional peak-energy frequency (V) and the non-dimensional total energy (e).

$$V = 3.5\ X^{-0.33} \tag{6.1}$$

$$e = 1.6 \times 10^{-2} X \tag{6.2}$$

where for a given wave-energy density spectrum S(f), f_m is the peak-energy frequency and $E = S(f)df$ is the measure of total energy per unit surface area with the constant factor ρg left out. The significant wave height is defined as $H_s = 4\sqrt{E}$.

Measurements during variable atmospheric conditions led Liu and Ross (1980) to define distinct relationships for stable and unstable atmospheric conditions:

Stable conditions

$$V = 2.05\ X^{-0.27} \tag{6.3}$$

$$e = 6.8 \times 10^{-8}\ X^{1.1} \tag{6.4}$$

Unstable conditions

$$V = 1.9\ X^{-0.27} \tag{6.5}$$

$$e = 1.2 \times 10^{-7}\ X^{1.1} \tag{6.6}$$

6.2 The Effect of Wind Stability

It is a recognized fact that waves on the ocean develop more rapidly and reach greater heights when the air temperature is lower than the water temperature. The effect of atmospheric stability has been analysed by Cardone (1969). This author developed an algorithm to calculate wind friction velocity (U_*) using wind velocity (U), air temperature (T_a), sea temperature (T_s) and height of measurements (Z) above the sea as inputs. Cardone's model is based on different sets of assumptions. Cardone proposes (p. 39) that "at least for situations in which the high frequency part of the wave spectrum is a reflection of the local wind (a condition common to active wave generating situations), the roughness parameter can be expressed in terms of physical constants and U_* only".

$$Z_o = A_1/U_* + A_2\, U_*^2 + A_3 \tag{6.7}$$

so that the drag coefficient, referred at 10 m, C_{10} is minimum at U_{10} = 6 m/s. Then

$$Z_o = 0.684/U_* + 4.28 \times 10^{-5}\, U_*^2 - 4.43 \times 10^{-2}. \tag{6.8}$$

Cardone also explains that a universal relation should exist between the non-dimensionalized wind shear and temperature gradient

$$\phi_u = \frac{Kz}{U_*}\frac{\partial u}{\partial z} \tag{6.9}$$

$$\phi_t = \frac{Z}{T_*}\frac{\partial \theta}{\partial Z} \tag{6.10}$$

If velocities and temperatures were measured at more than one elevation the problem could be solved readily. In most cases however wind velocity and air temperature are measured at one height only.

The gradient of potential temperature can be defined as

$$\frac{\partial\theta}{\partial z} = \frac{\phi_u\,(Z_a/L') - (\theta_a - \theta_s)}{Z[\ln(Z_a/Z_o) - \psi(Z_a/L')]} \tag{6.11}$$

where

θ_a = air temperature

Z_a = height at which θ_a is measured

θ_s = sea temperature

Z_o = roughness parameter (see equation 6.8)

U_* = friction velocity (shear velocity)

Then

$$\phi_u(Z/L') = \frac{Kz}{U_*}\ \frac{\partial U}{\partial Z} \tag{6.12}$$

$$\psi(Z/L') = 1 - \phi_u - 3\ln\phi_u + 2\ln\left(\frac{1+\phi_u}{2}\right) + 2\tan^{-1}\phi_u - \frac{\pi}{2} + \ell n\left(\frac{1+\phi_u^2}{2}\right) \tag{6.13}$$

$$L' = \frac{U_*^2\,\bar{\theta}\,[\ln(Z_a/Z_o) - \psi(Z_a/L')}{K^2 g(\theta_a - \theta_s)} \tag{6.14}$$

$$U_* = \frac{K\,Um}{[\ln(Zm/Zo) - \psi(Zm/L')]} \tag{6.15}$$

K = Cte = 0.4

The problem is solved by iteration:

1. An initial value for L' is calculated assuming $\psi = 0$ and $U_* = 0.04$ Um.

2. This first estimate of L' is used to solve equation (6.15) iteratively calculating ψ from equation (6.13), ϕ_u being solved implicitly by $\phi^4 - 18(Za/L')\phi^3 - 1 = 0$ and U_* is computed.
3. U_* is used to recompute the stability length from equation (6.14) iteratively.
4. A convergence criterion is set for $L'(n) - L'(n-1) < \epsilon$.

Liu and Ross (1980) have conducted experiments over Lake Michigan under different atmospheric stability conditions. They concluded that the discrepancy between stable and unstable atmospheric conditions could be accounted for by using Cardone's model to determine the wind friction velocity that integrates the atmospheric conditions. By analogy with the equations developed previously, a single equation is developed to account for stable and unstable atmospheric conditions:

$$e_* = 3.5 \times 10^{-5} X_*^{1.1} \qquad (6.16)$$

where the friction velocity U_* replaces the wind velocity at 10 m, $X_* = gF/U_*^2$ and $e_* = Eg^2/U_*^4$.

6.3 Unlimited Fetch

For the conditions of unlimited fetches, the wave height depends solely on wind velocity. Silvester (1974) summarizes the formulas obtained by different workers:

$H_{1/3} = 0.0268\ U_{10\text{-}12}^2$ Sverdrup and Munk, 1947; Bretschneider, 1957.

$H_{1/3} = 0.0510\ U_{7.5}^{5/2}$ Pierson, Neumann and James, 1955.

$H_{1/3} = 0.0133\ U_{grad}^2$ Darbyshire, 1959.

$$H_{1/3} = 0.0213\ U^2_{19.5}$$ Pierson and Moskowitz, 1964.

$H_{1/3}$: wave height in meters of the highest 1/3 of waves and taken as the equivalent of the significant wave height H_s.

U: wind velocity in meters per second at the height above sea level indicated by the subscript.

6.4 Differentiation Between Sea and Swell

JONSWAP (Hasselmann et al., 1976) has provided a substantial base to evaluate the nature of different types of waves. The e (non-dimensional energy) vs V (non-dimensional peak-energy frequency) relationship can be used as a model for prediction of equilibrium state for growing waves under uniform wind field (Hasselmann, 1978). The relation between e and V is defined by Hasselmann et al. (1976) as:

$$e = 5.1 \times 10^{-6}\ v^{-10/3} \tag{6.17}$$

and by Liu and Ross (1980) as:

$$\text{Stable conditions} \quad e = 1.26 \times 10^{-6}\ V^{-4.07} \tag{6.18}$$

$$\text{Unstable conditions} \quad e = 1.64 \times 10^{-6}\ v^{-4.07}. \tag{6.19}$$

It is assumed that wave growth patterns may start off-equilibrium and grow towards equilibrium until fully developed conditions are reached when V reaches a lower value of 0.13 to 0.15. Values of V lower than 0.13 are indicative of swell conditions as schematized on Figure 3. This criterion is used to distinguish sea from swell waves in the study area.

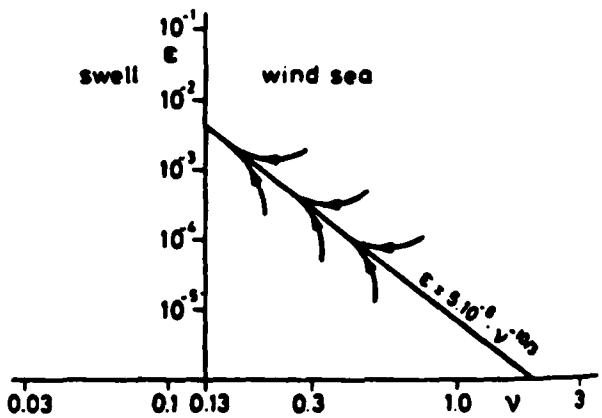

Figure 3. Wave growth shown in relation with non-dimensional total energy (e) and non-dimensional peak-energy frequency (V). After Hasselmann, 1976.

7. EVALUATION OF AMBROSE LIGHTSHIP WAVE HEIGHT AND WAVE PERIOD DATA

The first objective of this study is to provide wave heights and periods as input for the sediment transport model. For that purpose, the quality of data recorded at Ambrose Lightship is compared with those of PSEG.

7.1 Unlimited Fetch

7.1.1 Comparison of records from ALS and PSEG

To compare measurements recorded at ALS and FSEG both records were examined and those records corresponding to winds from unlimited fetches occurring simultaneously at both stations were retained (Table 1). Comparison of wind velocity, wave height and wave period is shown on Figure 4.

Wind velocity: The upper diagram of Figure 4 shows that wind velocities recorded at the two stations are essentially the same. The sharp peaks of some of ALS data probably result from the fact that wind velocity were read from an anemometer and represent instantaneous measurements while the records from PSEG are hourly averages from three anemometers.

Wave heights: Wave heights from both stations are reasonably well correlated although waves observed at ALS are often lower. This difference can be explained by the location of ALS further inside the apex of the New York Bight.

Wave period: No definite explanation is found to account for the marked discrepancy between computed wave periods at PSEG and the visual observations made at ALS. Evaluation of the accuracy of visually observed wave data indicates that visual observers may be biased and either overestimate (Schneider and Weggel, 1981) or underestimate (Quayle and Changery, 1982) wave measurements. The good agreement between wave heights as well as wind velocities make unlikely the probability that the wave periods at the two locations are as different as the records show.

Table 1

PSEG								ALS					
Mo	Da	Hr	Dir	Wv	Hs	Tm	ΔT	Hr	Dir	Wv	Hv	Tv	ΔT
9	8	21	150.00	4.00	.71	8.10	-7.00	19	180.00	4.63	.30	1.00	-2.78
9	12	9	105.00	.50	.71	9.30	-3.80	13	180.00	5.15	.30	3.00	2.22
9	12	15	150.00	3.00	.85	13.00	-3.80	16	180.00	8.24	.91	4.00	2.78
9	17	9	150.00	3.00	.44	8.10	-2.00	7	180.00	2.57	.00	.00	-1.67
9	18	15	180.00	3.50	.59	9.30	-2.00	19	180.00	7.21	.30	3.00	- .56
9	19	15	140.00	5.00	.62	9.30	-3.00	16	180.00	5.66	.30	3.00	1.67
9	19	21	140.00	5.00	.72	8.10	-3.00	22	180.00	7.21	.61	3.00	.00
9	20	9	90.00	.50	.68	8.10	-4.00	13	180.00	5.15	.00	.00	.56
9	21	15	185.00	10.00	1.43	4.60	-3.50	16	180.00	15.44	1.83	4.00	1.11
9	25	9	145.00	5.00	1.36	9.30	-8.00	7	135.00	10.30	.91	5.00	-4.44
9	25	15	180.00	5.50	1.22	9.30	-8.00	16	180.00	11.33	1.52	5.00	-2.78
9	27	15	170.00	6.00	.77	8.10	-4.00	16	180.00	9.27	.61	2.00	1.67
9	28	3	140.00	6.00	.77	10.80	-2.50	4	180.00	6.18	.30	3.00	.00
9	28	9	145.00	7.00	.57	9.30	-2.50	10	180.00	9.27	.30	3.00	1.11
9	28	15	140.00	7.00	.87	9.30	-2.50	16	158.00	7.21	.30	1.00	1.11
9	28	21	150.00	11.00	1.31	10.80	-2.50	22	180.00	15.44	1.22	4.00	.56
10	5	15	200.00	9.00	.69	9.30	-4.00	16	180.00	4.12	.30	3.00	5.56
10	11	21	135.00	5.00	.57	9.30	- .50	22	180.00	7.21	.30	1.00	-1.11
10	13	16	54.00	9.30	1.44	5.40	1.00	16	158.00	6.69	.61	2.00	-1.67
10	13	21	75.00	8.40	1.33	6.60	1.00	22	135.00	5.15	.61	1.00	-3.89
10	14	3	90.00	9.00	1.27	5.90	.00	4	135.00	9.27	.61	3.00	-2.22
10	14	9	120.00	9.50	1.32	5.40	.00	7	135.00	9.27	.91	3.00	-1.67
10	14	15	135.00	6.00	.85	5.00	.00	13	180.00	7.21	.61	3.00	.56
10	14	21	180.00	8.50	.92	4.10	.00	19	180.00	9.27	.91	3.00	1.67
10	24	21	150.00	4.50	.98	13.00	-2.00	19	180.00	5.15	.30	4.00	-1.67
10	28	9	90.00	5.00	.64	5.00	1.00	12	112.00	5.15	.61	4.00	-1.67
10	28	16	90.00	4.00	.62	5.40	1.00	15	112.00	5.15	.61	4.00	-1.11
10	28	22	140.00	4.00	.48	9.30	1.00	21	158.00	6.18	.30	4.00	-1.67
10	29	4	135.00	4.50	.44	9.30	1.50	3	180.00	7.21	.30	4.00	-3.33
10	29	10	150.00	4.50	.58	4.30	1.50	6	135.00	2.06	.00	.00	-1.11
10	29	16	175.00	5.00	.54	4.60	1.50	15	180.00	7.21	.61	4.00	1.11
10	30	10	165.00	5.00	.50	9.30	1.50	9	180.00	4.12	.00	.00	- .56
11	11	16	75.00	5.00	.88	10.80	-4.50	15	180.00	2.06	.30	3.00	-2.22
11	11	22	108.00	7.00	.94	10.80	-4.50	21	135.00	8.24	.30	4.00	-5.00
11	12	4	100.00	3.50	1.00	8.10	.00	3	112.00	5.15	.61	3.00	-3.33
11	12	10	100.00	7.00	1.06	5.40	.00	9	90.00	10.30	.61	4.00	-2.22
11	12	16	125.00	9.00	1.19	5.00	.00	15	135.00	9.27	.30	3.00	- .56
11	12	22	145.00	10.00	1.48	5.00	.00	21	135.00	13.38	.91	3.00	.00
11	19	16	195.00	5.00	.38	9.30	-2.70	15	180.00	4.12	.00	.00	.56
11	20	10	190.00	6.50	1.05	5.00	.00	9	180.00	7.72	.61	4.00	-1.67
11	20	16	200.00	8.00	1.11	5.40	.00	15	180.00	8.24	.61	4.00	1.11
11	23	16	215.00	5.00	.64	10.80	-7.00	15	180.00	4.12	.00	.00	-5.56
11	24	16	200.00	9.00	1.25	5.40	-2.50	15	180.00	10.30	.91	4.00	2.22

Mo = month, Da = day, Dir = wind direction, Wv = wind velocity, Hs = significant wave height, Tm = period of peak frequency, Hv = visual wave height, Tv = visual period, ΔT = sea-air temperature difference

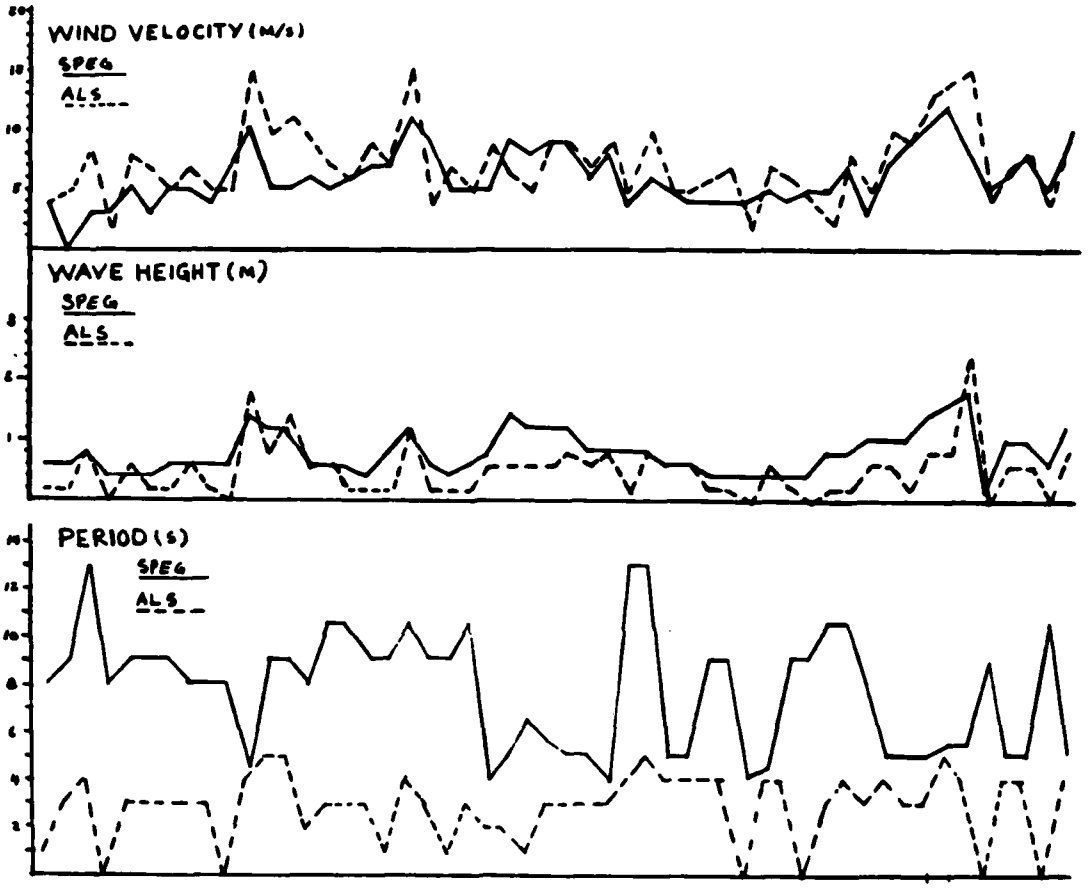

Figure 4. Comparison between the Public Service Electric and Gas of New Jersey (PSEG) data off Little Egg Inlet and the Ambrose Lightship data.

7.1.2 Alternative to determine wave period for ALS data (unlimited fetch)

To investigate further the discrepancy between wave periods at ALS and PSEG, we advance the hypothesis that the spectrum of waves at ALS is normal. In other words, it is assumed that the "shape invariance of wind-sea spectra" concept developed by Hasselmann et al. (1976) is valid in the New York Bight Apex. Based on the Pierson-Moskowitz (1964) spectra Hasselmann et al. propose:

$$f_m = \left(\frac{0.74}{1.25}\right)^{1/4} g/(2HU_{12.5}) = 0.14g/U_{19.5} \qquad (7.1)$$

where $U_{19.5}$ is the wind velocity in m/s at 19.5 m. At ALS the wind is measured at 28.7 m (94 ft). A wind velocity reduction of 4 percent (Silvester, 1974, Fig. 3-8) is used to transform the wind measured at a height of 28.7 m to a height of 19.5 m.

The distribution of wave periods corresponding to frequencies containing maximum wave energy at PSEG and wave periods observed visually at ALS are shown on Figure 5, as well as the computed wave period on the basis of wind speed, as discussed above. Figure 5 reproduces the lower portion of Figure 4 and outlines with more detail the discrepancy between the wave periods recorded at PSEG and those observed at ALS. The figure also shows that a better estimate of wave periods at ALS could be obtained using the relation: $T = 0.7289\ U_{19.5}$ than using visual observations. The value of the coefficient is related to height at which the wind velocity is measured. The following simplified correlation is used:

$U_{28.8}$	$U_{19.5}$	U_{10}
1.04	1.00	0.93
1.00	0.96	0.90

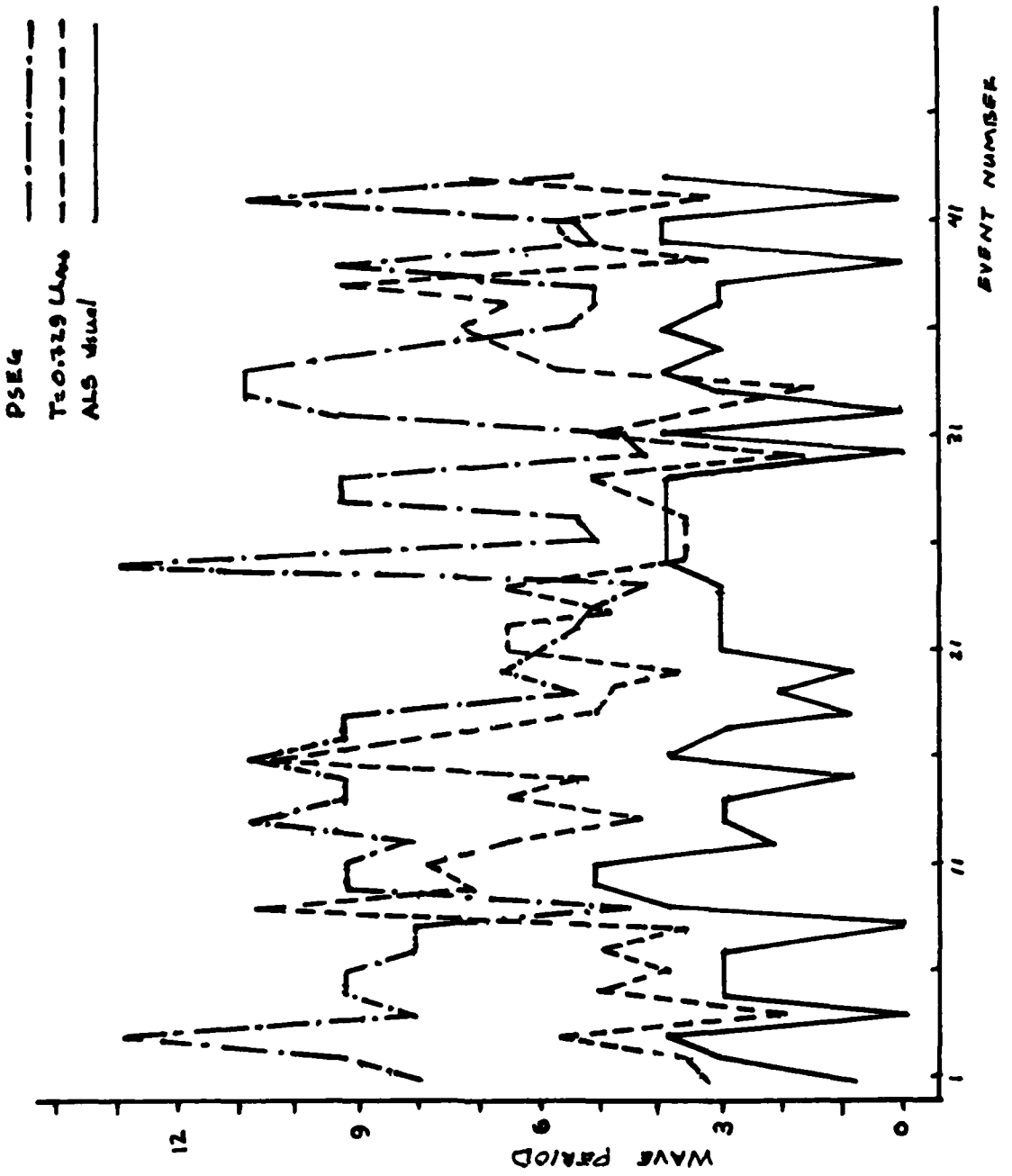

Figure 5. Comparison of wave periods for 43 concomitant events at Little Egg Inlet (PSEG) and the dumpsite. For the dumpsite, visual observations are plotted as well as wave periods calculated on the basis of wind velocity.

7.2 Limited Fetch

Limited fetches comparisons between ALS and PSEG are not possible. The correlation between wind generated waves and visual observations at ALS are discussed in the next chapter.

8. CORRELATION OF WIND AND WAVE RECORDS AT AMBROSE LIGHTSHIP

The second objective of this study is to determine the best equations to described the wave climate at Ambrose Lightship on the basis of wind conditions. The basic concepts elaborated in Chapter 6 are used for that purpose.

8.1 Limited Fetch

8.1.1 Wave Height

The Liu and Ross (1980) model is used to determine wave height and wave period. As discussed previously, these authors propose the following relationship:

$$e_* = 3.5 \times 10^{-5} X_*^{1.1} \qquad (8.1)$$

where

$e_* = Eg^2/U_*^4$ F: fetch

$X = gF/U_*^2$ E: total energy

$H_S = 4\sqrt{E}$ H_S: significant wave height

U_*: friction velocity (Cardone)

Figure 1 shows the fetches for the 16 points of the wind rose. The length of some of the fetches, the ENE fetch for example, could vary considerably. To gain some insight on the effective fetches versus the measured distance to the seashore, linear regressions were computed for visually observed wave heights versus computed wave heights for different

fetches and the results are tabulated on Table 2. Figure 6 also shows one example of linear regression. As the figure shows, as well as the data from Table 2, there are "residual" waves at zero wind velocity that are interpreted as reflecting the contribution of the swell.

8.1.2 Wave Period

For the computation of wave period, corresponding to the peak energy frequency, two equations are used depending on atmospheric stability as discussed previously (Liu and Ross, 1980):

For stable conditions $$V = 2.05\ X^{-0.27} \tag{8.2}$$

$$V = U_{10} f_m / g$$

$$X = gF/U_{10}^2$$

For unstable conditions $$V = 1.90\ X^{-0.27} \tag{8.3}$$

It reduces to

Stable conditions $$T_m = 0.09211\ F^{0.27}\ U_{10}^{0.46} \tag{8.4}$$

Unstable conditions $$T_m = 0.0995\ F^{0.27}\ U_{10}^{0.46} \tag{8.5}$$

These relationships are for winds measured at 10 m above sea level. The winds at ALS are measured at 28.8 m. A correction factor of 0.9 is applied to convert wind at 28.8 m to their equivalent at 10 m.

8.2 Unlimited Fetch

As mentioned previously, under unlimited fetch conditions the wave heights are a function solely of the square of the wind velocity and the wave periods are directly related to the wind velocity.

Table 2

	Measured Fetch Fetch = Distance to seashore				Effective Fetch Fetch = Adjusted to water depth and generate waveheights			
Direction	F(km)	a	b	R	F	a	b	R
NNE (22.5°)	24	0.24	.90	.710	24	.24	.90	.710
NE 45.	31	0.20	.61	.565	25	.21	.67	.554
ENE 67.5	55+	0.35	.28	.473	30	.37	.35	.432
E 90.0	UN							
ESE 112.5	UN							
SE 135.0	UN							
SSE 152.5	UN							
S 180.0	UN							
SSW 202.5	63	0.31	0.42	.571	25	.32	.64	.537
SW 225.0	24	0.42	0.68	.581	18	.43	.80	.583
WSW 247.5	14	0.38	0.64	.407	13	.38	.65	.401
W 270.0	13	0.24	1.12	.626	12	.24	1.15	.619
WNW 292.5	16	0.26	1.02	.672	16	.26	1.02	.672
NW 315.0	25	0.26	1.02	.748	25	.26	1.02	.748
NNW 337.5	19	0.23	0.76	.684	18	.23	.76	.684
N 360.0	22	0.11	1.15	.768	22	.11	1.15	.768

Basic Equation: $H_{visual} = a + bH_{computed}$

R: Correlation Coefficient for the linear regression equation

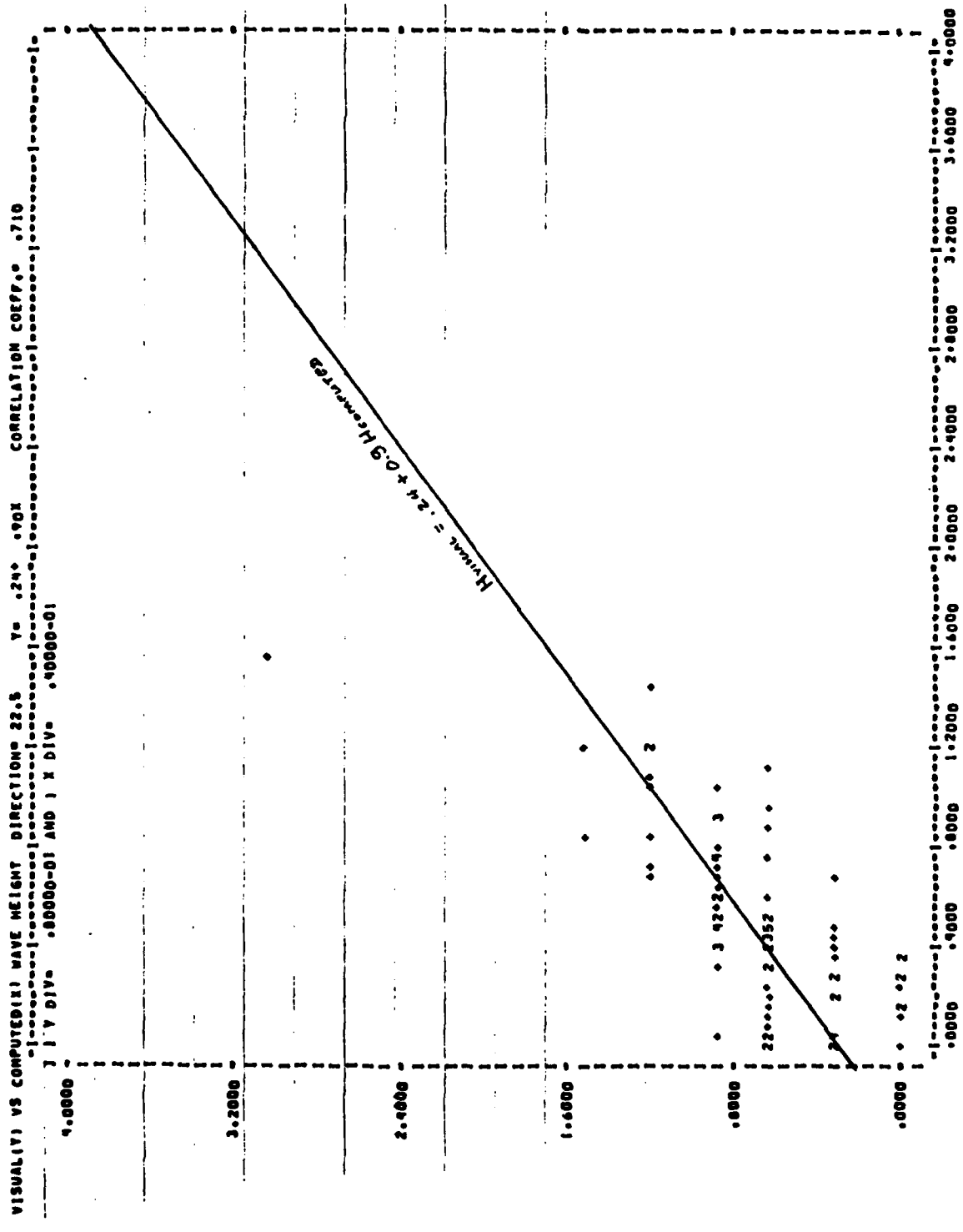

Figure 6. Regression of visual versus computed wave height for the ENE fetch.

It is informative to compare the characteristics of records from ALS and PSEG with those from other experiments. The parameters $V = f_m U/g$ (non-dimensional frequency) and $e = Eg^2/U^4$ (non-dimensional total energy) are often used for that purpose to produce plots of these two parameters in the form shown on Figure 3. Data from ALS for unlimited fetch using parameters e and V are shown on Figure 7. On the same figure are plotted the equations for Ross' stable and unstable conditions and also the JONSWAP equation. The shifting of the data towards the right confirms the observation made previously that the observed wave periods are shorter than expected (V being directly related to the wave frequency). However, the overall slope of the plotted data is in good agreement with Ross equations.

8.2.1 Wave Period

The analysis of wave period has already been discussed when comparing unlimited fetch records from ALS and PSEG in Section 7.1.1 and on Figures 4 and 5. We have come to the conclusion that depending on the height of wind velocity measurements

$$T_s = 0.7289\, U_{19.5} \tag{8.6}$$

$$T_s = 0.7009\, U_{28.8} \tag{8.7}$$

$$T_s = 0.7838\, U_{10} \tag{8.8}$$

8.2.2 Wave Height

Attempts were made to determine the relationship of the wave height to the square of the wind velocity on the basis of the recorded data. The first step to take is to distinguish wind waves from swell. As discussed previously, the parameter V can be used for that purpose. Liu and Ross (1980) indicate that wind waves are present when $V > 0.13$. The value $V = 0.13$ is

identified on Figure 7 and shows the repartition of wind-waves and swell for unlimited fetch records.

The relationship between the significant wave height and the wind velocity should have the form:

$$H_s = C\, U^2 \tag{8.9}$$

and we want to determine the constant C from actual records. For that purpose we assume that the data recorded at PSEG are more accurate than the visual observations from ALS because of the bias introduced in the observation of wave periods.

All the records from PSEG for unlimited fetches and for which $V > 0.13$ are used for calibration. A least-square routine is used for that purpose and the results are:

$$H_s = 0.01467\, U_{10}^2. \tag{8.10}$$

The values of the coefficient for the 95 percent confidence limits are 0.01339 and 0.01596 respectively. Figure 8 shows the distribution of the data used for calibration as well as the least square regression curve.

The value of the coefficient C is lower than those obtained from other studies. As mentioned previously the Pierson-Moskowitz equation as well as the JONSWAP results give

$$H_s = 0.0246\, U_{10}^2 \tag{8.11}$$

for $U_{10} - 0.93\, U_{19.5}$.

However, Figure 8 shows that the least square curve is already high for larger values of U and an increase of that coefficient would accentuate that tendency. There remains the possibility that some of the PSEG data for unlimited fetch are duration limited.

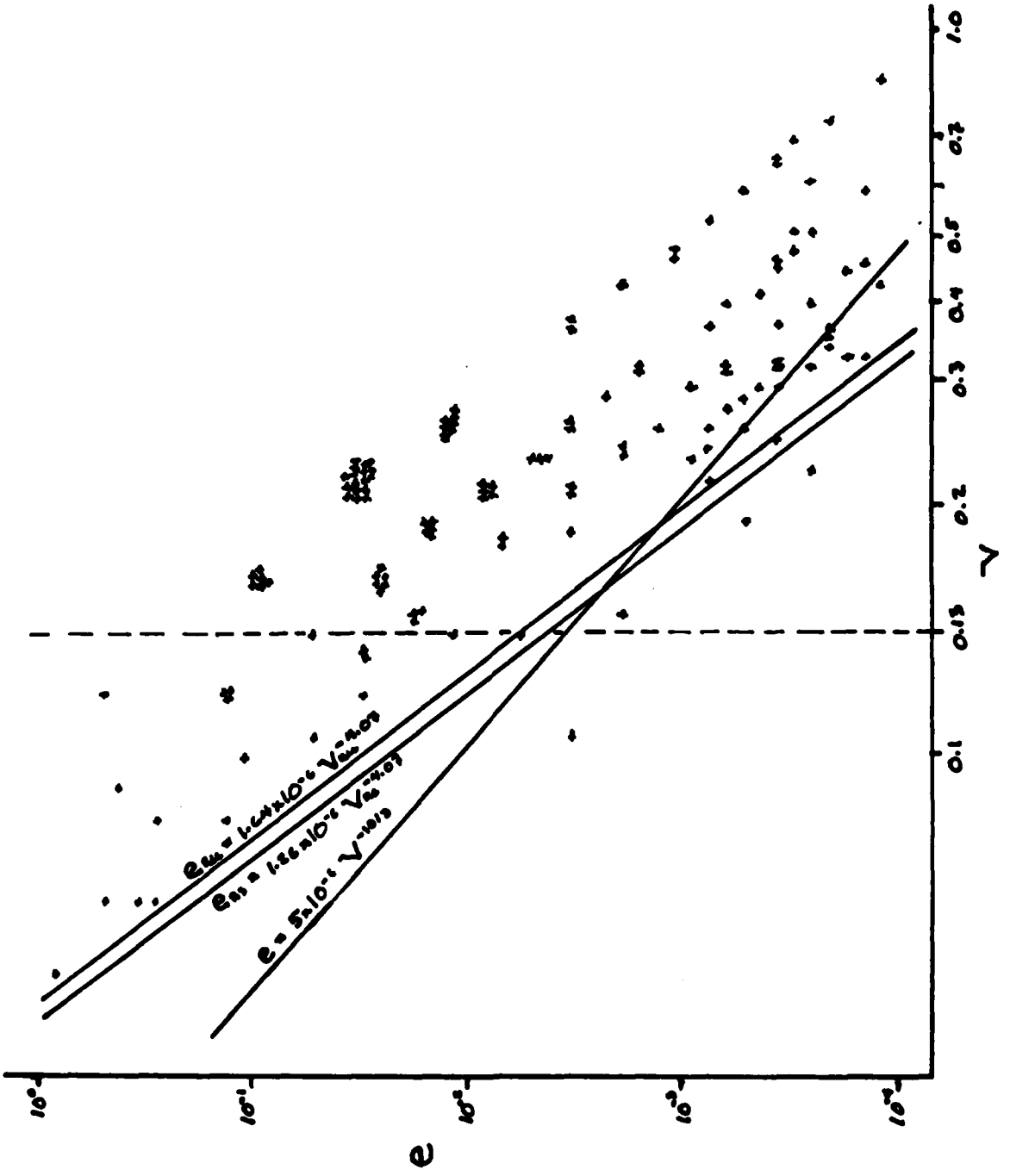

Figure 7. Plot of non-dimensional total energy (e) versus non-dimensional peak-energy frequency (V) for ALS data showing also linear regressions for JONSWAP as well as Ross stable and unstable equations.

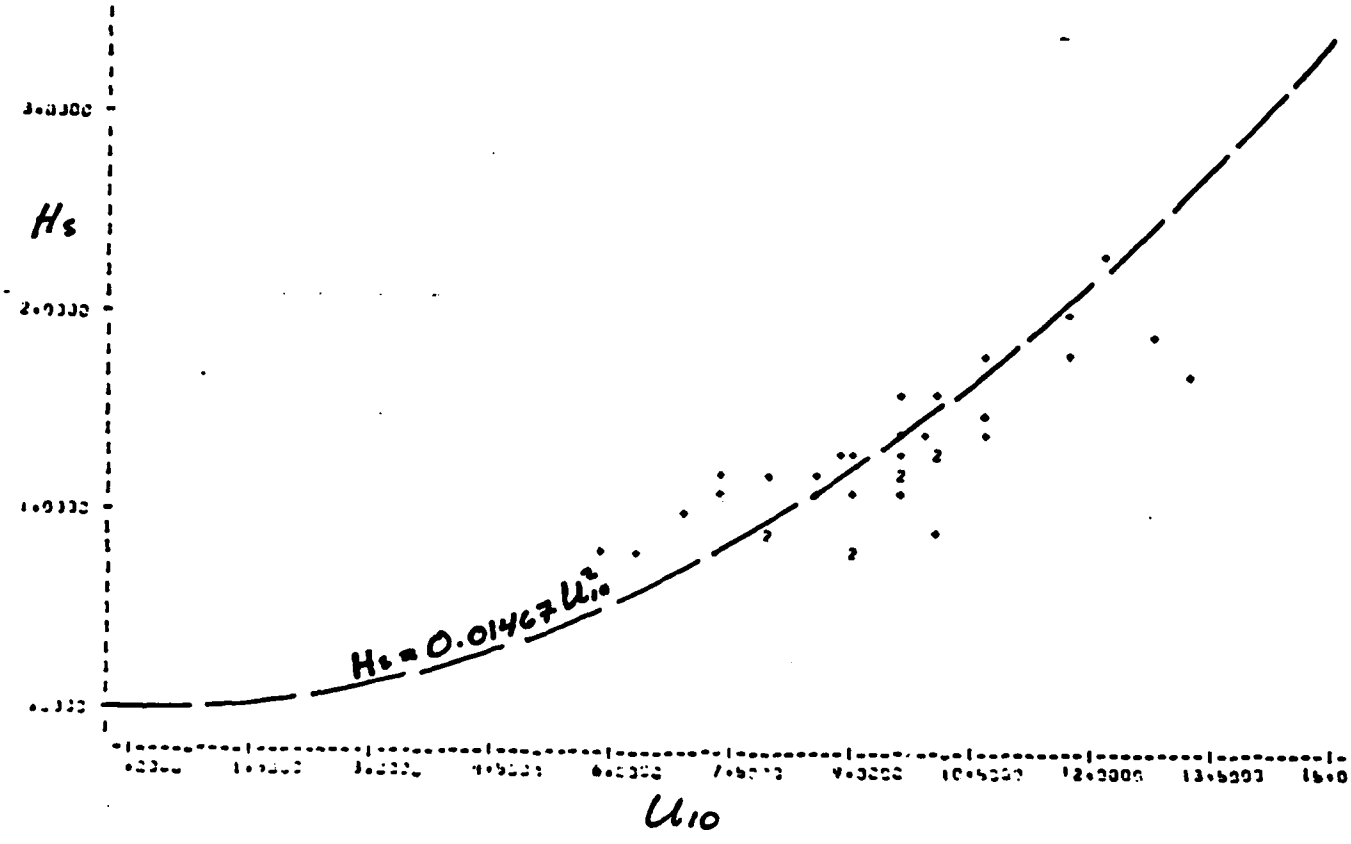

Figure 8. Correlation between significant wave height (Hs) and wind velocity (U_{10}) for unlimited fetches. Second degree best fit curve is also shown.

8.3 Wind Duration

The wind duration in the process of generation of waves is a parameter difficult to assess. For instance, Carter (1982), when summarizing JONSWAP results, notices that the identification of a duration equivalent to a given fetch is ambiguous and can vary by as much as 30% depending which relationship is used. In the present study, the fact that in some instances the generation of waves may be duration-limited is dealt with implicitly. Figure 9 shows graphs of significant wave height (H_s) vs wind speed (U_{10}). Graph 1 is obtained from PSEG wave data (Fig. 8) and Graph 2 is based on JONSWAP after Carter (1982). The lower constant obtained for PSEG data can be interpreted by comparing JONSWAP equations (Carter, 1982) with the results obtained in this study.

For duration-limited growing seas the JONSWAP parametric equation for significant wave height can be written as:

$$H_s = 0.0146\, D^{5/7} U^{9/7} \tag{8.12}$$

for which D is the duration in hours and U the wind speed in m/s at 10 m above the sea surface. For fully developed sea, the JONSWAP relation would be

$$H_s = 0.0240\, U^2. \tag{8.13}$$

Equations 8.12 and 8.13 are equated to determine the value of D as a function of U. It yields

$$D = 2.01\, U. \tag{8.14}$$

If the same procedure is followed using results from this study, that is, substituting Equation 8.10 for Equation 8.13, we obtain

$$D = 1.00\, U. \tag{8.15}$$

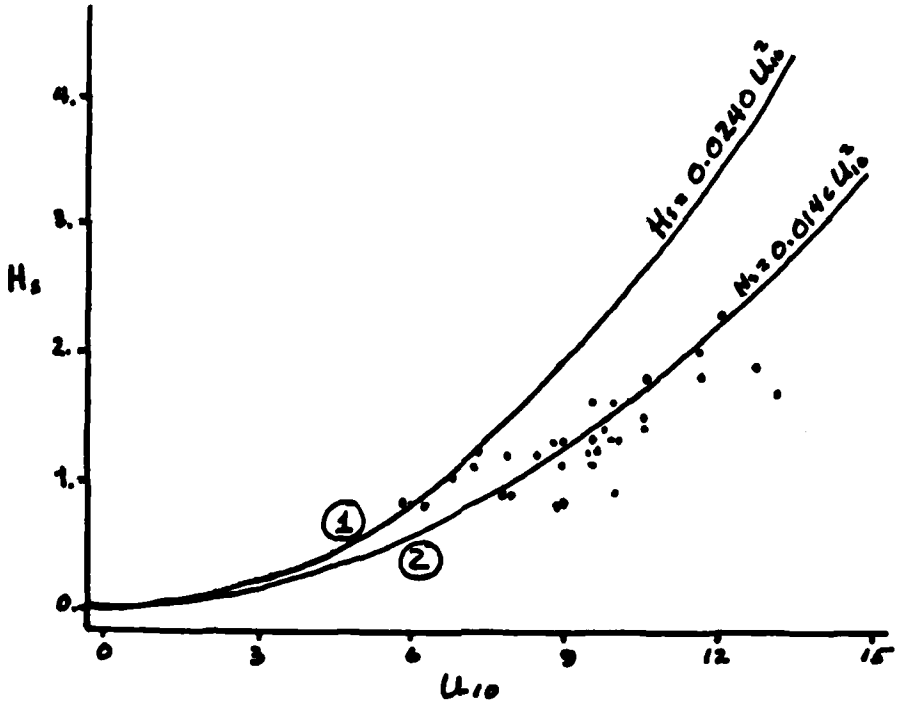

Figure 9. Comparison of the JONSWAP equation $Hs = 0.0240\, U_{10}^2$ and the one used in this study $Hs = 0.0146\, U_{10}^2$.

It means that when we use Equation 8.10 to calculate wave heights from unlimited fetches, we implicitly set that the generation of waves by the wind becomes duration-limited at the threshold D = 1.00 U, a lower limit than the JONSWAP one: D = 2.01 U.

This lower duration threshold for winds of this study is in agreement with the geographical location of the New York Bight Apex, where the unlimited fetch is restricted to the east to south quadrant. It is not a quadrant from which winds are prevailing (12.3 percent) as the upper histogram of Figure 2 shows. Those winds coming from east to south are likely to result from transitory weather patterns whose duration is limited.

8.4 Model Summary

In summary, the prediction of wave height and period at ALS based on wind speed (U), wind direction (D), and air-sea temperature difference DT ($DT = T_a - T_s$) is as follows:

Limited fetch $\qquad 0 < D < 90 \quad \text{or} \quad 180 < D < 360$

Significant wave height:

Use Cardone's friction velocity (U_*) which integrates height of wind measurement and air stability (DT)

$$e_* = 3.5 \times 10^{-5} X^{1.1}$$

$$H_{1/3} = (3.5 \times 10^{-5} (gF/U_*^2)^{1.1} 16 \times U_*^4/g^2)^{0.5}$$

Wave period (period of maximum wave energy)

$DT > 0 \Longrightarrow$

$$T_m = 0.0921 F^{0.27} U_{10}^{0.46}$$

$DT < 0 \Longrightarrow$

$$T_m = 0.0995\ F^{0.27} U_{10}^{0.46}$$

Unlimited fetch $\qquad 90 < D < 180$

$$H_{1/3} = 0.01467\ U_{10}^2$$

$$T_m = 0.7838\ U_{10}$$

9. CORRELATION OF WAVE HINDCASTING AND CV PROBE MEASUREMENTS

9.1 Transfer of Surface Wave Energy to the Bottom

Theories to describe water waves have been described extensively and their domains of application well defined. The depth (h) of the CV probe at the dumpsite is 30 m. The linear wave theory applies when $H/h \ll 1$ which is the case at the dumpsite and also $S = HL^2/2h^3 \ll \frac{16H}{3}$ where H is the wave height, L the wave length and h the water depth. However, the linear wave theory does not apply whenever $S > 8$. When the linear wave theory is applicable, the maximum orbital velocity (U_b) and orbital diameter (d_o) at the bottom are defined by:

$$U_b = \frac{H}{T \sinh\left(\frac{2Hh}{L}\right)} \tag{9.1}$$

$$d_o = \frac{H}{\sinh\left(\frac{2Hh}{L}\right)} \tag{9.2}$$

in which $L = 1.56\ T^2$ for $h/L > 0.5$; and for $h/L < 0.5$ L is approximated using:

$$L = L_\infty \left[\tanh\left(\frac{2Hh}{L_\infty}\right)\right]^{1/2}. \tag{9.3}$$

Among the parameters that determine U_b, the hyperbolic sine is the most limiting. This function increases exponentially and U_b becomes very small for $2\ Hh \gg L$. It means that at the depth of 30 meters waves have to be high, and more importantly have to have a long period to induce significant oscillations

on the bottom. The following examples demonstrate how the bottom orbital velocity varies as a function of wave period at a depth of 30 m:

$H_{1/3}$	T_m	U_b
1.0	5.0	1.00 cm/s
1.0	6.5	5.50
1.0	8.0	97.5

For all practical purposes, at a depth of 30 m, waves having a period shorter than 6 seconds have little effect on the bottom.

9.2 Comparison of CV probe and Wave Hindcasting Measurements

9.2.1 CV probe data

Measurements from the CV probe were recorded at 60-minute intervals. These data were averaged over 6-hour periods to produce four records per day directly comparable with the wave hindcasting data. Measurements of the north-south and east-west bottom current components were added vectorially. These data are shown on Figure 10 for the period November 19 to December 31, 1980. Figure 10a shows the water transparency which varies between 50 and 70 percent, the diminution of the transparency being directly related to the stirring of the bottom sediments. The measure of wave energy (Figure 10b) shows a strong correlation with the reduction of water transparency. The wave period (Figure 10c) does not show any apparent correlation with the wave energy, neither does the bottom current velocity (Figure 10d). The hourly records of bottom current velocities show better than this one the contribution of the semi-diurnal tidal currents to the bottom current field.

9.2.2 Comparison of data

The boxed section of Diagrams A and B in Figure 10 is shown with more detail on Figure 11. The hourly records of CV probe measurements of water

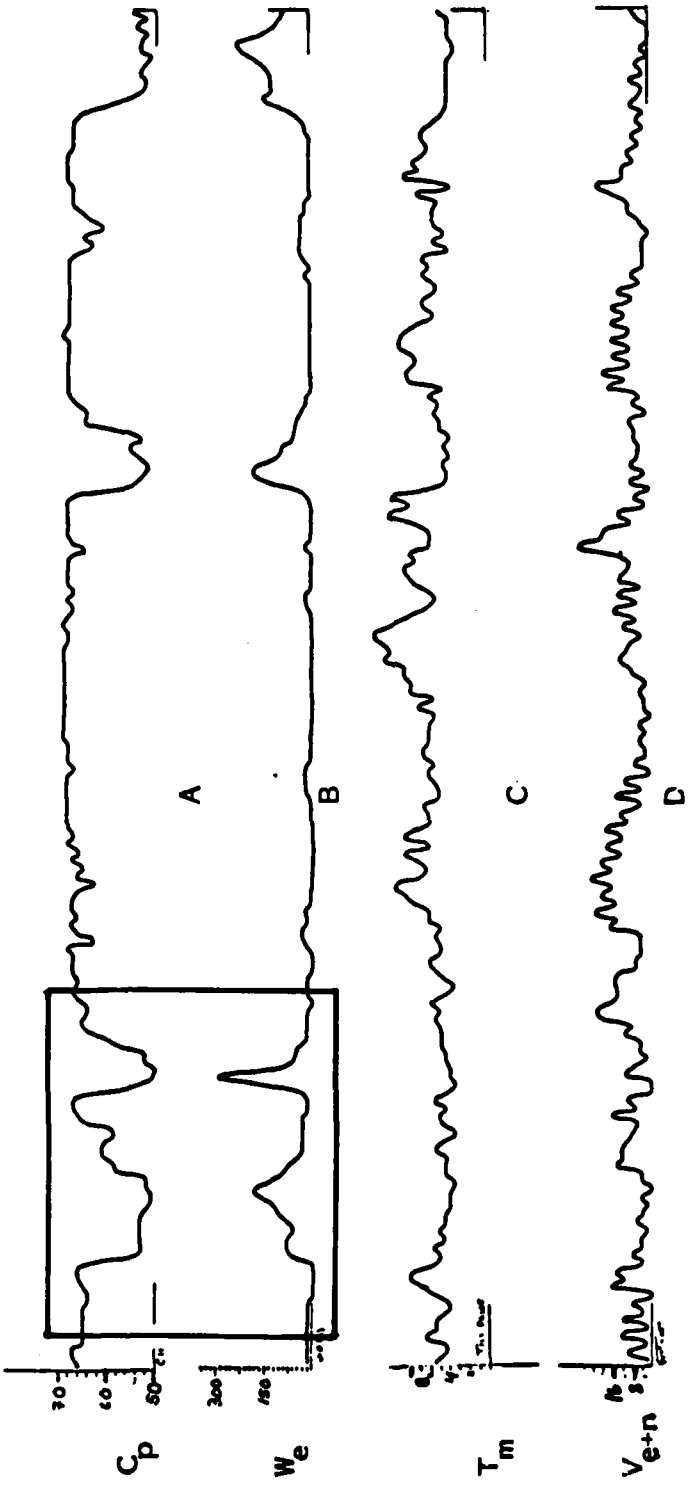

Figure 10. CV-probe measurements between November 19 and December 31, 1980. A: water transparency, B: wave energy, C: wave period, D: bottom current velocity.

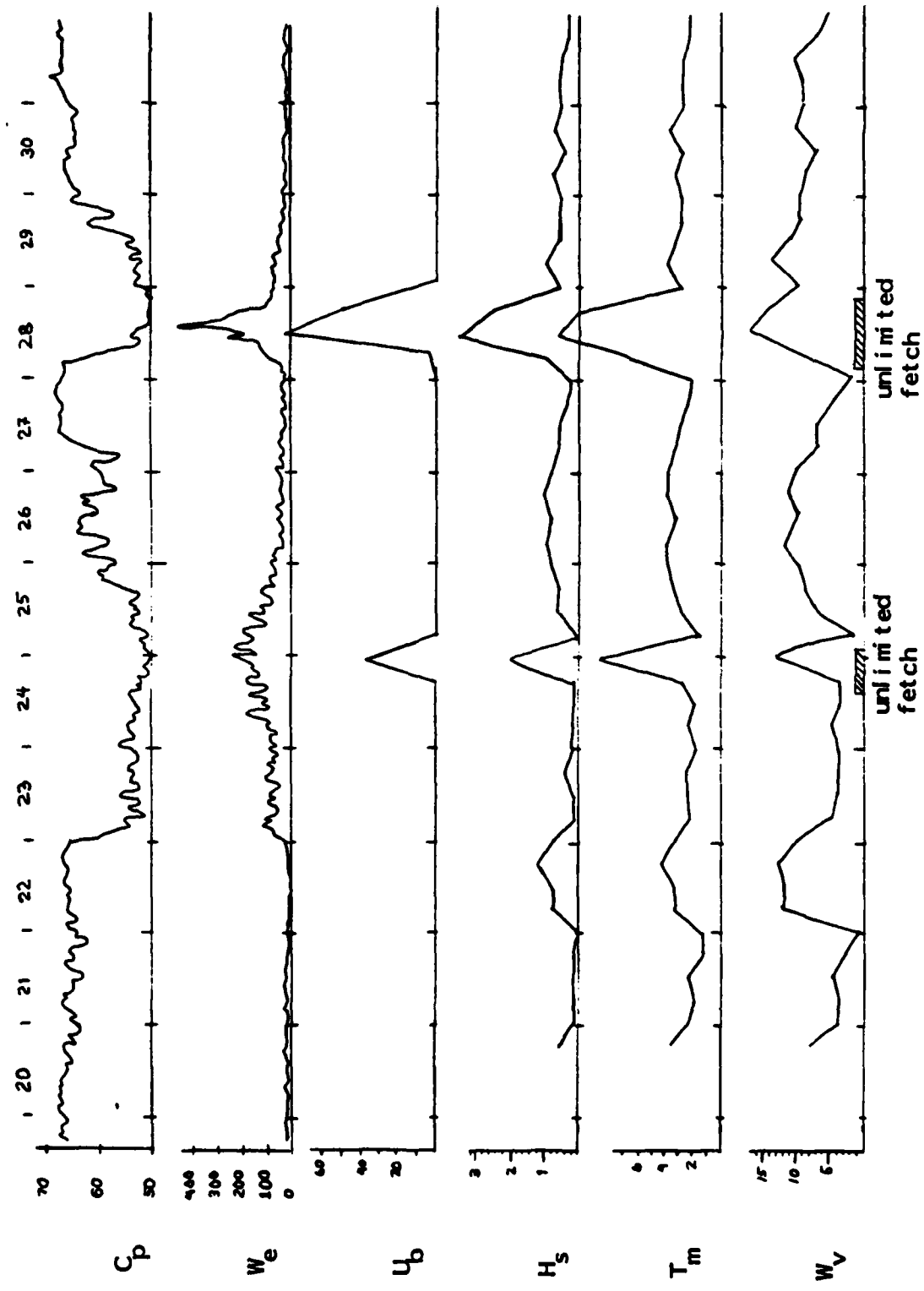

Figure 11. Details of measurements for the period 20 to 30 November 1980. Hourly records of water transparency (Cp) in percentage, wave energy (We) measured in cm^2/s^2, maximum bottom orbital velocity (Ub) in cm/s computed from surface waves, period of peak-energy frequency (Tm) and wind velocity (Wv) in m/s with indication of unlimited fetch intervals.

transparency (C_p) and wave energy (W_e) are transcribed directly for the period November 20 to 30, 1980. The two diagrams concur to outline two events: one of lesser magnitude and longer duration from November 23 to 25, and a shorter more intensive event on November 28. At the bottom of the figure is shown the wind velocity (W_v) recorded at Ambrose Lightship for the same period. Also shown on that same diagram are the two intervals during which the wind was blowing from offshore (unlimited fetch). Above this diagram of wind velocity are plotted the hindcasted wave periods (T_m) corresponding to peak energy frequency, and significant wave heights (H_s). More intense waves are naturally hindcasted when winds are blowing from offshore. Orbital bottom velocities (U_b) were computed using hindcasted wave heights and periods. The depth of water of 30 m considerably dampens the energy of surface waves, as discussed previously, and only the larger waves propagate to the bottom. This phenomenon is well outlined by the diagram U_b showing that orbital velocities on the bottom are significant during only two intervals, those during which higher wave energy was recorded by the CV probe. It confirms the adequacy of the wind hindcasting model.

Figure 12 compares wave energy recorded from the CV probe with hindcasted data for the whole period of deployment (November 19 - December 31). The wave energy as recorded by the CV probe is shown on diagram W_e of Figure 12. The other four diagrams are related to the surface wave hindcasting and outline the following: maximum bottom orbital velocity U_b, significant wave height (H_s), wave period (T_m), and wind velocity and direction (W). Not all the sequences of higher wave energy recorded by the CV probe have their counterpart in terms of wave bottom orbital velocities. Event 3, for instance, recorded by the CV probe, does not correspond to significant bottom orbital velocities generated by surface waves. Event 4 has a much stronger

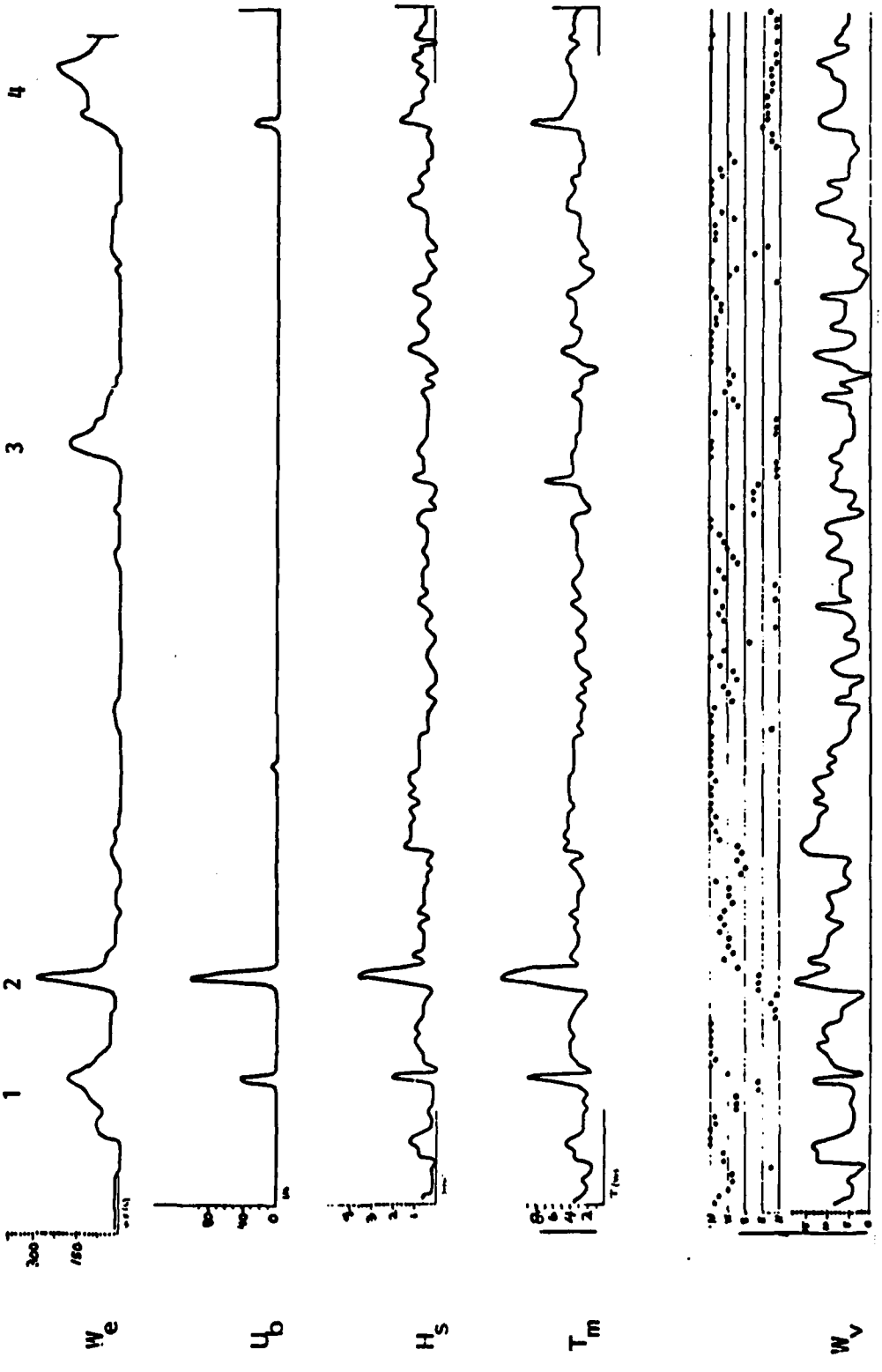

Figure 12. Same parameters as Figure 11 covering the period November 19 to December 31, 1980. The four major events for that period are labeled. The wind direction is also indicated.

show on the CV probe records than on those of bottom orbital velocities. To conclude, these data outline that wave hindcasting adequately outlines the impact of surface waves climate on bottom sediments, but it shows as well that not all the wave energy recorded on the bottom is generated locally and that swell waves also contribute to the transport of bottom sediments.

10. USE OF JOHN F. KENNEDY AIRPORT WIND DATA FOR WAVE HINDCASTING AT THE DUMPSITE

The immediate interest of using John F. Kennedy Airport (JFK) wind data is to extend the correlation between locally generated wind waves and CV probe measurements. The data available from Ambrose Lightship station end on December 31, 1980 and the CV-probe survey covers the period November 19, 1980 to June 23, 1981. The JFK data are used to extend this study to the end of the CV probe deployment. It is also an opportunity to evaluate the reliability of land stations for coastal wave hindcasting.

10.1 Calibration Procedure

10.1.1 Wind direction

The winds from JFK were found to be systematically lagging those from Ambrose Lightship (ALS). This lag is in agreement with the Ekman spiral effect: because of air friction, being greater on land than at sea, wind direction at the height of measurement departs more from the gradient wind at JFK than at ALS. Figure 13 shows the lag in wind direction between the two stations. As expected, the deflection is lesser for winds blowing from offshore.

10.1.2 Wind velocity

The wind velocity is higher at ALS than JFK. For November and December 1980 the average velocity for winds from all directions is:

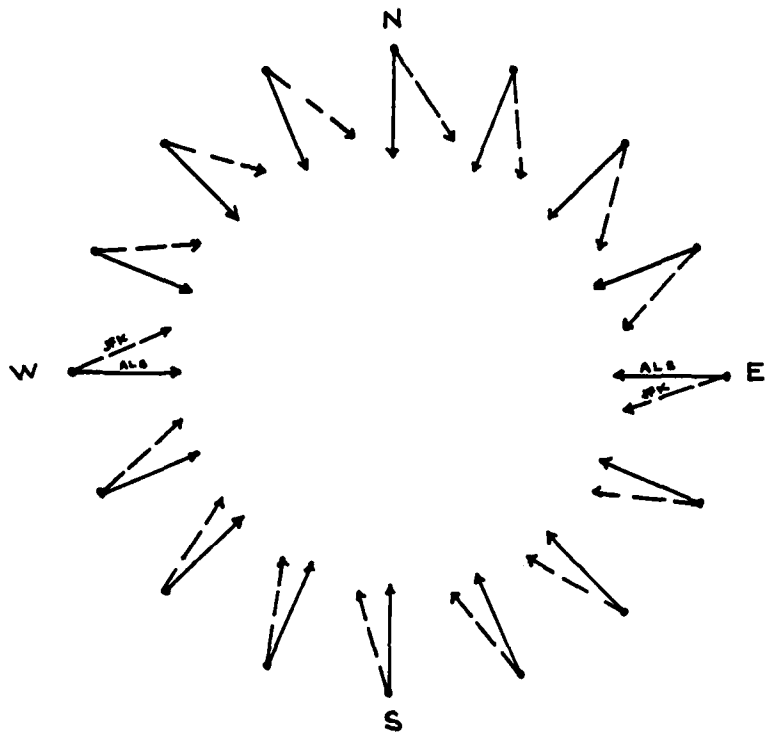

Figure 13. Differences in orientation between wind directions at Ambrose Lightship (full arrows) and John F. Kennedy Airport (dashed arrows).

JFK 6.68 m/s

ALS 8.34 m/s

The correlation between wind velocities at the two stations is not as systematic as for the direction. Winds were divided into two categories: onshore and offshore. For offshore winds no systematic trend is discernable and a constant value of 1.66 m/s was added to JFK wind velocities. For onshore winds, different regression equations were tested to correlate velocities from the two stations. The simplest and best fit is obtained with a linear regression:

$$W_{als} = 0.912 + 1.56\, W_{jfk} \qquad (10.1)$$

for which the correlation coefficient is R = 0.83.

10.2 Wave Hindcasting Using JFK Wind Data

A flow chart (Figure 14) summarizes the steps followed to compute wave heights and periods and maximum bottom orbital velocity and maximum bottom excursion using wind data from JFK Airport. The steps followed are described in this report and the numbers in parenthesis on the flow chart diagram are those identifying the equations used in the report.

10.3 Verification of Wave Hindcasting from JFK Airport Wind Data

The accuracy of the wave hindcasting based on JFK wind data can be verified by comparing the results with those recorded on the bottom at the dumpsite by the CV probe. As the CV probe measures the wave energy at the bottom, based on the variation of current velocities, the best criterion for comparison is to use the bottom orbital velocities computed from hindcasted wave heights and periods. The results are outlined as time series on Figure 15. The figure shows that the bottom orbital velocities hindcasted from JFK

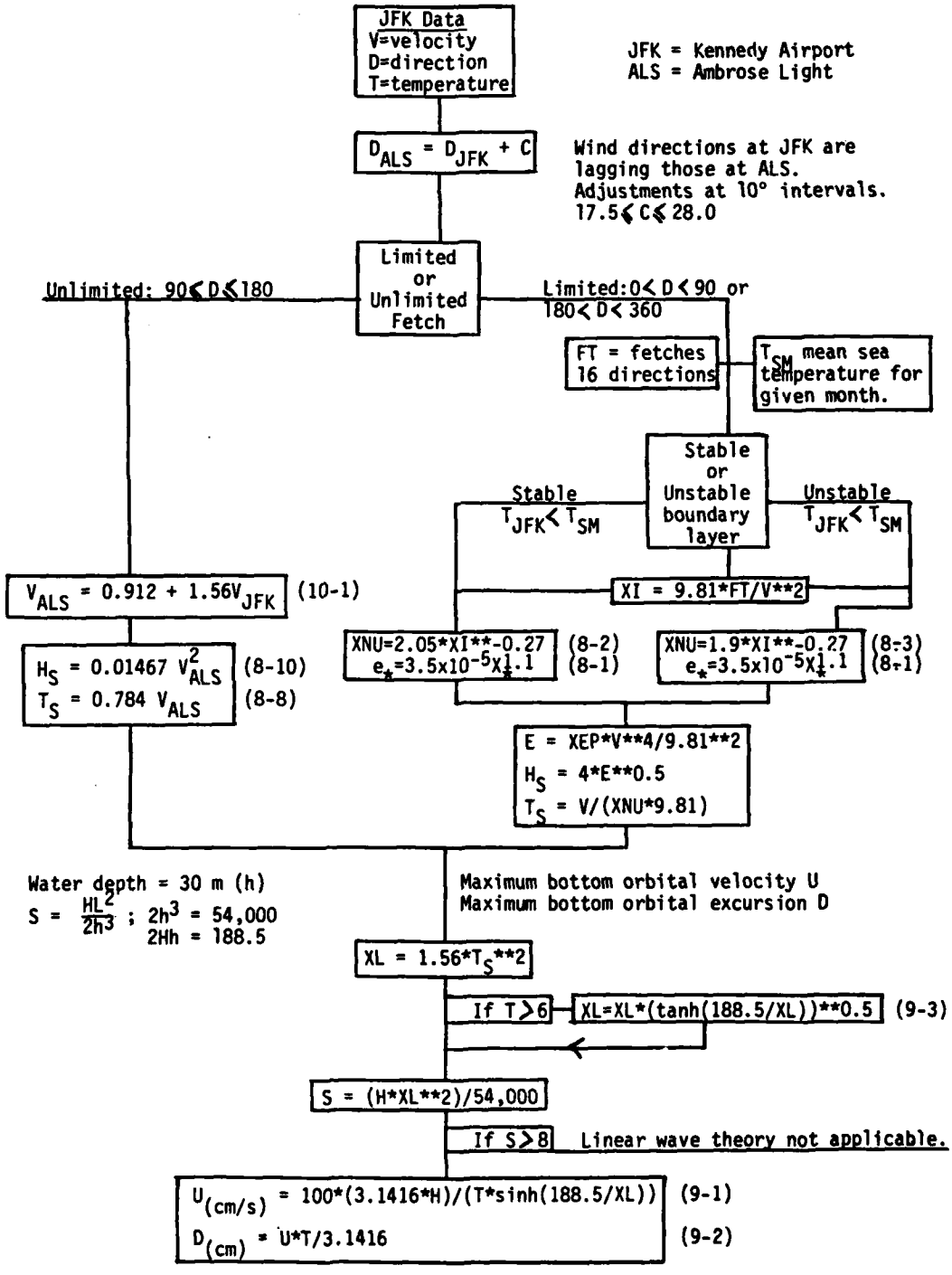

Figure 14. Flow chart for computation of maximum bottom orbital velocities using wind data from John F. Kennedy airport.

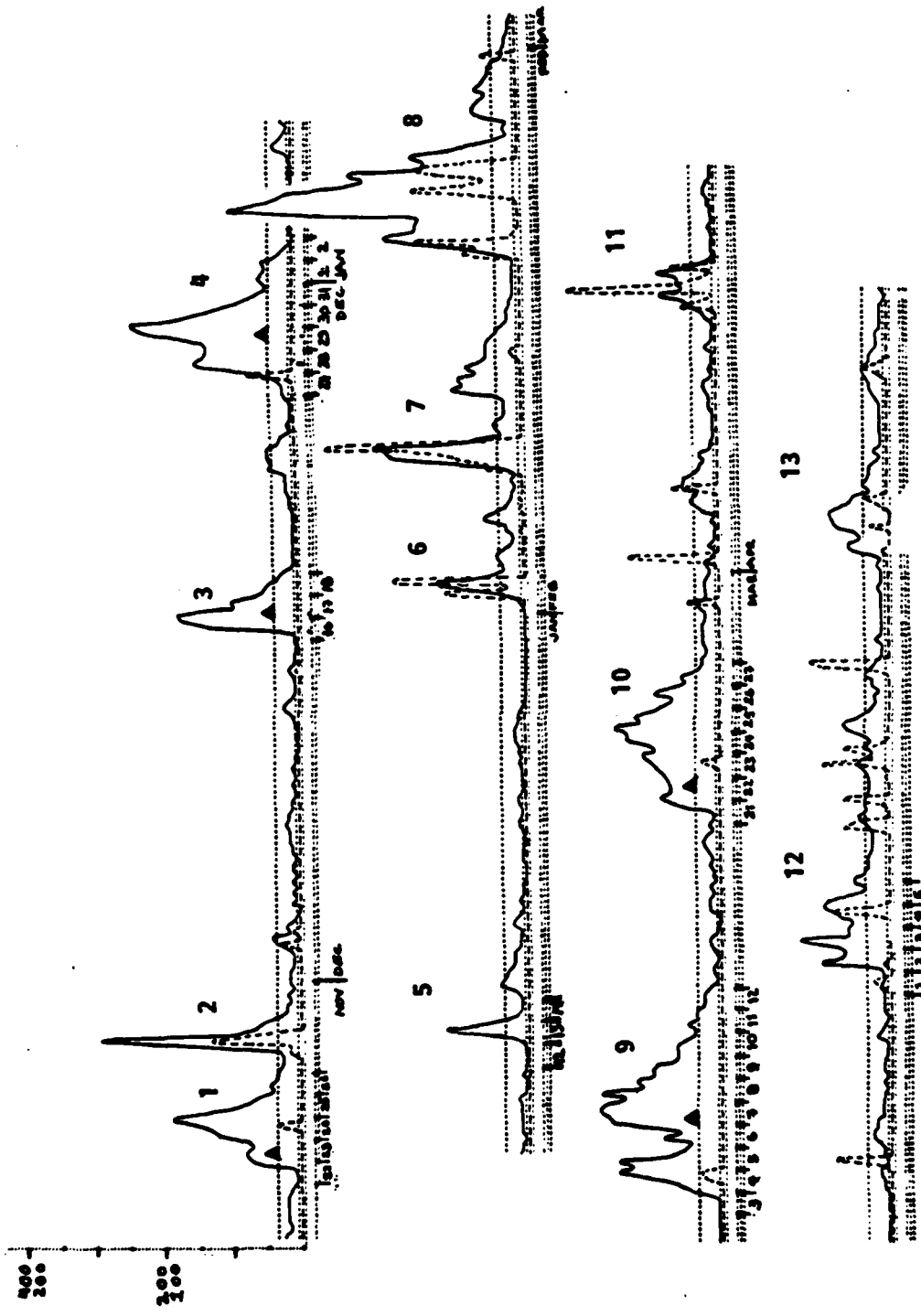

Figure 15. Time series of bottom wave energy (full lines, scale 0-400 cm^2/s^2) and computed maximum bottom orbital velocities (dashed line, scale 0-200 cm/s).

wind data are factual and correlate very well with the episodes measured by the CV probe on the bottom. The figure shows also that not all the events recorded by the CV probe are related to sea waves generated in the New York Bight. Swell waves have then to be examined.

11. WAVES GENERATED OUTSIDE THE NEW YORK BIGHT

Wave energy on the bottom was recorded at the dumpsite by the CV probe system during the period from November 19, 1980 to June 23, 1981. The continuous record of wave energy measured on the bottom is shown on Figure 15. The level of wave energy is shown by a solid line on that figure at a scale of 0-400 cm^2/sec^2. The dotted line on the same figure is a plot of the maximum bottom orbital velocity derived from wave hindcasts from wind records from JFK. As explained previously, the wind measurements at JFK are corrected for the study area and used to compute the heights and periods of waves generated at the dumpsite. These wave parameters are used to calculate the maximum bottom orbital velocities at the dumpsite. The results are plotted as a dotted line at the scale 0-200 cm/sec. The time series of wave energy measured by the CV probe outlines 13 more important events. The records for the month of June are not reproduced because no event of interest occurred during that last month of survey.

The time series for the maximum bottom orbital velocities (dotted line) shows a marked coincidence with many of the CV probe events, but not all. As the plot of maximum bottom orbital velocities is derived directly from wind conditions prevailing at the dumpsite, it implies that in some cases the wave energy recorded on the bottom at the dumpsite resulted from waves generated outside the New York Bight. The events on Figure 15 labeled 1, 3, 4, 5, 9 and 10 are specific cases when the waves generated by the winds prevailing at the

dumpsite did not have the dimension necessary to generate the wave energy recorded on the bottom. These six events are investigated to determine whether or not these records of high wave-energy intensity resulted from swell formed elsewhere on the Atlantic Coast and propagating in to the New York Bight.

The approach used is that suggested by Ross (1979), a refinement of Ross (1976), which presents a simple approach to hindcasting waves generated by hurricanes. Although originally intended only for use in circular hurricane wind fields, experience has shown its validity when applied to extra-tropical lows (Ross, personal communication). Adjusted geostrophic winds are used to specify the sea-surface wind in the parametric equations of Ross which are used to calculate the wave energy spectrum.

11.1 Methodology

Geostrophic wind (Silvester, 1974):

$$U_{sg}/g = (0.52/\sin\theta)\ \Delta P/\Delta n$$

θ = latitude in degrees

ΔP = pressure differential in millibars

Δn = spacing of isobars in degrees (latitude)

U_{sg} = geostrophic wind in dimensions commensurate with g (gravity).

Basic wave parameters (Ross, 1979):

$$\upsilon = f_m\, U_{10}/g$$

$$Er = \tau g/U_{10}^2$$

$$\epsilon = Eg^2/U_{10}^4$$

$$\upsilon = 0.97\ Er^{-0.21}$$

$$\epsilon = 2.25 \times 10^{-5}\ Er^{0.45}$$

$\gamma = 4.7\ Er^{-.13}$

$\alpha = 0.035\ \upsilon^{0.82}$

f_m = spectral peak frequency

U_{10} = wind velocity at 10 m = $0.7\ U_{sg}$

r = distance from center of depression to point of interest

E = total energy

Hs = $4\ \sqrt{E}$ · significant wave height.

Wave energy spectrum (Hasselmann et al., 1976):

$$E(f) = \alpha g^2 (2H)^{-4} f^{-5} \exp \left\{ -\frac{5}{4} \left(\frac{f_m}{f}\right)^4 + \ln \gamma \exp \left(-\frac{(f - f_m)^2}{2p^2 f_m^2} \right) \right\}$$

where $r = \begin{cases} \sigma_a, & f > f_m \\ \sigma_b, & f < f_m \end{cases}$

In the present case, $\sigma_a = \sigma_b = 0.1$.

11.2 Meteorological Conditions

The meteorological conditions prevailing on the Atlantic Coast when Events 1, 3, 4, 5, 9 and 10 were recorded are shown on Figure 16. The six maps show the weather patterns at 0700 EST for the dates specified.

It is assumed that the generation of swell waves that reached the New York Bight is associated with the offshore passage of well-defined barometric low pressure systems. The regions of wave formation with the proper orientation to reach the New York Bight are shown on each map. The horizontal pressure gradient in the generation area is used to calculate the geostrophic wind. The length of the radius from the generation region to the center of the depression and the distance to the New York Bight Apex are also determined from these maps. The input data for each event analysed are listed on Table 3.

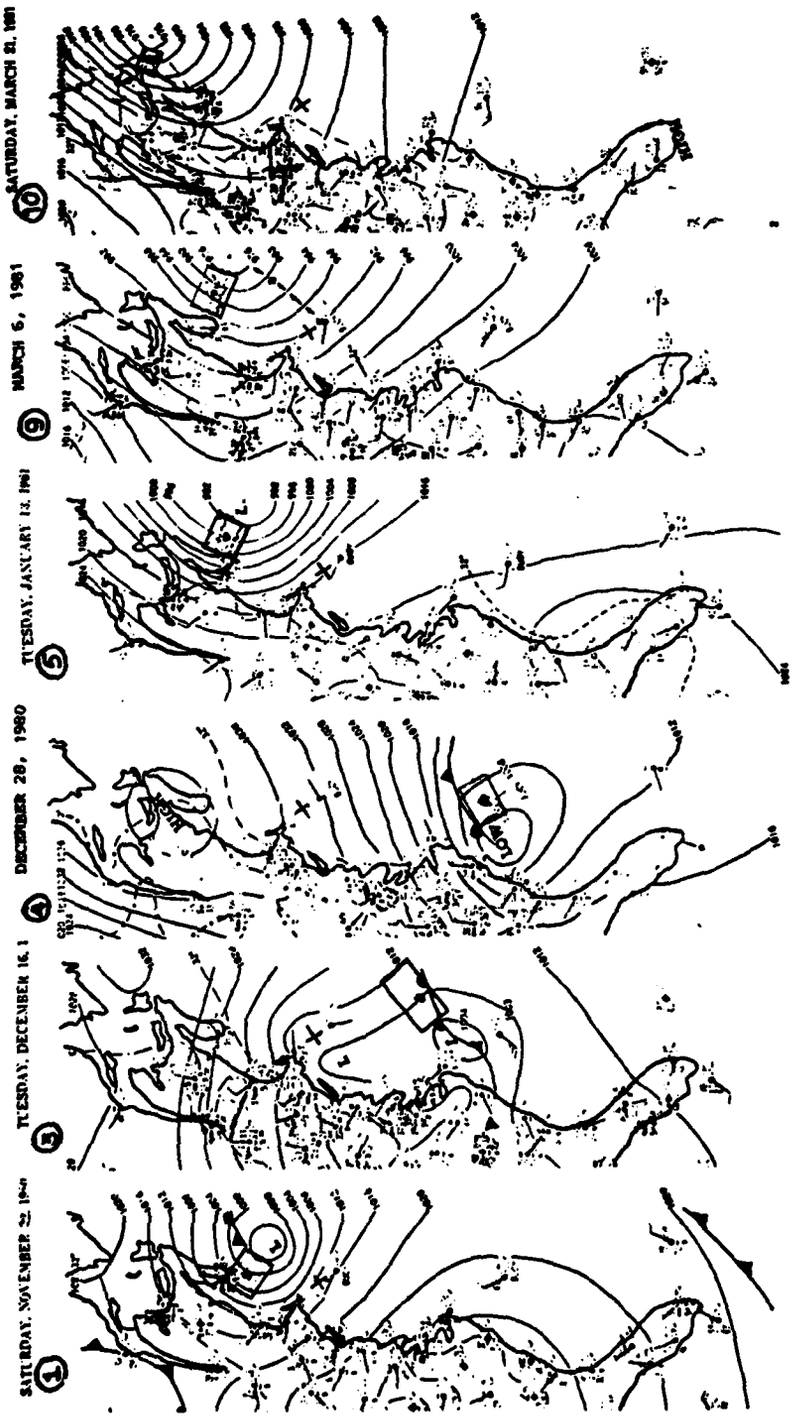

Figure 16. Weather patterns at 0700 EST for the dates specified on each map.

Table 3

Event	Date	dP	dL	Lat	Radius	Distance
1	22/11/80	8.0	1.7	43.5	195	650
3	16/12/80	4.0	1.5	35.0	296	600
4	28/12/80	4.0	1.5	32.5	203	950
5	13/01/81	8.0	1.8	43.5	222	850
9	06/03	12.0	2.4	43.6	205	888
10	21/03/81	8.0	1.25	45.0	138	1165

11.3 Wave Energy Spectra

Energy spectra of waves in the generation area are computed for each event. The results are tabulated on Table 4. The following parameters appear on the table: (1) reduced geostrophic wind velocity (U_{gs}) in m/s; (2) Philips parameter alpha (α); (3) gamma (γ); (4) nu (υ); (5) total energy (E); (6) peak energy frequency (f_m), and (7) significant wave height (H_s). Then for each 0.01 increment, for frequencies from 0.05 to 0.17, the level of energy and the time in hours (arrival) needed for waves of that frequency to reach the New York Bight Apex are calculated. The time of arrival of the peak energy frequency is also indicated by a black triangle on Figure 15.

The wave energy spectra are drawn on Figure 17. Examination of these wave energy spectra in relation with Figures 15 and 16 shows that the path of propagation of the different wave trains also plays an important role. For instance, even if Events 3 and 4 are less intense, the waves generated were facing the New York Bight Apex more directly than those coming from offshore Nova Scotia.

11.4 Discussion

The results presented in this chapter are interesting because they confirm that all the events recorded by the CV probe are related to wave activity, the waves being generated in the New York Bight itself or outside. However, the results presented in this chapter are only qualitative; bottom orbital velocities cannot be calculated at the present stage of investigation. To quantify the results, the wind velocity would have to be evaluated with more precision using gradient wind considering the translations of low pressure systems, and taking into account atmospheric conditions of stability or instability. Also the propagation of the waves from the generation area to

Table 4

Event 1 22/11/80	Event 3 16/12/80	Event 4 28/12/80	Event 5 13/01/81	Event 9 06/03/81	Event 10 21/03/81
W(m/s) = 24.4	W(m/s) = 16.6	W(m/s) = 17.7	W(m/s) = 23.0	W(m/s) = 25.8	W(m/s) = 32.3
Alpha = 0.0084	Alpha = 0.0069	Alpha = 0.0075	Alpha = 0.0081	Alpha = 0.0085	Alpha = 0.0099
Gamma = 1.645	Gamma = 1.409	Gamma = 1.505	Gamma = 1.593	Gamma = 1.659	Gamma = 1.851
NU = 0.177	NU = 0.138	NU = 0.154	NU = 0.169	NU = 0.180	NU = 0.215
TOT.E = 3.141	TOT.E = 1.147	TOT.E = 1.185	TOT.E = 2.789	TOT.E = 3.855	TOT.E = 6.417
FM = 0.071	FM = 0.081	FM = 0.085	FM = 0.071	FM = 0.068	FM = 0.065
HS(m) = 7.089	HS(m) = 4.284	HS(m) = 4.355	HS(m) = 6.680	HS(m) = 7.854	HS(m) = 10.133
Freq = 0.050	Freq = 0.050	Freq = 0.050	Freq = 0.050	Freq = 0.050	Freq = 0.050
Energy = 8.992	Energy = 0.165	Energy = 0.035	Energy = 7.599	Energy = 21.576	Energy = 53.035
Arrival = 11.574	Arrival = 10.683	Arrival = 16.915	Arrival = 15.135	Arrival = 15.811	Arrival = 20.744
Freq = 0.060	Freq = 0.060	Freq = 0.060	Freq = 0.060	Freq = 0.060	Freq = 0.060
Energy = 61.917	Energy = 7.170	Energy = 3.565	Energy = 54.857	Energy = 104.811	Energy = 210.667
Arrival = 13.888	Arrival = 12.820	Arrival = 20.299	Arrival = 18.162	Arrival = 18.974	Arrival = 24.893
Freq = 0.070	Freq = 0.070	Freq = 0.070	Freq = 0.070	Freq = 0.070	Freq = 0.070
Energy = 130.035	Energy = 27.388	Energy = 18.870	Energy = 116.256	Energy = 165.435	Energy = 227.831
Arrival = 16.203	Arrival = 14.957	Arrival = 23.682	Arrival = 21.189	Arrival = 22.136	Arrival = 29.042
Freq = 0.080	Freq = 0.080	Freq = 0.080	Freq = 0.080	Freq = 0.080	Freq = 0.080
Energy = 92.230	Energy = 46.026	Energy = 39.280	Energy = 86.978	Energy = 93.700	Energy = 112.792
Arrival = 18.518	Arrival = 17.094	Arrival = 27.065	Arrival = 24.216	Arrival = 25.299	Arrival = 33.190
Freq = 0.090	Freq = 0.090	Freq = 0.090	Freq = 0.090	Freq = 0.090	Freq = 0.090
Energy = 54.944	Energy = 37.916	Energy = 40.885	Energy = 52.179	Energy = 59.452	Energy = 73.423
Arrival = 20.833	Arrival = 19.230	Arrival = 30.448	Arrival = 27.243	Arrival = 28.461	Arrival = 37.339
Freq = 0.100	Freq = 0.100	Freq = 0.100	Freq = 0.100	Freq = 0.100	Freq = 0.100
Energy = 37.843	Energy = 25.089	Energy = 26.399	Energy = 36.005	Energy = 40.382	Energy = 48.838
Arrival = 23.148	Arrival = 21.367	Arrival = 33.831	Arrival = 30.270	Arrival = 31.623	Arrival = 41.488
Freq = 0.110	Freq = 0.110	Freq = 0.110	Freq = 0.110	Freq = 0.110	Freq = 0.110
Energy = 26.061	Energy = 18.087	Energy = 18.522	Energy = 24.855	Energy = 27.346	Energy = 32.599
Arrival = 25.462	Arrival = 23.504	Arrival = 37.215	Arrival = 33.297	Arrival = 34.786	Arrival = 45.637
Freq = 0.120	Freq = 0.120	Freq = 0.120	Freq = 0.120	Freq = 0.120	Freq = 0.120
Energy = 18.012	Energy = 13.096	Energy = 13.613	Energy = 17.206	Energy = 18.699	Energy = 22.087
Arrival = 27.777	Arrival = 25.641	Arrival = 40.598	Arrival = 36.324	Arrival = 37.948	Arrival = 49.786
Freq = 0.130	Freq = 0.130	Freq = 0.130	Freq = 0.130	Freq = 0.130	Freq = 0.130
Energy = 12.605	Energy = 9.455	Energy = 9.960	Energy = 12.053	Energy = 12.993	Energy = 15.255
Arrival = 30.092	Arrival = 27.777	Arrival = 43.981	Arrival = 39.351	Arrival = 41.111	Arrival = 53.935

cont.

Table 4

Event 1 22/11/80	Event 3 16/12/80	Event 4 28/12/80	Event 5 13/01/81	Event 9 06/03/81	Event 10 21/03/81
Freq = 0.140	Freq = 0.140	Freq = 0.140	Freq = 0.140	Freq = 0.140	Freq = 0.140
Energy = 8.961	Energy = 6.867	Energy = 7.299	Energy = 8.575	Energy = 9.193	Energy = 10.750
Arrival = 32.407	Arrival = 29.914	Arrival = 47.364	Arrival = 42.378	Arrival = 44.273	Arrival = 58.084
Freq = 0.150	Freq = 0.150	Freq = 0.150	Freq = 0.150	Freq = 0.150	Freq = 0.150
Energy = 6.478	Energy = 5.038	Energy = 5.390	Energy = 6.202	Energy = 6.624	Energy = 7.723
Arrival = 34.722	Arrival = 32.051	Arrival = 50.747	Arrival = 45.405	Arrival = 47.435	Arrival = 62.232
Freq = 0.160	Freq = 0.160	Freq = 0.160	Freq = 0.160	Freq = 0.160	Freq = 0.160
Energy = 4.761	Energy = 3.742	Energy = 4.022	Energy = 4.560	Energy = 4.856	Energy = 5.650
Arrival = 37.037	Arrival = 34.188	Arrival = 54.131	Arrival = 48.433	Arrival = 50.598	Arrival = 66.381
Freq = 0.170	Freq = 0.170	Freq = 0.170	Freq = 0.170	Freq = 0.170	Freq = 0.170
Energy = 3.554	Energy = 2.815	Energy = 3.035	Energy = 3.404	Energy = 3.619	Energy = 4.204
Arrival = 39.351	Arrival = 36.324	Arrival = 57.514	Arrival = 51.460	Arrival = 53.760	Arrival = 70.530

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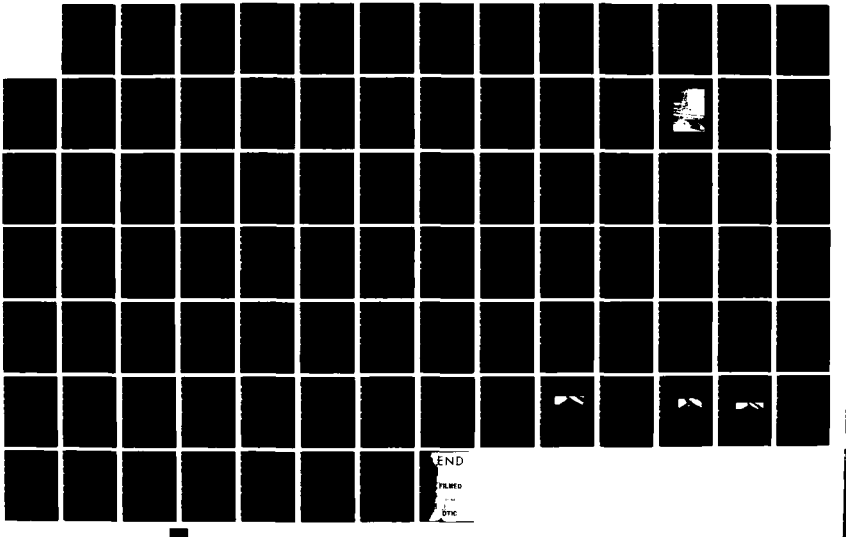

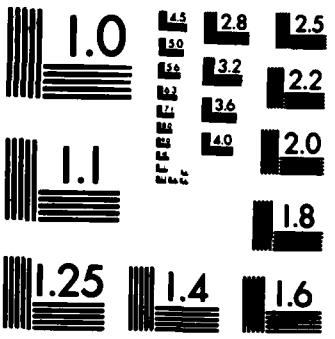

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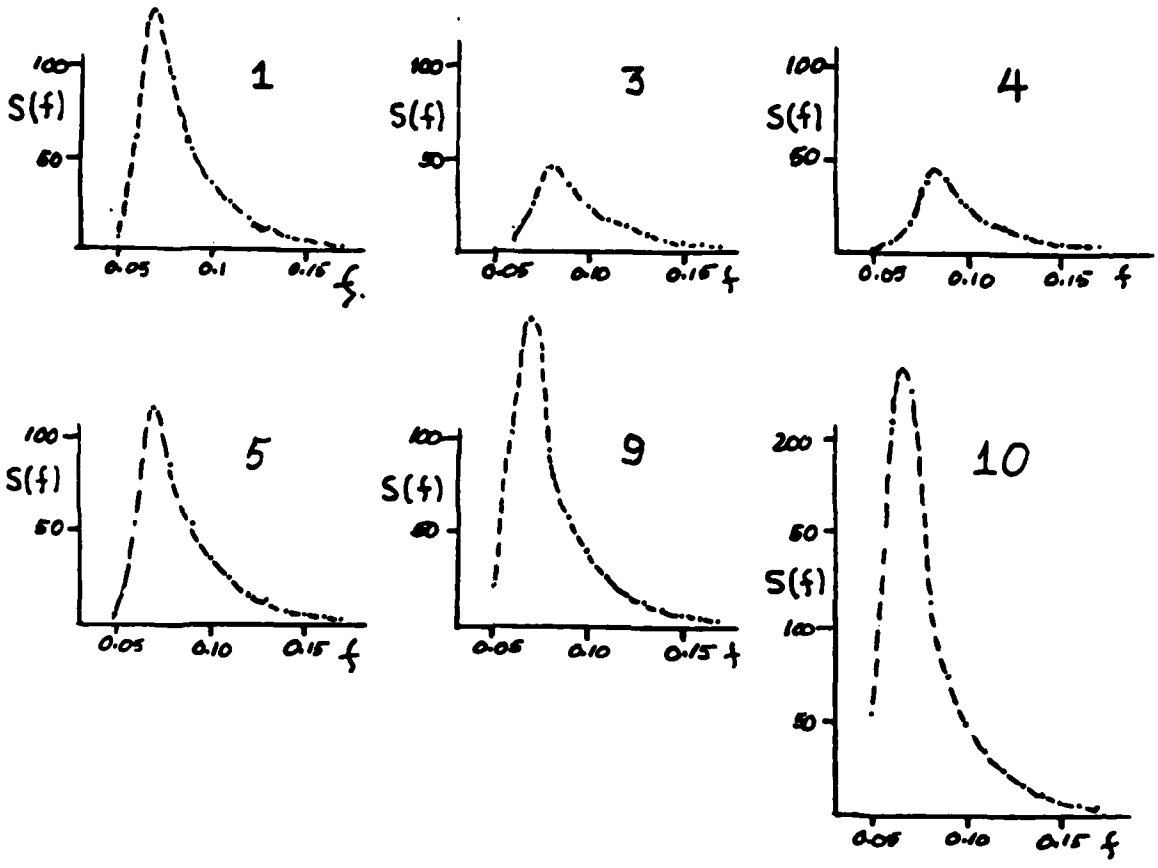

Figure 17. Energy spectra of waves (m^2-s) versus frequency (Hz) for the six events discussed in the text.

the point of interest would have to be examined for refraction and potential attenuation by winds and currents.

12. INFREQUENT EVENTS

The data available from Ambrose Lightship extend back to November 1956. It is possible to verify the impact of infrequent events, that is, storms of different intensities, suceptible to have affected the dumpsite area. Storm surges in the New York Bight have been described by Pore and Barrientos (1976). The events examined are listed as follows:

Table 5

Event	Days/Mo/Yr	Type	Name
1	08-09/03/57	E	
2	30-31/07/60	T	Brenda
3	09-13/09/60	H	Donna
4	14-15/09/61	T	Esther
5	06-07/03/63	E	
6	23-24/01/66	E	
7	27-28/08/71	T	Doria
8	18-20/02/72	E	
9	21-23/06/72	T	Agnes
10	09-10/08/76	H	Belle

H = Hurricane

T = Tropical storm

E = Extra-tropical storm

12.1 Sea Waves

Wave heights and periods, bottom orbital velocities, and bottom orbital diameters were computed using wind measurements at Ambrose Lightship. In the case of Hurricane Belle, the ALS station was evacuated and winds from John F. Kennedy Airport were used instead. The results are summarized on Figures 18 to 27. On most figures the increase and then decrease of wind velocity depict the passage of the storm. In many cases the wind direction is such that onshore winds are not a major constituent of the storm. The more important events are discussed separately.

Event 3 (Donna): 15-foot high and 7-second waves were reported at ALS for that hurricane.

Event 6: Fairly intense bottom orbital velocities (88 to 94 cm/sec) are hindcast because of the presence of onshore winds during that extra-tropical storm.

Event 7 (Doria): The most intense bottom orbital velocities (206 cm/s) of all events hindcasted. These high orbital velocities are associated with strong onshore winds (26 m/s) recorded at ALS.

Event 8: The second in intensity after Event 7 as bottom orbital velocities of 146 cm/s are hindcasted.

Event 9 (Agnes): Characterized not by the intensity of the event, but by the longer duration of significant bottom orbital velocities.

Event 10 (Belle): Below expectations because winds are blowing from north-east and the hindcasting model does not generate high waves locally.

12.2 Swell Waves

The spatial generation of waves by hurricanes has been analysed by Ross and Cardone (1978). Different models were explored and applied to the

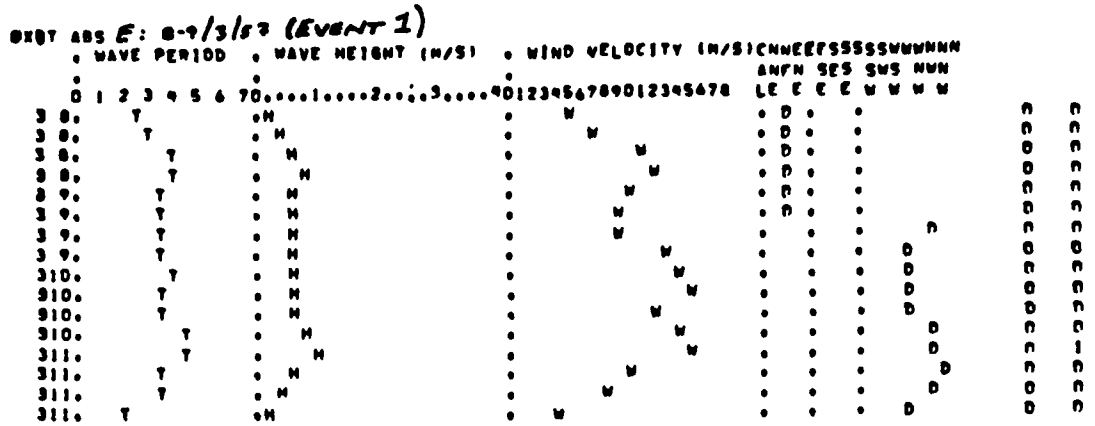

Figure 18

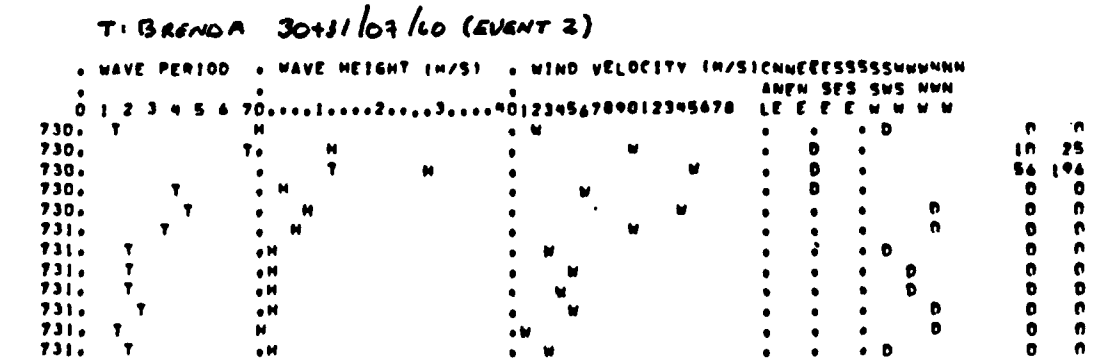

Figure 19

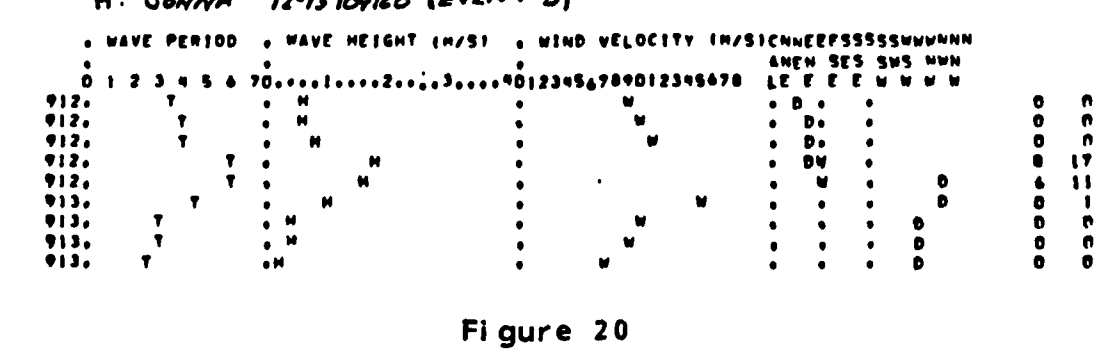

Figure 20

Figure 18-27. The four parameters shown are the computed wave period (T) in seconds and wave height (H) in meters, the wind velocity (W) in m/s and the wind direction (D). The scale is reproduced at the top of each figure. At the far left, the month and date are indicated and repeated for each record of the same day (ex: 730 means July 30). The two columns at the far right indicate: the first one the maximum bottom orbital velocity (cm/s) and the second one the maximum bottom excursion (cm).

T: 14-15/09/61 (EVENT 4)

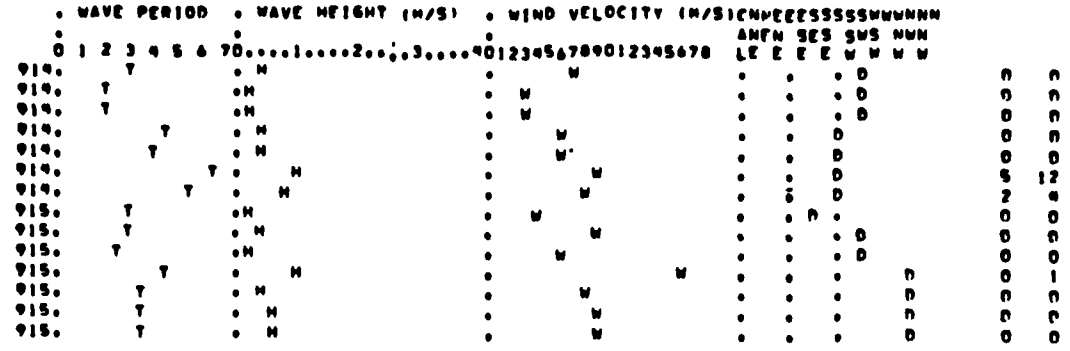

Figure 21

E: 6-7/03/63 (EVENT 5)

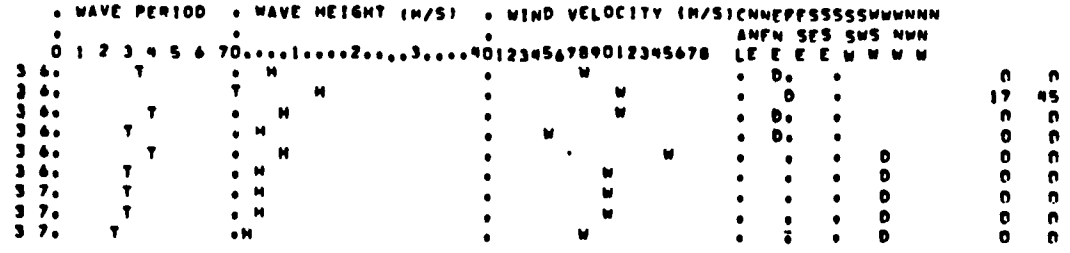

Figure 22

E: 23-24/01/66 (EVENT 6)

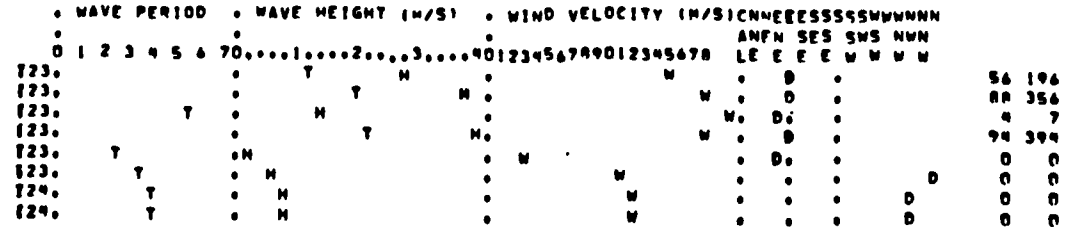

Figure 23

T: DORIA 27-28/09/71 (EVENT 7)

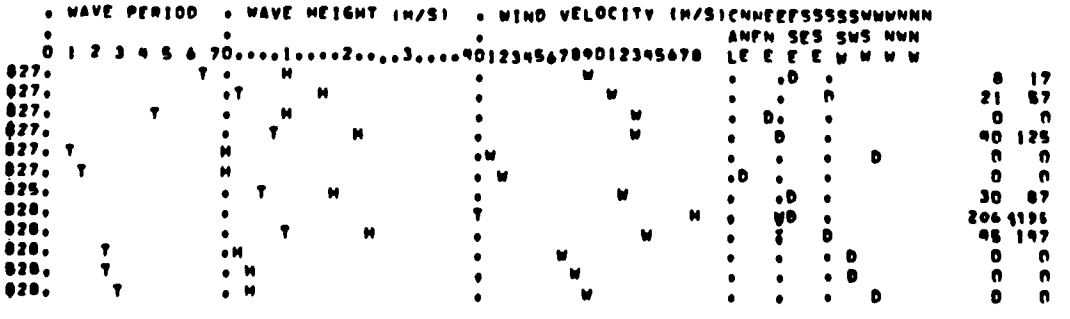

Figure 24

E: 18-21/02/72 (EVENT 8)

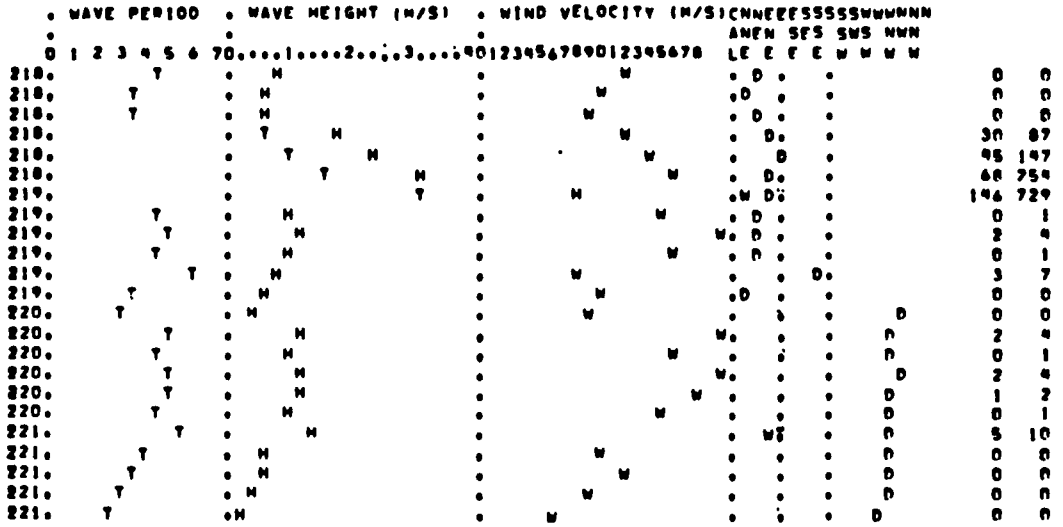

Figure 25

T: AGNES 21-23/08/72 (EVENT 9)

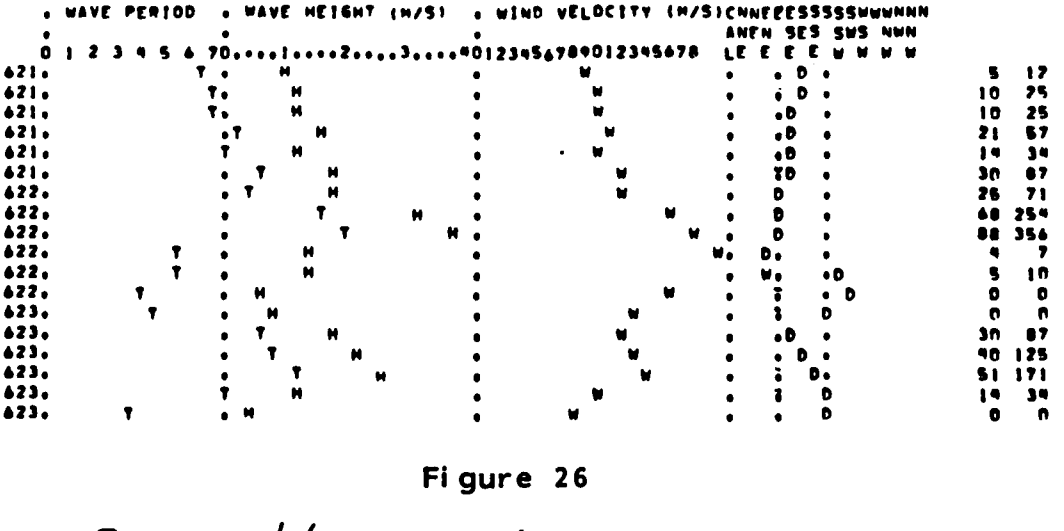

Figure 26

H: BELLE 9-10/8/76 (EVENT 10)

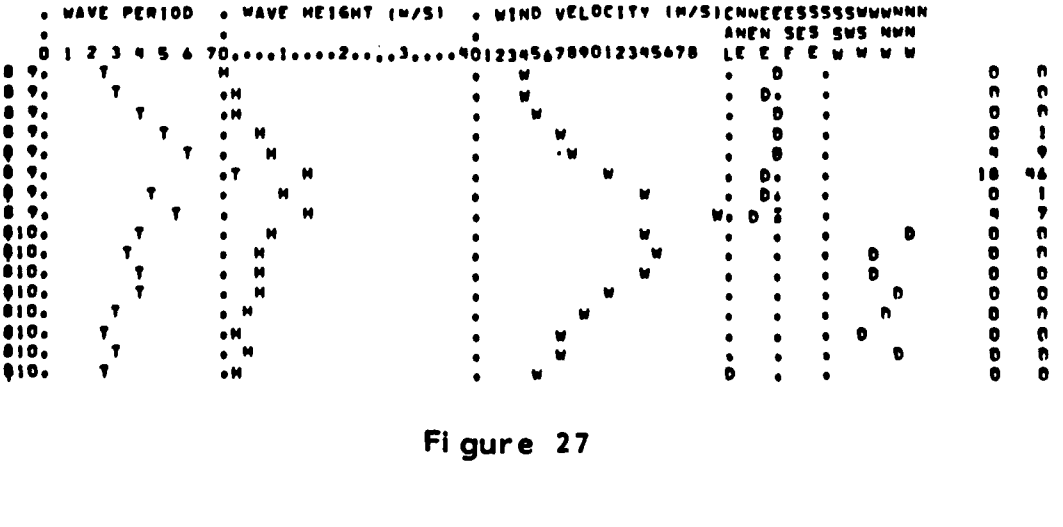

Figure 27

Atlantic Coast offshore the New York Bight. The results are reproduced on Figure 28. These outlines the potential of hurricanes to generate, under different conditions, swell waves in the New York Bight.

The National Hurricane Center has compiled a comprehensive analysis of all storms on the Atlantic Coast since 1886, including the maximum significant waves heights generated by each storm as it progressed along its course. With respect to the New York Bight, it is assumed that the maximum impact from a storm would be felt when the storm center reaches latitude 40°N because the waves formed in front of the storm center would then be propagating towards the New York Bight. The storm characteristics at latitude 40°N, or nearby, compiled by NHC are listed on Table 6. These data, when used in conjunction with Figure 28, permit a qualitative estimate of the swell waves reaching the New York Bight during major storms.

On the basis of these records, it appears that the most severe storm is the ill-fated 1938 hurricane, in which case the computed significant wave height reaches 13.5 meters. It is interesting to notice that "Gladys" (1975) produced 13.1 meter waves, but its center was farther seaward (67.0°W) longitude versus 73.0°W for the 1938 storm).

In summary, storms generating waves higher than 10 m [1938, 1959, 1975 (Gladys) and 1978 (Ella)] are not numerous enough to warrant probability analyses. We can only notice that the two extreme events: the 1938 storm (H_s = 13.5 m) and Gladys (H_s = 13.1 m) are 37 years apart.

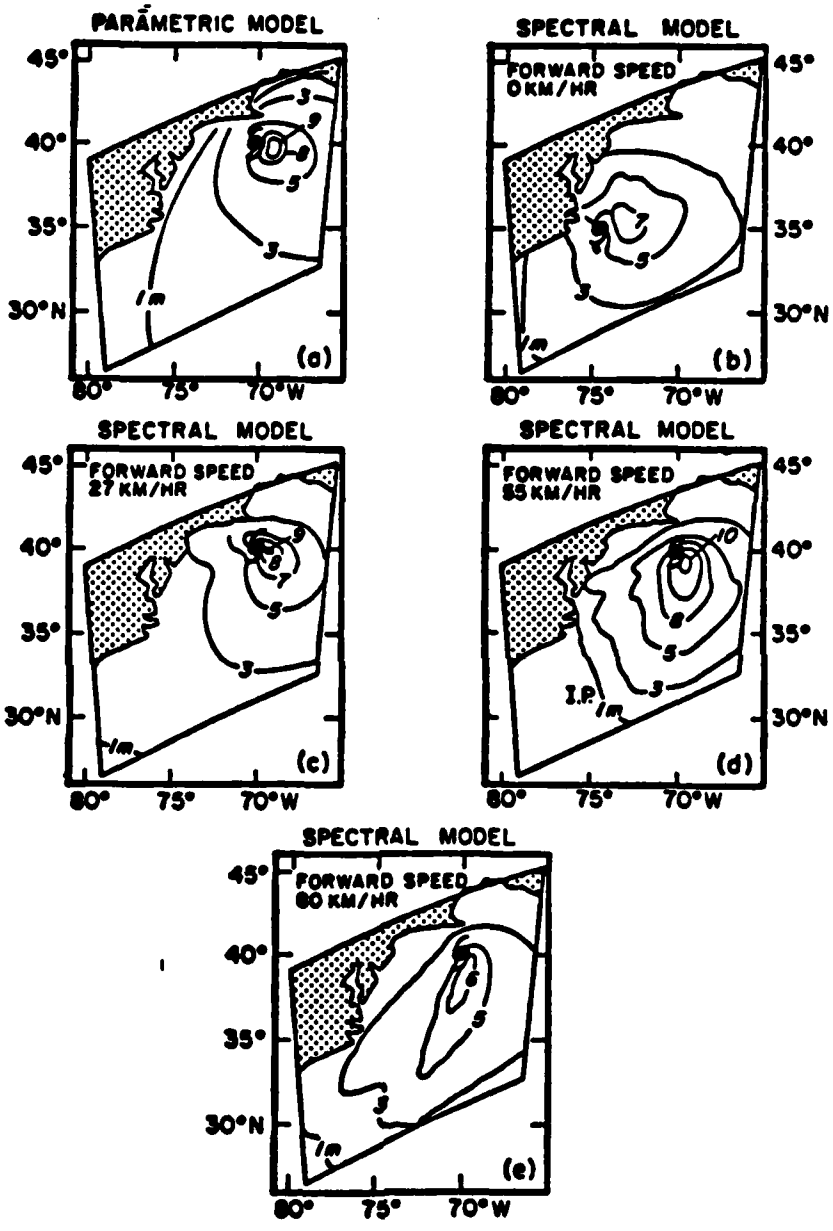

Figure 28. Contour diagrams of the significant wave height for storms of the U.S. Atlantic Coast (from Ross and Cardone, 1978).

Table 6

Year	Date	HR	Lat	Lon	Hs	Year	Date	Hr	Lat	Lon	Hs	
1886	08/26	00	39.9	67.8	6.7	1943	09/08	18	38.8	64.6	5.7	
1887	08/22	00	38.7	70.1	6.9	1944	07/19	06	38.6	62.0	5.3	
1887	08/26	06	39.9	63.2	8.8	1944	08/03	12	39.8	72.8	2.2	
1888	10/12	06	38.4	73.3	4.0	1944	09/15	00	39.9	73.2	7.5	
1888	11/27	06	39.8	70.3	6.4	1945	06/27	06	40.0	70.1	3.8	
1891	09/07	18	39.5	68.0	8.8	1946	07/09	06	39.6	61.6	4.3	
1891	10/05	18	39.9	67.8	7.5	1946	09/15	00	38.7	67.5	6.2	
1891	10/13	18	39.5	71.5	6.3	1948	09/01	06	39.0	65.1	6.4	
1891	10/19	12	39.0	63.9	7.4	1948	09/24	18	39.8	62.3	7.5	
1892	08/21	12	40.0	63.0	7.1	1948	10/15	18	38.5	47.9	2.4	
1893	06/18	06	39.8	70.2	5.8	1949	08/25	18	38.5	59.8	7.0	
1893	08/21	18	39.5	68.6	9.9	1950	08/21	00	39.4	69.5	8.1	ABLE
1893	08/24	06	39.4	73.9	7.6	1950	09/12	00	39.3	70.6	5.2	FOX
1893	08/16	18	38.4	66.1	4.8	1951	05/24	12	39.5	60.0	2.9	ABLE
1894	09/30	18	39.8	72.3	1.3	1951	10/06	12	39.5	65.7	6.2	HOW
1894	10/10	12	39.4	74.0	5.3	1952	09/07	12	39.0	64.0	6.7	BAKER
1894	10/27	00	37.8	66.2	9.1	1952	09/28	18	40.0	56.9	6.9	CHARLIE
1896	09/10	06	40.0	69.2	7.6	1953	08/15	00	39.3	72.3	6.2	BARBARA
1896	09/24	12	38.9	62.7	7.6	1953	09/07	06	38.6	70.3	7.2	CAROL
1896	10/13	12	40.0	67.2	6.5	1954	08/31	12	40.2	72.9	8.6	CAROL
1903	07/26	06	39.8	53.5	4.8	1954	09/11	12	38.0	73.0	8.3	EDNA
1903	09/15	06	39.1	75.0	6.8	1955	09/21	00	39.4	67.8	7.5	IONE
1906	09/10	18	39.8	58.1	7.5	1956	08/18	00	39.5	66.4	5.5	CLEO
1908	08/01	18	39.1	71.0	7.1	1956	08/29	12	39.8	70.8	7.9	DAISY
1908	09/17	12	39.6	64.1	6.1	1958	09/29	00	39.0	65.9	9.8	HELENE
1912	11/24	00	39.1	69.0	5.3	1958	10/11	12	39.3	56.0	7.1	JANICE
1916	07/21	06	39.9	71.4	6.2	1959	06/19	12	38.4	65.3	11.7	
1923	09/09	00	39.2	58.5	5.3	1959	07/11	06	39.5	72.4	3.5	CINDY
1923	10/01	06	39.1	61.9	9.6	1960	09/12	18	40.0	73.1	9.0	DONNA
1924	08/26	18	40.6	70.3	9.1	1961	10/08	06	39.2	64.7	8.0	FRANCES
1924	09/04	06	38.6	66.0	6.9	1962	09/02	00	39.7	65.0	2.9	ALMA
1926	08/07	18	39.6	65.6	6.9	1962	10/07	06	39.1	65.4	7.9	DAISY
1926	09/21	12	40.0	60.0	4.9	1962	10/22	00	39.5	59.7	6.5	ELLA
1926	10/24	00	39.2	50.1	6.3	1963	10/29	06	37.8	68.8	8.4	GINNY
1927	08/24	12	38.0	72.4	8.5	1964	09/04	00	38.7	56.9	7.9	CLEO
1932	09/09	06	39.5	67.7	7.4	1964	09/14	12	38.0	71.5	4.4	DORA
1933	09/17	12	38.9	72.1	5.1	1964	09/24	00	39.2	69.0	7.1	GLADYS
1933	10/07	18	39.4	65.9	9.5	1966	06/14	00	39.2	72.1	2.4	ALMA
1934	09/08	18	38.7	73.8	6.0	1966	07/21	06	39.5	63.2	5.9	CELIA
1935	08/24	18	39.7	57.6	7.7	1966	09/03	18	39.7	51.1	8.6	FAITH
1935	09/07	00	39.7	65.4	9.6	1968	10/21	00	38.6	68.3	6.8	GLADYS
1935	10/01	12	38.8	62.0	7.6	1969	08/12	00	38.6	68.0	8.0	BLANCHE
1936	09/19	00	38.6	74.0	7.1	1969	09/09	18	40.1	69.9	8.2	GERDA
1936	09/24	12	38.6	68.6	6.9	1969	10/17	12	39.6	60.2	6.6	KARA
1937	09/25	18	38.5	61.2	7.9	1971	08/15	12	39.7	67.2	7.1	BETH
1938	09/21	18	39.0	73.0	13.5	1975	07/28	00	39.3	67.2	6.6	BLANCHE
1940	09/02	06	39.8	70.3	6.1	1975	10/02	18	37.8	67.0	13.1	GLADYS
1940	09/16	12	39.7	67.6	6.1	1976	08/10	00	38.8	73.8	7.7	BELLE
1941	09/25	06	39.7	67.5	2.0	1977	10/15	00	39.2	63.3	6.2	EVELYN
1941	10/14	12	39.5	45.0	2.9	1978	09/04	12	40.0	63.0	10.4	ELLA

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ESTIMATES OF SEDIMENT TRANSPORT FROM LONG-TERM FLOW AND TURBIDITY MEASUREMENTS, DREDGED MATERIAL DUMP SITE, NEW YORK BIGHT APEX

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INTRODUCTION

This report covers the long-term, near-bottom flow and turbidity observations taken from November 1980 to June 1981 at the southeast quadrant of the New York dredged material dumpsite (Figure 1) as part of the study of a sediment cap placed on dredged material dumped there in 1980. Included in this report is an estimate of long-term erosion and deposition rates.

Goals of the Study

Observations of flow and turbidity were made to gain insight into the sediment transport conditions at the dumpsite over a significant portion of a year. Statistics from the observations were used in a quantitative model of near-bottom sediment transport to estimate the frequency and magnitude of transport events and were compared to field observations to assess the effectiveness of the modeling approach. Statistics from the modeled transport were then used to develop an estimate of the long-term rate of erosion (or deposition) at the dumpsite.

Environmental Background

Water circulation in this region is complex. A general flow to the southwest has been reported (Mayer et al., 1979). Superimposed on this flow is a secondary flow described as a clockwise gyre centered over the bank east of Christiaensen Basin; the western, northward-flowing arm of the gyre is thought to extend over the study area (Charnell and Hansen, 1974). Reversal of the southwest shelf flow, interactions with the nearby Hudson estuary, and shearing between surface and bottom flows induced by opposing flow directions, all act at various times to obviate simple explanations of flow. Present and past flow measurements in the New York Bight apex indicate that semi-diurnal tides and aperiodic storms are the principle sources of flow energy. Average

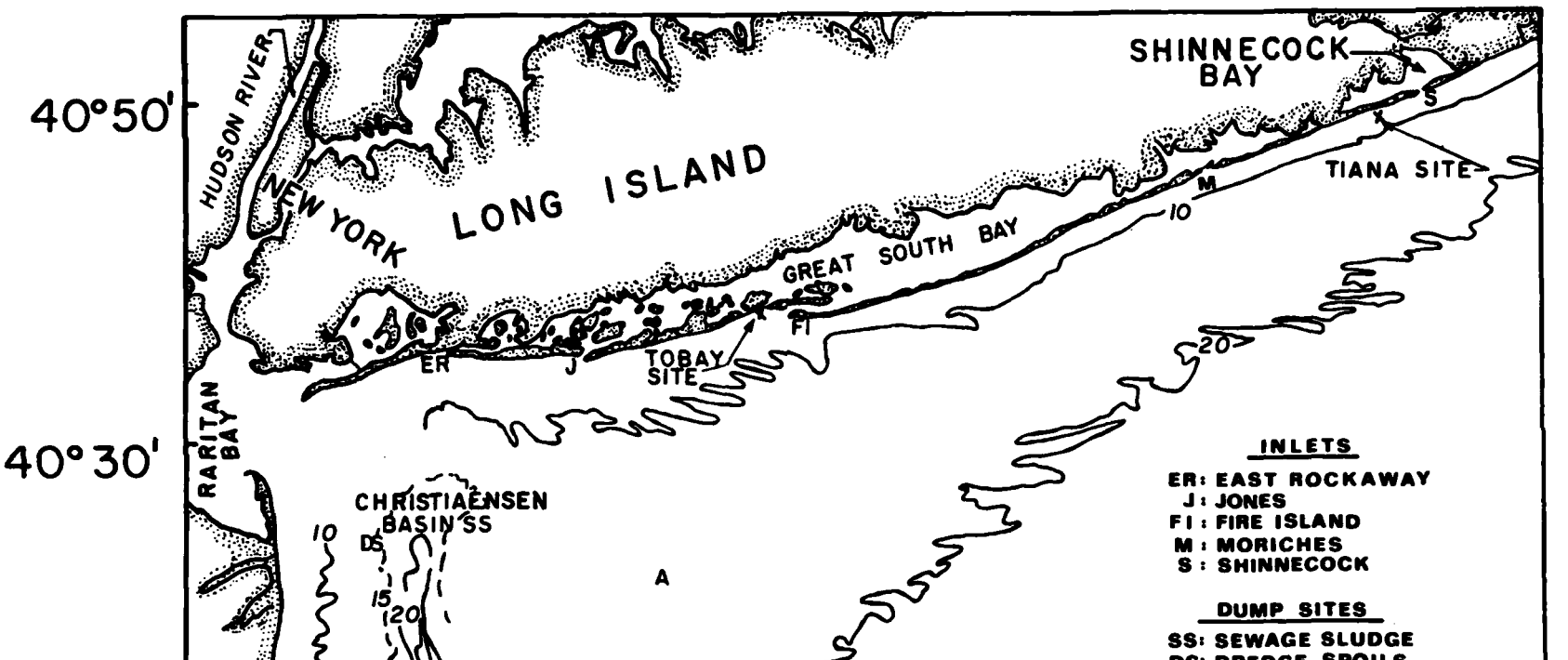

Figure 1. A portion of the New York Bight showing the Christiaensen Basin, the upper portion of the Hudson Shelf Valley (depression south of the Christiaensen Basin), and Bight apex dumpsites.

flow speeds can range from < 5 cm/sec for tidal flows to > 50 cm/sec in response to storms. Mean flow speeds observed during the present study never exceeded 30 cm/sec.

Since depths at the dumpsite are ≈ 30 m, only large surface waves are expected to induce significant orbital velocities near the seafloor. Past work (Grant and Madsen, 1978; Butman et al., 1979) indicates that at these depths waves do induce and/or enhance sediment transport.

Model Background

Several different models have been merged to perform the transport calculations. Although some of these models have been tested extensively in the laboratory, none has had adequately tested in the field. Therefore, transport calculations presented here must be conservatively viewed as order-of-magnitude estimates.

Since flow conditions in the study area may vary among quasi-steady tidal currents, wind-driven storm flows with little wave influence, and wave-dominated combined wave-current flows, the approach taken in calculating transport must also vary. This is because no single model exists which takes into account all of the above conditions. Further, extensive and detailed flow observations far surpassing funding and time allotted this project would be required to satisfy simultaneously the data requirements for models describing all of the above flow conditions. Our approach has been to use first-order approximations for some of the data requirements where the qualitative results are negligibly affected. For example, transport direction is a more important variable than the rate or magnitude of transport. Consequently, greater effort was spent acquiring data to assess direction than magnitude of transport.

For the steady flow case two models of bedload transport have been investigated. The first is due to Bagnold (1973) and relates the amount of sediment being transported in a steady current to the fluid power in excess of a threshold value. This leads to an expression relating the volumetric rate of transport q_B (all transport rates have units of volume of sediment/bed surface area/time) to fluid velocity cubed, u^3. In this model transport direction is the direction of the mean flow.

The other steady flow model investigated is based on the principle that the flow must exceed a threshold shear stress to initiate motion. After motion is initiated the mean flow seems to transport the sediment. This concept is supported by a large body of experimental data (Yalin, 1972; see Graf, 1971, for a more complete discussion) and is the basis for the pioneering approach of Shields (1936). By grouping together all important flow and sediment parameters into two dimensionless variables describing bed shear stress at erosion and sediment grain size, Shields (1936) was able to show that a smooth curve resulted, separating the transporting and non-transporting conditions for flat beds of uniform sediments. Many subsequent investigators have verified and amplified Shields results, but arguments have also been made that some transport occurs even at sub-threshold conditions due to the natural variability of bed shear stress in a turbulent boundary layer (Einstein, 1950). However, transport rates under sub-threshold conditions will likely be relevant only to problems having geologic rather than human time-scales. Consequently, we will limit ourselves to models which require a threshold for initiation of sediment motion.

Transport due to waves at the study area may be important, but due to the 30 m water depth, wave-induced transport is probably significant only during major storms. In a companion investigation of wind-wave models appropriate

for the study area, Drapeau (section C, this report) suggested that only long waves having periods equal to or greater than six seconds generate significant oscillatory currents near the bottom. As will be shown later, long-term, near-bottom flow measurements at the study area tend to support this hypothesis.

When both waves and currents are present, their boundary layers interact non-linearly; determination of the resulting bed shear stress must take these factors into account. In a series of papers, Madsen and Grant (1976), Smith (1976), and Grant and Madsen (1978, 1979) have presented models of boundary layer flow incorporating wave-current interactions in order to calculate sediment transport. The Grant and Madsen (1979) model solves the dynamics of the wave-current interaction through the concept of a linearized, combined, wave-current friction factor determined by the apparent bottom roughness. The apparent roughness depends on both the physical bottom roughness (grain size, small bedforms) and wave characteristics. The apparent roughness is always equal to or larger than the physical roughness. This results in the current experiencing a larger bottom resistance due to the presence of the wave. The mathematical form of this model is best developed in Grant and Madsen (1978) and is described briefly later in this report.

Near-bottom velocity in wave-current flows, combined with the appropriate wave-current friction factor, can be used to find the threshold erosional stress, following the results of Madsen and Grant (1976). Madsen and Grant and others (Komar and Miller, 1973; Sleath, 1978) suggest that the curve for threshold stress under oscillatory flows parallels but does not coincide with the curve Shields (1936) found for steady currents (Figure 2).

Transport rates under combined flows are not well studied empirically or theoretically. Only a few empirical studies exist (Inman and Bowen, 1962;

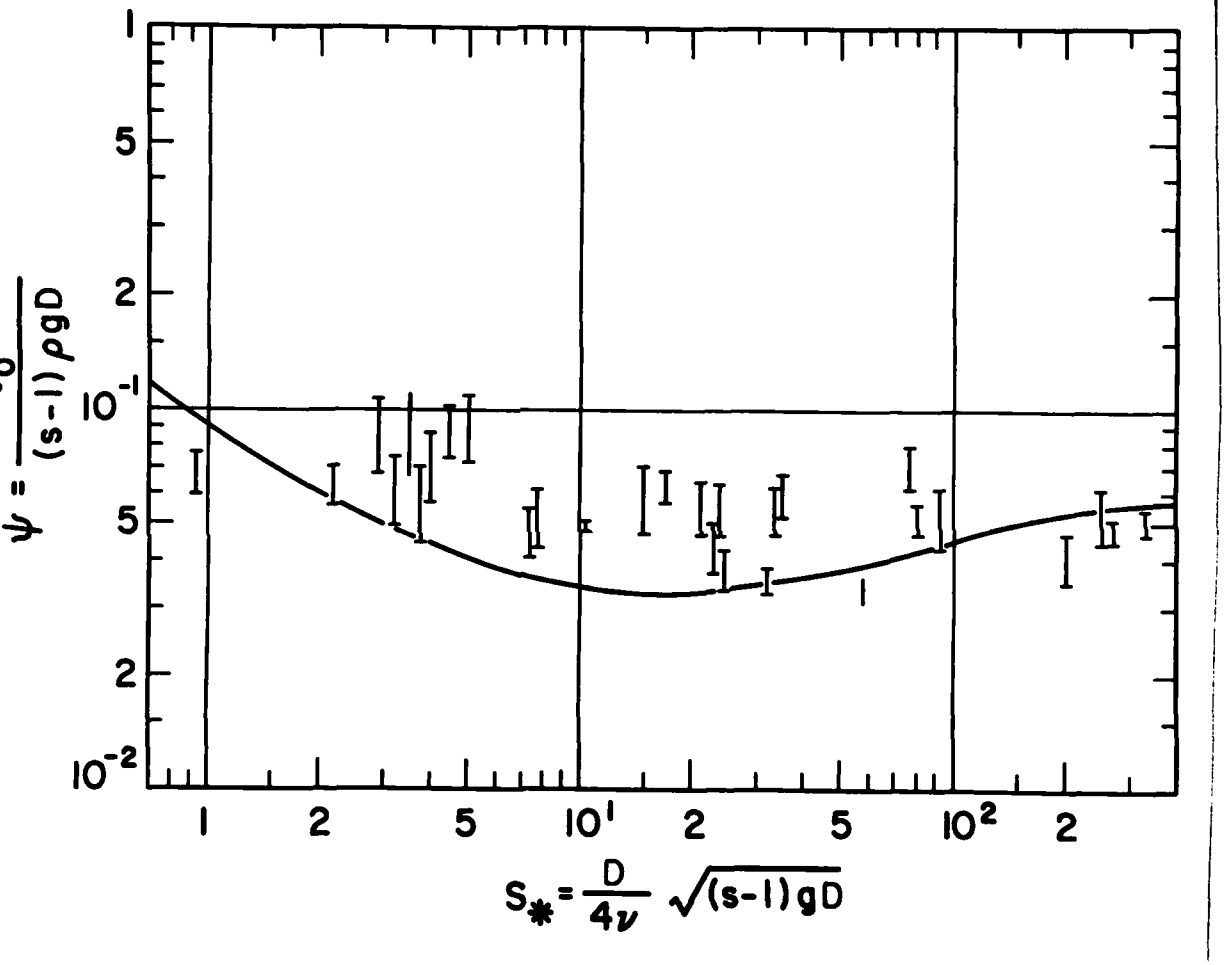

Figure 2. Shields curve for oscillatory flows (from Madsen and Grant, 1976).

Bliven et al., 1977; Hammond and Collins, 1979), while a much larger body of data and theory exist for transport under waves alone. Vincent et al. (1981) reinterpreted the data used by Madsen and Grant (1976) to calculate bedload transport rates, q, under combined flows. The approach suggested by Madsen had q proportional to bed shear stress τ cubed, or $q \propto \tau^3$. Since τ is proportional to velocity squared (u^2), Madsen and Grant's approach has $q \propto u^6$. Vincent et al. (1981) point out that most other investigators (e.g., Einstein, 1950; Bagnold, 1973) have assumed the volume of sediment transported is proportional to the product of τ and the transport velocity, yielding $q \propto u^3$. Using this approach and laboratory data for calibration, Vincent et al. (1981) derived a time-dependent combined-flow transport function which depends on the excess shear stress during each wave cycle to resuspend the sediment when it is then advected by the mean flow. This function was used in the present study when flow conditions were appropriate. Transport using the combined flow model can be orders of magnitude larger than for steady flow models when waves are present (Vincent et al., 1982a).

Important assumptions made in development of all the above transport models are that sediments are uniform in size and the sediment beds smooth and flat. This is rarely the case in natural ocean sediments and can lead to spurious results. The problem of non-uniform grain size distributions was also discussed by Einstein (1950). Einstein suggested that on poorly-sorted flat beds the larger grains protrude farther into the flow and partially shield the smaller ones. He recommends using a grain diameter representing the mode of the larger grains. Following Einstein, we use the 65th percentile of the distribution (65% of the grains are finer then d_{65}) as the representative size of bed sediments in the present study because of the poor sorting of the sediments in the sand cap.

METHODS

Field deployments of the CV probes (see below) to obtain flow and transport data were made at the stations shown on Figure 3. Station location data and deployment statistics are given in Table 1 and Figure 4. Data recovery was about 98% for CV1, 48% for CV2 and 86% for CV3. CV1, CV2 and CV3 were all located on the sand cap, and were placed on a north-south longitudinal transect to observe any deviations in flow pattern due to topography, gradients in transport due to erosion or deposition, and as insurance against loss of data due to failure or premature removal of the current meters.

The possibility of significant data loss was realized during all three deployments of CV2 because of battery failure, and during its final deployment when the probe was dragged up by a fishing vessel.

Instrument Systems

The concentration-velocity (CV) probes used in this study consist of microprocessor-controlled electromagnetic current meters (Marsh McBirney 585), coupled with an optical transmissometer (Sea Tech 100) for turbidity measurements, mounted together on a tripod (Figure 5). The current meter was specially programmed to control and power the transmissometer and record its output. The electromagnetic current meter calibration was checked before deployment, but not subsequent to it. Internal calibration checks on gain show no changes occurred during the deployment, but yield no information on zero drift. However, our past experience with these instruments suggests that zero drift is probably negligible. Zero drift and gain changes in the transmissometers were checked before and after deployments and found to be negligible. The pressure transducer was calibrated in the laboratory by applying known loads to the transducer.

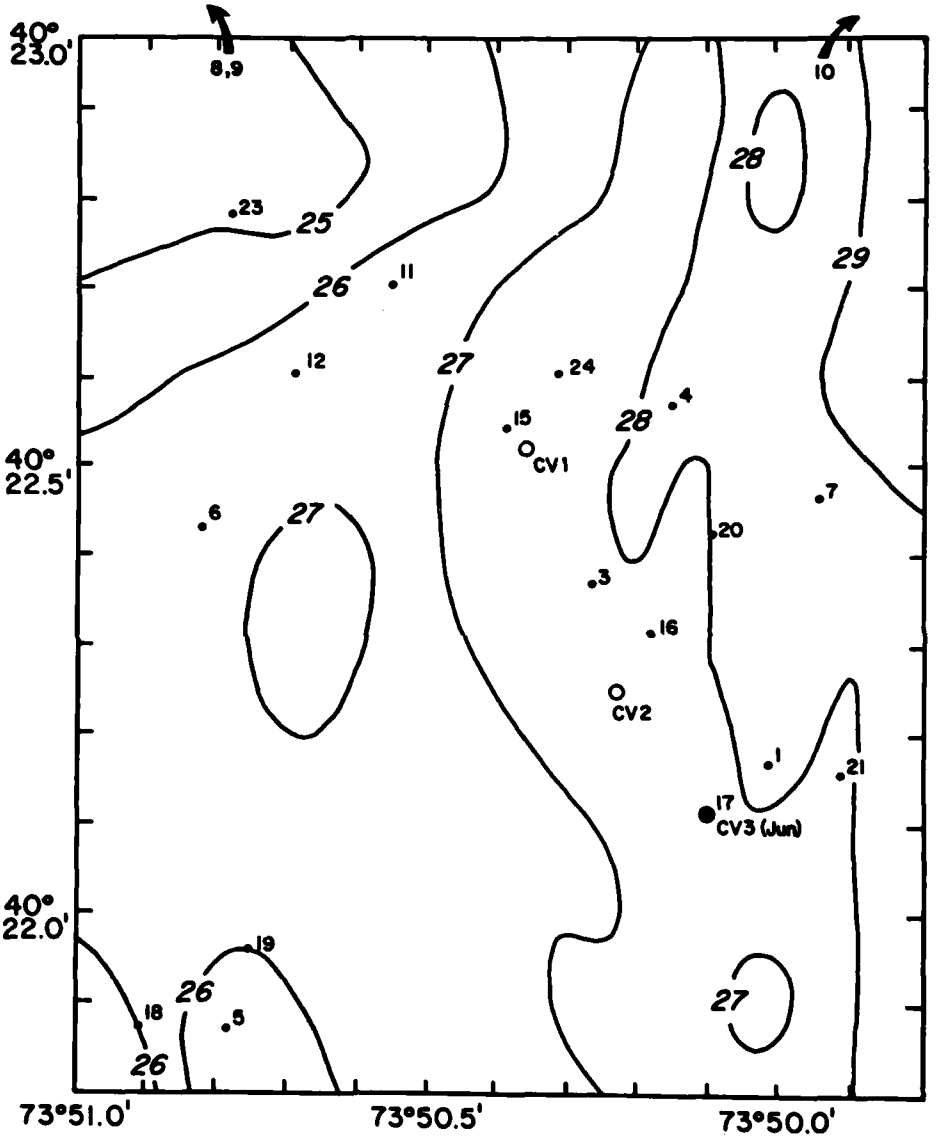

Figure 3. Study area in the southeast quadrant of the dredged materials dumpsite. CV probe stations are open circles. See Table 1 and Figure 4 for dates and location data. Stations marked by small solid dots are Seaflume locations (section B, this report). Depth in meters.

Table 1: Location Data for CV Probe Deployments.

CV1:	40°22.52'N 73°50.36'W	19 November 1980 - 26 June 1981
CV2:	40°22.25'N 73°50.23'W	19 November 1980 - 29 April 1981
	40°28.41'N 73°45.52'W	30 April - 3 May 1981 (dragged up)
CV3:	40°22.12'N 73°50.10'W	7 February - 26 June 1981

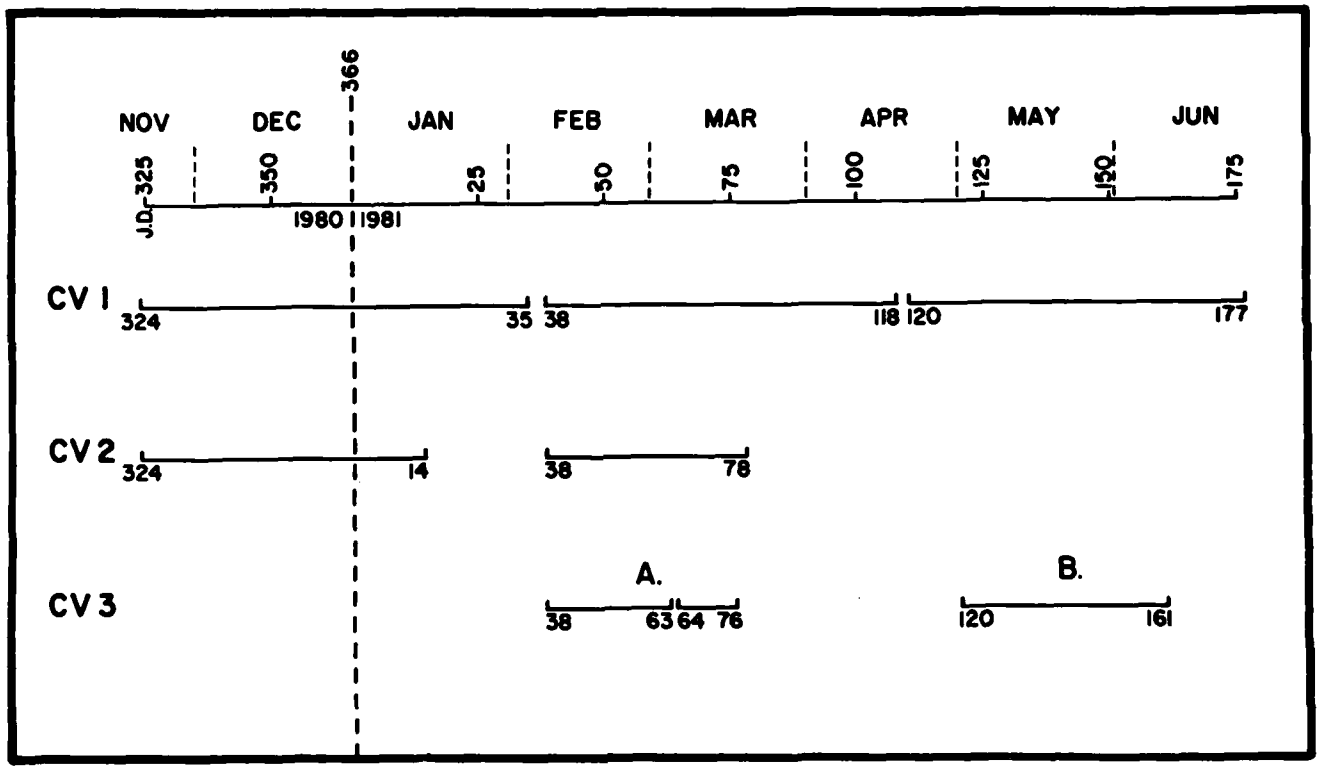

Figure 4. Deployment durations yielding useful data are indicated by the solid bars. Numbers are Julian days (JD) of each year.

Figure 5. CV probe used for flow and transport measurements. Rubber sphere with protruding electrodes for current measurement is underneath pressure housing for electronics. Sphere is 1 m off bottom. Transmissometer with horizontal light-beam path is under sphere. Not shown are subsurface float, acoustic release, and rope basket which are attached to top of probe when in place.

The current meter sensor was mounted one meter above the tripod base. The transmissometer was mounted below the current meter at about 50 cm above the tripod base. This arrangement minimized flow interference between the two sensors (Figure 5).

Flow velocity at 100 cm ($\vec{U}_{100}$) and percent transmission (Tr) were sampled once per second during measurement periods of three or four minutes. Averaged values of ($\vec{U}_{100}$, Tr) and ($\vec{U}^2_{100}$, Tr^2) were determined by the microprocessor and recorded for each burst. Arrow overbars indicate vector quantities. Intervals between measurements were one hour during the first deployment period from November 1980 to February 1981, and two hours in the following deployments. A pressure sensor on the current meter was used to determine average pressure P during each measurement period.

An attempt was made to use the $\vec{U}^2$, Tr^2, and P^2 values to demean the velocity, transmission, and pressure measurements in order to estimate their statistical variance. The pressure and velocity variance can also be used to estimate wave energy reaching the seafloor (Silvester, 1974). However, during the multiplication process roundoff errors accumulate in the microprocessor due to the limited bit size of the data words. These errors bias the calculation in an unpredictable way and attempts to calculate variance produced random results. This could be corrected by reprogramming of the microprocessor to increase the size of the data words, but the problem was recognized too late in the project schedule to effect this change.

The tripods were deployed with acoustic recall systems to prevent accidental fouling by surface vessels. The acoustic recall systems consisted of a release mechanism and bouyed rope basket holding sufficient rope to reach the surface and retrieve the tripods. These systems worked fairly well. Only one release failure occurred during eight deployments; an acoustic pinger on the tripod was used to locate and retrieve it by bottom dragging.

Instrument Calibrations and Computer Processing

Cassette tapes from the current meters were processed by standard programs on the laboratory computer. Data was first passed through a program which screens the data for easily identified bad data points. After initial editing and hand selection of the first good data record on the bottom, the data is converted from integer to engineering units.

The data were then computer plotted as times series to analyze relationships between flow and suspended sediment (Tr) and to identifiy spurious data points. Spurious data points were edited from the computer data files by hand. The resulting data set is the longest near-continuous record of near-bottom flow and suspended sediment obtained in the New York Bight apex.

Transmissometer Measurements

No attempt has been made to calibrate the Tr values in terms of suspended sediment concentrations. Percent transmission is highly dependent on size and composition (index of refraction) of suspended particles. These properties change with time even at the same site because of variation in contributions from aperiodic biological productivity, resuspension from local sources, and advection of suspended matter from outside the study area.

Bulk suspended matter concentrations near the seafloor are typically 1-10 mg/ℓ during tranquil periods and may reach much larger values during storms (Nelsen, 1979; Young et al., 1981). However, during tranquil periods suspended particles are probably silt and clay-sized with a large proportion of organic detritus due to dredged material dumping immediately north and west of the cap site, and sewage sludge dumping to the east. Both of these activities continued all during the probe deployments. The fine particle load in the Bight, except during the extreme wintertime, consist largely of algae and plankton. During resuspension events, coarser inorganic sediments are

resuspended but the grain sizes and compositions of resuspended particles at the 50 cm height of the sensor are not known or easily predicted. Thus, results of our transmissometer measurements are reported as simply percent transmission over a 0.25 m light path.

These relative values could easily be converted to optical attenuation units through the equation

$$I_R/I_S = \exp(-Cr) \tag{1}$$

where I_R/I_S is the ratio of light intensity measured at the receiver to the source intensity, r is the optical path length, and C is the attenuation coefficient. The ratio $(I_R/I_S) \times 100$ is identified as the percent transmission reported in the present study. While others have reported reasonable correlations between Tr and suspended matter concentrations in other parts of the water column (Drake, 1971; Meade et al., 1975), variability in size and composition of near-bottom suspensions, as discussed above, prevented similar calibration attempts in the present study.

RESULTS

Presentation of the results will be separated into two main sections, the first describing the characteristics and overall flow statistics of the mean flow. The second section will discuss estimates of sediment transport based on the observed flows and the waves generated by a wind-wave model developed for this study (Drapeau, section C, this report).

Mean Flow

Time-series plots showing relationships among plots of flow velocity $\vec{U}$, wave energy (WE) and percent transmission (Tr) are presented in Figures 6

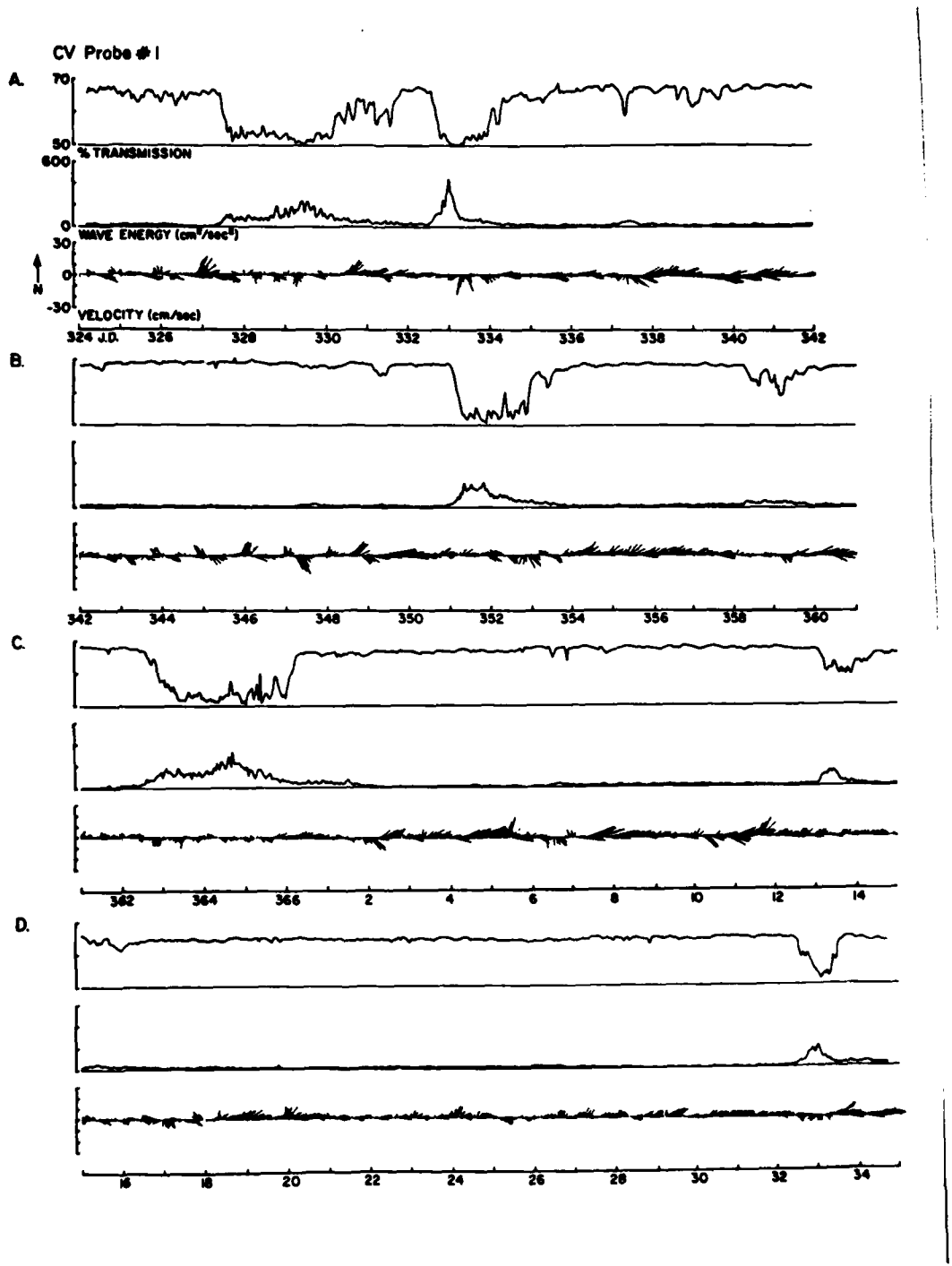

Figure 6a. Time-series plots of velocity and percent transmission data from CV1. Numbers beneath each graph set are Julian days in 1980 and 1981. Velocity plots are stick diagrams showing direction (north up, east to right, etc.) and speed (length of stick; scale at left).

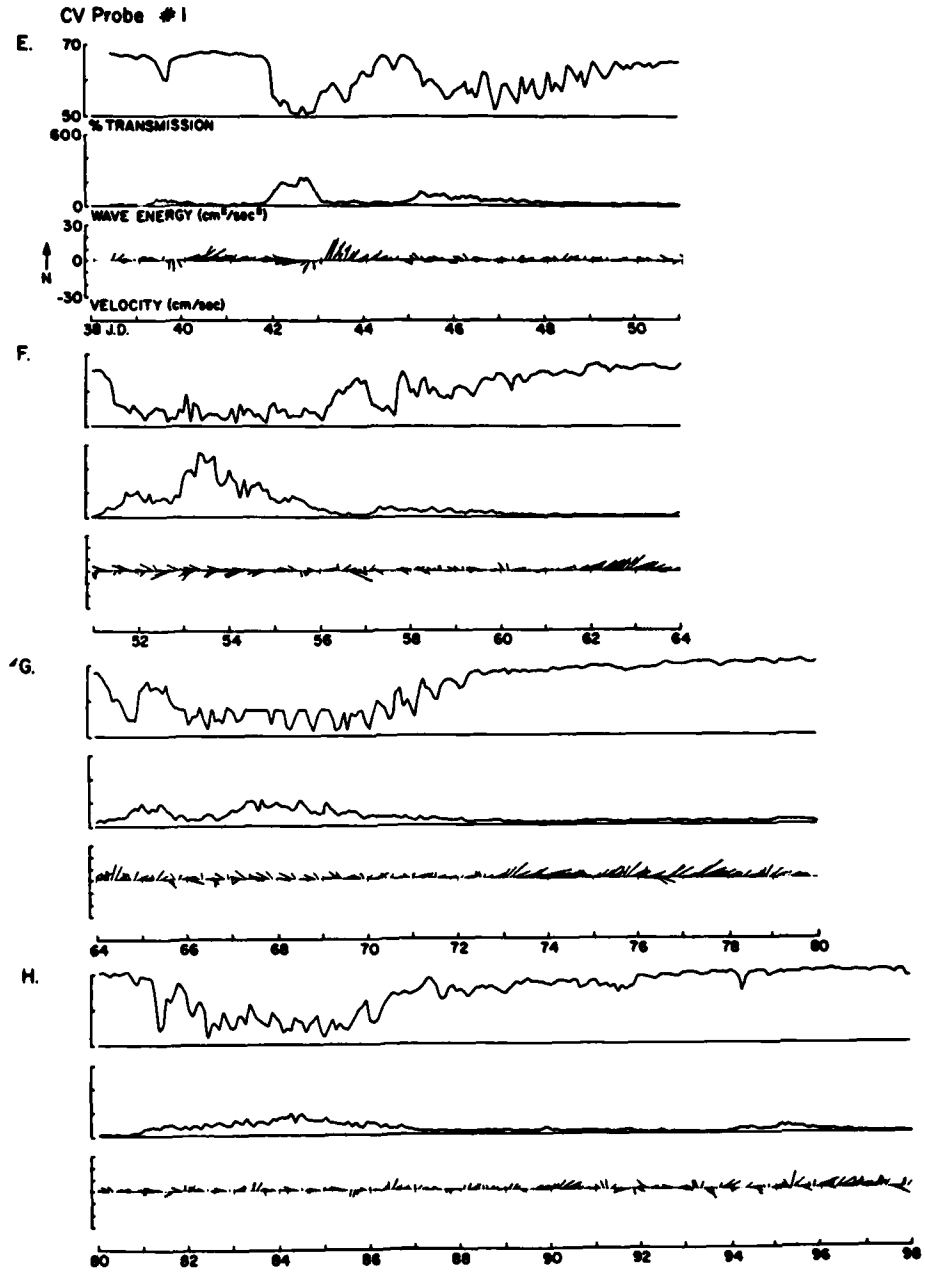

Figure 6b. Same as for Figure 6a.

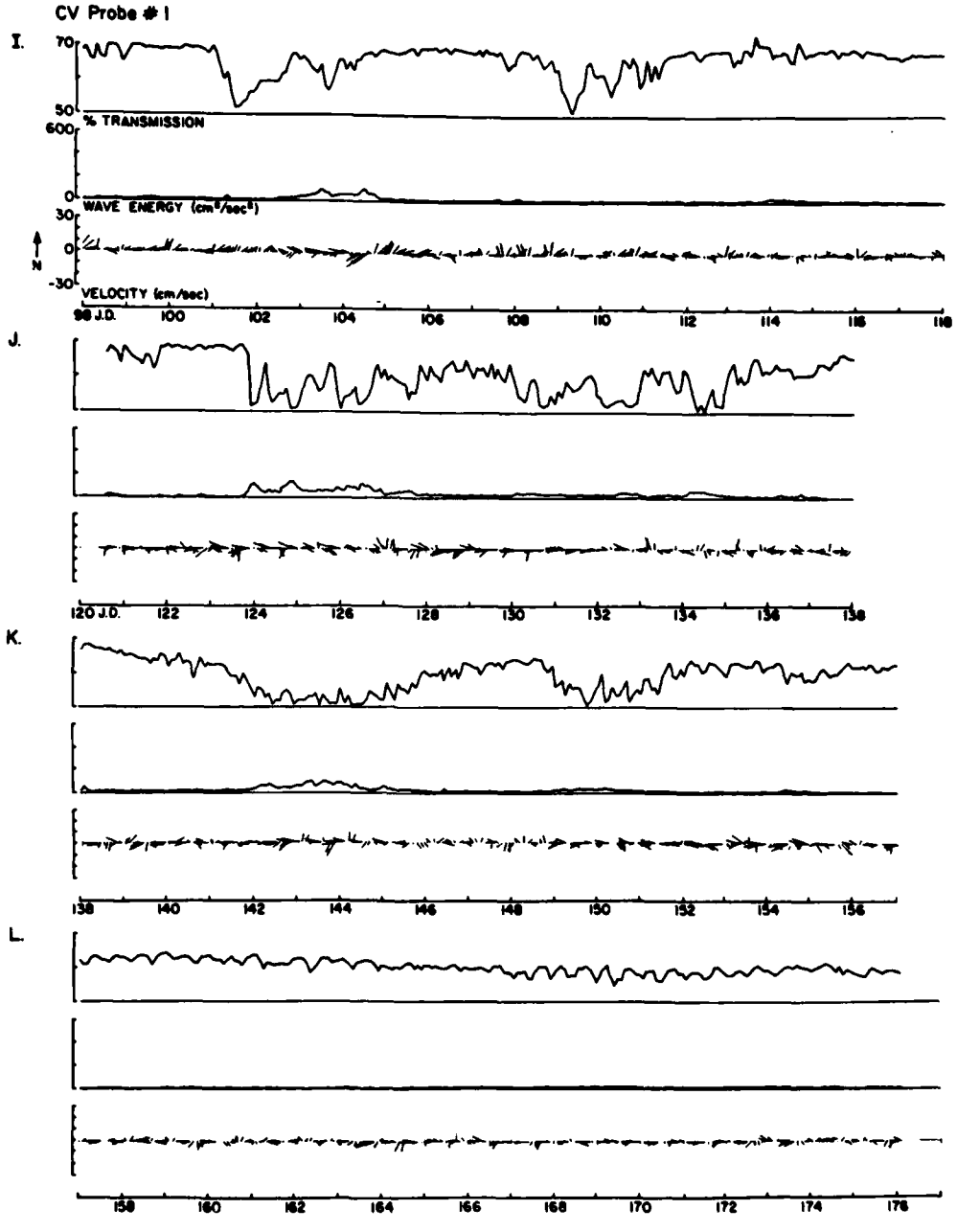

Figure 6c. Same as for Figure 6a.

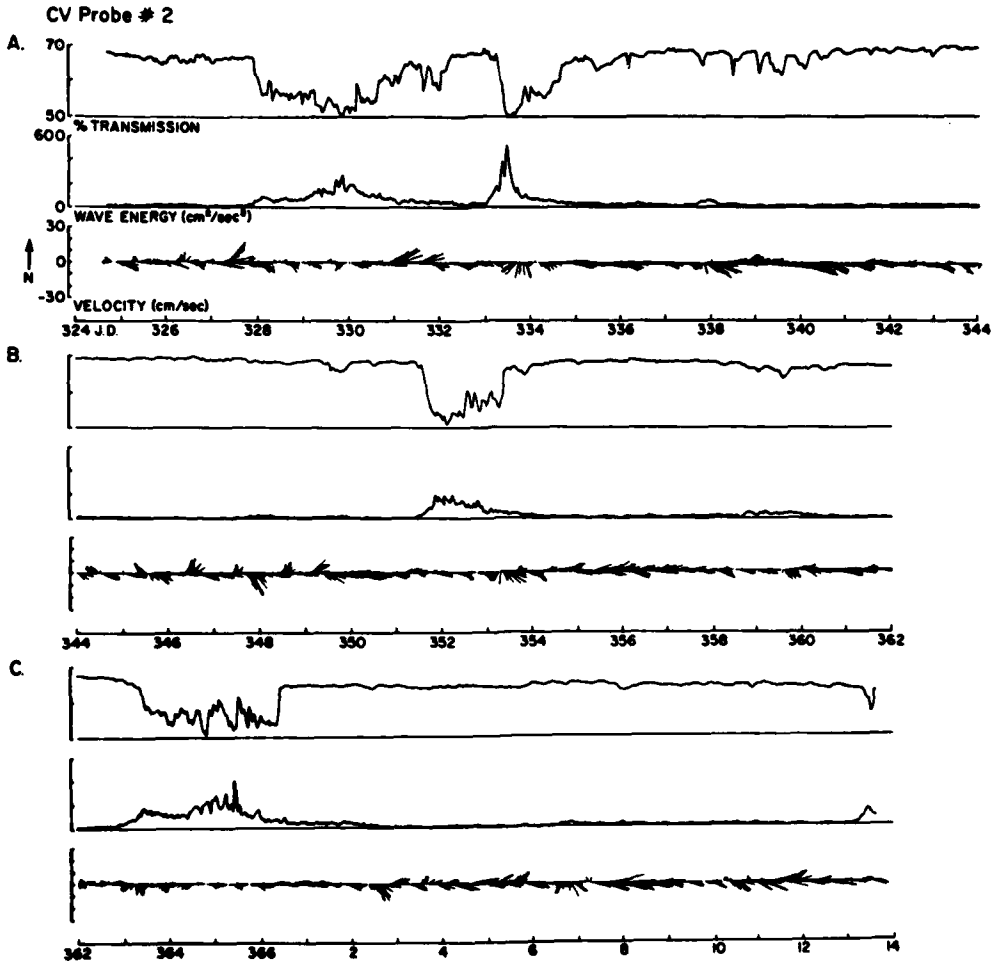

Figure 7a. Time-series plots of $\vec{U}$, WE and Tr data from CV2.

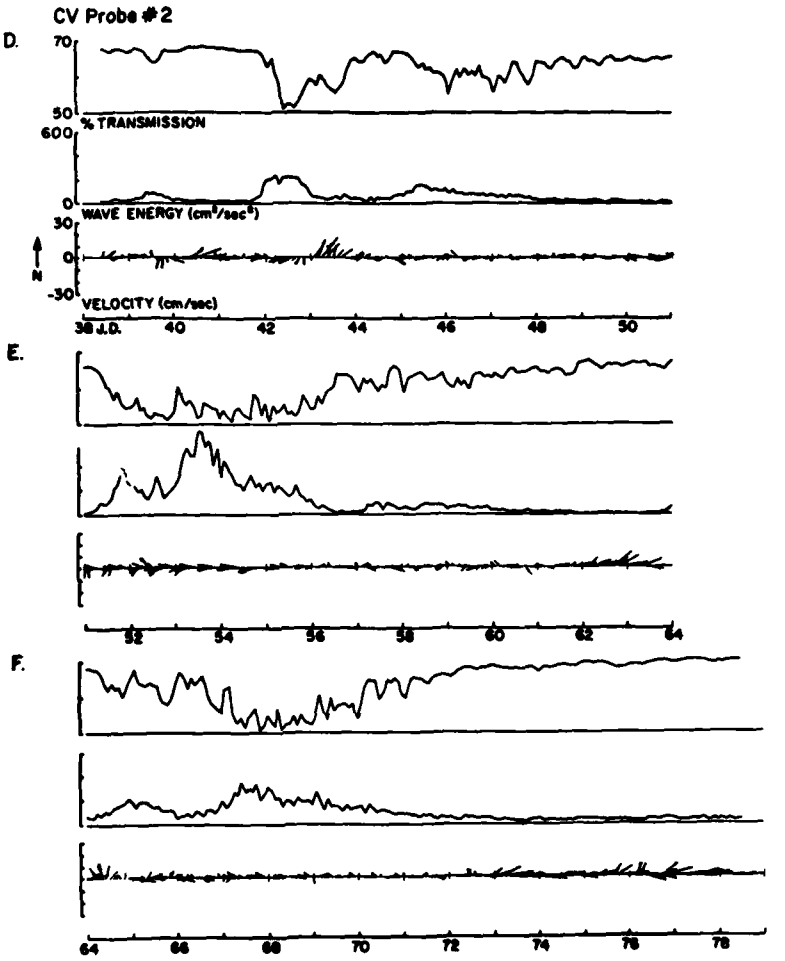

Figure 7b. Same as for Figure 7a.

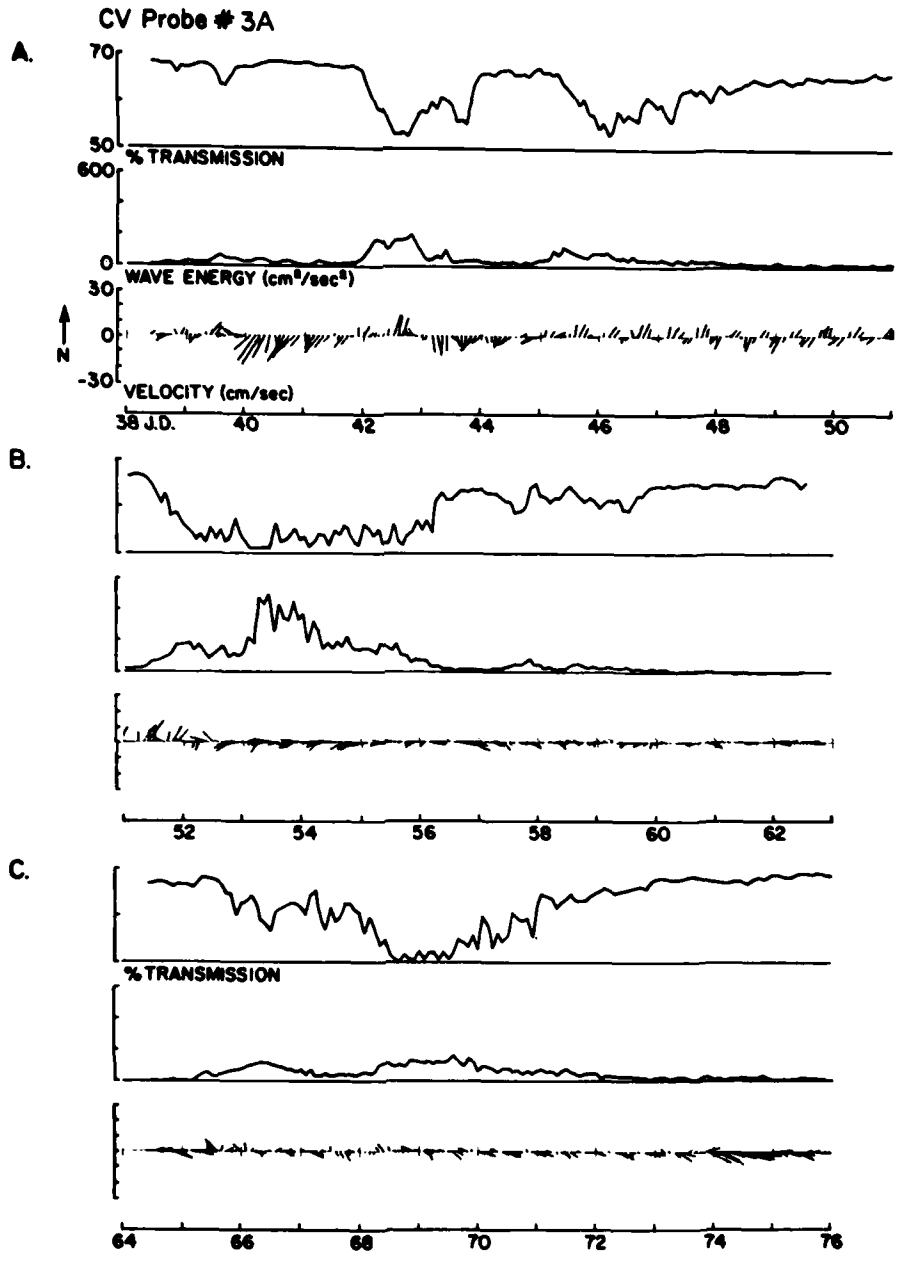

Figure 8. Time series plots of $\vec{U}$, WE and Tr data from CV3A.

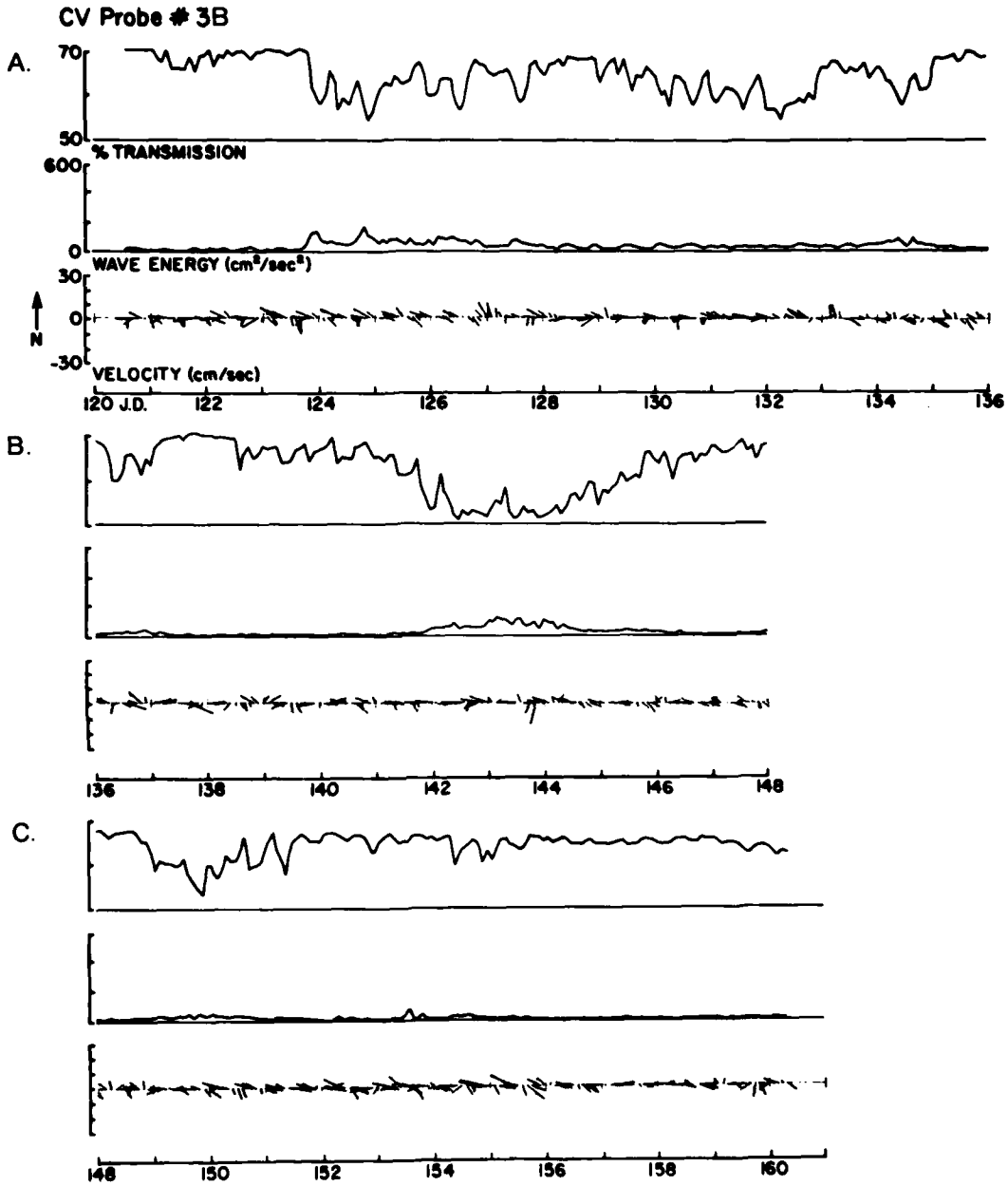

Figure 9. Time-series plots of $\vec{U}$, WE and Tr data from CV3B.

to 9. Visual comparisons of WE, and Tr immediately indicate the apparent importance of waves to resuspension at this site. There are few instances (e.g., Figure 6c, plot I, JD 101-102 and 109-111) where Tr decreases (turbidity increase) without a concurrent increase in WE. It must be emphasized that changes in Tr are likely to best reflect changes in fine (< 62 μm) suspended matter concentrations and therefore may not always indicate transport of coarser or heavier particles nearer than 50 cm to the bed. However, wave-induced bedload transport is closely tied to suspended load through release of the fine material in bed sediments by wave stirring of the slightly muddy bottom sediments (Young et al., 1981; Clarke et al., in press). Waves may also enhance vertical mixing of resuspended sediments of all sizes through an increase in the vertical eddy diffusivity over that due to a steady current alone (Vincent et al., 1982a).

Mean currents at 100 cm above bottom were generally on the order of 6 to 7 cm/sec during the deployments (Figure 10). Histograms representing all speed and direction observations from CV1 (Figure 10) are representative of CV1, CV2 and CV3 data.

Since high wind conditions usually result in both wave generation and advective forcing of the flow, it is not surprising that WE varies with U_{100}. However, high U_{100} values not associated with tides can be caused by forcing outside the local area. In those cases, high U_{100} values need not be accompanied by waves. This apparently did not occur during the present study.

Another case, high WE with average U_{100}, did occur during several periods (e.g., Figure 6a, plot C, JD 363-366; Figure 6b, plot E, JD 42-43; plot G, JD 67-70; plot H, JD 82-86). We shall show later that high WE during these events may have been from either long period swell or other turbulent flow mechanisms because local winds were insufficient to produce surface waves capable of stirring the bottom sediments.

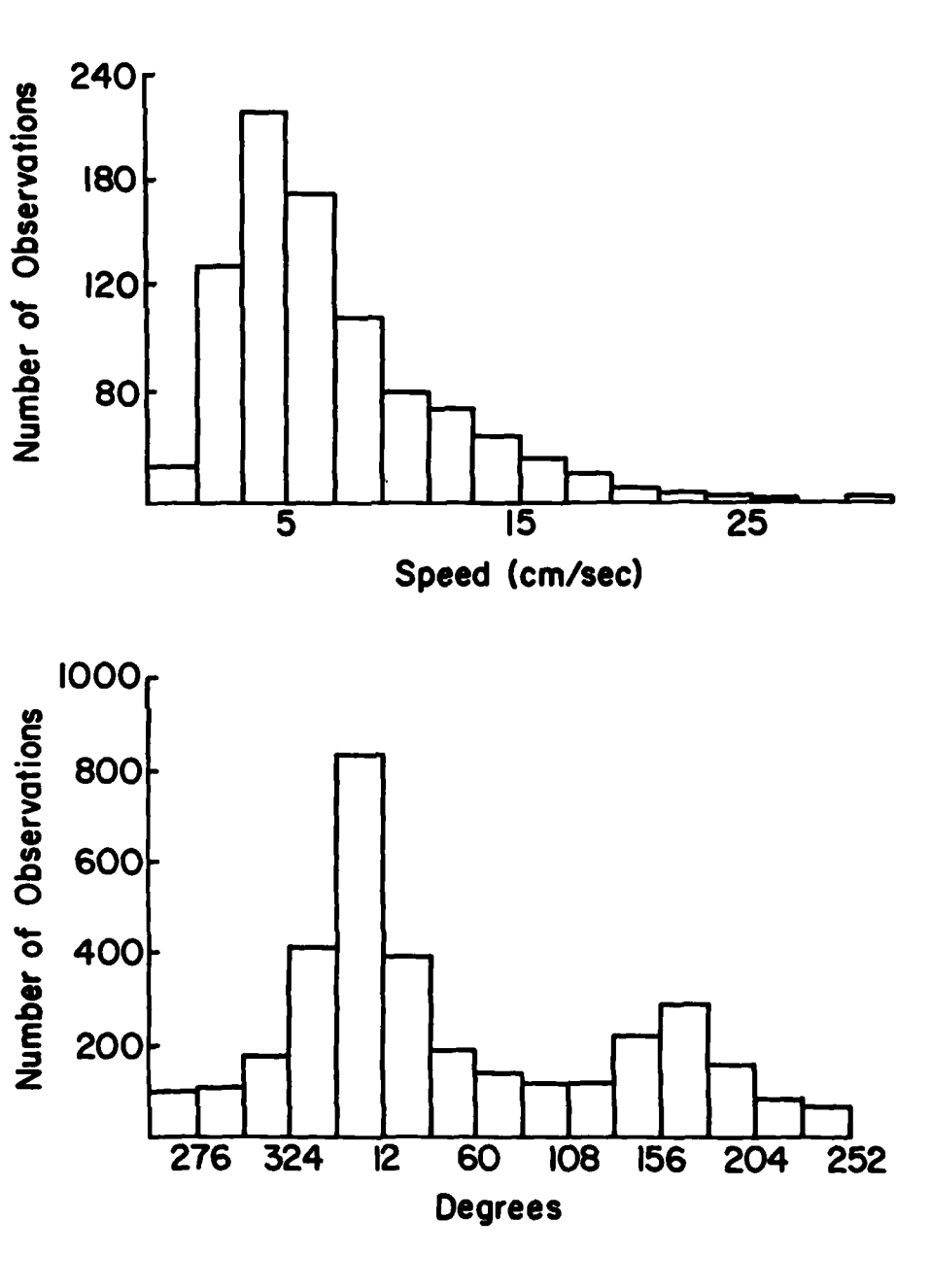

Figure 10. Histograms of mean flow speed and direction from probe CV1.

The net direction of suspended fine particle flux can be estimated qualitatively by plotting the north versus east components of the product of the vector velocity $\vec{U}$ and Tr, or $\vec{U} \cdot Tr$ for $Tr < 60\%$. The resulting scatter plot (Figure 11) indicates net flux to the south (177° true) We shall show later that calculated and observed fluxes are in generally good agreement.

Wave-Current Model Calculation

Before presenting results of the combined flow and mean flow transport calculations, a description is given of the theory and models.

Boundary Layer and Sediment Transport Theory: The interactions between the mean current and wave boundary layers are non-linear. This results in a turbulent shear velocity for the combined flow, U_{*cw}, defined by (Grant and Madsen, 1978)

$$U_{*wc} = \frac{1}{2} (f_{wc}\ \alpha)^{1/2}\ |\vec{U}_b| \tag{2}$$

$$\alpha = 1 + \left(\frac{|\vec{U}_a|}{|\vec{U}_b|}\right)^2 + 2\ \frac{|\vec{U}_a|}{|\vec{U}_b|}\ \cos \phi_c \tag{3}$$

where f_{wc} is a combined wave-current friction factor, $\vec{U}_b$ is the maximum wave-orbital current velocity in the potential flow region just outside the thin wave boundary layer, as determined by measurement or linear wave theory (Grant and Madsen, 1978; Vincent et al., 1982a), and ϕ_c is the angle between $\vec{U}_a$ and $\vec{U}_b$. The reference velocity $\vec{U}_a$ is not defined explicitly by Grant and Madsen but is assumed to take into account the affects of the waves on the mean flow. The same problem exists for definition of ϕ_c; $\vec{U}_a$ and ϕ_c are usually determined as part of an iterative procedure used to determine the value of other wave boundary layer variables. As Vincent et al. (1982a) note,

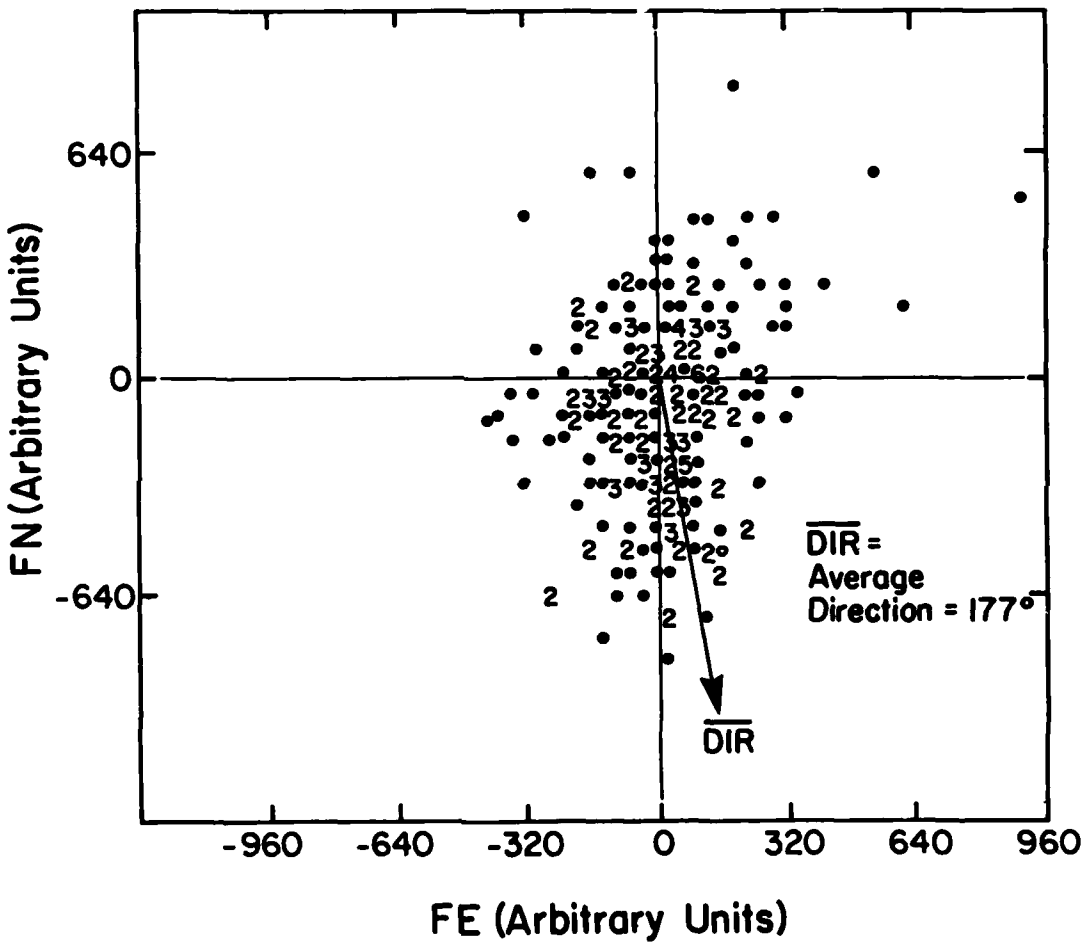

Figure 11. Plot of the CV1 north (FN) versus east (FE) flux components when Tr < 60%. Numbers indicate number of observations and symbol ● indicates ten or more observations.

determination of $\vec{U}_a$ and ϕ_c are critical to the calculation of transport rates since they may differ considerably from the speed and direction of the flow as taken directly from the CV probes or similar sensors.

The steady flow velocity at height z ($\vec{U}_z$) inside the rough turbulent wave boundary layer is related to physical boundary roughness K_b by

$$\vec{U}_z = \frac{\vec{U}_{*c}}{\kappa}\left(\frac{U_{*c}}{U_{*wc}}\right) \ell n \frac{30\ z}{K_b} . \tag{4}$$

Outside the wave boundary layer U_z is related to the combined flow boundary roughness K_{wc} by

$$|\vec{U}_z| = \frac{U_{*c}}{\kappa} \ell n \frac{30\ z}{K_{wc}} . \tag{5}$$

The combined-flow roughness K_{wc} is an apparent roughness due to the presence of the wave which accounts for the grain roughness and the wave motion. The ratio K_c/K_{wc} is always greater than one and is defined by

$$\frac{K_{bc}}{K_b} = 24\left(\frac{U_{*wc}}{|\vec{U}_b|} \cdot \frac{A_b}{K_b}\right)\left(1 - \frac{U_{*c}}{U_{*wc}}\right) \tag{6}$$

where U_{*c} is the mean flow friction velocity, A_b is the amplitude of the near-bottom orbited motion, and the bed roughness K_b is defined as the sediment grain diameter.

Few laboratory studies are known to the author on transport rates under waves or combined flows (Manohar, 1955; Inman and Bowen, 1962; Kalkanis, 1964; Abou-Seida, 1965; Bliven et al., 1977; Sleath, 1978). Of these, only the Inman and Bowen and Bliven et al. studies include combined flows. No field studies of wave or combined flow transport rates appear to be available in the literature.

Threshold under waves or combined flows seems to follow laws similar to those proposed for threshold conditions under steady currents. Several laboratory studies of wave threshold (Komar and Miller, 1973; Madsen and Grant, 1976; Dingler, 1979; Hammond and Collins, 1979) indicate that the threshold condition for uniform sediments under waves may be expressed by the wave Shields number, ψ_{TH}, a dimensionless shear stress, or

$$\psi_{TH} = \frac{0.5\ \rho\ f_{wc}\ |\vec{U}_w + \vec{U}_a|^2_{CRIT}}{(\rho_s - \rho)\ gD} \ . \tag{7a}$$

Substituting (2) into (7a) yields

$$\psi_{TH} = \frac{0.5\ \rho\ f_{wc}\ |\vec{U}_w + \vec{U}_a|^2_{CRIT}}{(\rho_s - \rho)\ gD} = \frac{\rho |U^2_{*wc}|_{CRIT}}{(\rho_s - \rho)\ gD} \ . \tag{7b}$$

Here ρ and ρ_s are water and sediment density, respectively, g is the gravitational constant, D is sediment grain size, and $\vec{U}_{CRIT} = \vec{U}_w + \vec{U}_a$ represents the combined wave and steady current velocity at threshold.

Instantaneous volumetric bedload transport rates q are given variously as (Madsen and Grant, 1976)

$$q_{MG} = 40\ WD\ \psi^3\ \frac{\vec{U}}{|\vec{U}|} \qquad (\psi \geq \psi_{TH}) \tag{8}$$

$$q_{MG} = 0 \quad (\psi < \psi_{TH}) \tag{9}$$

and (Vincent et al., 1981)

$$q_v = \vec{U}\ C^* = 0.09\ (\psi - \psi_{TH})\quad \vec{U} \quad (\psi \geq \psi_{TH}) \tag{10}$$

$$q_v = 0 \quad (\psi < \psi_{TH}) \tag{11}$$

where C* is the volumetric concentration of sediments per unit area of bed surface with units of length. The transport rate is perhaps better related to the product of the excess shear stress required to lift the sediment into suspension and the mean flow required to transport it. This yields $q \propto \hat{U}^3$, a form more in agreement with the results of Bagnold (1973) than those of Madsen and Grant (1976). Differences in calculated transport rates from field studies are discussed in Vincent et al. (1982a) and indicate best agreement between q_{MG} and q_v at "moderate" rates of transport. At high rates q_v is in better agreement with the results of laboratory transport experiments than q_{MG}; at low rates q_v tends to underpredict while q_{MG} gives good agreement with laboratory results (Vincent et al., 1981). The consequence of using one or the other of equations (8) or (10) in the present study are described below.

An alternate procedure has also been used to find ψ_{TH}. Sleath (1978) has reconsidered the results of several previous investigations of wave threshold and has suggested a revised wave-Shields diagram (Figure 12) which has ψ_{TH} as a function of the non-dimensional grain size

$$D_* = \left[\frac{(\rho_s - \rho)}{\rho} \frac{g}{\nu^2}\right]^{1/3} D \tag{12}$$

where ν is kinematic fluid viscosity. Comparisons are given below between transport rates calculated using equation (7) and the ψ_{TH} values from in Figure 12.

Transport rates in the above equations are instantaneous values with time intervals scaled by typical wave-time scales (e.g., wave period T). The flow data collected for the present study include only vector-averaged velocities

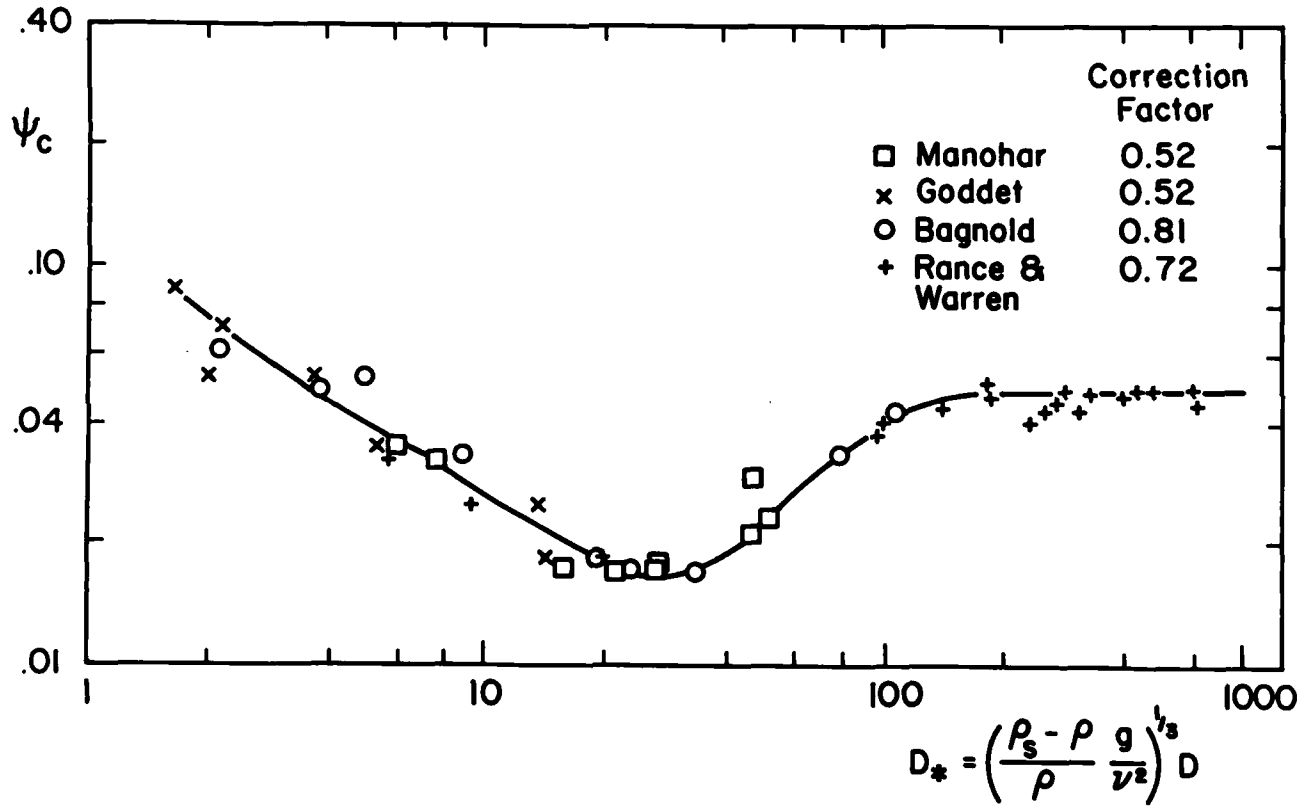

Figure 12. Shields curve for oscillatory flow as modified by Sleath (1978).

$\langle\vec{U}\rangle$ from the CV probes in the form of north (V_N) and east (V_E) velocity components sampled at 1 Hz and averaged over periods of three to five minutes every one or two hours. Thus, the current measurements include the effect of oscillatory and mean flows, and the oscillatory components cannot be extracted. Instrumental procedures for extracting the variance (waves) from the mean flow, described in the previous section on instrument systems, were not successful.

At the depths of the study area (25-30 m) we can expect the oscillatory currents due to waves to be nearly symmetrical. Hence, the vector averaging procedure for V_N and V_E should tend to minimize the oscillatory contribution to $\langle\vec{U}\rangle$. However, other residual unsteady flow components will not be averaged out and will introduce errors into the value of $\langle\vec{U}\rangle$ which are difficult to estimate. If the flow were stationary (invariant in time) and steady, the instantaneous turbulent fluctuations, U', in $\vec{U}$ would conform to

$$U' = \langle\vec{U}\rangle - \vec{U} \tag{13}$$

and would tend to sum to zero over suitable averaging periods. Information on the variability of $\vec{U}$ when wave currents exceed mean flow currents, based on data from combined flows at other locations in the New York Bight, indicates it is small in frequency ranges corresponding to the averaging period for $\vec{U}$ compared with wave-induced variability (Lavelle et al., 1978; Vincent et al., 1982b; Clarke et al., in press). Hence, we infer that errors in $\langle\vec{U}\rangle$ for mean flow are small for the purposes of this study. However, for purposes of sediment transport calculations we must somehow account for the wave-current interactions to avoid violating the assumptions of the transport theories.

Several approximations must be made to apply the bedload theories for combined flows to the CV probe data. First, average values for $\vec{U}_a$ and $\vec{U}_b$ must be chosen for equations (2) and (3). Grant and Madsen (1978) indicate an iterative procedure to find $\vec{U}_a/\vec{U}_b$. In the present study the reference velocity $\vec{U}_a$ was approximated by $\vec{U}_{100}/2$ based on results of Vincent et al. (1982a). This is a first order approximation at best, but it will be shown below that this and other approximations of the parameters required to estimate transport have a reasonably small effect on the results.

Grant and Madsen (1978) emphasize that the direction and magnitude of the combined-flow bottom stress is not a simple vector sum of the wave and current. However, for purposes of our study there is no alternative but to define ϕ_c as the reference direction of U_a, the direction given by the vector sum of the current plus wave.

The wave-current friction factor f_{wc} is also found by approximation. First, the wave friction factor f_w is found as a function of A_b/D using an iterative procedure based on the results of Jonnson (1966). This is combined with the estimated current friction factor f_c as

$$f_{wc} = \frac{|\vec{U}_a|\, f_c + |\vec{U}_b|\, f_w}{(|\vec{U}_a| + |\vec{U}_b|)} . \qquad (14)$$

Current friction factors depend also on grain size and bedforms present. A value of $f_c = 2\, U_{*c}^2/U_a^2$ (Sternberg, 1972) was used at first to estimate f_c, but proved unstable because of imprecision in estimating U_{*c} and U_a. A constant value of $f_c = .005$ was chosen for the present study in the mid-range of expected values for the bedforms and sediment types encountered (Sternberg, 1972).

The value of $\vec{U}_b$, the near-bottom wave orbital velocity, was derived from a wind-wave generation model developed for this study (Drapeau, section C, this report). Surface significant wave heights H_s and periods T_s were determined as a function of wind speed at nearby Kennedy Airport after correction for distance from the site. These waves, representing the averages of the highest 1/3 of the waves generated locally during the periods of current measurement, were used to find maximum values of $|\vec{U}_b|$ and $|A_b|$ through linear wave theory (Silvester, 1974). This value of $\vec{U}_b$ and the values of f_{wc} and α are used in equation (2) to find $U_{*_{wc}}$ which is used in equation (7b) to find ψ_{TH}.

The effects of selective attenuation with depth of the high-frequency portion of the surface wave spectrum are well known. An empirical correction

$$\frac{H_s}{H_b} = \frac{1}{0.16 + \cosh kh} \tag{15}$$

where h is depth, k is wave number and H_b the apparent wave height associated with depth h has been suggested by Draper (1957). This correction was used in this study.

Transport is then found by calculating the value of

$$q = \int_0^{2\pi} f(\psi)\, d\beta \tag{16}$$

where β is phase angle of the wave. In practice, the calculations are done at increments of $\beta = 2\pi/36$. When $\psi > \psi_c$, $f(\psi)$ is found according to equations (8) or (10).

Bedload under steady currents was calculated using the empirical equation first given by Bagnold (1973) and later modified by Gadd et al. (1978). This relationship

$$q_B = 4.48 \times 10^{-5} \, |(|\vec{U}| - U_{TH})|^3 \tag{17}$$

was suggested by Gadd et al. to be the form best fitting most laboratory results. Direction is from the mean flow reference velocity, $\vec{U}_{100}$.

Another steady flow model, more closely fitting the hypothesis that excess shear stress is responsible for suspension while the mean flow is responsible for advection, is

$$q_{EXC} = 9.3 \times 10^{-7} \, |(\vec{U}_{100} - U_{TH})|^2 \, \vec{U}_{100}. \tag{18}$$

Direction here is also given by the mean flow reference velocity.

Resuspension of fine sediments follows the ideas suggested by Clarke et al. (in press). In a bed of mixed sands and muds the fines are released during transport of the sands. However, because of their low settling velocities, the fines are mixed relatively far above the bed and tend to form uniform suspensions. The concentration of resuspended fines depends on the percent of fine sediments in the bed and on the depth of erosion which is a function of the rate of coarse bedload transport, or

$$q_F = \vec{U}C$$

$$C = \frac{MC^* \rho_s}{B} \tag{19}$$

where M is the percentage of mud in the bottom sediments, and B is the scale thickness of the layer of uniform suspension.

Operationally, the calculation proceeds by first comparing $\vec{U}_{100}$ with orbital wave velocity $\vec{U}_w$. If $\vec{U}_{100} >> \vec{U}_w$ and $\vec{U}_{100} > U_{TH}$, then $q = (q_B, q_{EXC})$. If $\vec{U}_w > \vec{U}_{100}$ and $\vec{U}_w > U_{TH}$, then $q = (q_{MG}, q_v)$.

Before presenting the results of transport calculations from the CV probe measurements, comparison is made between the methods described above using average waves and currents with methods presented by Grant and Madsen (1978) and Vincent et al. (1982a) which take into account each wave separately. The data used were obtained from field measurements of waves and currents on the inner shelf off Long Island, New York (Vincent et al., 1982a). The data include velocity profiles (three points) within 1.0 m of the bed, and bottom pressure, both sampled at 1 Hz for five minutes every four hours. These data were used to calculate q_v using average waves and currents, and q_v on a wave-by-wave basis. Comparison of the results (Figure 13) indicates good agreement between the two methods. Linear regression indicates that $r^2 = 0.89$ and the slope of the best fitting line is 1.08. This lends support to use of the approximations described above in applying the averaged version of the Grant and Madsen (1978) model to the present data set.

Transport Calculations and Discussion: Bedload transport rates were calculated according to the equations given above for q_{MG}, q_v, and q_{EXC}. Vincent et al. (1981) showed that measured transport rates under waves are under-predicted by q_{MG} at low rates while q_v tends to over-predict by about the same amount. At high transport rates q_v agrees well with the independent transport measurements while q_{MG} tends to over-predict. Thus, choice of the best bedload transport model for the present study must be somewhat subjective since the only independent transport measurements obtained by which calculated rates can be judged were semi-quantitative estimates of suspended load flux from the CV probe measurements. The CV probe measurements give only indirect information on the actual bedload transport rates.

Flow data from CV1 and wind waves from wind speeds measured at J. F. Kennedy Airport (Drapeau, section C, this report) were used in the bedload

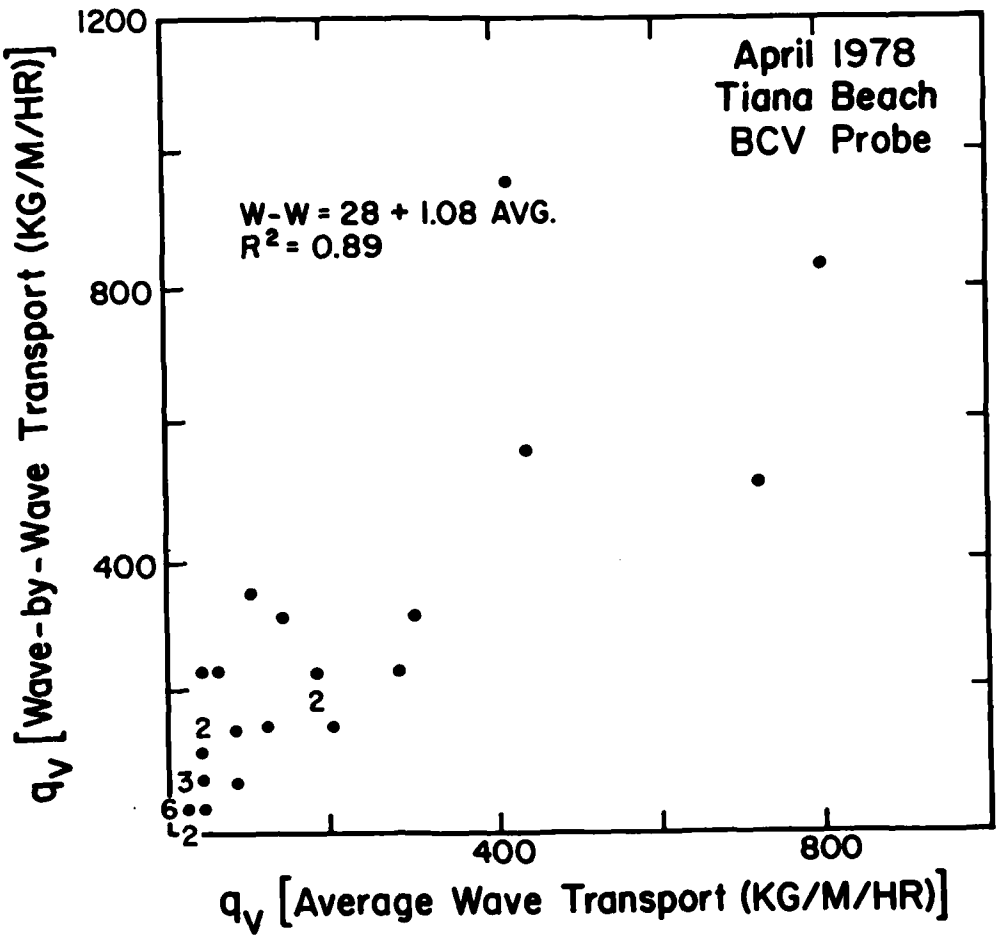

Figure 13. Comparison between values of q_v calculated using averaged wave and current values and q_v using wave-by-wave analysis.

equations and the resulting time series are plotted along with the series of Tr and WE (Figure 14).

Qualitative agreement among the various bedload estimates, Tr, and WE is reasonably good. Major events are well correlated, but several lesser WE and Tr events are not reflected in the bedload estimates. Recalling that bedload depends mainly on wave-current interactions, we investigated the possibility that swell waves, not predicted by local conditions, may be responsible for some of the resuspension events. A model developed by Ross (1979) was used by Drapeau to predict swell due to wind gradients generated by large-scale low pressure systems centered at various locations on the eastern seaboard of North America during ten WE events. Arrival times of the swell waves in the study area and other wave characteristics consistent with those required to resuspend sediments were in good agreement for six of the ten events supporting the hypothesis that these resuspension events may have been generated by swell waves. However, the effects of swell are not generally considered in the bedload calculations because the estimated precision of swell wave heights and directions is low.

Progressive vector plots of q_v and q_{MG} (Figure 15) indicate good agreement in average directions but a factor of two differences in rates. Few events produced transport during the study period. Transport evidently occurred during only about 5% (44 of 849) of the deployment measurements. Two of these transport events account for over 50% of total transport during the deployment.

The most intense transport event during the deployment occurred during March (JD 51-56; Figure 6b, plot F; Figure 7b, plot E). Mean speeds were not particularly high during this event compared to other periods (e.g., JD 73-79; Figure 6b, plot G), the major difference being the presence of waves. Highest

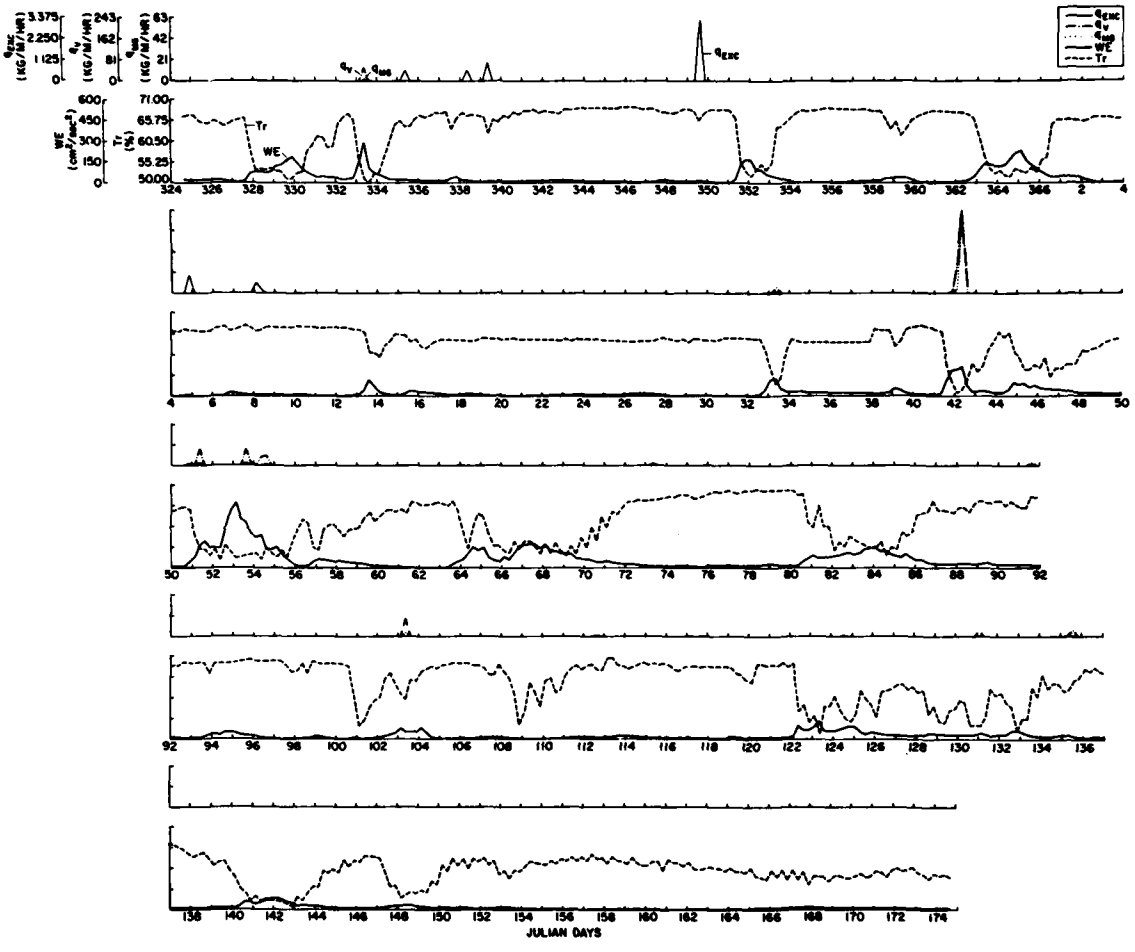

Figure 14. Time-series of calculated bedload transport rates based on CV1 and wind-wave model data compared with bottom wave energy (WE) and suspended sediment (Tr) from CV1.

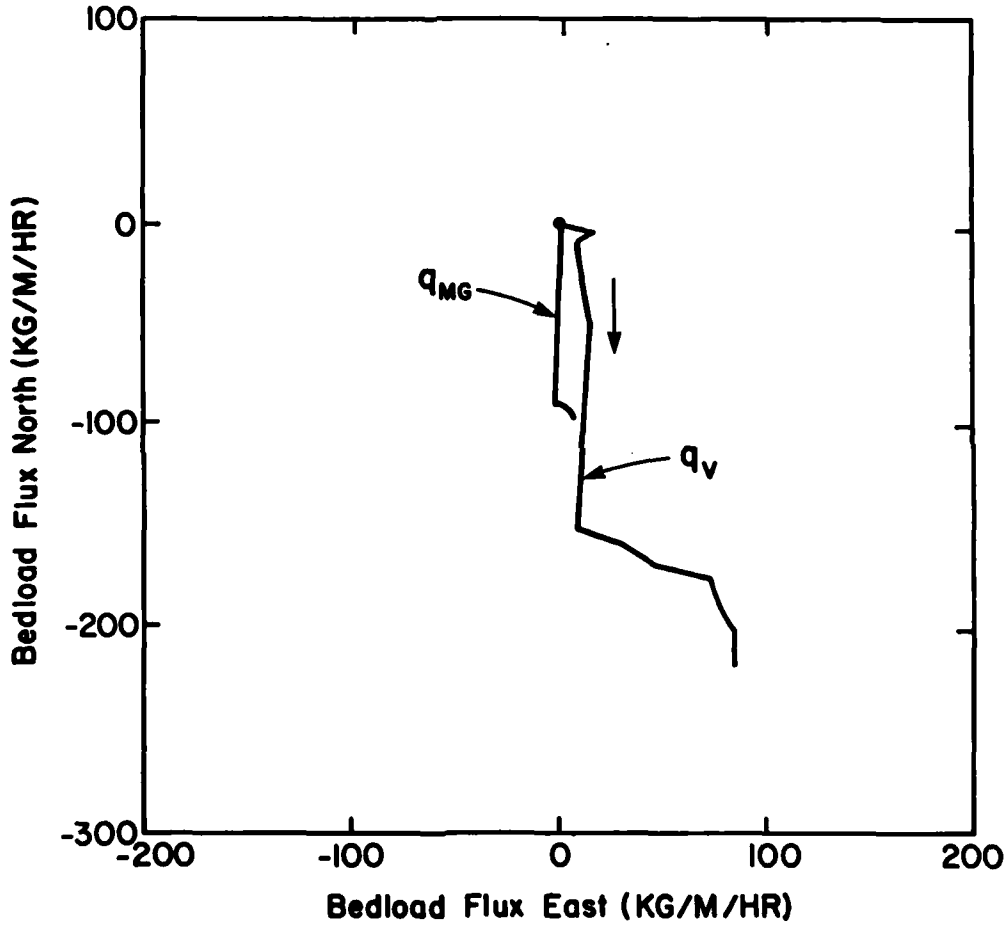

Figure 15. Progressive vector plots comparing q_V and q_{MG} for CV1. Period covered is from November 1980 through June 1981.

mean flow speeds often occurred during periods of lowest wave energy. Han and Mayer (1981) report highest correlations between wind forcing and bottom currents occur when water column stratification is weakest. Thus, before stratification strengthens in April or May, we should expect strong winds to be most strongly coupled to mean flows in addition to generating surface waves.

Several contradictory examples can be cited from the data in Figures 6 to 9. These lend no positive support to the hypothesis described above. Thus, while winds may generate waves capable of transporting the bottom sediments, wind stress magnitude and direction may be just as important as parameters in developing response in the mean flow and hence significant bedload transport. Similar ideas concerning wind-current coupling have been suggested elsewhere (Nelsen et al., 1978; Mayer et al., 1979, Han and Mayer, 1981).

In Vincent et al. (1981, 1982b) the threshold Shields number for transport ψ_{TH} was found from the steady flow curve presented by Miller et al. (1977). Designating this threshold Shields number by ψ_M and the one suggested by Sleath (1978) for waves by ψ_S, the value of q_v can be calculated both ways for comparison.

Values of q_v using ψ_M produce much larger transport rates than ψ_S (Figure 16). This is because, for the sediments at the CV1 site, $\psi_S > \psi_M$ (.04/.03), and q_v is highly dependent on $\psi-\psi_{TH}$ (equation (10)). Net transports calculated using the three wave-current methods are shown in Figure 17. While rates vary, as expected, the directions are similar. Nearly coincidental directions of q_v and q_{MG} are the result of the similar approximations made in determining the wave and current directions used in calculation of both rates.

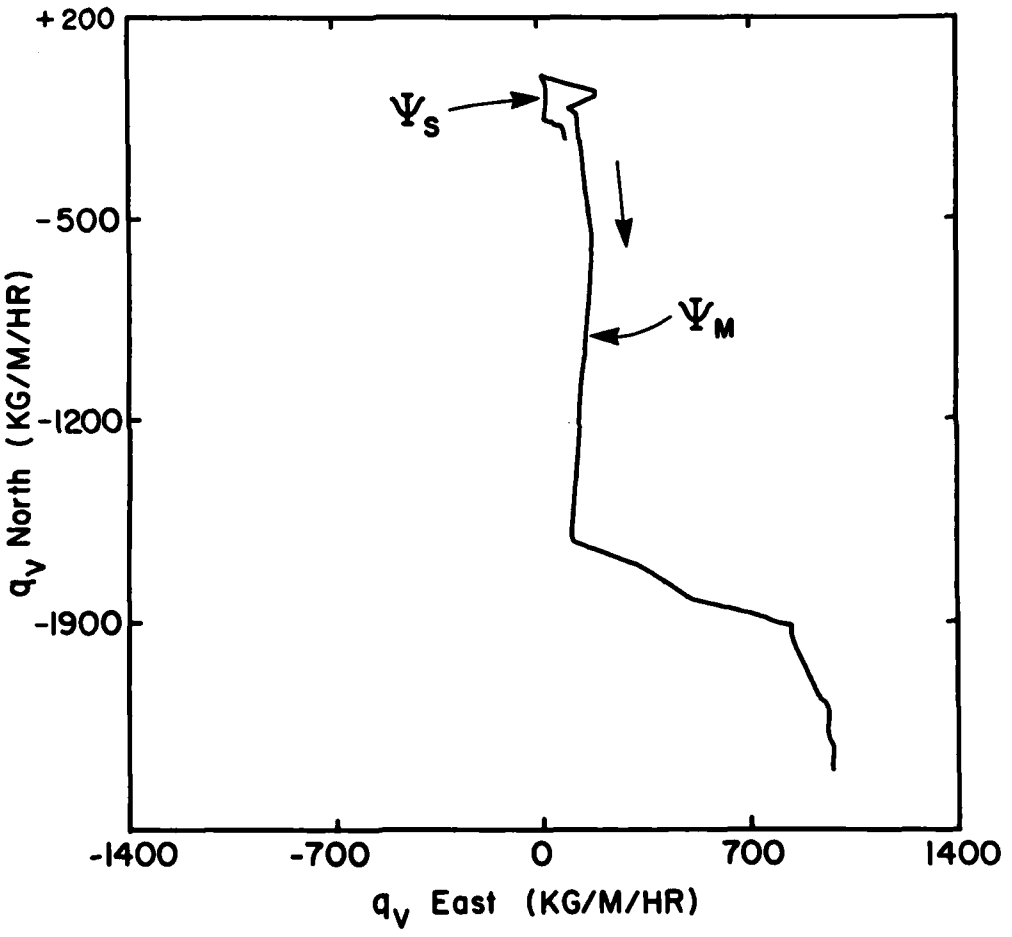

Figure 16. Comparison of q_v for CV1 using the Shields parameter ψ_s for waves (Sleath, 1978) with ψ_M, the one for steady flows (Miller et al., 1977).

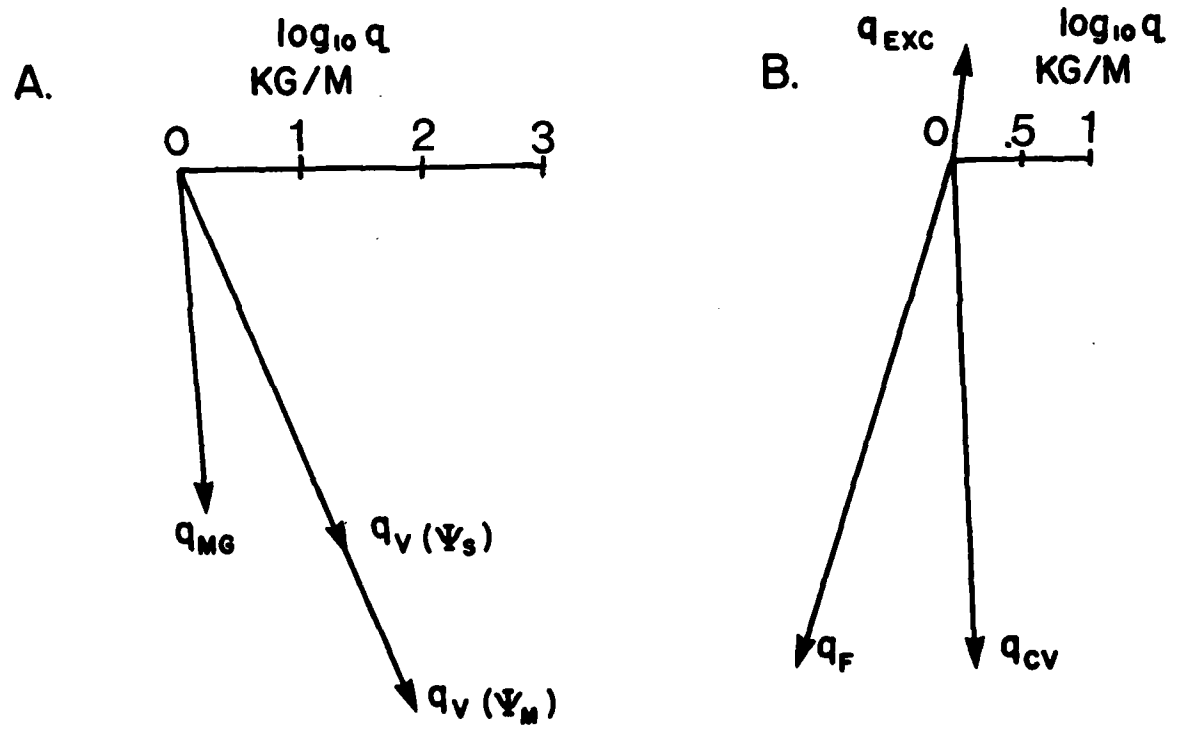

Figure 17. A: Net transports using the three wave-current methods: q_{MG} and q_v using ψ_M and ψ_s. B: Net fine sediment transport from equation 19 (q_F) versus from CV probe measurements (q_{CV}).

Flux directions and rates from CV1 measurements during the 214-day deployment are thought to best represent fine suspended matter transport (Figure 18). Fluxes were calculated as $(F_N, F_E) = \vec{V}_{N,E} \cdot Tr$: units are therefore arbitrary. Net fine sediment transport direction calculated by equation (19) is reasonably close to the direction of net flux from the CV probe measurements (q_{CV} on Figure 17) and from bedload transport rates. However, had only steady flow threshold and transport equations been considered (either equations (17) or (18)), net transport direction (Figure 17) would have been opposite to the wave-current bedload (q_V, q_{MG}) and CV probe flux directions (q_{CV}). This observation emphasizes the importance of waves to sediment transport on the continental shelf.

CONCLUSIONS

The goal of this study has been to estimate the transport rates and directions of sediments capping a dredged material deposit in the inner New York Bight. Various models were used to obtain these estimates and the resulting transport directions were found to be in excellent agreement with each other and with the direction of suspended sediment flux from the CV probe measurements.

A lesser degree of confidence can be attributed to the transport rate estimates. First, the calculation of U_{*wc}, and hence excess ψ, assumes that the mean flow boundary layer is fully described by equation (5). The mean flow shear velocity U_{*c} is normally determined in the field by measurement of velocity at three or more points along a normal to the bottom. Thus, the assumption of the semi-logarithmic mean velocity profile was not testable from the CV probe measurements which included only one velocity measurement. Likewise, no data were obtained from the thin (~ 1-5 cm thick) wave-boundary layer.

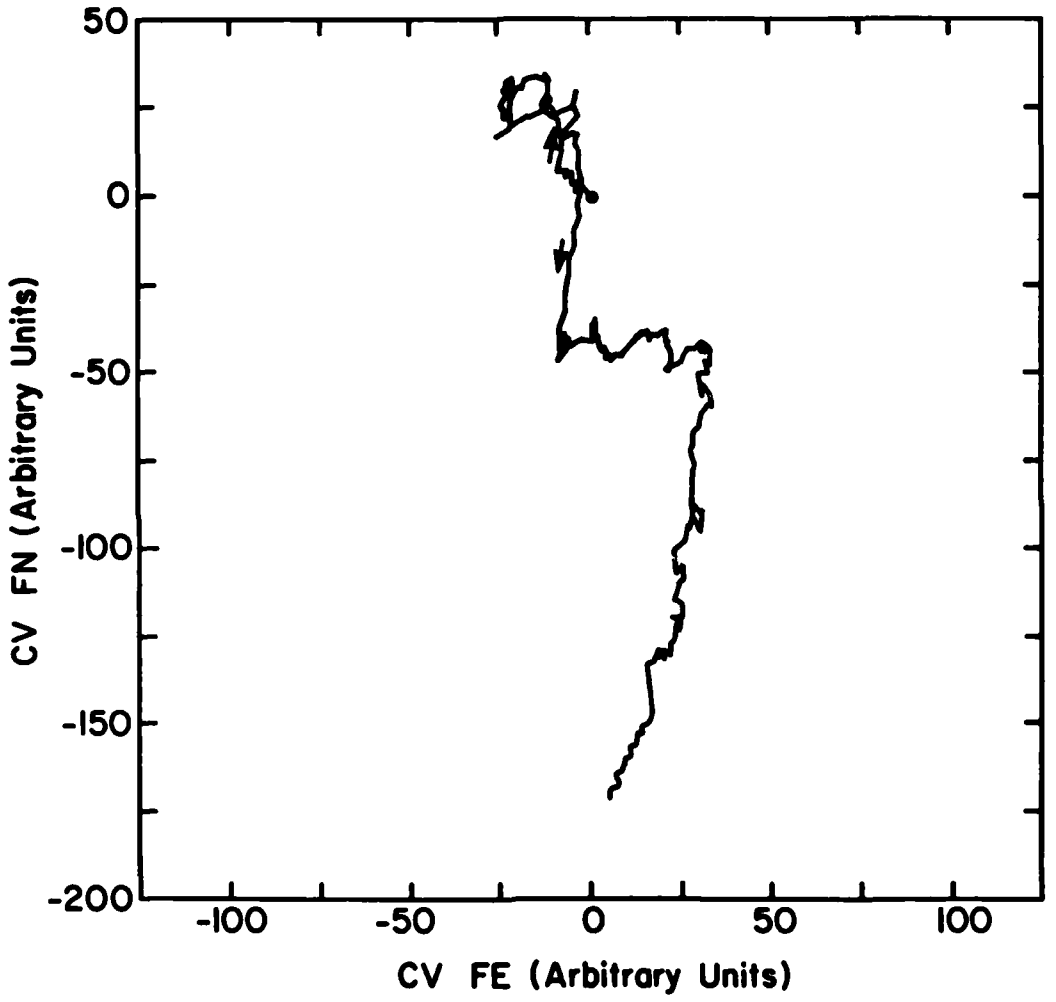

Figure 18. Progressive vector plot of CV probe flux. The labels CV FN and CV FE are north and east flux components. Total deployment duration of 214 days is shown.

Secondly, the transport rates in equations (8) and (10) are based only on laboratory experiments; no field verification of transport rates under waves or combined flows are available. It is, therefore, not surprising that q_V and q_{MG}, for example, should vary by a factor of two, but no rational process is suggested for choosing between these two values of q.

Comparison of wave-current transport rates with steady flow rates indicates that steady flow velocities seldom exceeded threshold and these events did not coincide with periods when waves were effectively stirring the bottom. Moderate waves combined with relatively mild currents proved sufficient to produce transport events which would not have occurred under the waves or currents alone. Steady-flow transport rates are at least an order of magnitude less than wave-current rates. While no great confidence is given to their exact values, it is felt that the relationships among the rates is a reasonable reflection of transport actually taking place at the dumpsite.

Transport rates on shallower and deeper portions of the dumpsite were calculated assuming similar mean flows, but with appropriate changes in wave characteristics due to depth variations. Rates at 21 m (shallowest portion of the dumpsite) were about 20% greater than at the CV probe site (23 m). Rates at 30 m were about 20% less than at 23 m.

In a companion study, Clarke (section E, this report) suggests that under long-term averaged waves and currents little change in cap thickness occurs after 100 moderately energetic transport events and that transport directions are along a north-south axis. It appears that the weight of all results of the dumpsite studies infer that little or no change will occur to the sediment cap over many years. Further south, along the Virginia coast, aperiodic extreme events, such as the "once in a hundred years" Ash Wednesday storm of 1962 (Moody, 1964) have been responsible for transport of extremely large sand

volumes. In the case cited by Moody, the crest of a sand ridge ten meters in height was transported about one kilometer from its previous location. Water depths in the Moody study area were somewhat shallower than at the dredged material dumpsite, and sediment grain size was coarser and much better sorted. If such an extreme event were to occur over the dredge material dumpsite studied here, considerable transport could be expected, but not as much as occurred at Moody's site.

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SIMULATION OF SEDIMENT TRANSPORT AT THE DREDGE MATERIAL DUMPSITE USING COMBINED WAVE AND CURRENT STATISTICS

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INTRODUCTION

The sand cap at the dredge material dumpsite can be regarded as a mound of sandy material on the ocean floor. Two questions of major importance concerning the cap are: (1) What is the expected life of the cap? and, (2) What would be the consequences of cap breaching? These two questions will be answered based on computer models of the combined near bottom wave orbital velocity and mean current flow, and of the effects of these flows on bottom material.

The first question is addressed by means of a Monte-Carlo simulation of storm events. Combined wave and mean current events with statistics matching observations of flow at the dredge material dumpsite were randomly generated. After including the production by the sand cap bathymetric perturbation of both wave shoaling and mean flow veering, the erosion caused by the simulated storms was calculated. After integrating events for three years the predicted erosion was only a few centimeters so that cap life should be centuries.

The effects of breaching were addressed by using a model developed for modeling fine sediment transport in the New York Bight as a whole. This model assumes that fine grained sediment undergoes a random walk whose statistics are determined by wave driven resuspension and mean flow determined advection. If the cap should be breached then the fine sediment underlying the cap would be exposed to resuspension events and after a few years the surface layer of exposed sediment would reach equilibrium within the Bight Apex.

SAND TRANSPORT (Cap Life)

Given the problem of predicting the future evolution of a hill of sandy material on the ocean floor, the most straightforward method is to time integrate the rate of change of depth with time. Symbolically, the depth at time T, D(T), is given by

$$D(T) = \int_{T_o}^{T} \frac{dD}{dt}\, dt + D(T_o) \qquad (1)$$

The rate of change of depth dD/dt can be calculated using the continuity equation from the divergence of the bed-load transport $\vec{Q}(t)$. The quantities D, $\vec{Q}$ and dD/dt are functions of spatial position.

Assuming that sand is transported only as bed-load, dD/dt is given by

$$\frac{dD}{dt} = \nabla \cdot \vec{Q} \qquad (2)$$

There are many methods for calculating the bed-load transport $\vec{Q}$ from observed flow quantities and sand parameters. The simplest formulations such as the Bagnold (Gadd et al., 1978) relation which depend only on the mean flow speed will not be adequate in the wave dominated environment of an open continental shelf. The two most widely accepted methods for calculating Q in a combined wave and mean flow regime are those due to Madsen and Grant (1976) and Vincent et al. (1981). The Vincent approach will be used here as it is simpler and is more suitable for incorporation in a simulation where $\vec{Q}$ will have to be calculated at many spatial points and many time steps in order to evaluate the rate of change as given by equation 2, and then to integrate using equation 1 to find the change in water depth.

The Vincent method is based on the concept of traction carpet depth or C*. The depth of the traction carpet is empirically related to the wave orbital velocity at the bottom through use of the Shield's parameter (Vincent et al., 1981) which is a non-dimensionalized form of the bottom shear stress. C* is found to be a linear function of the wave Shield's parameter above a threshold, ψ_T. The sand contained within the traction carpet is then advected by the mean flow, so that $\vec{Q}$ is proportional to the mean flow velocity and the excess Shields parameter. Thus, given the mean flow, the wave orbital velocity at the bottom, and the sediment parameters (grain size, and density), the Vincent relation gives an unambiguous value for the discharge $\vec{Q} = .09\ (\psi - \psi_T)\vec{u}$.

In order to estimate the mean flow velocity, and the wave orbital velocity at the spatial and temporal scales necessary to evaluate equations 1 and 2, a statistical approach has been used. As a result of other modeling efforts a large body of current meter data has been processed into summary statistical form (Clarke et al., in review). In addition, a large body of wave height, direction and period measurements is available from the MESA project (Lettau et al., 1976). In order to use numerical methods to calculate change of bottom depth from equation 2, the discharge $\vec{Q}$ must be calculated on a fairly regular grid with spacing small enough to resolve the flow features of interest. This in turn requires that mean flow and wave velocities be known on the same grid. For the case of the COE dump site this spacing might be on the order of 200 meters.

In order to provide the most realistic simulation practical, the Monte-Carlo method was used. The mean and variance of the historical velocity data was extracted, and used in conjunction with a random number generator to generate Gaussian psuedo-random variables with the same statistics as the

observed currents. The time scale needed in equation 1 was estimated by the use of correlation times to measure the duration of typical resuspension events as explained in Clarke et al. (1982). The necessary Gaussian psuedo-random variables are four-dimensional because there are two components of mean flow and two components of wave orbital velocity. The covariance matrix $\sum$ is thus four by four, but it can be decomposed conceptually into four two-by-two matrices

$$\sum = \begin{bmatrix} \sum_u & \sum_{wu} \\ \sum_{uw} & \sum_w \end{bmatrix} \tag{3}$$

The submatrix $\sum_u$ represents the covariance (variances and cross-correlation of the individual velocity components) of the mean flow and was extracted directly from the summary statistical data. Similarly, the submatrix $\sum_w$ involves only the wave orbital velocity and can be estimated from historical wave data. The remaining two submatrices are transposes of each other, $\sum_{uw} = \sum_{wu}^T$, and are the most difficult to estimate, since they involve the cross correlation of mean flow and wave orbital velocity. Fortunately, the data provided by the November 1980 to June 1981 deployments of the CV probes provided measurements of both mean flow and wave orbital velocity so that these matrices could be estimated by computing the correlation between the mean flow and the mean square wave orbital velocity during the deployments.

In order to further refine the simulation, the wave orbital velocity component of the random Gaussian vector was corrected for shoaling affects over bottom topographic variations. In addition, the mean flow component was used as a boundary condition (flow at infinity) for a potential flow solution over a Guassian bottom depth perturbation. This potential flow was then extrapolated to the bottom by use of a friction factor of .005.

The potential flow solution was obtained by Fourier transforming the bottom bathymetry; note that a Gaussian bump has a Gaussian transform. If D* (m, n) is the transform of the bathymetry D(x, y), then the flow over D can be expressed as

$$\vec{u} = \vec{u}_\infty + \int dm \int dn\ D^*(m, n)\ \Delta\vec{u}(m, n) \tag{4}$$

where $\Delta\vec{u}(m, n)$ is the flow over a sinusoidally corregated bottom with wavenumbers m and n. This works because the potential flow equations are linear. Convenient basic solutions over corrugated bottoms are provided by the shallow water linear wave theory. Shallow water theory is used because the Froude number is assumed small, and the acceleration of gravity is adjusted so that the linear wave solutions are stationary in the presence of the mean flow. This implies that the relation between the depth of the corrugations and the flow perturbation is given by

$$|\Delta\vec{u}(m, n)| = |\vec{u}_\infty|\ D^*(m, n)/D_\infty \tag{5}$$

This can be substituted into the inverse Fourier relation to give an expression for the total flow perturbation. This integral is still a little complicated, but after a stationary phase asymptotic evaluation is done, the total flow perturbation is given by

$$\Delta u_x = \frac{\Delta D}{D}\left[\frac{x}{x^2 + \sigma_x^4\, y^2/\sigma_y^4}\right]\left[xu_x + yu_y\ (\sigma_x^2/\sigma_y^2)\right] \tag{6a}$$

$$\Delta u_y = \frac{\Delta D}{D}\left[\frac{y}{y^2 + \sigma_y^4\, x^2/\sigma_x^4}\right]\left[yu_y + xu_x\ (\sigma_y^2/\sigma_x^2)\right] \tag{6b}$$

where σ_x and σ_y are characteristic widths of the Gaussian bathymetry perturbation. The typical shape of the streamlines for this potential flow solution is shown in Figure 1 for flow over a symmetrical Gaussian bump with height 70% of the water depth. Because of the large height of this bump (contours of depth are dotted) the flow streamline curvatures are much exagerated over what can be expected for bathymetric perturbations in the open ocean.

Use of depth corrections to wave orbital velocity and also the use of a perturbation solution to the mean flow as given by equations 6, allows the use of only a regional value for the psuedo-random mean flow and wave orbital velocity. Without these corrections the gradient in equation 2 is identically zero so that no change in depth occurs. The inclusion of the effects of wave shoaling and mean flow perturbation produce a non-zero change and hence a change in bathymetry.

Given a Gaussian bathymetry perturbation, its change over time can then be estimated by generating psuedo-random values for flow parameters in order to simulate transport events. The covariance matrix $\sum$ derived from observation is used to generate these simulated flows. The wave orbital velocity is corrected for shoaling, and the mean flow is corrected for the effect of the bathymetry perturbation at each point on a spatial grid. Figure 2 shows the triangulated grid used in this simulation; it is 15 by 15 cells in size. The cell size was either 400 meters or 100 meters, depending on whether the dump site as a whole or just the capped area was being simulated. The Vincent bedload transport formulation is then used to calculate a discharge $\vec{Q}$ at each of the grid cells so that the finite difference form of the divergence operator can be used to evaluate equation 2 to find the rate of change of depth in a grid cell. Finally, the time integral in equation 1 is

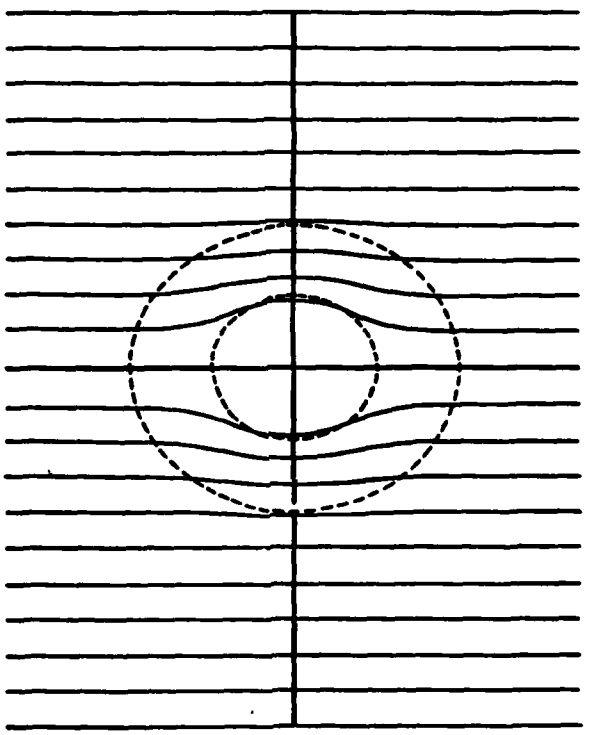

Figure 1. Steamlines of flow over symmetrical Gaussian bottom perturbation.

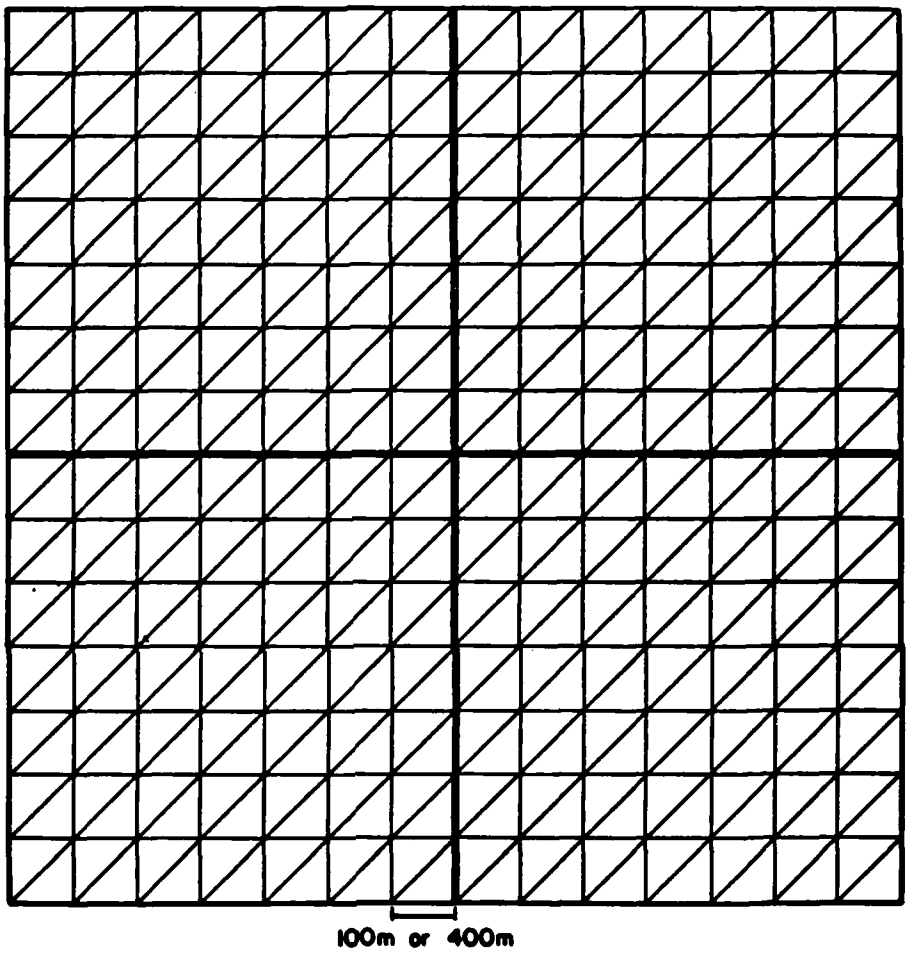

Figure 2. Grid used in sediment transport simulations.

implemented by summing over a number of these simulated events. Because of computer time limitations, only 100 events could be used in each simulation run. At the event frequency reported in Clarke et al. (1982) , this corresponds to about three years. Note however, that because only summary statistics are used in the simulation, events of greater intensity than actually observed will be produced by the psuedo-random generator.

RESULTS OF SIMULATION

There are two ways that bathymetry-induced transport gradients could cause the erosion and breaching of the sand cap. First, the regional bathymetry of the dump site as a whole could induce a transport gradient that would tend to erode the sand cap. Since the sand cap is located to the southeast of the main dumping area, this would require that the southeast portion of a large scale bottom perturbation would be primarily erosive in the observed flow climate at the dump site. Second, the bathymetry perturbation of the sand cap itself might be subject to erosion. In this case a smaller scale perturbation would have to be primarily subject to erosion in the flow climate at the dump site.

To examine these two possibilities simulations were carried out for a symmetrical bottom perturbation as shown in Figure 3. The contour units are in meters, and a latitude/longitude scale has been added so that the center of the perturbation is located at the center of the dump site as a whole. Results of the simulation are shown in Figure 4 as contours of net change after 100 flow events in centimeters. The contours in Figure 4 have been subject to smoothing to remove statistical noise produced by the limited number of events simulated. The small size of the net change (less than 10 cm) reflects the small size of the flow perturbations caused by the

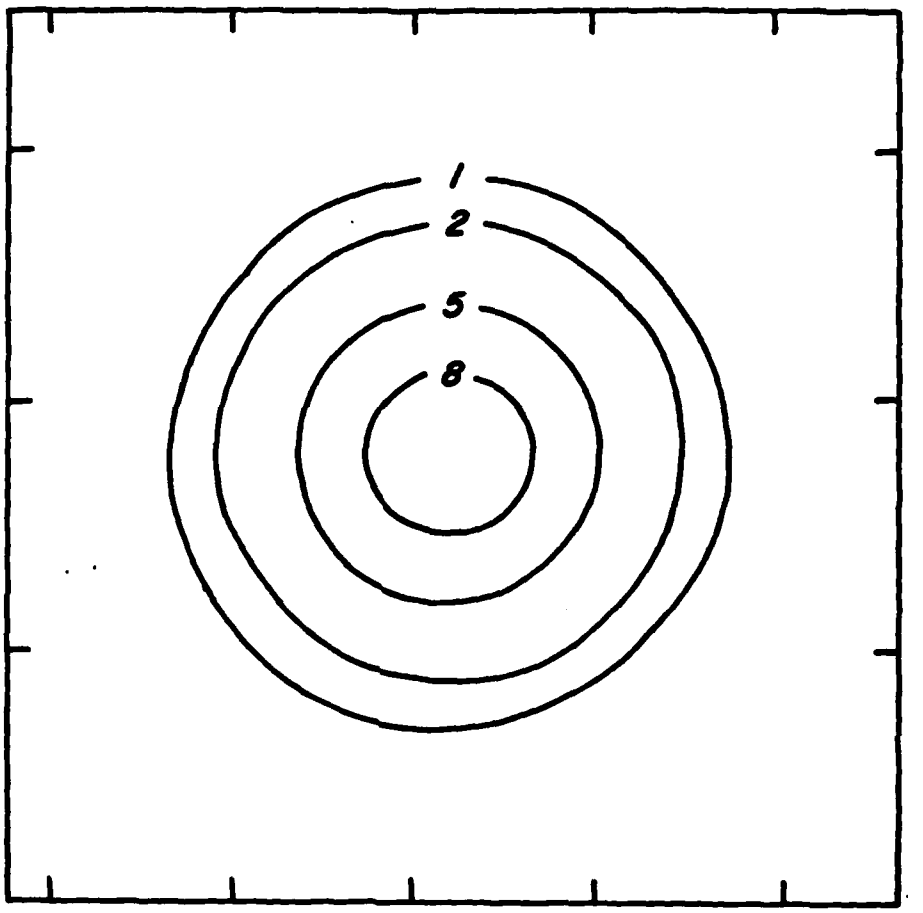

Figure 3. Bottom bathymetry perturbation used to simulate overall dump site in meters. Scale marks along the edges are in units of one minute of latitude and longitude, respectively, at the dumpsite latitude.

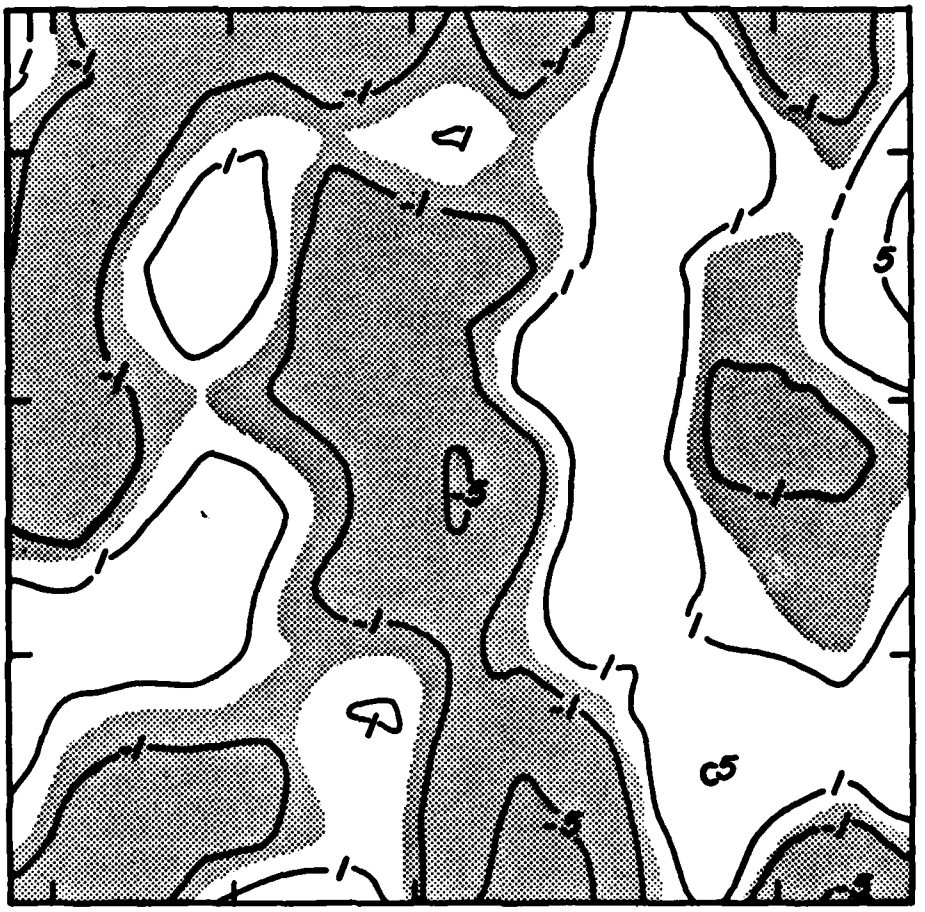

Figure 4. Simulated net change in overall dumpsite bathymetry in centimeters. Stippled area underwent erosion. Scale is the same as in Figure 3.

bathymetric perturbations. Despite the bump in the bottom the combined wave orbital velocity and mean flow field remains nearly homogenous so that the divergence in equation 2 is nearly zero.

One can discern a pattern in the contours of Figure 4, nonetheless. There is a primarily North-South trending pattern, almost a ridge and swale pattern to the change. This is consistent with other theories of bottom perturbation growth (e.g. Huthnance, 1982) which predict growth of linear features at an angle to the flow. It is extremely interesting that the present simulation, which includes the effects of surface waves as well as mean flow, produces much the same prediction as the Huthance theory which only takes into account mean flow. The patterns predicted are much the same: ridge like features at an angle to the mean flow, which here is nearly North-South. The quantitative prediction of wavelength is similar also; both predict that the ridge-like perturbations will have a scale of several kilometers.

The effect of the transport gradients produced by the overall dumpsite bathymetric perturbations on the sand cap should be small. If the sand cap lies in the southeast corner of the circle at about the 2 m contour (Fig. 3), these would be between -1 and +2 cm change. Since these changes produced during the three year simulation study are only a fraction of a meter, the effect on cap life would be negligible.

Figure 5 shows the symmetrical bottom perturbation used to examine erosion at the cap site. Latitude and longitude lines have been added as if the perturbation was at the cap site. Smoothed contours of the net change calculated from simulation of 100 flow events are shown in Figure 6. The contour units are again centimeters so that the change over the three year simulation is only a fraction of a meter. At the peak of the bathymetric

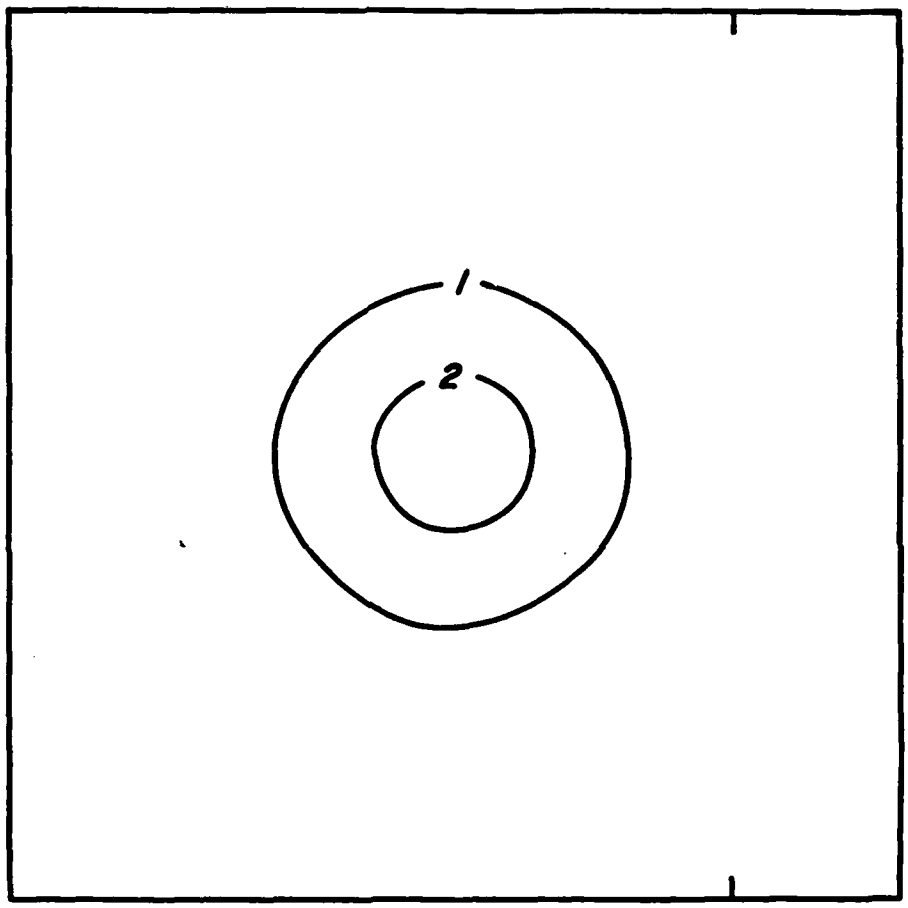

Figure 5. Bottom bathymetry perturbation used in simulation of sand cap. Height in meters. Scale: top and bottom lines are one minute of latitude (one nautical mile) apart; distance between tick marks and left margin is one minute of longitude at the latitude of the cap site.

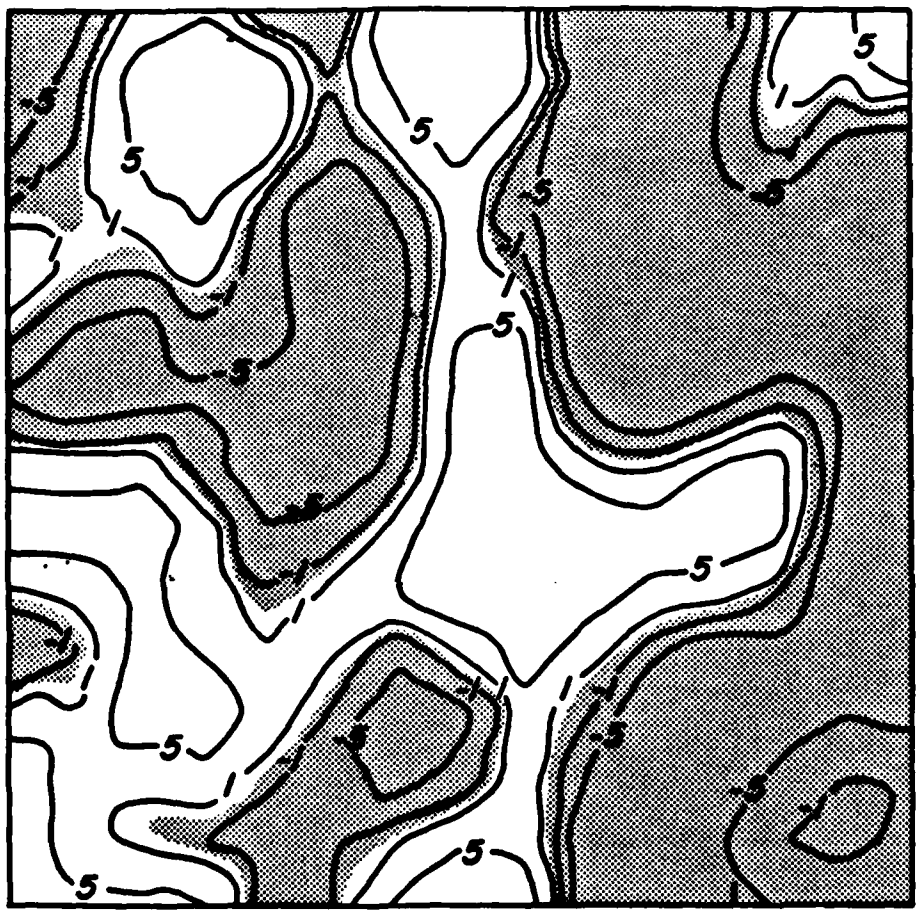

Figure 6. Simulated change in bathymetry of sand cap in centimeters. Stippled area underwent erosion. Scale is the same as Figure 5.

perturbation the change is positive so the perturbation grows, but immediately to the northwest it is negative, so that it is difficult to judge whether the net change is positive or negative. The change is very small however, so that the cap life should be very long.

Note that the characteristic separation of positive and negative features in Figure 6 is on the order of a kilometer. This is also consistent with the Huthnance theory which predicts that shorter features will grow but with a larger angle to the flow. If the contours in Figure 6 are interpreted as a ridge and swale topography, the alignment is much more nearly east-west and so make a larger angle with the mean flow.

In conclusion, erosion/deposition by the mechanism examined here will have little influence on the life of the sand cap. The flow perturbations induced by bathymetric variations are not large enough to produce significant gradients in transport.

CONSEQUENCES OF CAP BREACHING

If for some reason, anthropogenic or natural (unlikely), the sand cap should be breached, it would be of interest to predict the resulting dispersal of fine-grained contaminant-bearing sediment. The diffusion model developed by Clarke et al. (1982) is capable of answering this question. Figure 7 shows the New York Bight region with subregions used in the diffusion model outlined.

The numerical model of fine sediment transport assumes that the movement of this material on the continental shelf results from a series of statistically independent movements of the individual sediment particles. Each particle is thus undergoing a random walk and the mathematical theory of random walks can be used to solve the sediment transport problem. The

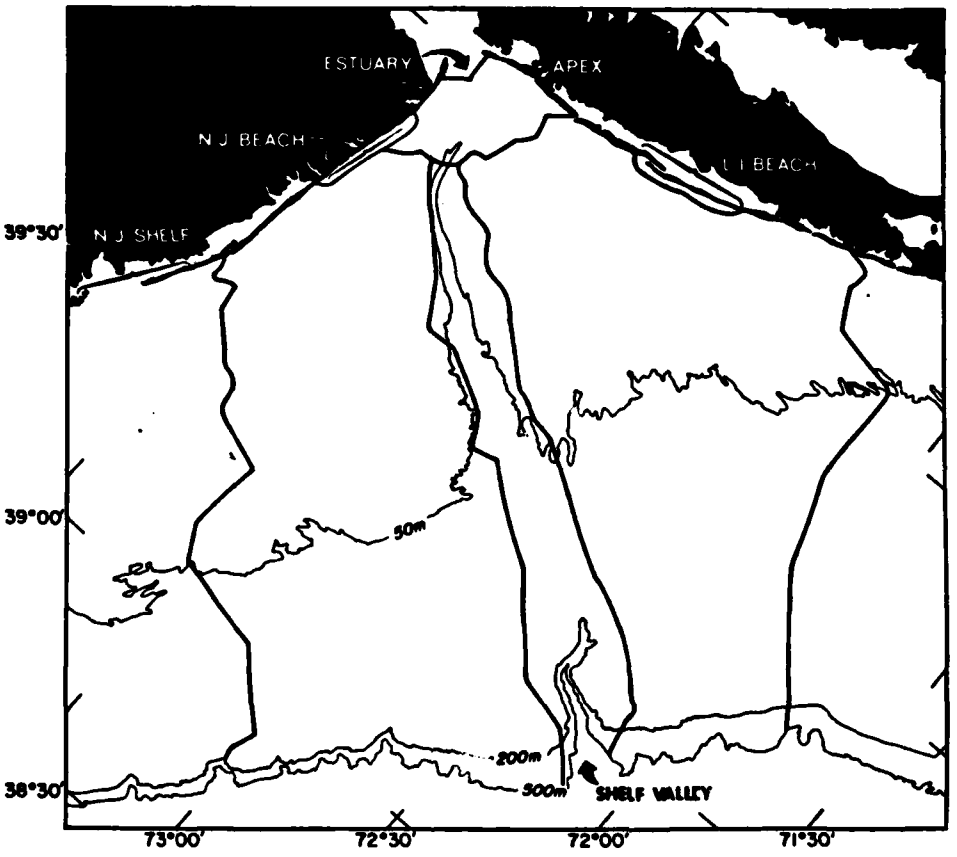

Figure 7. Bathymetric map of the New York Bight region with subregions used in this study outlined.

independent movements are assumed to be produced by resuspension due to surface wave activity and transport by mean flows. Even if periods of high surface waves are correlated with respect to the mean water motions, the effect is to produce additional advection so that the resulting sediment distribution obeys a diffusion-advection equation.

The results of running the model are shown in Figures 8 and 9 as a contour map of percent fine sediment in the upper centimeter of the bed at one year and 100 years after a perturbation (dump) at the dredge material dump site covering a model grid cell to a depth of 1 cm with fine sediment. At first, advection dominates and sediment is swept rapidly to the New Jersey shore. Later, diffusion dominates and the sediment spreads into a bilobate dispersion pattern centered around the Hudson Shelf Valley. Diffusion into the valley is lower there because of the lower magnitude of the diffusion coefficients. The maximum concentration of the sediment cloud has shifted away from the original site to the corner of the Bight. This is a consequence of the geometry of the Bight and is characteristic of dumps made in the apex region. Dispersion is slightly faster to the south partly because of the mean advection term is biased to the southwest and partly because of the regions of higher average diffusivity off the New Jersey coast.

In Figure 10 is shown the percentage of the initial perturbation that arrives at various regions within the New York Bight versus time. These regions, which are outlined in Figure 7, were chosen to be representative of environmentally sensitive regions. The percentages increase as a function of time as the cloud of sediment increases in size and begins to impinge upon the regions. Later the amount decreases as the total amount of sediment in the Bight decreases as it leaks over the shelf edge. This pattern of the amount of sediment arriving at shore areas versus time is typical for dumps in the apex region.

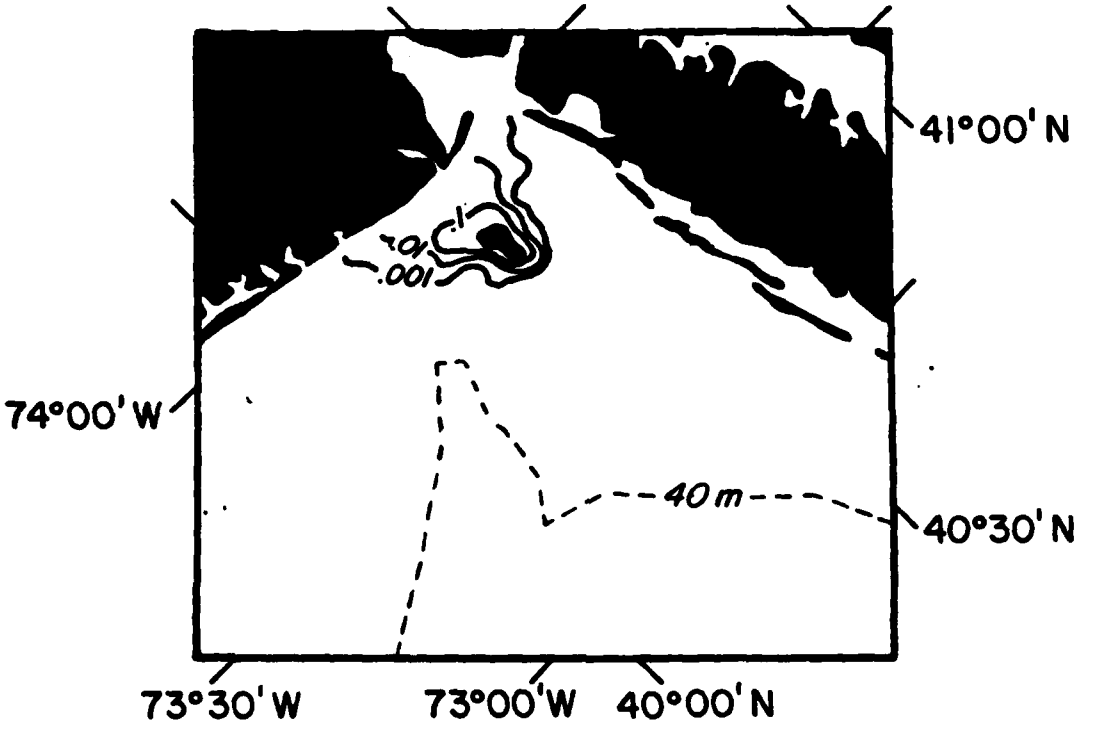

Figure 8. Contour map of sediment distribution one year after a dump at dredge spoil dump site. Units are percent fine sediment in surficial sands by weight.

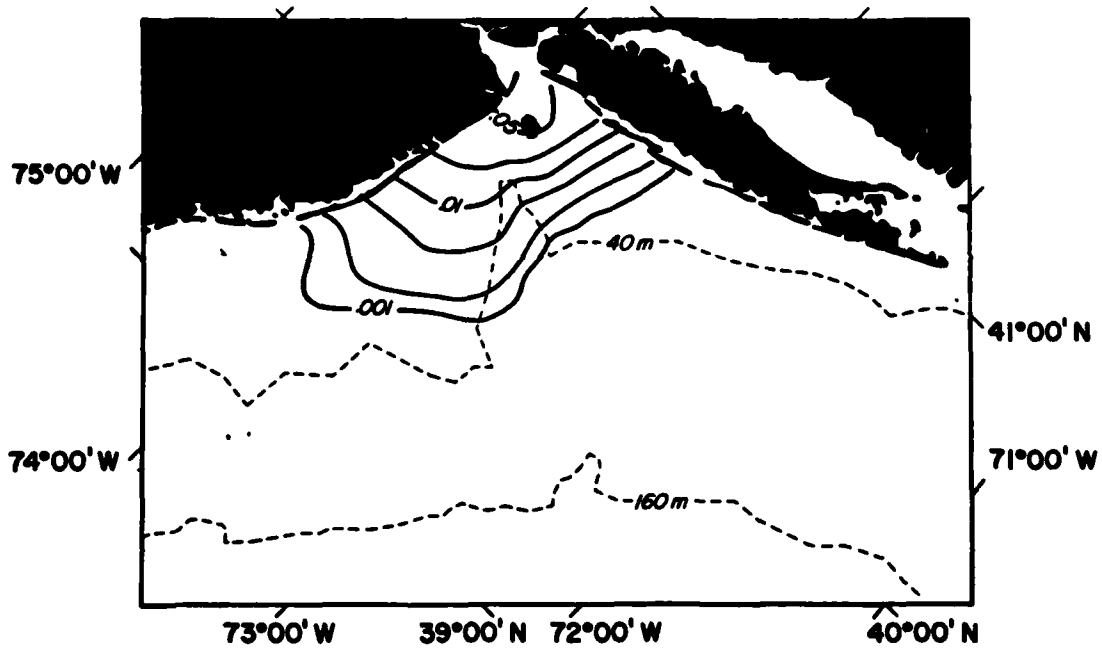

Figure 9. Contour map of sediment distribution 100 years after a dump at dredge spoil dumpsite. Units are percent fine sediment in surficial sands by weight.

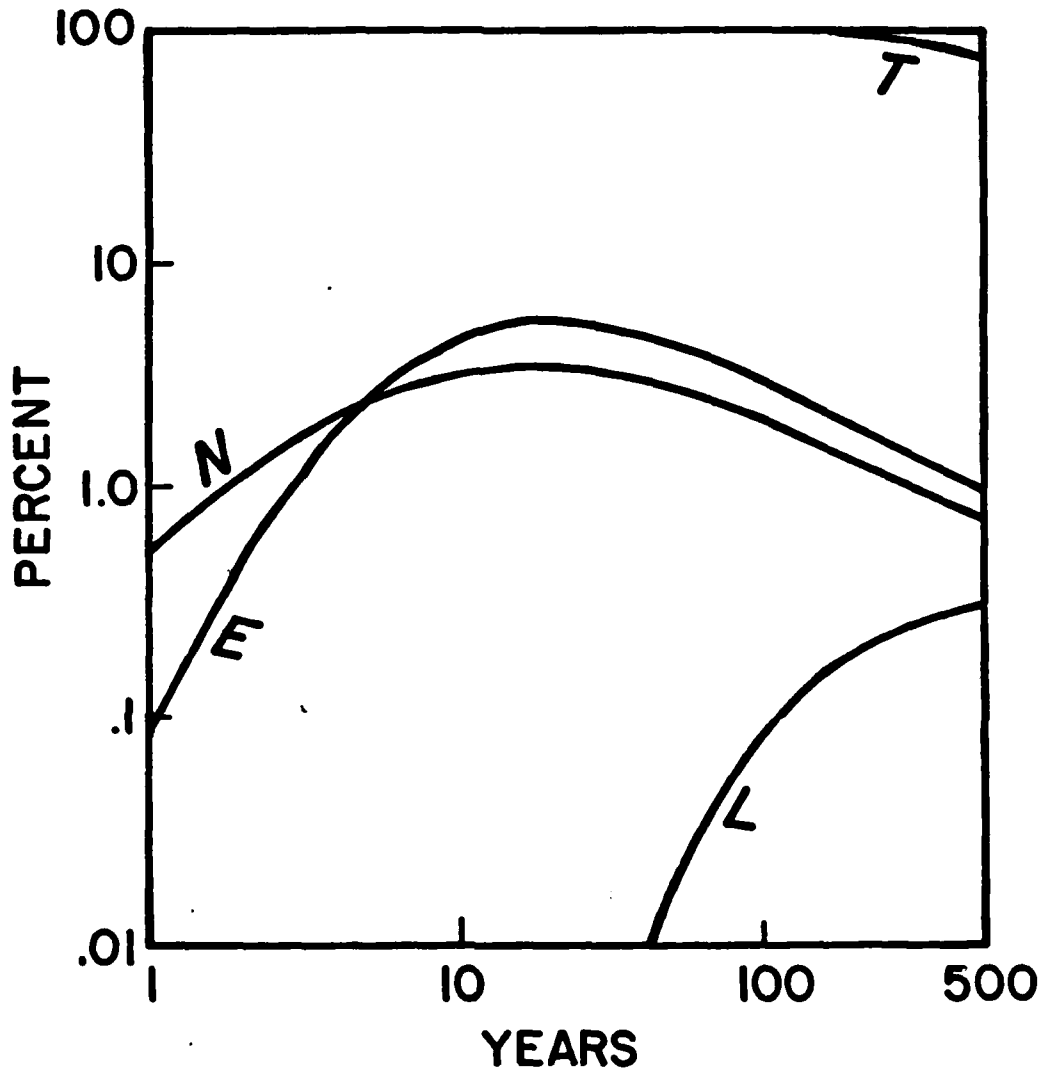

Figure 10. Percentage of initial perturbation at dredge spoil dump site arriving at selected regions of the New York Bight versus time. T = total, N = New Jersey Beach, L = Long Island Beach and E = estuary.

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F. SUMMARY

New York harbor dredgings considered unsuitable under the the ocean dumping pollution criteria were dumped in the southeast quadrant of the New York dredged material dumpsite and subsequently capped by clean mud and then clean sand.

A five-part study was undertaken by NOAA to determine (a) what, if any, changes to the cap took place over the winter of 1980-1981, (b) the bottom current velocities necessary to initiate resuspension and erosion of cap sediment, (c) the long-term probability of erosion by wind-generated waves, (d) bottom currents and sediment transport which occurred during the 1980-1981 winter, and (e) the mathematical probability of sediment transport due to waves and bottom currents.

A. Surfical Sediments

Sediment data taken in November 1980 and June 1981 indicate:

(1) A generally smooth central area covered with 80% cap sand. The area of high sand content was somewhat reduced during the period by an influx of mud.

(2) Along the northern edge of the cap, patches of rough bottom consisted of up to 30 to 50% mud and 30% gravel in November. By June, some of the rough areas were smoothed out, gravel content was reduced to less than 5%, and areas of 30 to 50% mud content enlarged. Most of the gravel along the eastern edge of the dumpsite was construction rubble fringing the cellar dirt dumpsite immediately to the east. On other portions of the cap, gravel-sized particles were mostly rock and shell fragments.

(3) Along the eastern edge of the cap were extensive areas of rough bottom which moved slightly westward during the period. Gravel content remained high (10 to 50%), and encroached slightly westward. Mud content increased more, with expanded areas of over 30% mud.

(4) Mean grain size of the sand-sized fraction remained about the same in the central cap area, and became finer along the northern, eastern, and southern edges.

Bathymetric changes mapped by COE indicate a slight amount of erosion, less than the margin of survey error. The net effect is a slight removal of sand with some replacement by mud.

B. Threshold Erosion Velocities

Field experiments were carried out during both November 1980 and June 1981 cruises to determine the threshold current velocity needed to initiate bottom sediment resuspension on the cap. These were done using the SEAFLUME, a three-sided, open-bottom channel which forces water along the bottom at increasing speeds. Sediments at the 13 sites averaged 7.1% gravel, 75.3% sand, and 17.5% mud, and had an average mean sand diameter of 2.4 ϕ (fine sand). Threshold shear velocities at the seabed interface (U_*) ranged between 0.6 to 1.4 cm/sec, with erosional current velocities 100 cm above the seabed (U_{100}) from 14 to 31 cm/sec. Values of U_* and U_{100} averaged 1.04 and 23 cm/sec respectively, for the November cruise, and 1.00 and 21 cm/sec for the June cruise.

C. Wave Hindcasting

Wave data from Ambrose Light from November 1956 to December 1980, and from wave recorders off Little Egg Inlet, New Jersey, 75 km south of the

dumpsite, during September through November 1974, were compared with wind data from Kennedy Airport and Ambrose Light. Mathematical correlations were made, taking into account fetch, wind stability, and differences between sea and swell. Predictive formulas for wave height and period at Ambrose Light were then made. Using formulas for transfer of surface wave energy to the bottom, a comparison was made between measurements (of bottom current and water transparency) taken by the CV probes during the deployment period November 1980 to June 1981 and bottom energy predicted by hindcasting.

The results show that the wave hindcasting technique correlated very well with bottom measurements, but that at least one bottom transport event corresponded with a time of sea swell, not locally generated wind waves. In addition, bottom current data correspond well with wave hindcasting using Kennedy Airport wind data.

The last part of this section studied effects of infrequent, intense offshore storms in generating swell. The results show up to 200 cm/s bottom orbital velocity with a transport excursion of 120 m during six hours, but with a duration time of only one measurement period (six hours). Furthermore, although the build-up period during which bottom currents exceeded transport threshold velocities may be up to 36 hours, after the peak passed, velocities immediately dropped to well below threshold.

D. Sediment Transport Estimated from Bottom Flow and Turbidity Measurements

Data were collected on the sediment cap from CV probes which measure current speed and direction 100 cm above the bottom and water turbidity 50 cm above the bottom. One probe collected data during the whole study period, November 1980 to June 1981, a second probe from November 1980 to April 1981, and a third from February through June 1981. Calculations for transport rate and directions were made using several models incorporating average wave and

current data, and wave data only, the former giving slightly better results. Three wave-current methods were then compared.

The results of all methods used agree that net transport direction is to the south. However, transport calculations vary according to method used: bedload transport was from 100 to 2500 kg/m, and net fine sediment transport was from 4 to 650 kg/m during the 214-day deployment period. These variations are due to using transport rates, in the formulation of transport equations, which were based on laboratory experiments only; no field verification of rates under waves or combined wave and current flows are available. The data indicate that steady-flow transport rates are at least an order of magnitude less than wave-current transport rates; steady-flow velocities seldom exceeded threshold values and were out of phase with wave-generated bottom transport events. Moderate waves combined with mild currents did produce transport events which would not have occurred with waves or currents alone. Transport rates were also calculated at varying depths assuming similar mean flows: rates at 21 m (the shallowest dumpsite depth) were 20% greater than at 23 m, and 20% less at 30 m than at 23 m.

E. Sediment Transport Simulation

Mathematical simulations were made of transport at the cap site using combined wave and current data with two assumptions: (a) that the cap site was a portion of a larger, circular, bathymetyric bottom perturbation (the dredged material dumpsite as a whole 2.2 n. mi. across and 8+ m high; and (b) the bottom perturbation of a circular sand cap 0.4 n. mi. across and 2+ m high. Monte-Carlo simulations of bed-load transport for each were made for 100 flow events of random strength over a three year-period. Summary statistical data for wave height, direction and period taken in the New York Bight were used to calculate the mean and variance for flow and wave orbital

velocities. These were compared with these same parameters taken from the cap site CV probe deployments from November 1980 to June 1981.

The results for the whole dumpsite simulation indicate that the net change of the circular mound is a maximum erosion of 5 cm over a small area of the crest. One to five cm of erosion occurs as three irregular north-south-trending areas over the 4 n. mi. square. The cap site, at this scale, would have net changes from -1 cm (erosion) to +2 cm (deposition).

The separate calculation for the cap shows large areas of both -5 cm and +5 cm with sharp gradients between them. The crest of the mound shows deposition which extends east of the mound, but the northwest corner is eroded (-5 cm). The changes are still small.

There is a tendency in both cases to form an irregular ridge and swale topography. For the whole dumpsite, the orientation is north-south with crest spacing of about 3 km. For the cap, the orientation is northeast-southwest with a spacing of about 1 km.

Examiration of the direction of dispersal of fine sediment was also made using a diffusion-advection equation. Results of eroding a bed of fine sediment 1 cm thick and 100 m square (1 m^3) show initial transport westward towards the New Jersey shore with 0.01% to 0.1% fine sediment concentrations in the surficial sediment after one year; after 100 years, diffusion has spread the sediment so that the highest concentration is 0.05% around the New York harbor mouth, decreasing to 0.001% half-way down the Long Island and New Jersey coasts, with a considerable seaward excursion.

Conclusion

Evidence from in-situ, experimental, and mathematical data indicate relatively small amounts of erosion at the cap site on an annual basis assuming "normal" yearly conditions. The 2 to 5 cm erosion over three years

from mathematical modelling translates into 0.02 and 0.05 ft/yr, or 45.7 and 18.3 yrs/ft of erosion. Thus the cap, which is four to eight feet thick, appears to be safe for the time being. However, the severe effects of a "hundred year" storm could very likely be an order of magnitude or more larger, so that portions of the cap might be breached from that storm alone. Bear in mind that the cap material is fine sand, the most easily eroded material.

For a margin of safety, it is recommended that additional cap material be placed over the present cap. This should be sediment consisting of clean sand as coarse as is reasonably possible with grain size larger than 0.25 mm.

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