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Sediment Capping of Subaqueous Dredged Material Disposal Mounds: An Overview of the New England Experience 1979 - 1993

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This monograph focuses on four early capping projects. A detailed record of both disposal operations and subsequent monitoring of these capped mounds provides a checklist of recommendations for a successful capping project. The results of the first experimental capping project (Stamford-New Haven), initiated in 1979, suggested that with careful navigational controls point-dumping at a taut-wired buoy could be used to form a discrete mound of contaminated dredged material. In addition, these results suggested that precise deposition of capping material, both at the center and at the flanks of the mound of contaminated material, could be accomplished with careful navigation and project planning.

A successful capping project requires an effective monitoring program in addition to pre-project planning and organized dredging and disposal operations. The DAMOS Program initiated a three-pronged approach to monitoring:

- ensure physical stability and complete cap coverage of the mounds;
- monitor the benthic ecosystem response and biological recovery rates;
- analyze the ability of the caps to isolate chemical contaminants.

A coring investigation was initiated to resolve questions concerning the chemical integrity of the interior of the mounds. Many of the recovered cores showed a distinct chemical boundary between the contaminated material and the cleaner material of the cap, up to 11 years after capping. The investigation documented that the texture and distribution of contaminants in the disposed sediments depend to some extent on the dredging and disposal techniques used to form the capped mound.

Final recommendations from the early DAMOS capping experience include specific tasks to be *completed before, during,* and *after* the formation of a capped mound. Pre-operational planning will ensure optimal conditions for a successfully capped mound. Dredge and disposal operations should be organized and well-documented; the use of precision navigation and a taut-wired, moored buoy to ensure precise disposal of dredged material are recommended. Finally, a reasonable and efficient monitoring program should be in place before dredging begins.

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SEDIMENT CAPPING OF SUBAQUEOUS DREDGED MATERIAL DISPOSAL MOUNDS: AN OVERVIEW OF THE NEW ENGLAND EXPERIENCE 1979 - 1993

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This report is dedicated in memory of
Carl G. Hard, Jr.
who pioneered the technique of capping.

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The increased need for disposal of material dredged from numerous industrialized harbors in New England led to experiments in covering, or capping, contaminated material deposited on a level seafloor with cleaner dredged material. The assumption behind these experiments was that a sufficiently thick layer of sediment would isolate the contaminant from the aquatic ecosystem. Capping operations and associated monitoring programs were conducted as part of the Disposal Area Monitoring System (DAMOS) Program, a regional program initiated in 1977 by the New England Division (NED) of the US Army Corps of Engineers (USACE).

After more than 10 years of capping operations, enough data had been collected to warrant a retrospective volume. This monograph was compiled from three specific viewpoints :

- a historical review of capping operations from original experiments in Long Island Sound in 1979 to the present;
- a synopsis of the viability of capping as a dredged material disposal alternative;
- a practical description of capping and monitoring techniques for agencies considering this disposal practice.

When capping was first considered, technical operations were organized to address specific concerns formalized by the USACE after extensive consultation with the scientific community. These concerns included the adequacy of the available technology to point-dump; the difficulties associated with discriminating between cap and covered material; and the possibility that, on impact, cap material might displace the sediments to be covered. Not only have the concerns been addressed, but focusing on potential operational problems has also improved the techniques that have proved successful.

This monograph focuses on four early capping projects. A detailed record of both disposal operations and subsequent monitoring of these capped mounds provides a checklist of recommendations for a successful capping project. The results of the first experimental capping project (Stamford-New Haven), initiated in 1979, suggested that with careful navigational controls point-dumping at a taut-wired buoy could be used to form a discrete mound of contaminated dredged material. In addition, these results suggested that precise deposition of capping material, both at the center and at the flanks of the mound of contaminated material, could be accomplished with careful navigation and project planning.

A successful capping project requires an effective monitoring program in addition to pre-project planning and organized dredging and disposal operations. The DAMOS Program initiated a three-pronged approach to monitoring:

- ensure physical stability and complete cap coverage of the mounds;

- monitor the benthic ecosystem response and biological recovery rates;
- analyze the ability of the caps to isolate chemical contaminants.

Physical monitoring of the early capped mounds was accomplished primarily with acoustic and visual methods. These data indicate that capped mounds have been stable even after the passage of three hurricanes. There has been little evidence of erosion or physical breaching of capped mounds. Biological monitoring has confirmed that, in general, there has been no adverse effect on biota due to contaminants located within the mound (exception noted below). Whole-sediment chemistry data have been collected to assess contaminant levels at the surface of the capped mounds. These results have shown that contaminant concentrations of surface sediments have remained near background levels since capping. The term "contaminant" is used here to describe those compounds, either natural or anthropogenic, which, in high enough concentrations, may pose a human health threat.

Monitoring results have, however, also revealed problems during the developmental stage of some of the capped mounds. One capped mound in particular (MQR) showed signs of subnormal rates of biological recolonization. The complex disposal history of MQR did not conform to the idealized model of a capped mound, and, in fact, served to test the developing capping protocols. Complications discovered during monitoring were used to confirm the original recommendations for successfully capped mounds and to establish new guidelines for operational and monitoring procedures.

A coring investigation was initiated to resolve questions concerning the chemical integrity of the interior of the mounds. Many of the recovered cores showed a distinct chemical boundary between the contaminated material and the cleaner material of the cap, up to 11 years after capping. The investigation documented that the texture and distribution of contaminants in the disposed sediments depend to some extent on the dredging and disposal techniques used to form the capped mound.

Monitoring protocols have been refined since the initiation of DAMOS, and a new approach to monitoring has been developed that focuses on dredged material management. The new approach, known as tiered monitoring, uses a flow chart of monitoring approaches and results to help the dredged material manager make decisions on disposal and capping alternatives.

Final recommendations from the early DAMOS capping experience include specific tasks to be completed before, during, and after the formation of a capped mound. Pre-operational planning will ensure optimal conditions for a successfully capped mound. Dredge and disposal operations should be organized and well-documented; the use of precision navigation and a taut-wired, moored buoy to ensure precise disposal of dredged material are recommended. Finally, a reasonable and efficient monitoring program should be in place before dredging begins.

1.0 INTRODUCTION

1.1 Background

Coastal waters, especially harbor areas, have been used directly and indirectly for the disposal of industrial waste. This waste, and the contaminants associated with it, ultimately has been deposited in marine sediments, most frequently within or near harbors and industrialized coastlines. A working definition of contaminated sediments is "those that contain chemical substances at concentrations which pose a known or suspected environmental or human health threat" (NRC 1989).

Research efforts continue to unravel the impact of contaminated sediments on marine ecosystems and the contaminant pathways from marine sediments through the food chain to eventual consumption by man. Policy decisions regarding the removal or isolation of existing contaminated sediments are complex. There are substantial risks and costs associated with any action, as well as with the choice of no action. Removal of contaminated sediments introduces secondary effects including sediment resuspension and potential remobilization of contaminants. These removed sediments must be chemically or biologically treated, or relocated in an area which minimizes the impact on the local ecosystem.

Leaving the sediment in place is not without risk or cost. Contaminated sediments generally accumulate in depositional zones and will eventually be buried. If buried by sufficient amounts of noncontaminated sediments, the contaminants will be isolated and will no longer pose a health risk (NRC 1989). However, until they are covered, in-place sediments may act as a long-term "source" of contaminants to nearshore environments as they are intermittently disturbed by waves generated by storms and vessel traffic. These nearshore environments generally provide the greatest risk to human health.

In the event that it becomes necessary to remove coastal sediment, as in the case of dredging of navigational channels, a cost-effective management strategy is required. Risk evaluations of dredged sediment have traditionally used elutriate and bioassay analyses in order to classify the sediments as contaminated or noncontaminated. Approximately 95% of the total volume of dredged material is considered noncontaminated (Palermo et al. 1989).

If the sediment to be removed is considered to be contaminated, the disposal alternatives are limited. Alternatives for contaminated dredged material are containment options (subaqueous or upland) and treatment. Unresolved containment issues include the availability of space (especially on land) and the degree of isolation that can be achieved. Biological, chemical, and physical treatment methods are being developed, and each has its own advantages and disadvantages. Treatment is used for highly contaminated sediments, but large-scale facilities for treating contaminated dredged material do not currently exist in the United States and are expensive to maintain.

Capping is a subaqueous containment method which uses natural material (i.e., noncontaminated dredged material) to isolate the contaminants from the environment. Although capping is a containment method, the environmental considerations are much different than they are for land-based containment (i.e., landfills). Material disposed on land is subject to leaching from ground water; therefore, liners are used to prevent contaminants from leaching out of the sediments and entering the ground water (and eventually drinking water sources). Marine sediments are already submerged; primary movement of pore water is due to active consolidation in the initial stages of sediment deposition.

To consider capping as a viable disposal alternative, several questions must be answered:

- Can disposal operations form a defined mound and ensure complete cap coverage?
- Is the cap effective at a) containing contaminants with no evidence of leakage and b) isolating contaminants from the aquatic ecosystem?
- Will the capped mound remain physically stable?

1.2 Objectives

This monograph is a critical review of the use of caps of clean sediment to isolate contaminated dredged material in mounds on the seafloor. The operations and associated monitoring programs reviewed here were conducted as part of the Disposal Area Monitoring System (DAMOS) Program. DAMOS is a regional program initiated by the New England Division (NED) of the US Army Corps of Engineers (USACE).

Since its inception in 1977, DAMOS has generated a substantial amount of data contained in a series of published contributions, unpublished reports, and data files. Because the logistical approaches to capping and monitoring methods evolved over this time, valuable information is scattered throughout the DAMOS record. This monograph presents a synthesis and review of the available information, with annotated data tables and figures developed to provide access to hitherto obscure or inaccessible data. By compiling this information into one document, we hope to facilitate application of the knowledge gained from 14 years of DAMOS capping experience (1979 to 1993) to future capping and monitoring activities.

1.3 Introduction to Capping

Navigable waterways are an important component of our coastal resources. Used extensively by commercial shipping, recreational vessels, and naval fleets, coastal waterways and harbors provide an essential link from land to sea. The northeastern United States is particularly blessed with abundant natural harbors and sheltered waterways. However, few of these harbors or channels are naturally deep, and they require frequent maintenance dredging to permit use by modern vessels. Unfortunately, these same harbors are the storage areas for the effluent of modern, industrialized cities.

Most effluent contaminants tend to be absorbed onto sediments; therefore, the concentration of these contaminants tends to be higher in sediments than in water. During dredging, these sediments are disturbed, creating a plume of suspended sediments around the dredging operation. It is unknown if or how much contaminant material is released to the water column through desorption from the particulate matter and release of the interstitial water. Different dredging methods appear to be more appropriate for different contaminant classes (Cullinane et al. 1989).

Techniques for the safe disposal of these dredged sediments are the focus of this monograph. Management of dredged material disposal in the United States has adapted to the passage of major environmental legislation, including the Federal Water Pollution Control Act Amendments of 1972, also known as the Clean Water Act, and the Marine Protection, Research and Sanctuaries Act of 1972, also known as the Ocean Dumping Act. These laws, in combination with international regulations sanctioned at the London Dumping Convention (IMCO 1975), established the regulatory authority for designation of disposal sites and specified responsibilities for the oversight and control of both dredging and disposal operations (Park and O'Connor 1981). This legislation has led to increased regulations and tighter guidelines for ocean disposal of dredged material. At the same time, the Resource Conservation and Recovery Act of 1976 imposed strict regulations for land-based disposal of hazardous solid waste.

In New England, implementation of these regulations significantly reduced the number of coastal and land-based sites deemed suitable for disposal of contaminated dredged material. Sediments showing unacceptable mortality to biota or ecologically significant potential for bioaccumulation must receive additional treatment to satisfy the London Dumping Convention. Ocean disposal of these sediments is permitted only if the material is "rapidly rendered harmless" by physical, chemical, or biological processes in the sea (EPA/USACE 1977, 1991).

The increased need for disposal of material dredged from numerous industrialized harbors in New England led to experiments in capping contaminated material deposited on a level seafloor with cleaner dredged material. The assumption behind these experiments was that a sufficiently thick layer of sediment would isolate sediment-bound contaminants and render them harmless. If contaminated harbor and channel sediments could be isolated in this way, the dredging operations would achieve two important goals: first, maintaining navigable waters and second, isolating potentially harmful material from contact with ocean biota and humans.

A variety of special "handling" techniques were also introduced to minimize material losses during dredging operations and to maximize long-term containment of sediments and associated contaminants at disposal sites. Clamshell buckets and hopper barges routinely are used to increase the compaction of the sediments (cohesion), thereby reducing the potential for loss of sediment during dredging and transport. Additionally, the use of highly accurate electronic positioning systems and taut-wired, moored buoys for precise disposal of material have proved particularly successful.

For the purposes of this monograph, the term "mound" will be used to describe the deposit formed by the disposal of contaminated dredged material which is subsequently covered with cleaner material (Figure 1-1). The term "cap" will be used to describe that subsequent deposit formed by the disposal of relatively cleaner dredged sediments. The term "contaminant" will be used to describe those inorganic and organic elements and compounds, either natural or anthropogenic, which, in high enough concentrations, may pose a human health threat. It is important to emphasize that, for brevity, the term contaminant is used here to describe all analyzed components, regardless of their concentration.

1.4 Record of Capping in New England

The New England Division (NED) has conducted more shallow-water capping activities than any other USACE division. This experience has generated a distinct evolution of techniques and an approach to monitoring that is unique within the Corps, attracting national attention and interest (NRC 1989). Monitoring results, managed through the DAMOS Program, have consistently shown these caps to be stable with no evidence of contaminant release. Capped mounds have withstood the passage of hurricanes, and so can provide valuable information on the stability of cap material and mobility of contaminants over time. This record, including mistakes, lessons learned, and successes, can help guide future activities in New England and throughout the world. Pressures to use the open ocean for disposal of contaminated dredged material have increased, and many areas of the United States may need to implement capping in the future.

The use of clean sediment layers to provide barriers limiting leachate migration and to control surface erosion of waste deposits has been a standard practice at municipal and industrial disposal sites on land for many years. However, no planned capping project took place at an underwater site in the United States until 1979. Capping projects prior to that time were "de facto" operations in which burial

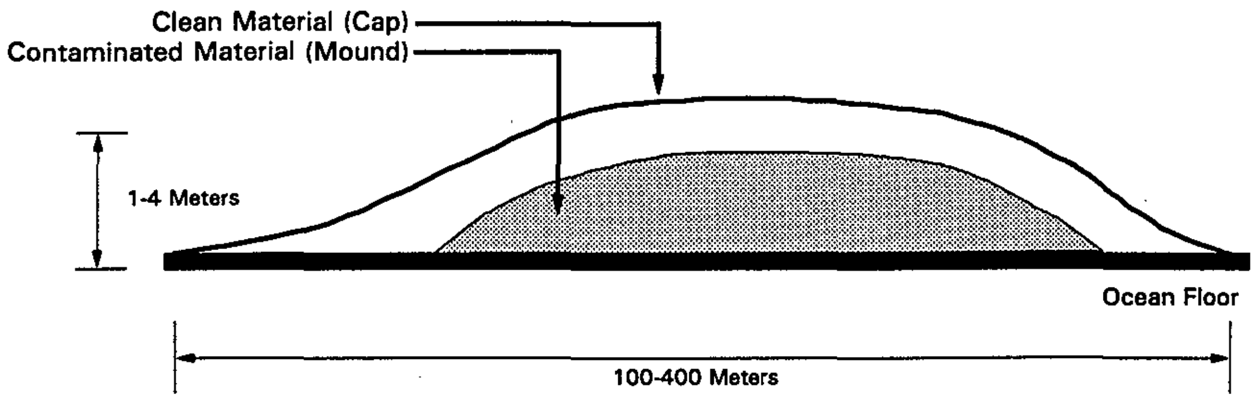


Figure 1-1. Schematic section of a capped mound

of contaminated material was the result of project phasing; the more contaminated material was dredged and deposited first and covered by progressively less contaminated, cleaner sediments. Whether this "de facto" approach was a success remained unknown. The 1979 NED project at the Central Long Island Sound Disposal Site (CLIS) made capping procedures formal. Specifications in the dredging plans required that the contaminated sediment from the harbor of Stamford, Connecticut, be capped with cleaner material dredged from the entrance channel of New Haven, Connecticut.

As a result of the operational success of the 1979 Stamford-New Haven project, controlled, or planned, capping became an important component of the management of open-water disposal sites and is used with increasing frequency in New England. Many capping projects have been performed within the NED's CLIS, New London, and Portland Disposal Sites under the DAMOS Program. Other Corps districts have completed capping projects, such as those at the Mud Dump site in New York (Mansky 1984) and in the Duwamish Waterway in Seattle, Washington (Sumeri 1984a, 1984b). Capping has also been used at several sites in western Europe and in Japan (Shields and Montgomery 1984) and proposed for use in an experimental project where existing submarine borrow pits were to be used as receiving sites for contaminated dredged material (Bokuniewicz 1983).

1.5 Monitoring of Capped Mounds

When capping was first proposed, the NED, following the recommendations of several environmental groups, formed a Scientific Advisory Committee (SAC) to review project plans, to make recommendations regarding operational procedures, and to detail requirements associated with both short- and long-term monitoring. The Committee suggested that the proposed capping be viewed as an experiment. Further, they advised that the effectiveness of the capping operations should be verified by *in situ* monitoring.

The majority of the capping projects contained a field monitoring component. In New England, field observations of cap integrity and evaluations of the success of disposal protocols have been collected as part of the DAMOS Program (e.g., Morton et al. 1984a). In each of the other capping projects conducted outside New England, special monitoring programs were initiated to evaluate both short- and selected long-term effectiveness criteria (O'Connor and O'Connor 1983, Parker and Valente 1987, Truitt 1986). In addition to these field programs, the USACE sponsored several laboratory investigations intended to assist in determining the optimal cap thickness and the effectiveness of various sediment layers as barriers inhibiting contaminant migration (Gunnison 1984, Brannon et al. 1984, 1985, 1986, 1987).

Fourteen years of monitoring capped mounds in New England have provided a data set of sufficient duration to permit evaluation of the relatively long-term effects of capping contaminated dredged material. This data set represents the longest single record of capping activity and covers a broad spectrum of physical, chemical, and biological characteristics. The results provide baseline evidence in support of capping as a viable disposal method. As capping moves into deeper water, the lessons learned in shallow water will be available for program design and testing.

The following report summarizes capping activities at CLIS over a period of four years and collects into one document the monitoring results obtained as part of these projects. The report first provides background on the capping operations and reviews the operational guidelines as they have been modified with experience. It then describes the results of monitoring and subsequent investigations conducted to assess the physical, biological, and chemical structure of the capped mounds. Finally, the report recommends guidelines for both capping operations and associated monitoring activities.

2.0 NEW ENGLAND CAPPING OPERATIONS

NED capping operations have evolved since the initiation of the program. Following the proposal of the first capped mound project, Stamford-New Haven, the SAC issued a report expressing particular concerns on the following points: the adequacy of the technology available to point-dump and successfully cover relatively small volumes of material; the amount of capping material needed to cover the mound to ensure adequate containment; the difficulties associated with discriminating physically or chemically between cap and covered material (in order to judge the effectiveness of the cap); and the probability that on impact cap material might displace or mix with the sediments to be covered. These issues were addressed by investigating the effects of various dredge and disposal methods and by comparing different quantities and types of mound and cap sediments.

Point-dumping was accomplished during creation of the very first experimental capped mound (Stamford-New Haven) by requiring the barges to open the hopper doors only after pulling alongside the marker buoy. Taut-wired buoys were used to reduce the area of the center of the mound. Previously, barges released dredged material while steaming across a dumpsite (Bokuniewicz 1989). Data from the experimental program suggested that point-dumping should be utilized in order to restrict the spread of mound material, while cap material should be spread laterally.

Nationally, the most commonly used dredging technique has been hydraulic; this method fluidizes the sediments into a slurry with >80-90% fluids, thereby reducing or destroying sediment cohesion (Bohlen 1990). Of the currently utilized dredge methods, the mechanical clamshell bucket was found to be the most effective at maintaining sediment coherence. The importance of this fact was recognized later in identifying dredged material in cores (Section 4.0). In addition, storage of dredged material in a hopper barge allows some dewatering and consolidation before disposal, so that material loss in the water column is minimized.

Initially, attention was focused on cap:mound ratios in order to determine the quantity of capping material which would ensure complete mound coverage. The success of a capping operation was later found to depend on many factors more relevant than cap:mound ratios, even when estimates of the volume of dredged material were uncertain. However, the following discussion includes dredged material volume estimates and cap:mound ratios to provide this information in a historical context.

Both sand and silt were used for capping material in early operations to test the effects of variable grain size and water content on potential mixing of cap and mound material. Early monitoring demonstrated that both sand and silt could be effective at isolating contaminated sediments. Sand caps are more visually and chemically distinct than silt caps. The quantity of mixing during dredging operations has been directly addressed in recent coring investigations (Section 4.0), and the results suggest that silt caps may induce less mixing with mound material than sand caps. These results do not suggest that silt caps are more effective at containing contaminants. It is possible that more sand material than silt is required to form an impervious cap.

A DAMOS computer model has been developed as a tool for planning and managing disposal operations. This model predicts the configuration of a capped mound and aids in estimating the amount of capping material required to isolate any contaminants in that mound (Appendix A). By predicting mound radii and capping volumes for a given amount of dredged material, the model helps NED managers plan appropriate capping ratios.

Evaluations of early capping operations highlight the requirements for operational success, including pre-project planning, accurate navigation, and careful record-keeping. In reviewing the historical record of the NED capping projects, the focus will be on "lessons learned" because this information is valuable for any future capping efforts.

2.1 Central Long Island Sound Disposal Operations

This report describes four capping projects conducted in the Central Long Island Sound Disposal Site (CLIS): Stamford-New Haven, Mill-Quinnipiac River, Norwalk, and the two Experimental Cap Sites. These are the most comprehensive and best-documented of all the capping projects conducted by the NED. In addition, they were the only early capping projects in which specific capping material was prescribed. The "de facto" method mentioned above, in which the contaminated material was dredged and deposited before less contaminated material, was used in many other capping projects (e.g., Portland, Brenton Reef, New London, other capped mounds at CLIS; Bajek et al. 1987).

Each of the CLIS capping operations will be discussed in historical progression to establish what factors influenced the degree to which the project was or was not successful. This linear account serves as a valuable record of the early capping operations and provides a checklist of recommendations for future capping projects.

All the capped mounds formed as a result of these four projects are located within the boundaries of CLIS. This 5.2 km^2 (2 nm^2) area is located approximately 10 km south-southeast of New Haven, Connecticut (Figure 2-1). Water depths over the disposal site range from approximately 17 to 25 m.

CLIS lies within one of the most intensively studied regions of Long Island Sound. Detailed oceanographic studies of the area began in the 1950s with the pioneering work of Gordon Riley and his co-investigators at Yale University's

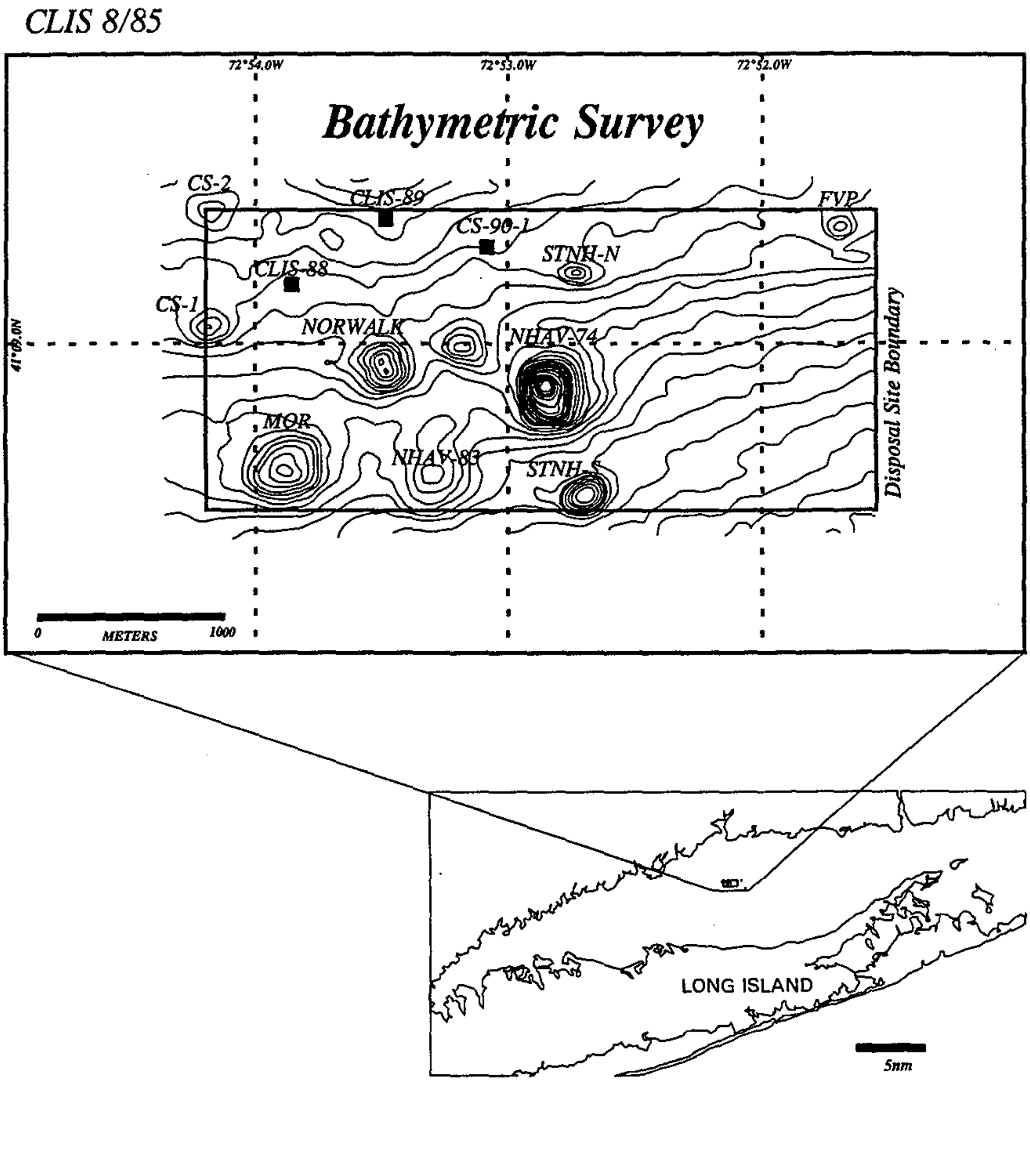


Figure 2-1. Long Island Sound and the Central Long Island Sound Disposal Site

Bingham Oceanographic Laboratory (Riley 1952, 1956, 1967). In the 1970s the disposal site and several adjacent areas used as reference or control stations were extensively surveyed as part of initial studies required by the Clean Water Act to detail environmental effects associated with dredged material disposal (Gordon et al. 1972, Rhoads 1973, Bohlen and Tramontano 1974a,b). In addition, these surveys provided a basis for a variety of research studies detailing the physical, chemical, and biological characteristics of the central Sound, relating them to the more general class of estuaries or coastal embayments (e.g., Gordon and Pilbeam 1975, Turekian et al. 1980, McCall 1977, Rhoads et al. 1979, Saltzman 1980). These data provide a valuable baseline supplementing the data sets obtained by the monitoring surveys conducted as part of the individual capping projects.

2.2 Stamford-New Haven

The first planned capping operation conducted by NED was the Stamford-New Haven (STNH) project which began in 1979. High concentrations of selected heavy metals were measured in the sediments of the upper reaches of Stamford Harbor, which caused a delay in maintenance dredging. Sediment deposition and infilling proceeded to a point where navigational access for commercial vessels was limited to high tide periods.

Sedimentation was particularly pronounced within the east branch of the upper harbor (Figure 2-2), an area dredged previously in 1942. Field surveys of the area conducted by NED personnel in 1978 indicated that restoration to the authorized channel depth in this area would require removal of approximately 50,500 m^3 of sediment. More detailed surveys conducted just prior to dredging resulted in an upward revision of this estimate to approximately 58,100 m^3.

Laboratory analyses indicated that the majority of sediments to be dredged from Stamford Harbor were fine-grained silts and clays with elevated levels of oil, grease, and volatile organics. In addition, they contained moderate to high concentrations of a variety of heavy metals including lead (Pb), zinc (Zn), mercury (Hg), and copper (Cu; Table 2-1). Based on these physical and chemical data, the sediments were characterized as highly contaminated according to the New England River Basin Commission (NERBC) guidelines used by NED and the States of Connecticut and New York at the time (Table 2-2; NERBC 1980). These data, in combination with laboratory bioassays that identified a potential for adverse biological effects (Moore 1978), indicated that special procedures would be required if the material was to be deposited at an open-water site.

To satisfy these special handling requirements, NED proposed open-water disposal of the Stamford sediments at CLIS with the resulting deposit to be capped by material dredged from New Haven Harbor (USACE 1978). These latter sediments were to be obtained from several locations along the main stem of

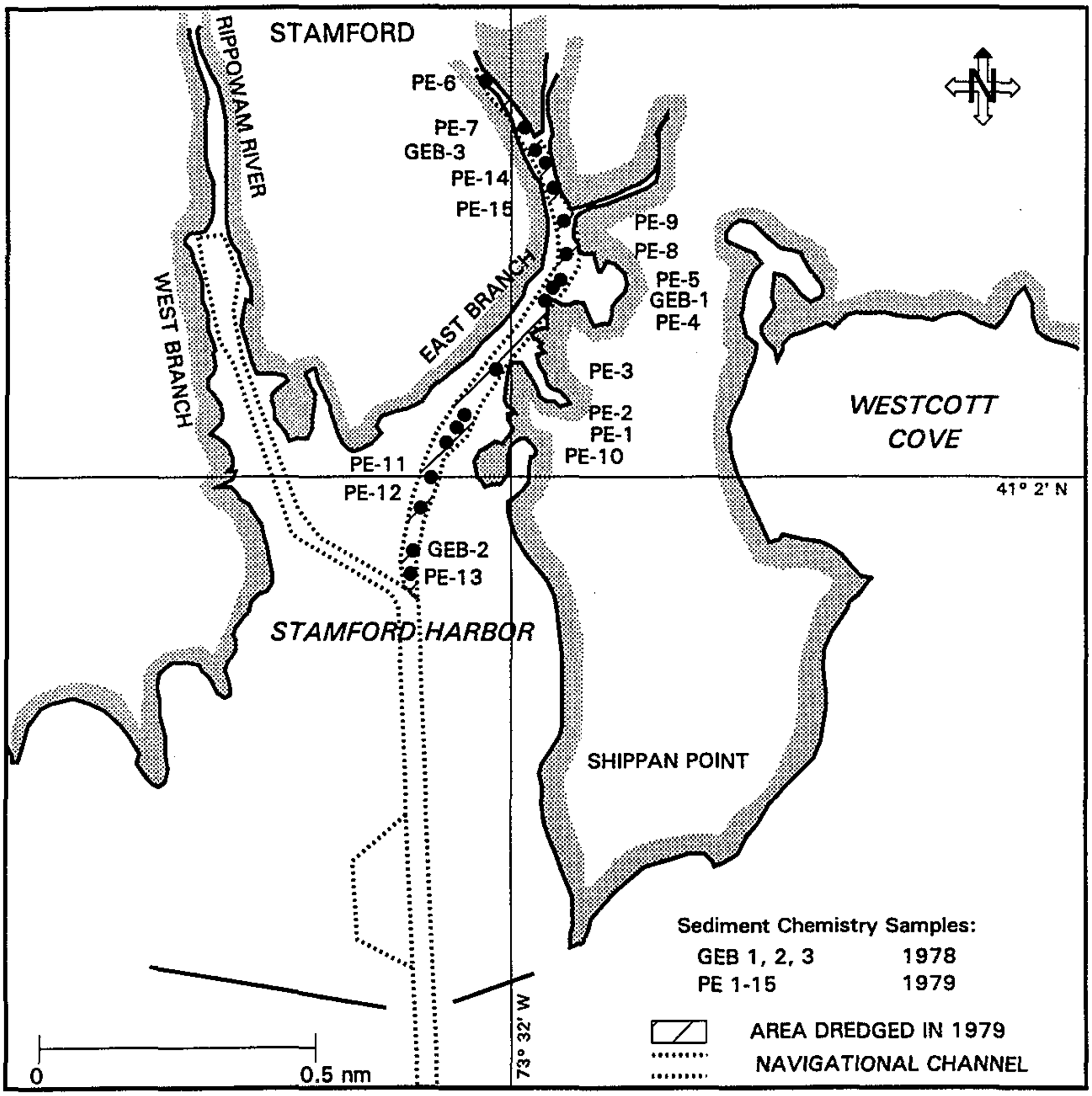


Figure 2-2. Stamford Harbor, Connecticut, with sample locations

Table 2-1

Pre-Dredge Mound Material Bulk Sediment Characteristics

Dredge Location: **Sample ID*:** **Year Collected:**	**Stamford** **GEB-1 to GEB-3** **1978**	**Black Rock** **BR-1 to BR-37** **1983**	**Norwalk (Mound)** **PE-8, PE-9, PE-10** **1979**	**Mill River** **PE-1, PE-2** **1980**
Liquid Limit	120 - 156	112 - 210	76 - 105	198 - 205
Plastic Limit	46 - 56	44 - 84	36 - 45	82 - 83
Plastic Index	74 - 100	32 - 142	40 - 60	103 - 115
% Solids	29 - 41	23.4 - 48.8	39 - 71.5	23 - 24
Sediment pH	6.95 - 7.4	7.0 - 7.6	7.1 - 7.6	6.7 - 7.0
% Volatile Solids	5.8 - 17	7.0 - 16.1	1.4 - 5.6	16.2 - 29.1
ppm Oil & Grease	3560 - 28,900	8400 - 44,000	559 - 3430	10 - 500
ppm Mercury	0.95 - 2.9	0.12 - 1.41	0.3 - 2.7	2.4 - 4.1
ppm Lead	195 - 1099	190 - 2200	31 - 272	450 - 825
ppm Zinc	441 - 2417	560 - 1180	86 - 170	625 - 1145
ppm Arsenic	7.6 - 12.7	2.1 - 10.1	2 - 6.3	4
ppm Cadmium	4.9 - 45.3	7.5 - 58	2 - 3	200 - 260
ppm Chromium	NA	NA	25 - 78	NA
ppm Copper	342 - 1167	890 - 3400	45 - 131	570 - 915
ppm Nickel	61 - 151	50 - 250	20 - 28	89 - 95
ppm Vanadium	27 - 61	100 - 987	8 - 47	50 - 100

* Samples collected prior to dredging; station locations are shown in Figures 2-2, 2-4, 2-6, and 2-7.

NA = Not available

Table 2-2

NERBC Contaminant Classification

	Low (ppm)	Moderate (ppm)	High (ppm)
As	<10	10-20	>20
Hg	<0.5	0.5-1.5	>1.5
Total PCBs			>1.0
DDT			>0.5
Pb	<100	100-200	>200
Cd	<3	3-7	>7
Cr	<100	100-300	>300
V	<75	75-125	>125
Zn	<200	200-400	>400
Ni	<50	50-100	>100
Cu	<200	200-400	>400

	Class I	Class II	Class III
% Oil & Grease	<0.2	0.2-0.75	>0.75
% Volatile Solids	<5.0	5-10	>10
% Fines (silt & clay)	<60	60-90	>90

the navigational channel (Figure 2-3). Material in the area ranged from fine-grained silts and clays along the northern reaches of the channel to sands near the Harbor entrance adjoining Long Island Sound.

Bulk sediment chemical analyses and elutriate tests showed the majority of New Haven material to be low to moderately contaminated sediments (Tables 2-2 and 2-3). Based on laboratory bioassays, the material was deemed suitable for use as cap material. Pre-project estimates indicated that the dredging required to provide the desired depths in this channel would entail removal of approximately 87,900 m^3 of sediment. This figure was later revised upward to approximately 129,200 m^3.

The proposed capping project was subjected to extensive public review. In response to the concerns raised by the SAC, NED developed a disposal plan requiring the Stamford sediments to be divided and placed at two distinct locations within CLIS. The capped mounds were to be separated along a north-south line to minimize cross contamination due to transport driven by the local near-bottom current field. The southern deposit was to be capped with fine-grained silts, and the northern deposit was to be covered with coarser grained silts and sands.

The project was to be monitored carefully to detail the areal extent of the capped mounds and the physical integrity of the cap, and to ensure a minimum cap thickness of approximately 50 cm, a value thought to represent twice the maximum thickness which might be disturbed by benthic biota (Brannon et al. 1984). Direct (diver), remote, and acoustic observations were to be obtained along defined transects in combination with sediment samples for chemical and biological analyses. All sampling was to be conducted within an accurately positioned grid with surveys continuing over at least a two-year period in an effort to permit initial assessment of both short- and long-term effects of the disposal operation (Appendix B).

NED conducted a series of bathymetric and grab sample surveys in January and March 1979 to assist in siting the disposal points and to establish reference points for later use in the assessment of the horizontal and vertical distribution of deposited material (Appendix C). A CLIS reference station was also sampled, a location used previously by Yale University investigators as a reference or control for studies conducted in the CLIS region. Analysis of the biological characteristics of samples obtained within the disposal site boundaries indicated relatively low concentrations of benthic organisms, making it difficult to obtain the biomass required for analysis of body burden concentrations of selected contaminants (NUSC 1979a). Consequently, body burden analyses were eliminated from the initial survey results. In the past three to four years, sampling techniques for body burden analyses have been investigated (Rhoads et al. 1994).

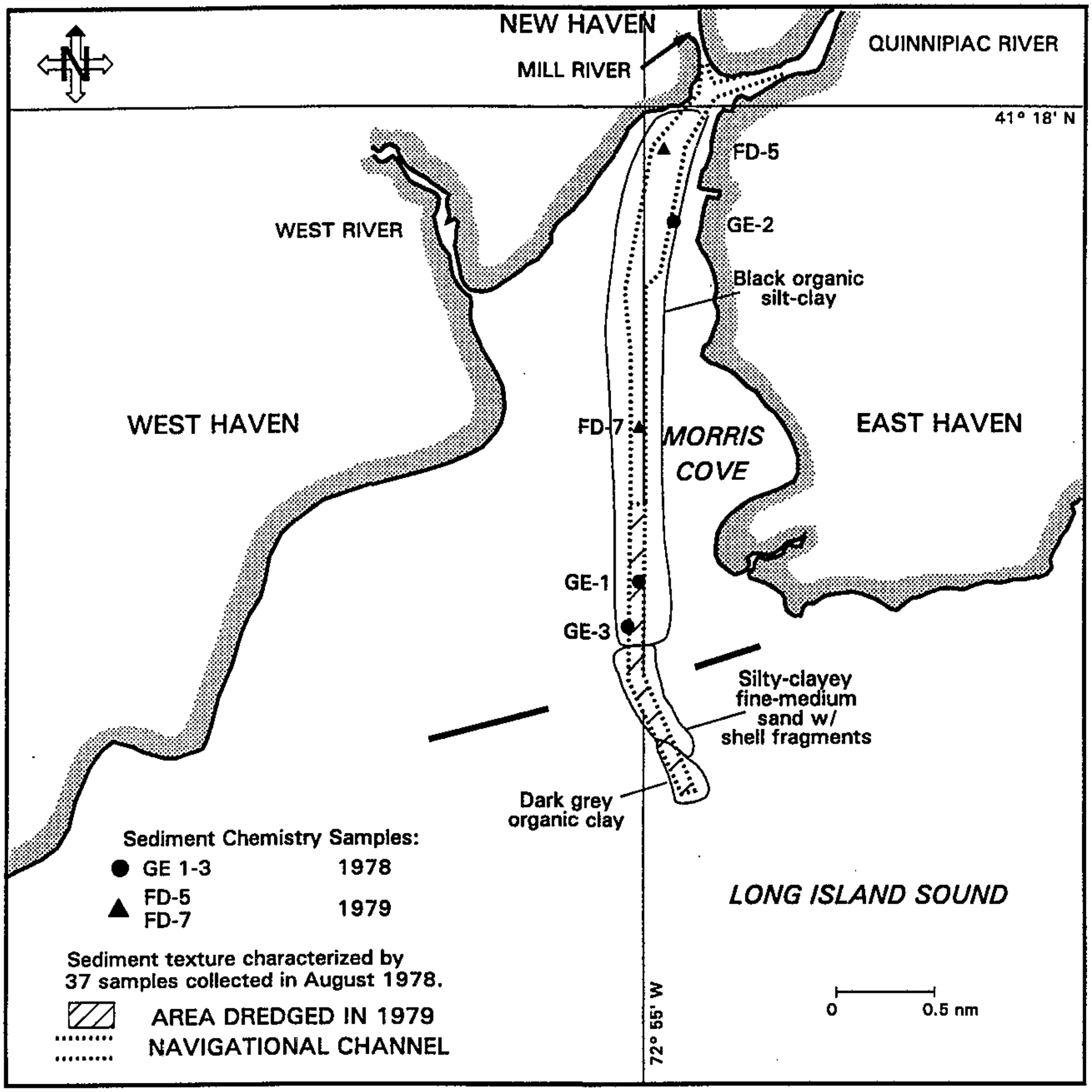


Figure 2-3. New Haven Harbor, Connecticut, with sample locations

Table 2-3

Pre-Dredge Cap Material Bulk Sediment Characteristics

Dredge Location:	**New Haven**	**New Haven**	**Norwalk (Cap)**	**Quinnipiac River**
Sample ID*:	**GE-1 to GE-3**	**FD-5, FD-7**	**PE 6**	**PE-3, PE-4, PE-10**
Year Collected:	**1978**	**1979**	**1979**	**1980**
Liquid Limit	112 - 117	139, Non-Plastic (NP)	108	96 - 148
Plastic Limit	42 - 46	52, NP	46	43 - 60
Plastic Index	69 - 71	87, NP	62	53 - 88
% Solids	30 - 34.16	20.87 - 71.40	38	38.17 - 45.6
Sediment pH	7.3 - 7.5	6.8 - 7.0	7.4	6.4 - 7.2
% Volatile Solids	5.5 - 6.49	0.8 - 7.7	5.2	7.56 - 13
ppm Oil & Grease	1750 - 3235	340 - 7740	2240	2100 - 2410
ppm Mercury	0.6 - 0.7	0.25 - 0.74	1.7	1.8 - 2.9
ppm Lead	107 - 131	38 - 210	61	180 - 270
ppm Zinc	234 - 250	41 - 472	190	307 - 995
ppm Arsenic	5.4 - 7.6	2.0 - 11.6	4.8	2 - 7
ppm Cadmium	2.3 - 4.8	0.1 - 7.0	4.0	330 - 490
ppm Chromium	NA	NA	94	NA
ppm Copper	154 - 192	59 - 367	188	410 - 530
ppm Nickel	26 - 60	25 - 87	39	85 - 94
ppm Vanadium	58 - 66	9 - 70	16	50 - 80

* Samples collected prior to dredging; station locations are shown in Figures 2-3, 2-4, 2-6.
NA = Not available

2.2.1 STNH Disposal Operations

Two taut-wired, moored buoys were deployed marking the locations of the selected Stamford-New Haven North (STNH-N) and South (STNH-S) disposal points (Figure 2-1). Clamshell dredging of the east branch of the Stamford Harbor channel began 25 March 1979, and material was transported to the disposal area using hopper barges. Initial disposal was confined to the southern buoy location in predisposal water depths of approximately 22-23 m. Between 25 March and 22 April approximately 38,000 m^3 (disposal barge log estimate) of Stamford sediment was deposited at the southern buoy.

On 23 April, the primary disposal point was shifted to the northern buoy location, in water depths averaging approximately 19 m. Between 23 April and 16 June 1979, approximately 31,000 m^3 (disposal barge log estimate) of Stamford material was deposited at the northern disposal point. Harbor dredging was terminated in mid-June to avoid any potential impacts on spawning species.

Dredging of New Haven Harbor silts to provide a cap for the southern site deposit began on 1 May 1979 and continued until 15 June 1979. Clamshell and associated hopper barge techniques were used to dredge and transport approximately 110,000 m^3 (disposal barge log estimate) of silts to the southern capped mound. Sand-sized material to provide a cap for the northern disposal project was dredged by the USACE hopper dredge Essayons from the mouth of New Haven Harbor during the period 16 to 21 June 1979. The latter dredging resulted in the placement of a total of approximately 112,000 m^3 (disposal barge log estimate) of sand capping material, 65,000 m^3 near the center of the mound and the rest approximately 100 to 300 m from the center.

Initial bathymetric surveys at STNH-N and STNH-S were conducted before disposal, after disposal of Stamford material, and after disposal of New Haven capping material (Appendix C). The results of this monitoring are fully discussed in Section 3.1.2.

On completion of the postdisposal surveys, additional "clean up" dredging was conducted in Stamford, resulting in the placement of an additional 6,000 m^3 of material at the STNH-S during the period of 26 September through 18 October 1979. This sediment subsequently was capped with material dredged from New Haven Harbor during the period of 29 January through 3 June 1980. According to disposal barge log records, this latter dredging resulted in the placement of an additional 110,700 m^3 of sandy silts to supplement the cap at STNH-S. Disposal volume estimates for the Stamford-New Haven project resulted in cap-to-contaminated-material ratios of 1.3:1 for STNH-N (sand cap) and 5:1 for STNH-S (silt cap) based on available disposal barge estimates (Table 2-4). The cap:mound ratio estimate for STNH-S is relative because of the 6000 m^3 of Stamford

Table 2-4

Central Long Island Sound Capping Operations Project Characteristics

Project Name	Dates	Contaminated Mound Volume m^3	Capping Sediment Volume m^3	Ratio Cap:Mound	Reference
Stamford-New Haven North	April-June, 1979	26,000 (ST)	33,000 (NH-sand)	1.3:1	Morton 1983, Barge Logs
Stamford-New Haven South	March-June, 1979	38,000 (ST)	110,000 (NH-silt)	5:1	Barge Logs
	September-October, 1979	6,000 (ST)			
	January-June, 1980		110,700 (NH) Total: 220,700		
Norwalk Harbor	April-May, 1980	19,900 (NOR-Cl.III)	48,000 (NOR-Cl.I+II) 180,300 (NOR-Cl.I+II) Total: 228,300	11.5:1	Barge Logs, Feng 1982
	January-June, 1981	70,000 (NOR-Cl.III)	280,000 silts	4:1	Morton 1984
Mill-Quinnipiac River	March-June, 1982	42,000 (MR)	133,200 (Q)	3.2:1	Barge Logs
	March-June, 1982	70,000 (MR)	190,000 (Q)	2.7:1	SAIC 1984 Bathymetry
	March-May, 1983	66,800 (BR)	400,200 (NH)	6:1	Barge Logs
Cap Site 1	April-May, 1983	33,200 (BR)	53,700 (NH-silt)	1.6:1	Barge Logs
Cap Site 2	April-May, 1983	38,100 (BR)	42,000 (NH-sand)	1.1:1	

ST = Stamford Harbor
NH = New Haven Harbor
NOR = Norwalk Harbor; Class I and II materials for cap, Class III materials for mound
MR = Mill River
Q = Quinnipiac River
BR = Black Rock Harbor

material which was placed between the two periods of cap deposition.

2.2.2 STNH Operations: Conclusions

Several observations and recommendations were made as a result of the STNH project (Morton 1980a):

- The cohesion of the mound material was an important factor in reducing the spatial distribution of the mound sediments.
- Point-dumping, using a taut-wired buoy, was an effective method of dredged material placement.
- Capping should take place as soon as possible after mound deposition.
- In addition to cap disposal at the buoy, a portion (at least 1/3) of the capping material should be disposed along the radius of the mound material to ensure complete coverage.
- Bathymetric monitoring during mound and cap disposal was an effective tool for modifying program design during disposal operations.

2.3 Norwalk

Following the operational success of the Stamford-New Haven project, NED next used capping as part of maintenance dredging of Norwalk Harbor, Connecticut, in 1980-81 (Figure 2-4). The proposed project called for clamshell dredging of approximately 230,000 m^3 of sediment from the navigation channel, with open-water disposal planned for the CLIS Disposal Site (USACE 1979).

Sampling surveys showed the material from Norwalk Harbor to be primarily fine-grained silts and sands. Sediments from the harbor entrance to Fitch Point Light (Figure 2-4) were classified as predominantly low to moderately contaminated material based on their physical characteristics (Tables 2-2 and 2-3). These sediments contained low concentrations of all the NERBC contaminants with the exception of Hg, which was found in elevated concentrations even at the more southerly sampling stations.

North of Fitch Point Light, contaminant concentrations increased, particularly for Hg and Pb. The bulk of sediments to be dredged from this area were moderately contaminated material (Tables 2-1 and 2-2). In addition to the NERBC range of contaminants, concentrations of nitrobenzene and naphthalene (EPA 1977) sufficient to make the associated sediments unsuitable for open-water disposal without further testing were found in a small area along the western edge of the channel near the I-95 roadway bridge.

To accommodate the range and character of contamination found in Norwalk Harbor, NED proposed a multifaceted dredging program. Dredging would be phased so that the highly

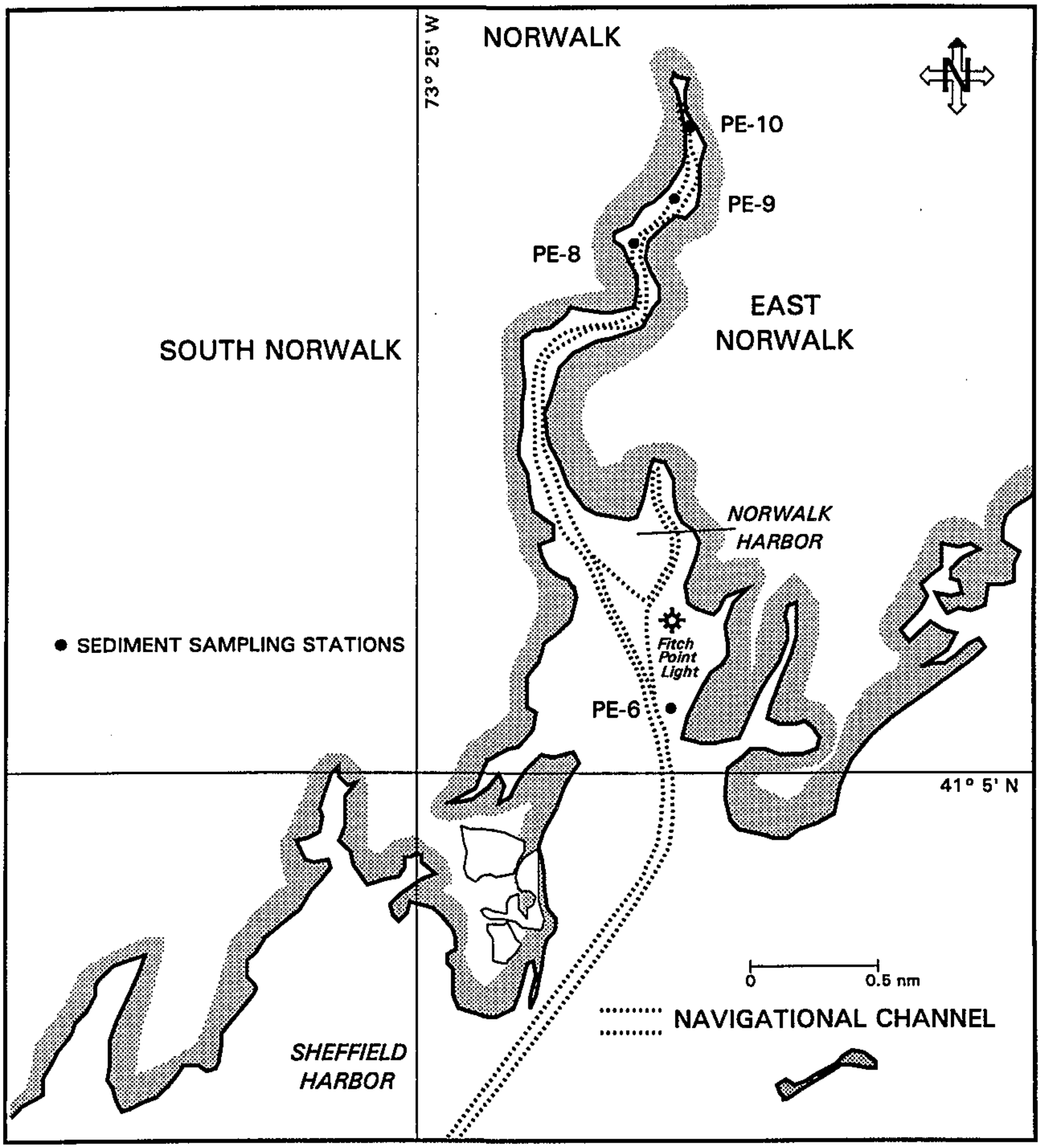


Figure 2-4. Norwalk Harbor, Connecticut, and sample locations

contaminated material would be deposited within CLIS at a point separate from, and to the west of, the Stamford-New Haven capped mounds. The new disposal site was named Norwalk (NOR) after the sole source area (Figure 2-1). The contaminated deposit was to be capped by cleaner (having low to moderate levels of contaminants) material obtained from the outermost sections of the navigation channel.

The estimated 1600 m^3 of sediment containing nitrobenzene and naphthalene would be placed as a conservative measure in a subaqueous pit to be dredged within the harbor and covered with 1-2 m of clean sediment. Justifications for open-water disposal were based on the previously demonstrated ability to achieve point placement and coverage in the Stamford-New Haven project, and the results of laboratory bioassays simulating benthic conditions which showed that, despite elevated contaminant concentrations, exposure to the Norwalk sediments resulted in negligible biological impacts (ERCO 1979).

2.3.1 NOR Disposal Operations

Clamshell dredging of Norwalk Harbor began on 11 April 1980. Harbor water depths limiting dredge access necessitated the removal of some low to moderately contaminated sediments before the highly contaminated material. The low to moderately contaminated sediments were transported to the selected disposal point (Figure 2-1) via hopper barge. Dredged material deposition was concentrated in the south of NOR (Morton 1981).

Plans called for placement of highly contaminated sediments prior to final deposition of cleaner sediments to form the finished cap. The initial dredging continued until 30 May 1980 when operations terminated to avoid the shellfish spawning periods. On termination, approximately 67,900 m^3 of sediment had been dredged, of which 19,900 m^3 was estimated to be highly contaminated material (Feng 1982).

The Norwalk dredging and open water disposal resumed on 31 January 1981 and continued through 3 June 1981. Monitoring surveys during this period indicated a rather haphazard distribution of material and a less than optimum mound and cap coherence (Morton 1981). Feng (1982) and Brooks (1983) reported that approximately 180,300 m^3 of additional, relatively clean sediment from Norwalk Harbor was placed at NOR in the period between January and June 1981 (Table 2-4).

A bathymetric survey conducted in the middle of this period of disposal (27-29 April 1981) showed a new mound to the north of the disposal buoy, containing primarily sediments from the northern end of Norwalk Harbor. The volume disposed between 31 January and the period of the survey (late April) was calculated to be about 60,000 m^3 (Morton 1981), approximately 1/3 of the total placed through June (Table 2-4).

A bathymetric survey was conducted in August 1981 following the completion of disposal operations. The final reported disposal volumes for the 1981 disposal season were approximately 70,000 m^3 of highly contaminated material capped with 280,000 m^3 of low to moderately contaminated material from the outer Norwalk Harbor, resulting in a 4:1 capping ratio (Table 2-4; Morton et al. 1984b). There is some potential error in the estimates of volumes of low, medium, and highly contaminated material dredged from Norwalk Harbor because these classifications are an arbitrary scale used to describe natural sediment variations (Section 3.3). The estimates of "cap" and "mound" ratios at NOR are problematic because the records of each barge load sediment contaminant class and its ultimate disposal point are no longer available. In addition, this cap:mound ratio is misleading because again, as at STNH-S, the cap and mound materials were interspersed, especially since a significant portion of the "cap" material was deposited first.

The bathymetry from a January 1982 survey showed a decrease of approximately 1 m across the capped surface, probably due to consolidation (Section 3.1.3; Morton et al. 1984b). Subsequent bathymetric surveys have shown a stable dual mound configuration (Figure 2-5).

2.3.2 NOR Operations: Conclusions

Subsequent monitoring has shown no negative impact of the disposal operations at NOR. Several factors were notable:

- Operational procedures should emphasize coherent mound disposal followed by cap disposal.
- If relatively uncontaminated sediments need to be removed first, they should not be included as part of the mound.
- Accurate sediment classification of source material for mound and cap should be established; the gradational character of Norwalk "cap" and "mound" sediments made later distinction between these two problematic.

2.4 Mill and Quinnipiac Rivers

During the spring of 1982, NED initiated a third capping project to accommodate sediments to be removed as part of federal maintenance dredging of areas in the Mill and Quinnipiac Rivers adjoining the northern limits of New Haven Harbor (Figure 2-6). Preliminary surveys showed sediments within the Mill River to contain concentrations of oil and grease sufficient to place them in the NERBC highly contaminated category (Tables 2-1 and 2-2). The material was characterized by high concentrations of fibrous residue or wood pulp, which limited sediment cohesion. This unique sediment texture, combined with the

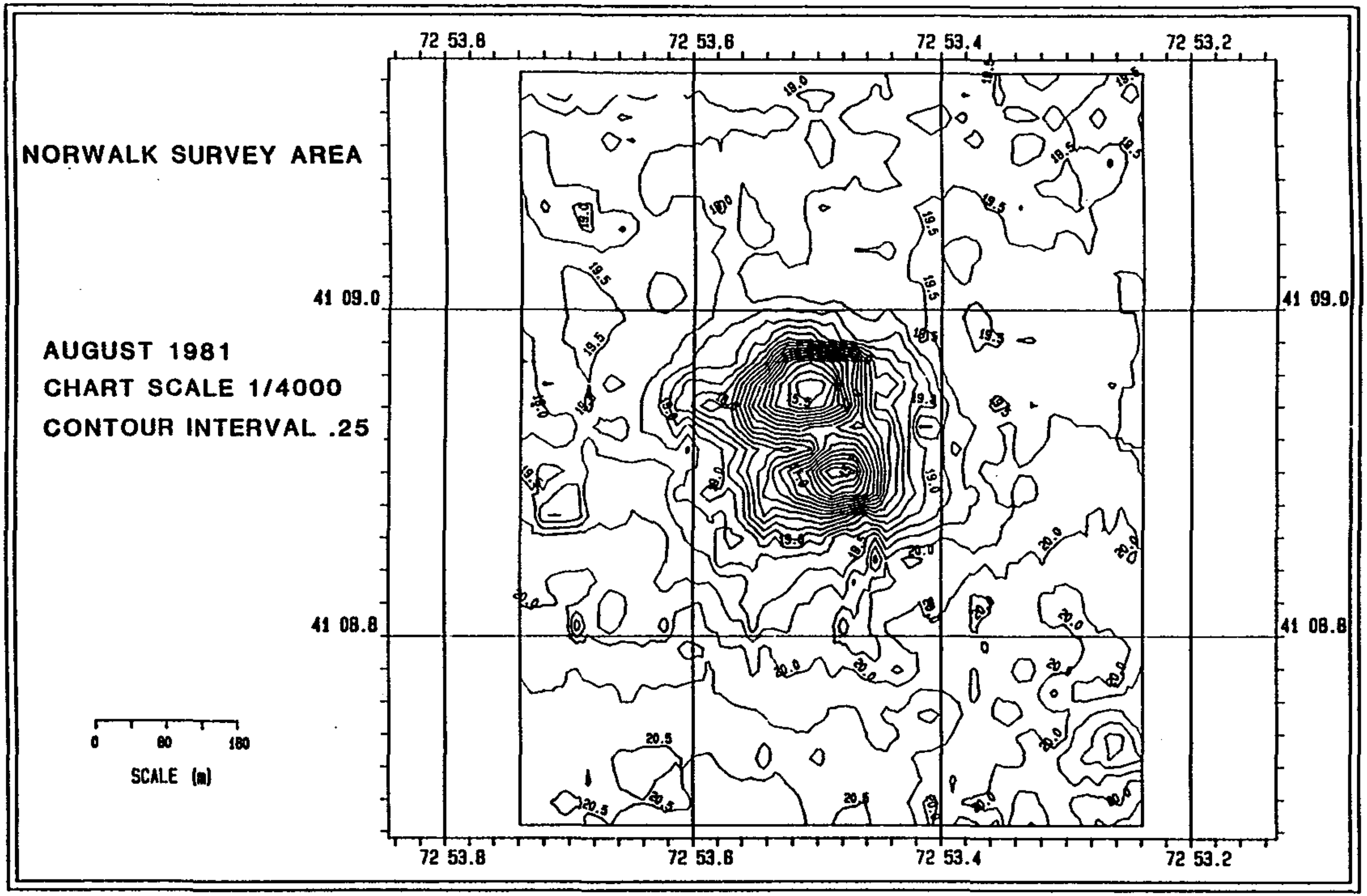


Figure 2-5. Bathymetric profile of the Norwalk capped mound, 1981

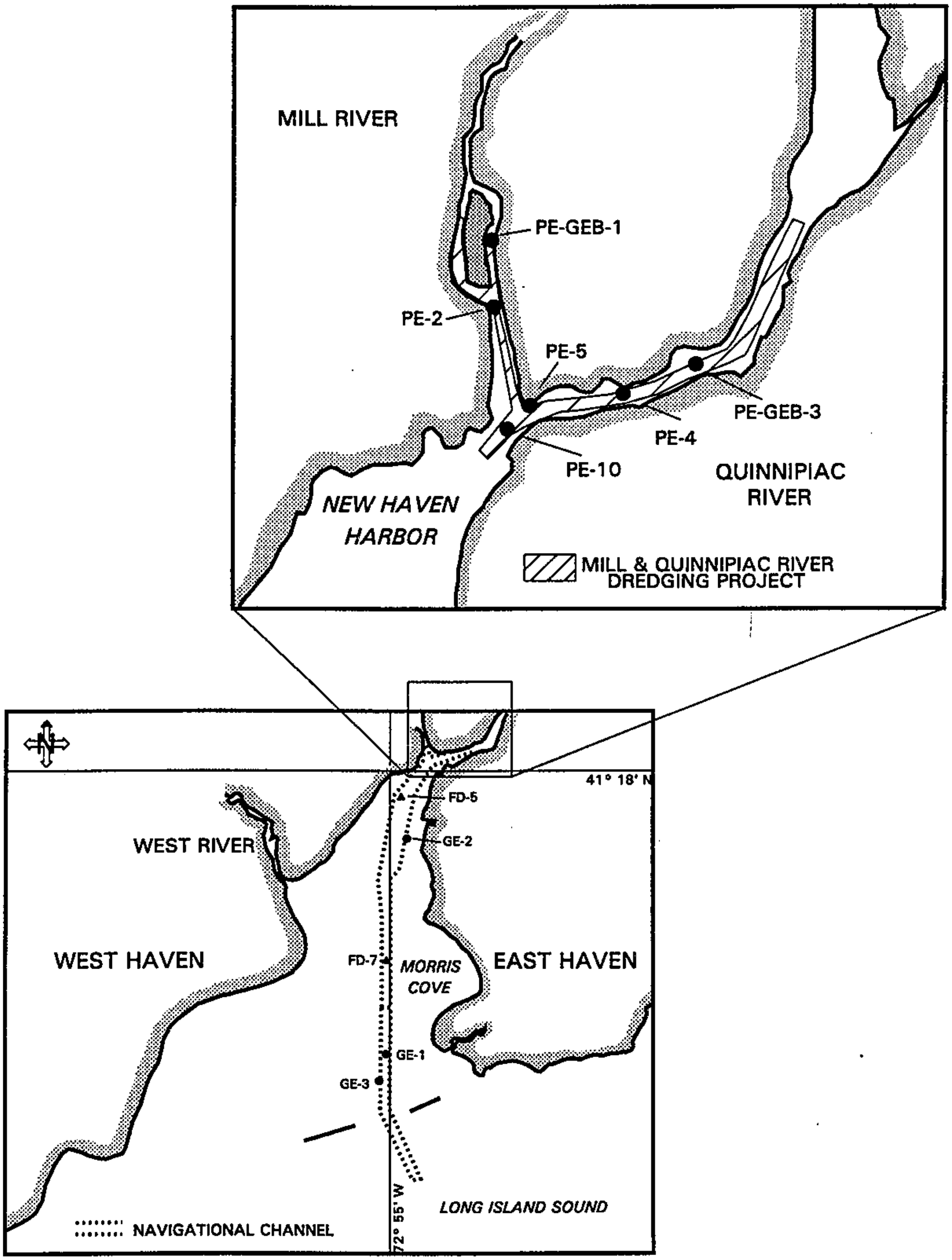


Figure 2-6. Mill and Quinnipiac Rivers with sample locations

relatively high water content measured in the Mill River sediments, increased the dispersive properties of the material. In addition, chemical analysis of the Mill River sediments indicated high concentrations for most of the heavy metals tested. Cadmium (Cd), for example, was measured in concentrations up to 260 ppm (Table 2-1).

Sediments to be dredged from the Quinnipiac River were much more stable geotechnically, lacking the fibrous wood pulp component found in the Mill River sediments. However, they were only slightly less contaminated, with concentrations of Hg, Pb, Cd, and Cu still within the NERBC highly contaminated category (Tables 2-2 and 2-3). Laboratory bioassays and bioaccumulation studies of selected contaminant levels present in the dredge site material showed minimal toxicity and uptake associated with exposure to either Mill or Quinnipiac River sediments (ERCO 1980a, b, ERCO 1981a, b). Despite these bioassay results, the USACE determined that open-water disposal would be feasible only if the relatively mobile Mill River sediments were capped with the more stable Quinnipiac River material. Dredging and disposal operations of Mill and Quinnipiac River sediments are discussed in Section 2.4.1.

In late spring of 1983, the Mill-Quinnipiac River mound (MQR) received an additional 66,800 m^3 of contaminated material dredged from Black Rock Harbor near Bridgeport, Connecticut (Figure 2-7). This operation was conducted in conjunction with the Field Verification Program (FVP), a multiyear joint research program sponsored by the Environmental Protection Agency and the USACE (Peddicord 1988). Laboratory analysis of sediments from Black Rock Harbor indicated that the material was predominantly in the NERBC highly contaminated category and had high concentrations of a variety of organic and inorganic compounds (Table 2-1 and 2-2, USACE 1982; Rogerson et al. 1985). These included heavy metals, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). Laboratory bioassays indicated that exposure to this sediment had the potential to induce unacceptable mortalities in local biota (ERCO 1980c,d).

The results of the bulk chemical analyses and bioassays led to the determination that open-water disposal of the Black Rock sediments should be followed by capping with cleaner material to minimize biotic exposure and/or contaminant migration. To satisfy this requirement, NED proposed to cap the Black Rock Harbor sediments placed at MQR with silts to be dredged from New Haven Harbor. Previous analyses had shown the latter material to contain moderate levels of the NERBC contaminants (Tables 2-2 and 2-3; USACE 1979).

2.4.1 MQR Disposal Operations

Clamshell dredging of the Mill River began on 31 March 1982. Material was transported by hopper barge to the CLIS

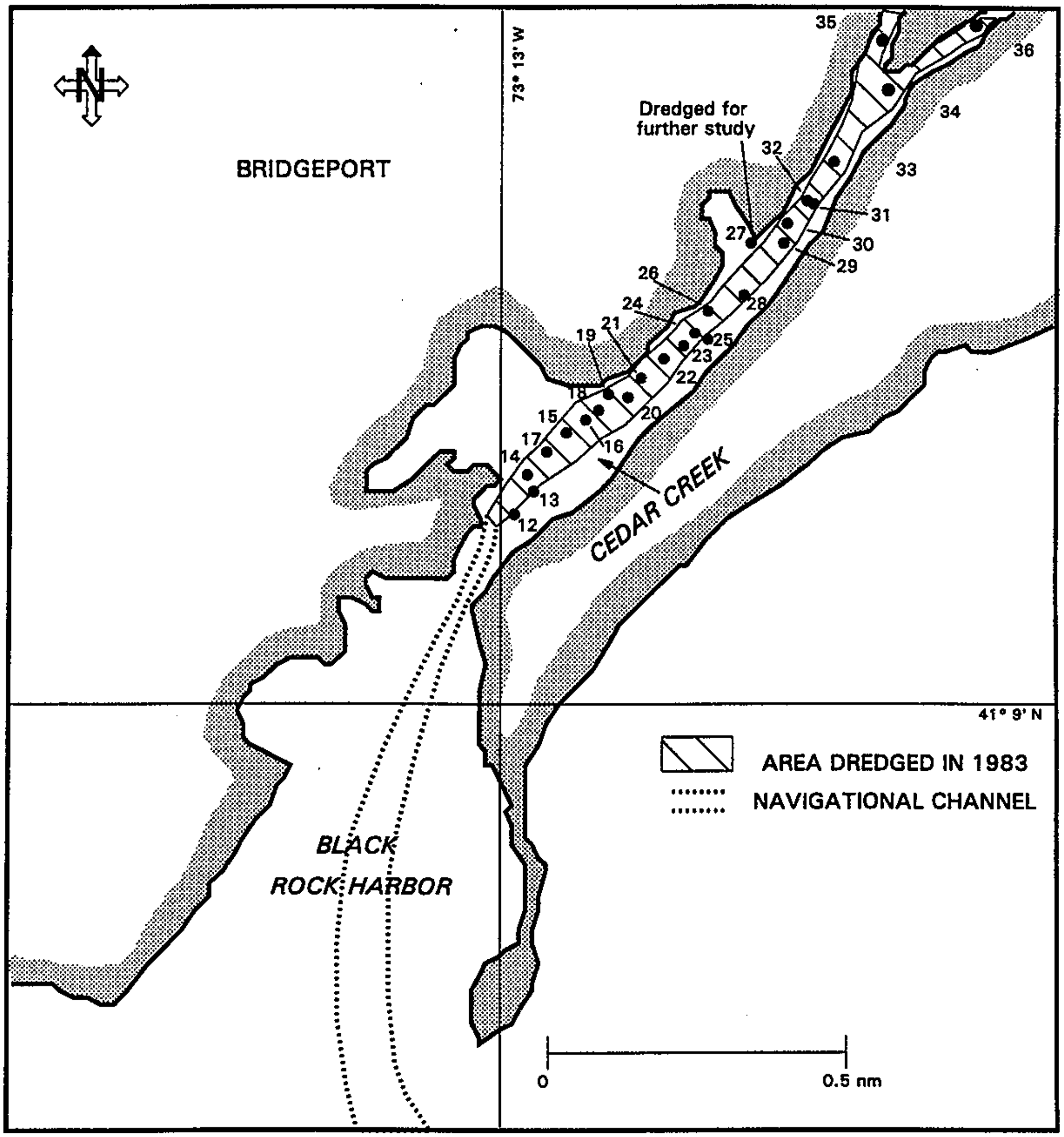


Figure 2-7. Black Rock Harbor, Connecticut, with sample locations

Disposal Site and placed at the MQR buoy located near the southwestern corner of the CLIS site (Figure 2-1). Water depths in this area ranged from 20 to 21 m. This location was selected to minimize interference with the previous capped mounds. Disposal barge logs indicated that approximately 42,000 m^3 of high-water-content Mill River sediment was placed prior to the initiation of Quinnipiac River dredging. This latter operation, beginning in early May 1982 and completed prior to the first of June, resulted in the placement of approximately 133,200 m^3 of silts as a cap layer over the Mill River sediments, resulting in a disposal barge log cap:mound ratio estimate of 3.2:1.

Dredged material volume estimates obtained by comparing bathymetric profiles before and after disposal of each unit disagree substantially with the disposal barge log values. Volume calculations based on depth differences were approximately 70,000 m^3 of sediment dredged from the Mill River and 190,000 m^3 from the Quinnipiac River, resulting in a 2.7:1 capping ratio (Table 2-4; Morton et al. 1984a).

Given the variations in sediment water content and compaction induced by the dredging operation, it is not surprising to find substantial differences between disposal barge estimates and measured in-place volumes. These characteristics have been discussed by several investigators (e.g., Tavolaro 1984). Normally, however, this combination of factors results in in-place volumes that are less than disposal barge volumes (Section 3.1). The volume calculation data, based on depth differences for the Mill River dredging, show in-place volumes to be significantly larger than those detailed on the NED log. This in part may be a result of the unique textural quality (i.e., wood pulp) of the disposed material. In addition, incomplete records confound estimates of disposal barge volumes.

Clamshell dredging of Black Rock Harbor and subsequent disposal at Mill-Quinnipiac (MQR) began on 9 March 1983 and continued through 18 April 1983. Dredging of New Haven Harbor began on 29 March and was completed on 17 May. NED disposal barge logs indicated that approximately 67,000 m^3 of Black Rock sediment was placed at the MQR mound and capped with approximately 400,000 m^3 of additional New Haven material, which resulted in a 6:1 cap ratio for this second layer of MQR (Table 2-4).

This ratio is again misleading and somewhat compromised by the fact that the periods of deposition of Black Rock and New Haven material overlapped to some extent (Figure 2-8). The majority of Black Rock material was disposed before New Haven. Subsequent to the final New Haven cap deposition, however, two barge loads of Black Rock material (approximately 3,000 m^3) were deposited at MQR. This disposal sequence complicated evaluation of this project and may have resulted in a thin layer of Black Rock material at the surface. A more complete discussion of monitoring results of this capped mound is included in

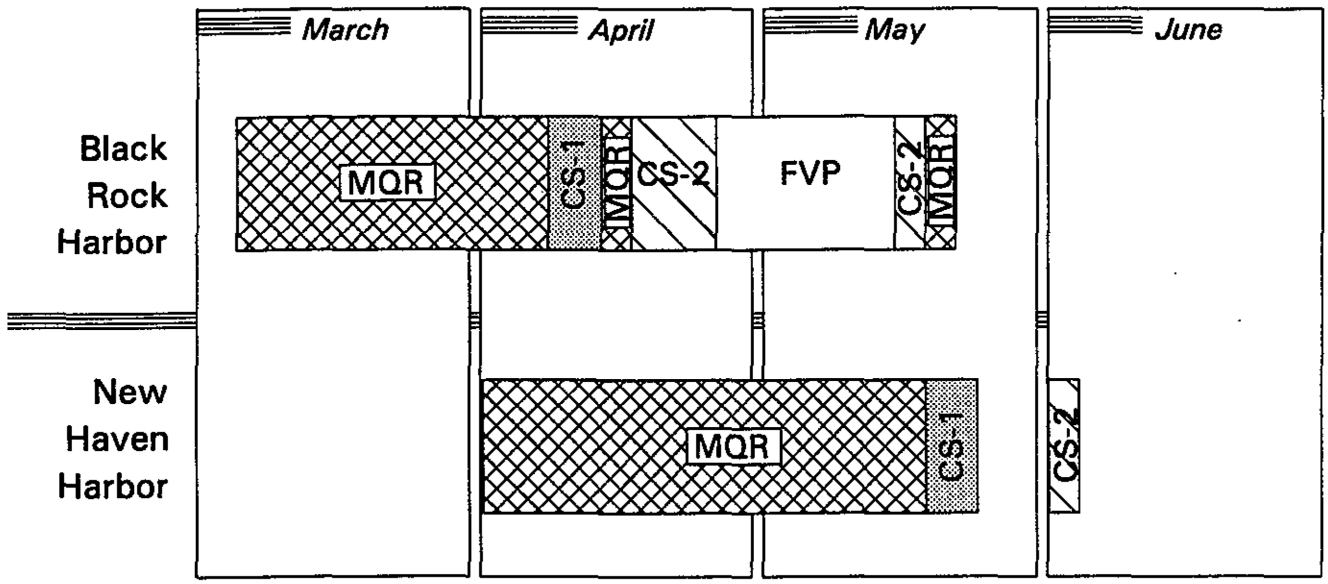


Figure 2-8. Disposal operations schedule, Black Rock and New Haven Harbors, spring 1983

Sections 3.2 (Biological Monitoring) and 3.3 (Chemical Monitoring). The available data make it qualitatively clear that conditions at MQR are dominated by factors associated with the Black Rock Harbor and New Haven sediments rather than any effects caused by the previously placed Mill and Quinnipiac River material.

2.4.2 MQR Operations: Conclusions

Continued monitoring since disposal has defined more precisely the operational problems at MQR, and will be discussed in Section 3.0. However, in assessing the operations at MQR, the following points should be emphasized:

- The inability to resolve differences between disposal barge log estimates and volume calculations was directly affected by incomplete or unavailable disposal barge log records.
- Deposition of Black Rock Harbor material at the end of the disposal sequence complicated analysis of subsequent monitoring data at MQR.

2.5 Cap Sites 1 and 2

In 1983, coincident with the Black Rock/New Haven Harbor phases of disposal at MQR, NED conducted a controlled capping operation at CLIS under conditions essentially similar to those applied during the Stamford-New Haven project in 1979. Contaminated material from Black Rock Harbor was to be placed at CLIS at two points along the northwestern margin of the site in water depths of approximately 17-18 m (Figure 2-1). The southern mound (CS-1) was to be capped with finer grained silts and clays similar to those at STNH-S whereas the northern mound (CS-2) was to be capped with sandy silts as at STNH-N. All capping material was to be obtained by maintenance dredging within New Haven Harbor.

This capping operation, in combination with the placement of an uncapped deposit of Black Rock Harbor material at the FVP mound (Figure 2-1), permitted three comparisons to be made: (1) comparisons with the Stamford-New Haven project; (2) comparison of capped and uncapped mounds (CS-1 or CS-2 vs. FVP); and (3) comparison of some aspects of the effectiveness of mud vs. sand sediment caps as a barrier or impediment to contaminant migration (Morton et al. 1984a).

2.5.1 CS-1 and CS-2 Disposal Operations

Dredging of sections of Black Rock Harbor and subsequent disposal at Cap Site 1 began on 6 April 1983 and continued through 14 April 1983 (Figure 2-8). NED disposal barge log records indicated that approximately 33,200 m^3 of sediment was placed at CS-1. Disposal operations at Cap Site 2 were more intermittent, with operations beginning on 18 April 1983 and continuing until 18 May 1983 (Figure 2-8). Disposal barge logs indicated that approximately 38,100 m^3 was placed at CS-2.

Capping operations for both CS-1 and CS-2 began in May 1983. Approximately 53,700 m^3 of New Haven silts was placed at CS-1 (17-23 May 1983) and 42,000 m^3 of New Haven sand at CS-2 (30 May-3 June 1983). Based on these disposal volume records, capping ratios of 1.6:1 and 1.1:1 were disposed at CS-1 and CS-2, respectively (Table 2-4). Subsequent surveys using a combination of acoustic and photographic techniques indicated in-place volume estimates of approximately 24,200 m^3 of Black Rock and 56,300 m^3 of New Haven sediment at CS-1, and 23,700 m^3 of Black Rock and 30,900 m^3 of New Haven material at CS-2, resulting in slightly higher cap:mound ratios (2.3:1 and 1.3:1, respectively).

The percent difference between the disposal barge log records and volume difference calculations for capping material at CS-1 was negligible (a gain of 2.4%). The difference between disposal barge and volume difference calculations for mound material at CS-1 and cap material at CS-2 was approximately 15%, and 23% for mound material at CS-2.

Considerable difficulties were encountered during disposal operations at CS-1: cap material was deposited southwest of the intended disposal point, resulting in uneven coverage of the Black Rock Harbor material. The cap apex was roughly 100 m southwest of the apex of the contaminated material mound (Figure 2-9; Morton et al. 1984a, 1984b). There were areas of the eastern margin of CS-1 that did not receive a cap layer measurable by bathymetric methods (>20 cm).

Complete coverage was reported at CS-2. Cap thicknesses ranged from 20 to 40 cm along the eastern margin to as much as 1.4 m on the western border of CS-2 (Figure 2-10; Morton et al. 1984b). At this time, DAMOS surveys routinely incorporated photographic documentation of sediment disturbance using Remote Ecological Monitoring of the Seafloor (REMOTS®) technology (discussed in Section 3.2.2). Follow-up REMOTS® surveys identified sections of the flanks of CS-2 where the layer of reworked sediment from bioturbation exceeded sand cap thicknesses (Morton et al. 1984b).

The Cap Sites demonstrate the importance of precise navigation and point-dumping for achievement of a successful capping project. These operations differed from the original capping disposal plans. Taut-wired, moored buoys were to be used during the disposal of contaminated sediments in order to reduce the spread of material requiring capping, and LORAN-C was to be used for disposal of capping material in order to cover a larger area (Morton et al. 1984b). LORAN-C is a navigational system which defines a location based on distance from shore-based transmitting stations with known geographic locations. Problems developed in the operation of the LORAN-C receivers during the CS-2 capping operation. Consequently, the remainder of the capping operation at CS-2 was accomplished using a taut-wired buoy as

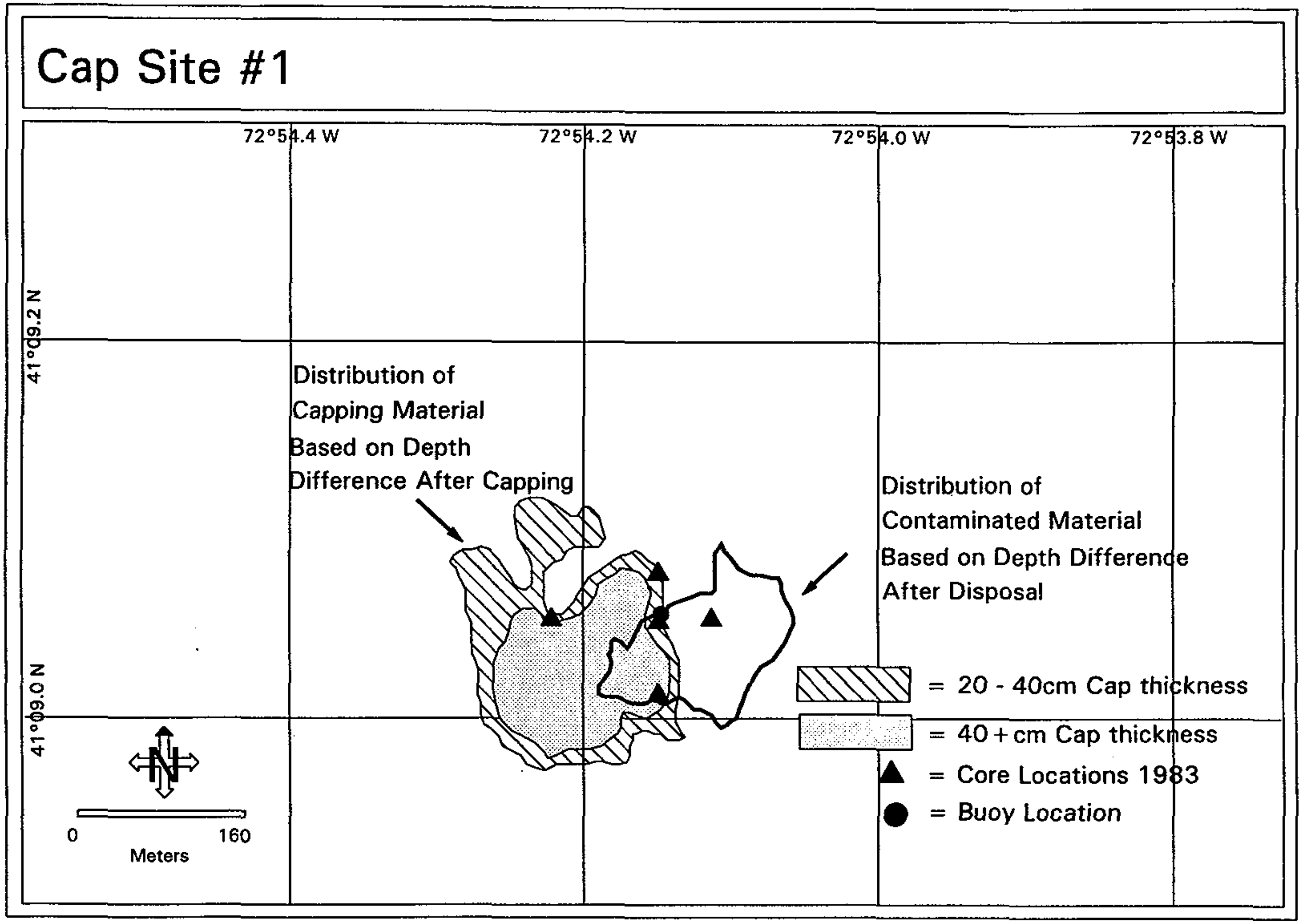


Figure 2-9. Distribution of dredged material at Cap Site 1 (adapted from Fredette et al. 1992)

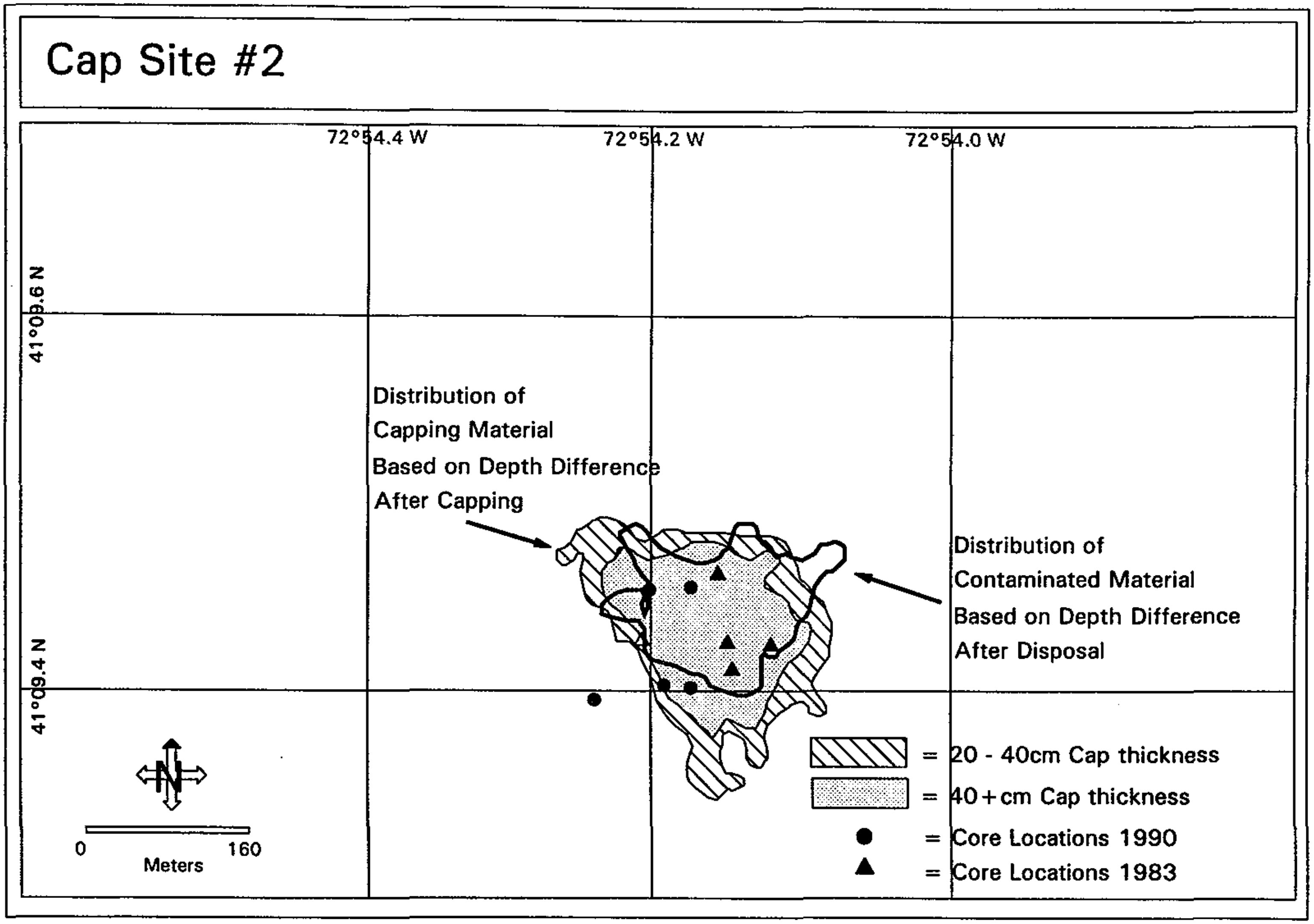


Figure 2-10. Distribution of dredged material at Cap Site 2 (adapted from Fredette et al. 1992)

the navigational reference. CS-1 was capped using only LORAN-C as an aid for locating the mound. It appears that using the buoy as a navigational reference instead of LORAN-C during the capping operation at CS-2 actually helped reduce cap placement errors compared to those at CS-1.

The southwest bias of the cap at CS-1 may be related to navigation during the disposal operation and the sources of material for the capped mound. The pattern of mound and cap placement at CS-1 is consistent with the direction of approach of the disposal barges; Black Rock Harbor (mound) disposal barges steamed from the northwest to the correct LORAN coordinates and returned, and New Haven (cap) disposal barges steamed from the north to the intended disposal points. LORAN-C alone does not have the resolution required for precise point-dumping. The bi-directional approach may have caused the offset of the mound and cap.

2.5.2 Cap Site Operations: Conclusions

The discovery that the cap at CS-1 was offset from the mound is further evidence that postdisposal monitoring and data analysis are essential to document any potential problems as a result of disposal activity or changes in capped mound stability in the long term. Accurate navigation aided by taut-wired buoys has been shown to be the most effective method of both point-dumping and completely covering capped mounds.

2.6 Summary of the Early Capping Experience

The CLIS capping experience provided a clear methodology to follow for the formation of a completely covered mound. After the first operation, Stamford-New Haven, the basic disposal operation guidelines were established:

- Use a taut-wired buoy and accurate navigation for both cap and mound sediments.
- Reduce the spatial distribution of cohesive mound sediments by point-dumping, or positioning the disposal barge loads as near to the buoy as possible.
- Dispose of a portion of the cap around the radius of the mound to ensure complete coverage.
- Complete a discrete disposal sequence, first with a mound deposition phase, followed by cap placement.

Additional guidelines were established as more capping projects were completed:

- Keep accurate records.
- Characterize mound and cap sediments prior to disposal.
- Monitor prudently to confirm the stability of the capped mounds.

3.0 MONITORING STUDIES

The first experimental capping operations were conducted simultaneously with a monitoring program designed to measure the short-term effectiveness of the capping objectives (Appendix B). Initial concerns regarding the long-term environmental impact of capping contaminated sediments resulted in both periodic monitoring surveys and investigations targeted to resolve specific questions. The primary objective of the capping operations was to isolate the underlying contaminated material from the ambient water column and local biota. The ability of a sediment layer to accomplish this goal depends on a variety of physical, biological, and chemical processes. These three characteristics, although closely interrelated, were monitored independently.

The first indications that capping was, indeed, a viable disposal method came from precision bathymetric surveys scheduled before disposal, after disposal of mound material, and periodically after capping. Results from these surveys showed that dredged material could be placed precisely and that the caps remained in place after disposal. These bathymetric surveys were closely followed by biological and chemical monitoring that confirmed the stability and integrity of the sediment caps.

Physical monitoring was designed to observe the capped mounds for signs of erosion or physical breaching and to ensure complete cap coverage. Methods used have been primarily acoustic and visual. Biological monitoring, consisting of visual assessments and chemical analyses of organisms, was conducted to ensure that contaminants within the mound were not having an adverse impact on the benthic ecosystem. Recently, biological monitoring procedures have focused on efficient monitoring with accompanying management response. Chemical monitoring was initiated to confirm that surficial sediments retained low contaminant concentrations. Questions concerning chemical mobilization from the mound to the surface of the cap have been addressed more recently (Section 4.0).

3.1 Physical Characteristics

The primary concerns raised by the Scientific Advisory Committee related to the physical stability of the capped mounds. Successful disposal operations alone could not determine the long-term fate of a capped mound. Ability to construct a coherent mound had to be demonstrated. The committee also questioned whether coarse-grained, sandy material could be placed over fine-grained sediments with higher water content; the concern was that the impact of the sand could disperse the underlying contaminated material and limit the physical integrity of the cap.

3.1.1 Methods

Morphology and short- and long-term stability of capped mounds have been examined by the DAMOS Program using a variety of direct and indirect methods.

Particular reliance has been placed on acoustic profiling techniques. Since the beginning of the DAMOS Program in 1977, high resolution bathymetric observations have been included in all surveys. Survey systems and associated high accuracy electronic navigational techniques have evolved progressively, providing increased accuracy in ship positioning, depth measurements, and associated sediment volume calculations.

The bathymetric profiling system used during the 1979 Stamford-New Haven project provided resolution sufficient to detail changes in water depth of approximately 20 cm (Morton 1980b, 1983b). By 1987, incorporation of higher frequency, narrower beam-width systems and improved, computer-based data processing procedures had improved system resolution by about 10 cm. The associated sediment volume estimates were further improved by the inclusion of the REMOTS® sediment-profiling camera system (Rhoads and Germano 1982) in many of the monitoring surveys conducted after 1982 (Appendix C). This system, with a vertical resolution of millimeters, permitted accurate mapping of sediment distributions along the flanks of the capped mound, an area difficult to resolve using conventional acoustic techniques.

3.1.2 A Case Study: STNH

The first NED capped mound projects, Stamford-New Haven North and South (STNH-N and STNH-S), were the most intensively studied and documented. Bathymetric surveys and SCUBA diver observations were used to document capped mound coherence and stability. The passage of Hurricane David within 6 months of disposal provided a natural laboratory to test the long-term stability of a capped mound.

The acoustic data obtained during the Stamford-New Haven project (STNH) provided immediate confirmation that it was possible to point-dump dredged material to form a well-defined, coherent deposit centered at a specified point (NUSC 1979a-f, SAI 1980a). In the spring of 1979, STNH-N and STNH-S received 31,000 and 38,000 m^3 of contaminated material, respectively, according to disposal barge load estimates, and formed discrete mounds approximately 100 m in diameter (Table 2-4 and Figure 3-1).

Material transport and loss during the disposal operation were estimated by comparing dredged material volumes shown in the NED disposal barge logs to those calculated using the bathymetric data. For example, the total volume of Stamford material deposited at each mound was calculated by comparing the pre- and post-Stamford disposal bathymetry. At STNH-S, the results of the volume calculation for Stamford material were 34,000 m^3, which accounted for 90% of the barge load estimate. The estimate was later revised by quantifying the volume of material on the mound flanks, below the resolution of the bathymetric methods at the time, using SCUBA observations and bottom sampling. An estimate of an additional 1980 m^3 brought the total

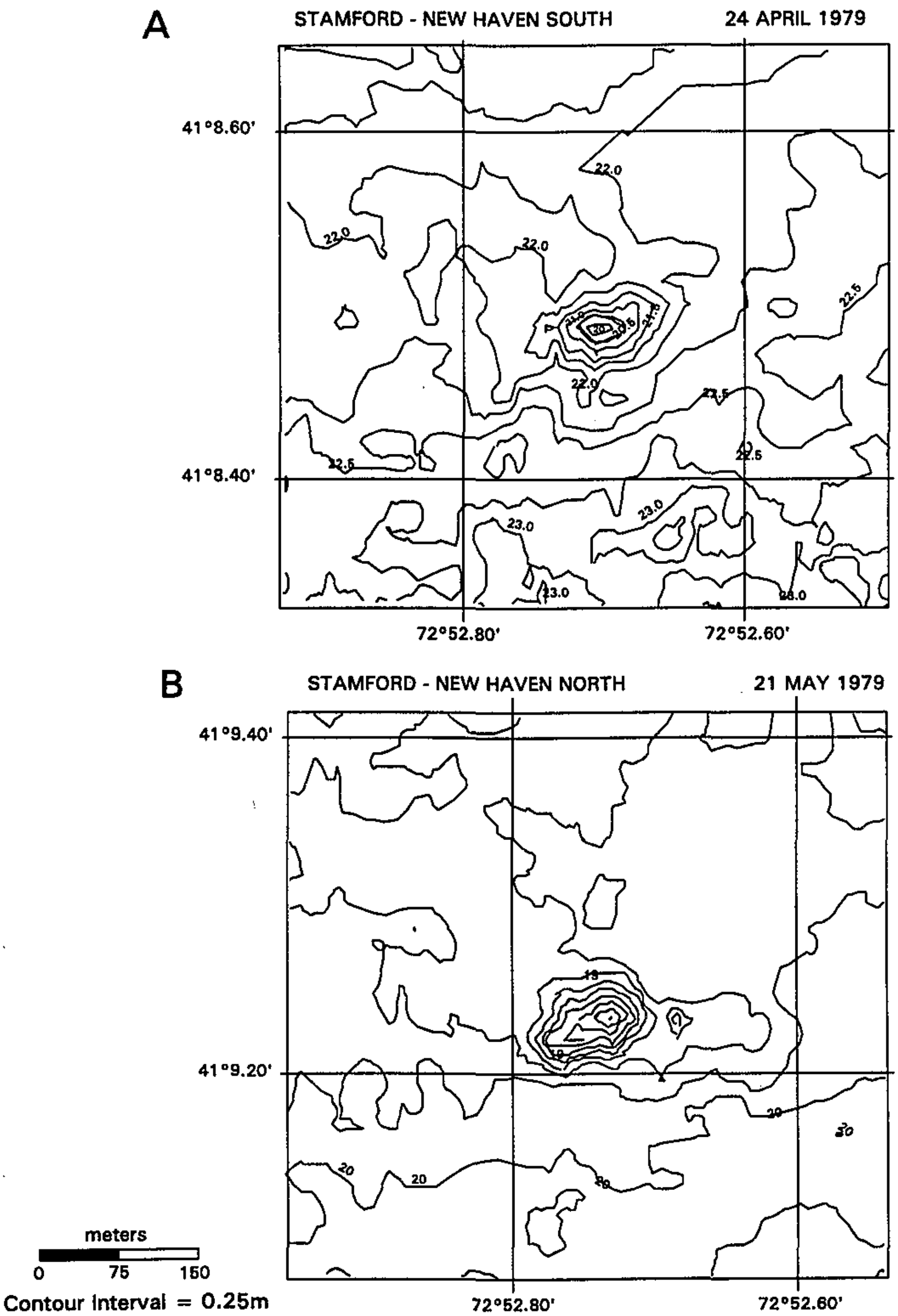


Figure 3-1. Bathymetry of (A) STNH-S and (B) STNH-N following deposition of Stamford (mound) material

calculated volume of Stamford material at STNH-S to within approximately 95% of the barge estimate (Morton 1980a).

Comparisons showed material losses of both cap and mound at the southern site ranging from 3 to 5%, with the majority of in-place material residing in the well-defined capped deposit (Morton 1983b). Given the resolution of the acoustic system and the errors inherent in disposal barge volume estimates (Tavolaro 1984), the overall agreement between the bathymetric data and the disposal barge logs must be considered excellent. The indicated losses are similar to those previously reported (Gordon 1974, Bohlen 1978) and suggest limited far-field dispersion of sediments and associated contaminants during disposal.

Volume calculations based on depth differences of New Haven material at STNH resulted in subsequent placement of 33,000 m^3 of sand over STNH-N and 72,000 m^3 of silt over STNH-S. Comparisons at the northern site were complicated by the high water content of the sands induced by the hydraulic dredge. The bathymetric surveys showed minimal lateral spreading of the initial capped deposits (Figure 3-2). The major changes in dimensions induced by capping were confined to the vertical. Both deposits were well-covered with cap material: cap thicknesses ranging from approximately 3.5 m on STNH-N to more than 4.5 m over STNH-S after capping operations in spring-summer 1979 (Figure 3-2 and 3-3; Morton 1983b).

The STNH project also showed that coarser grained material could be placed over finer grained deposits without significant displacement and/or dispersion of the finer material. Comparisons of pre- and postcapping bathymetric contours indicated that major changes were confined to the buoy locations. Spreading of the flanks was more pronounced at STNH-N, but diver observations showed this to be primarily the result of sand movement rather than dispersed silt-clays (Figure 3-2; Morton and Karp 1980, Morton 1983b). The upper surface of the central part of STNH-N consisted primarily of New Haven material, and vertical overturning or mixing during cap placement appeared to be minimal from diver observations. This was later confirmed by visual and chemical analyses of coring investigations (Section 4.0).

The later addition of New Haven capping material ($\sim$110,000 m^3) in the spring of 1980 (Table 2-4) was followed by a bathymetric survey in June 1980. Much of this material was disposed at the center of STNH-S to cover a small, secondary volume (6,000 m^3) of Stamford material deposited on the 72,000 m^3 cap. However, 34 barge loads were disposed at specific LORAN-C points to thicken the cap south and west of the buoy (SAI 1980b). Comparison of the June 1980 bathymetric survey to the prior survey in November does not reveal a large increase in the overall height of STNH-S. However, the June profile does reflect a wider distribution of material, especially to the west where a new pile was detected (Figure 3-4).

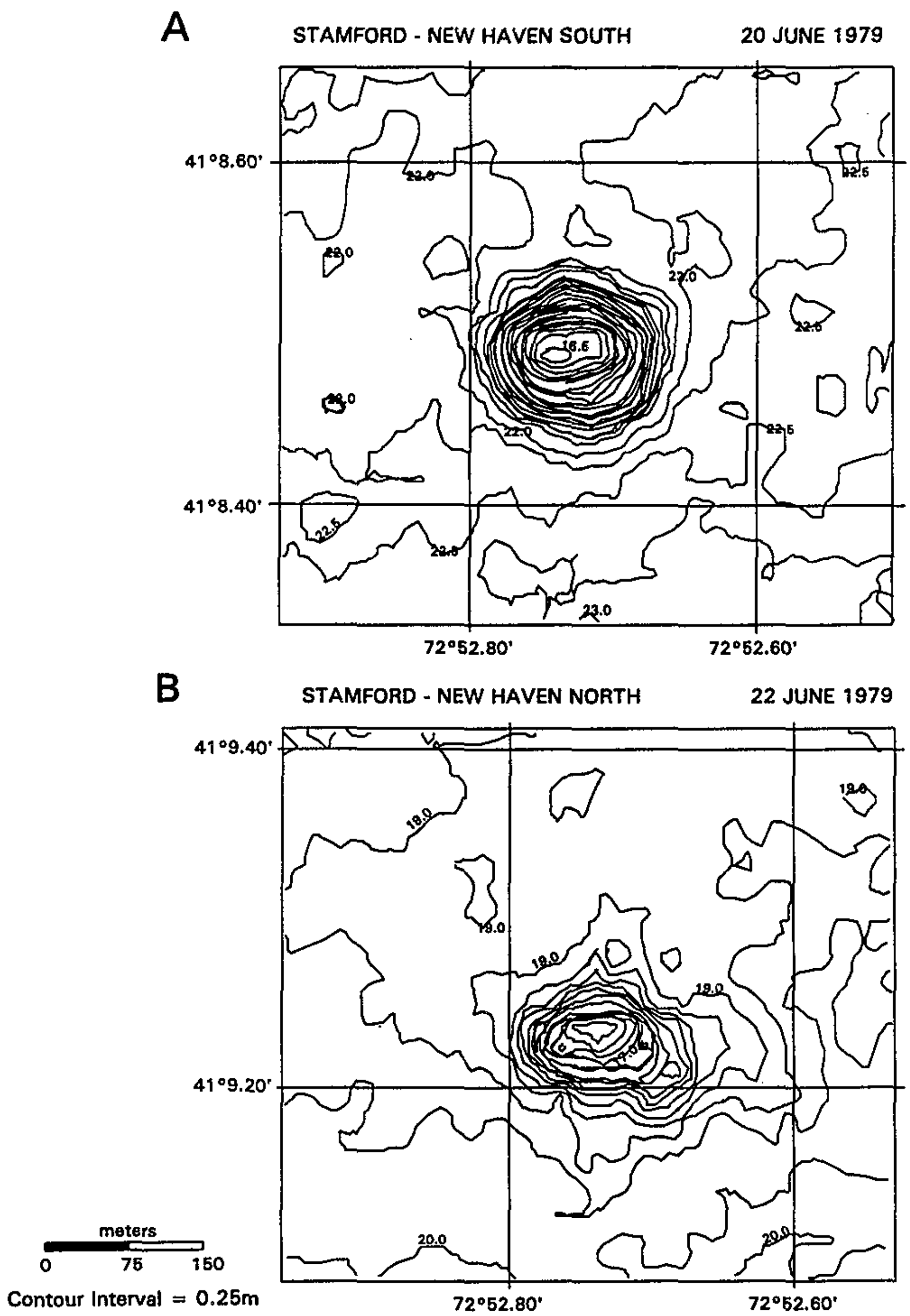


Figure 3-2. Bathymetry of (A) STNH-S and (B) STNH-N following deposition of New Haven (cap) material

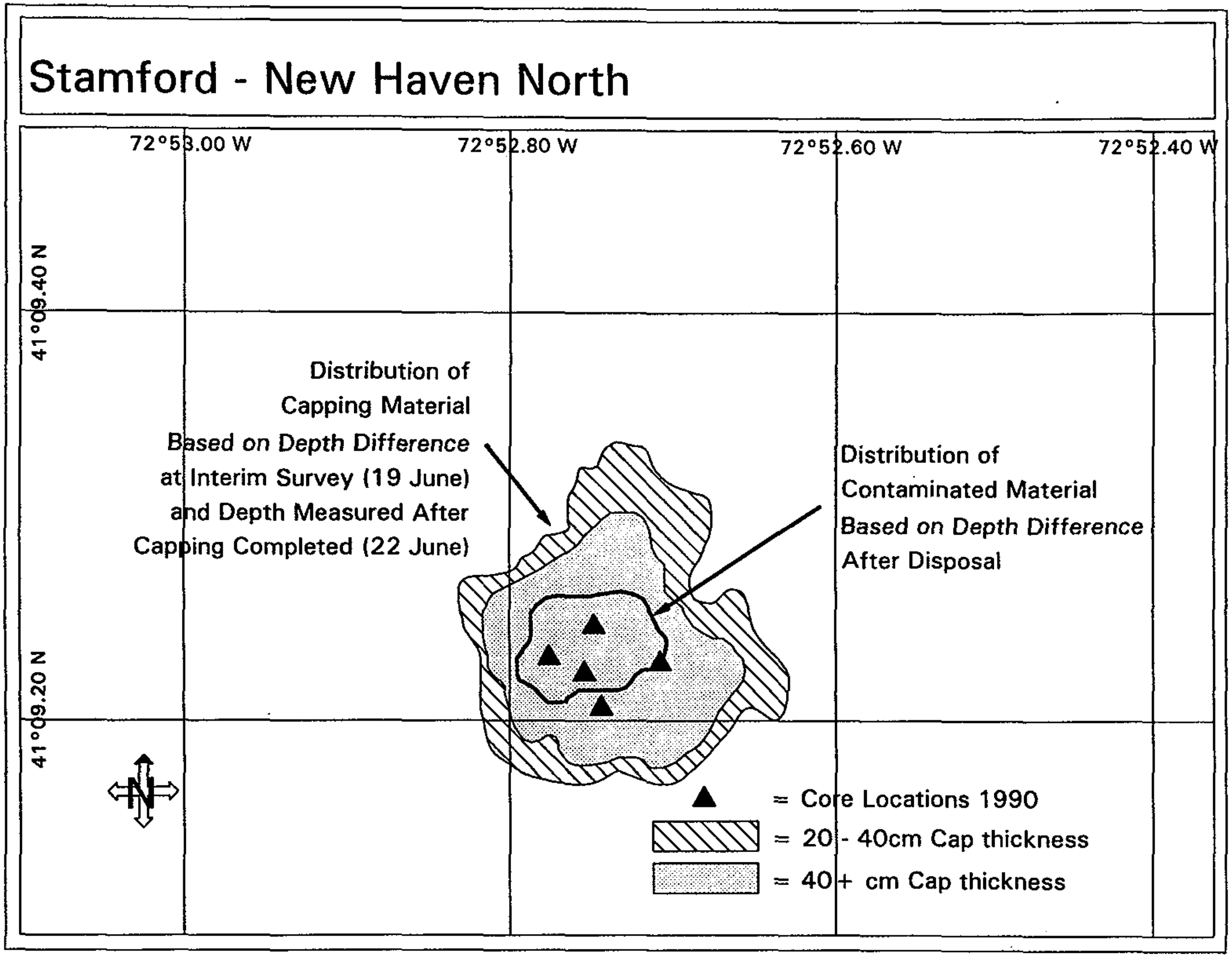


Figure 3-3. Distribution of dredged material at STNH-N (adapted from Fredette et al. 1992)

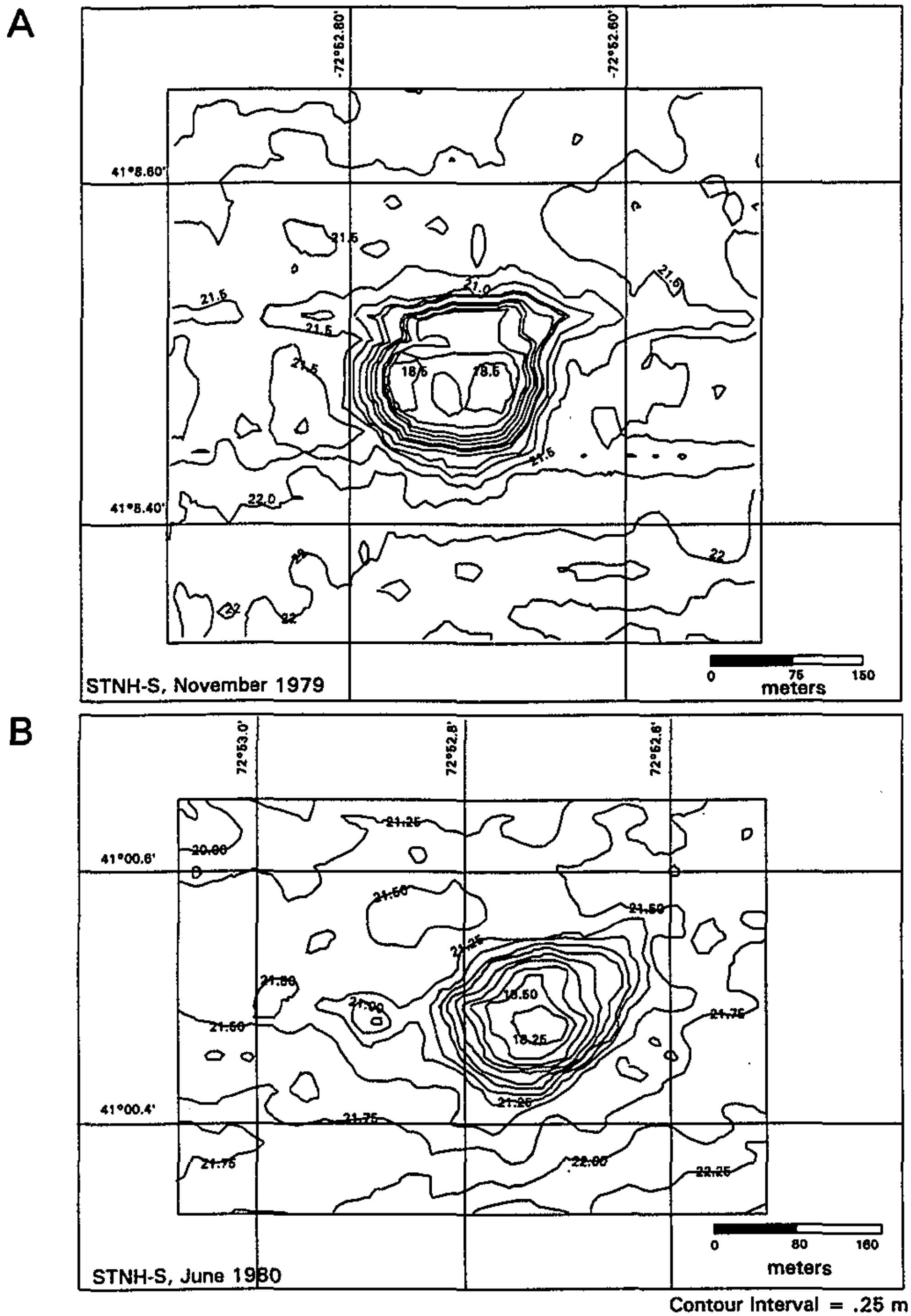


Figure 3-4. Bathymetric profiles of Stamford-New Haven South following deposition of (A) Stamford material, fall 1979 and (B) New Haven material, spring 1980

The initial combination of bathymetric and SCUBA diver observations indicated that the STNH capping exercise was an operational success. Formation of a discrete mound and cap was proved to be feasible under controlled conditions. Physical monitoring next approached the problem of the stability of capped mounds.

3.1.3 Long-Term Cap Stability: Consolidation vs. Erosion

The passage of Hurricane David in September 1979 provided an opportunity to document the response of the relatively new STNH capped mounds to storm-associated disturbance. Reviews of the bathymetric profiles obtained in November 1979 indicated a significant change in the contours of STNH-S and the apparent loss of approximately 10,000 m^3 of volume (Figure 3-2A and 3-4A). Although located in shallower water, STNH-N displayed contours essentially similar to those measured in the June 1979 and August 1979 bathymetric surveys (Morton 1980a).

Earlier studies of the factors responsible for the observed volume losses at STNH-S concluded that the most probable cause was erosion due to increased boundary shear stress associated with the storm-induced surface wave-field. It was postulated that the effects were more pronounced at STNH-S because of a substantial difference in boundary roughness, the northern sand cap being significantly smoother than the southern silt-clay cap (Morton and Karp 1980). Geotechnical factors potentially associated with mound stability, including water content and pore pressure characteristics, were not measured at the time. As a result, it was not possible to evaluate whether the observed volume loss was the result of erosion, rapid consolidation, or slumping.

A recent modeling study by Poindexter-Rollings (1990) may shed some light on the apparent loss of material from STNH-S. Her study used results of geotechnical measurements of dredged material to predict consolidation of capped and uncapped mounds. The model predictions compared favorably with measured change in bathymetric height over time (Figure 3-5). These results suggested that the apparent loss of material at STNH-S between August and November 1979 may represent rapid consolidation (Figure 3-5B) rather than effects of the hurricane. However, the initial consolidation should have begun, according to her results, before the August 1979 bathymetric survey. The addition of 110,000 m^3 of cap material to STNH-S in the spring of 1980 was not included as part of her work; therefore the settlement curve for STNH-S predicts more rapid consolidation than actually occurred (Figure 3-5B).

Poindexter-Rollings (1990) used a one-dimensional finite strain consolidation model (MOUND) to predict consolidation. The inputs to this model were based on parameters derived from laboratory measurements, reported disposal volumes, and bathymetric surveys. She acknowledged that clamshell dredging does not necessarily change the properties of

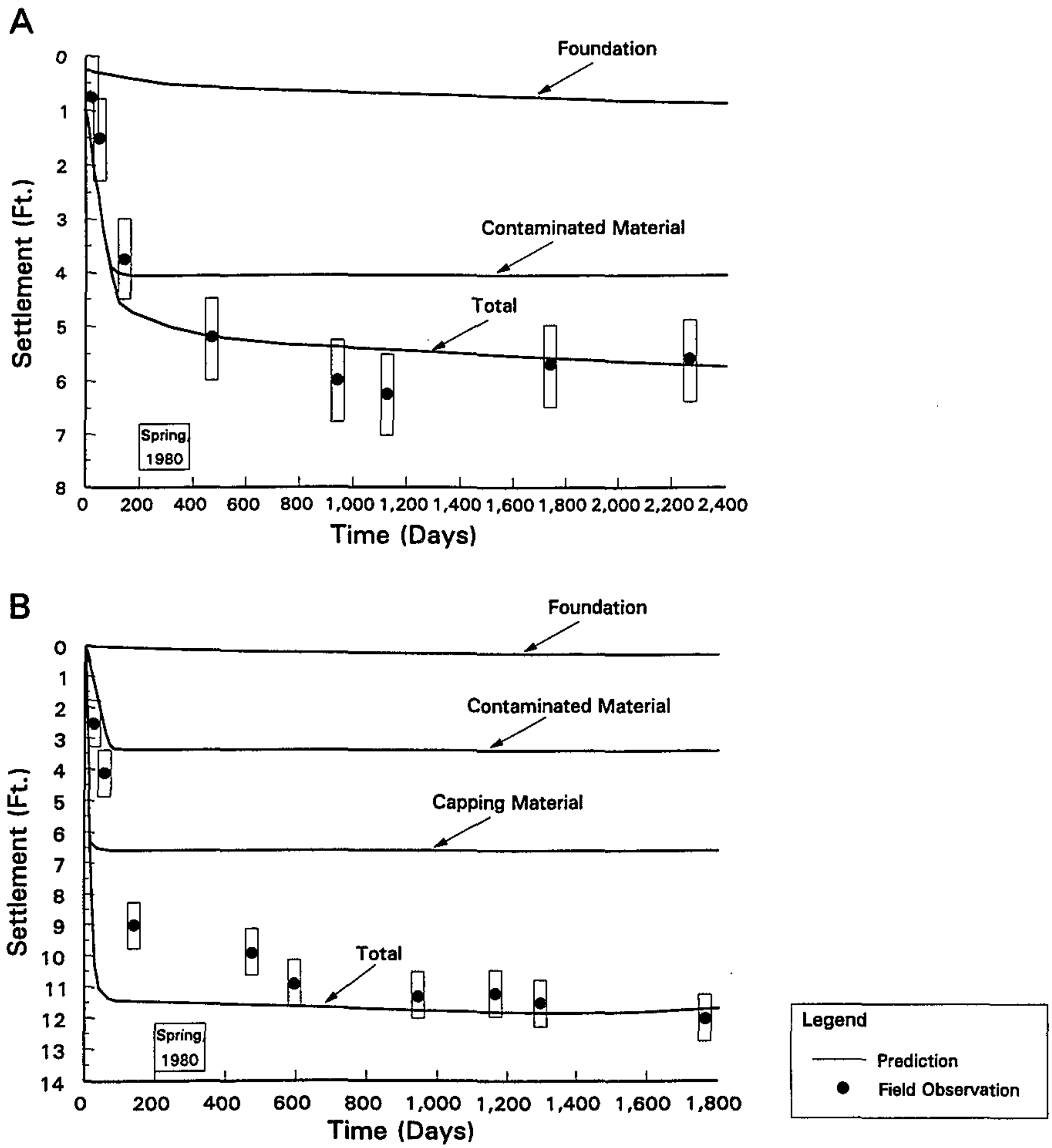


Figure 3-5. Time-rate consolidation curves at center of (A) STNH-N and (B) STNH-S (adapted from Poindexter-Rollings 1990)

dredged material (e.g., void ratios and water content). However, one of the initial conditions of the model was that the mounds were formed of slurried sediment. This initial condition may not be valid in many circumstances, thereby exaggerating the rate of consolidation.

Silva et al. (1991) collected core material for geotechnical analyses and also modeled his results. Due to limitations of the MOUND model (it is not as accurate for multilayer situations), they compared the results using both the MOUND model and the CONSOL model (Wong and Duncan 1984). They calculated 0.74 and 2.5 m of consolidation at STNH-N and STNH-S, respectively. Compared to "actual" bathymetric changes near the center of each capped mound, these estimates of consolidation account for approximately 75% of the observed change. More importantly, consolidation using the CONSOL model showed a substantial consolidation of the basement, or ambient bottom, as well as the mound material.

Both studies concluded that a large percentage of the apparent loss of material at STNH-S after Hurricane David could be due to geotechnical compression. Both predicted an increased consolidation at STNH-S, in part due to the higher water content of the silt cap material. In addition, both models predicted that consolidation should occur rapidly after the initial formation of a capped mound.

Over the past 14 years, monitoring surveys have been conducted often, with additional cruises after selected storm events (Appendix C). The results of these surveys indicated that, despite the passage of several significant storms with characteristic energy levels equivalent to or in excess of Hurricane David (e.g., Hurricane Gloria in 1985), contours at both STNH-N and STNH-S remained essentially similar to those observed in 1980 (e.g., SAIC 1989, 1990a).

Given the resolution of the acoustic systems, the similarity in sequential bathymetric contour plots suggested that total transport to date has resulted in less than 10 to 20 cm of erosion from the caps. Higher resolution observations provided by REMOTS® analysis supported this conclusion, showing that sediment erosion during Hurricane Gloria was limited to between 0.2 and 2 cm (SAIC 1989, Fredette et al. 1988). The data indicated that the capped mounds were quite stable over a period of years. This longer term record supported the suggestion that the initial change observed at STNH-S was a function of the age of the deposit and possibly the associated degree of consolidation (Fredette et al. 1988).

3.1.4 Physical Monitoring: Conclusions

Acoustic and direct and indirect visual methods have shown that

- Contaminated sediments have been effectively covered by cap sediments, with no evidence of appreciable mixing or displacement.

- Capped mounds have remained in stable configurations for up to 14 years.

- Geotechnical modeling suggested that consolidation occurs rapidly upon completion of disposal.

- The similarity of bathymetric contours over the decade suggests that erosion is minimal.

- No evidence indicates that the cap has been physically breached by storms, strong bottom currents, or any anthropogenic influence such as bottom trawlers.

- Qualitatively, the data favor scheduling disposal operations during the late winter-early spring period to permit as much consolidation and surface stabilization as possible prior to the onset of the fall hurricane season.

3.2 Biological Characteristics

From an environmental management standpoint, the primary purpose of capping is to isolate dredged material contaminants from the biological communities found in and around open-water disposal sites. These contaminants have the potential to affect local biota adversely and, through food chain transfer, the larger environment and potentially the human population. The response of biological communities to capped mounds should be considered of primary importance in any evaluation of capping programs. To date, there have been no clear indications of biological disturbance from capped mounds after re-establishment of a benthic community on the freshly deposited material. One possible exception to these conclusions occurred at MQR and will be discussed below.

3.2.1 Early Monitoring Approaches

Since the initiation of dredged material disposal monitoring in Long Island Sound in the early 1970s, all field surveys have included components detailing selected characteristics of the biological community resident on and adjacent to the capped disposal mounds. Initial surveys examined both water column and benthic components, with primary emphasis placed on the benthic infaunal community (Morton and Karp 1980).

In benthic studies conducted from 1980 to 1983, grab samples of the surface sediments were obtained with a 0.1 m^2 Smith-McIntyre sampler and sieved through 1.0 mm sieves. Macrofauna were sorted, identified, and counted to obtain measures of community structure (Brooks 1983). Most of the variability observed within the benthic data appeared to be related to the combination of disturbance (Rhoads et al. 1978) and variations in sediment grain size (Brooks 1983). Temporal and/or spatial variations in population characteristics could not be associated simply with sediment chemistry. Trace element and volatile solids concentrations measured at the center of STNH-N and STNH-S were approximately equal to or less than those measured at the reference stations (Section 3.3.2; Brooks 1983). Species abundance and numerical abundance were also higher at STNH-N than at the reference station, probably reflecting the dramatic shift in grain size from the siltier material at the reference area to the predominantly sand cap.

In addition to direct benthic sampling, in 1980-81 caged mussels (*Mytilus edulis*) were deployed on bottom-mounted racks at STNH-N and STNH-S deposits, at NOR, and at a reference area to monitor bioaccumulation associated with solute and particulate transport. Bags of mussels, located approximately 1 m above the sediment-water interface, were periodically sampled by divers and returned to the laboratory for analysis of tissue concentrations of selected trace elements and organic contaminants (Feng 1982). Plots of the measured tissue concentrations over time showed strong seasonal patterns (Figure 3-6).

The year-long caged mussel data set (April 1980 - June 1981) had strong temporal variability in tissue contaminant concentrations. This variability was closely correlated with water temperature, nutritional and reproductive state, and season. The highest levels were found in winter when the wet/dry tissue ratios and suspended sediment concentrations were highest. The variations associated with these factors were orders of magnitude larger than any that could be assigned to dredged material disposal (Feng 1982). Similar results have been obtained from mussel cages deployed at active dredged material disposal sites in eastern Long Island Sound (Arimoto and Feng 1983). The lack of a clear correlation between contaminant body burdens and active disposal supports the conclusion that any "signal" of suspended contaminants due to erosion from the capped mounds would be lost in the general background "noise" of suspended contaminants within the Sound (Feng 1982).

These results are not surprising given the affinity of metal and organic contaminants for sediments. Because contaminants are so strongly bound to sediments, it is very unlikely that the suspended contaminant signal in Long Island Sound would be even weakly influenced by contaminants eroded from the capped mound surface. If surface sediments from the capped mound are resuspended, the sediments in the area surrounding the mound will also be resuspended, and the signal will be lost in the noise of the ambient sediment cloud. This is particularly true when the measured contaminants have been integrated over long time periods by tissue uptake and depuration. Although the program of mussel deployments was ended for these reasons, this "negative" evidence is important and useful from the viewpoint of environmental management because it placed boundaries on the scale of possible effects (SAIC 1989).

Analyses of data sets from both the benthic community and caged mussel experiments showed no significant signals that could be related to the presence of capped mounds. The lack of a detectable signal, either from water column

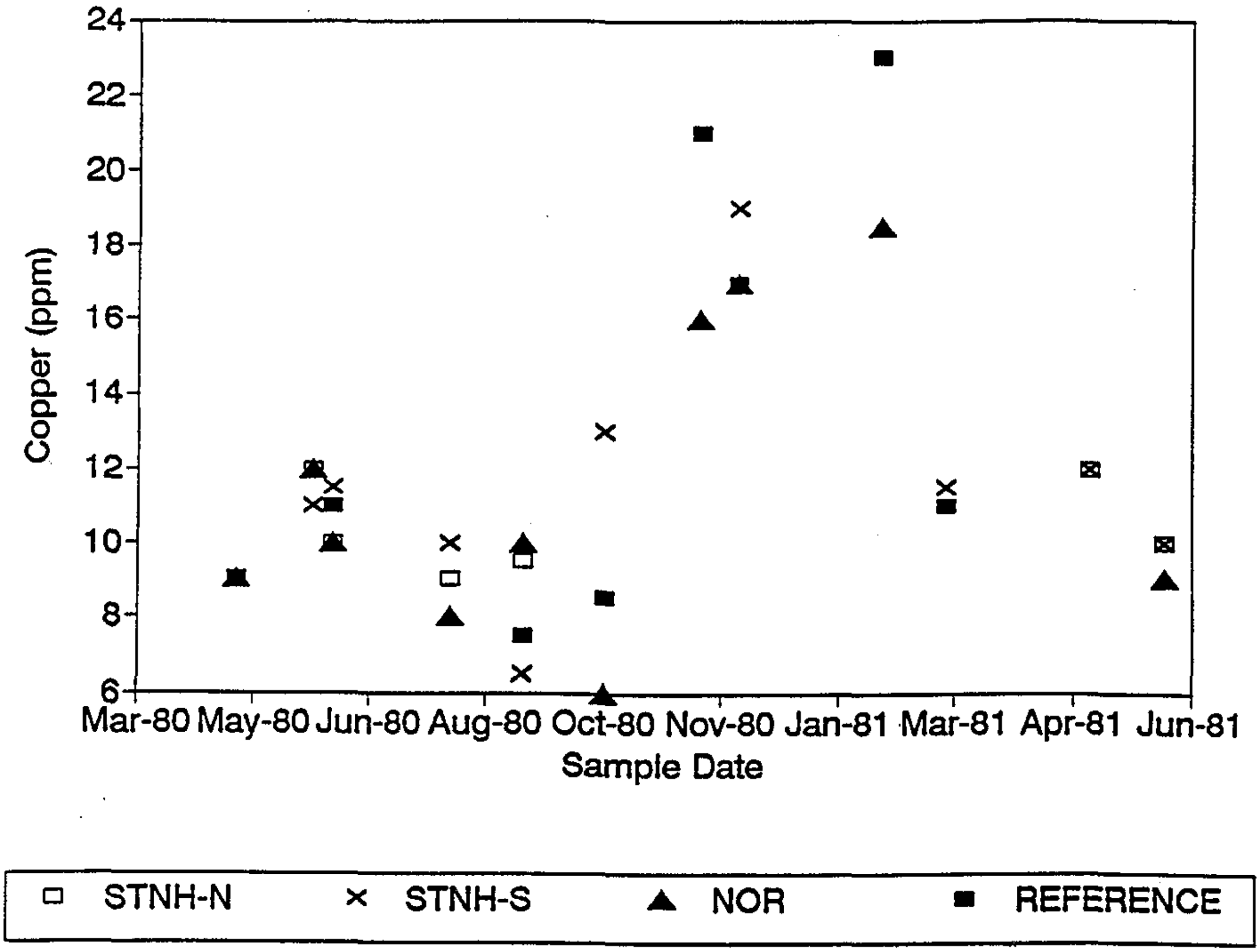


Figure 3-6. Temporal variations of Cu (dry weight) concentrations in *Mytilus edulis* maintained at Stamford-New Haven North and South, Norwalk, and the reference site

contamination or from nonspecific forms of environmental degradation, does not prove that the capping operations successfully contained all of the contaminants. However, it is clear from these data that any undetected release did not have immediate or widespread consequences to the benthic community structure or significantly accumulate in the tissues of suspension-feeders tethered near the bottom.

Subsequent biological samplings of the capped disposal mounds have included benthic grabs on an intermittent basis for community analysis and bioaccumulation (SAIC 1989). The primary emphasis has been placed on recolonization characteristics as monitored through the use of REMOTS® technology. The disposal of dredged material capped with natural sediments is analogous to the burial of a section of the community by a layer of new habitat. By following the processes associated with recolonization (bioturbation, oxygenation, succession), it is possible to glimpse an integrated picture of the biological response to disposal. This picture may lack specifics of contaminant bioaccumulation but, unlike the mussel data, can contain important clues to the processes affecting the response of the community. Most importantly, effective management of capped mounds requires timely information on the relative health of the biological communities developing at the surface. Only with rapid, predictive monitoring techniques can remedial actions be applied efficiently if capping operations are not successful.

3.2.2 Sediment Profile Imaging

Since 1982, the REMOTS® sediment-profile camera has been included routinely in DAMOS surveys of the CLIS capped disposal mounds (Appendix C). In addition to physical-chemical evaluations such as grain size and surface boundary roughness estimates, REMOTS® photographs provide a visual indication of the successional status of the benthic community, allowing an assessment of the recolonization rates of dredged material deposits. The most commonly documented successional stages in the DAMOS Program are Stage I (very small polychaetes and amphipods) and Stage III (larger burrowing macrofauna).

Evaluations of infaunal successional stages are combined with measured physical parameters (e.g., the redox state, presence of methane gas in the sediment, etc.) to develop a quantitative measure, or index, of disturbance or "stress." This calculated Organism-Sediment Index (OSI) is believed to provide a sensitive indicator of the response of the benthic community to a variety of stresses, including exposure to contaminated sediment (Rhoads and Germano 1986).

REMOTS® observations can be used to document the long-term biotic health of a capped mound. One of the advantages of reviewing the historical DAMOS data is that the applicability of environmental monitoring approaches can be appraised. For example, time-series plots of OSI values at the CLIS mounds and the CLIS reference station show strikingly clear trends in benthic stress and recolonization patterns.

REMOTS® data were not incorporated into the DAMOS Program until approximately three years after the completion of STNH-S disposal operations. The 1983 REMOTS® survey at that station indicated that most of the surface area was dominated by Stage I species, with Stage III species appearing only occasionally. Associated habitat indices generally showed conditions favoring continuing colonization (Figure 3-7). By 1986, the area dominated by Stage I organisms had been reduced slightly, and the abundance of Stage III species had increased. The OSI distribution showed a similar increase (Figure 3-7). This trend continued into 1987, with surveys showing an increased dominance of Stage III organisms and increasing organism-sediment indices.

This progressive recolonization response appears to indicate long-term environmental stability without any indication of substantial sediment-associated toxicity and morbidity. In light of the bioassay results indicating that exposure to the Stamford material would result in finite mortality in the benthic community (Moore 1978), the observed trend suggests that the cap of New Haven silts was effective in isolating local biota from the sediment contaminants associated with the Stamford material.

3.2.3 A Case Study: MQR and the FVP

Monitoring results from MQR have indicated slower biological recolonization rates after disposal relative to other CLIS capped mounds, the uncapped FVP mound, and the CLIS reference area. These monitoring data have included REMOTS® photographs (most recently, summer surveys in 1991 and 1992), sediment sampling and chemical analyses, and bioassay studies. The complicated disposal history at MQR, in tandem with the unusual monitoring results gathered since disposal completion, prompted more intensive investigation of MQR following the tiered monitoring protocols initiated by NED to manage dredged material disposal mounds (Germano et al. 1994).

A survey of this area in 1983 following deposition of both Mill and Quinnipiac River sediments showed benthic conditions to be essentially identical to those existing at STNH-S, as discussed above (Figure 3-8). Stage I organisms dominated the surface, and OSI values ranged between 4 and 11. Following this survey, Black Rock sediment was placed at MQR and then capped with a large volume (400,000 m^3) of New Haven Harbor silts (Table 2-4). However, as mentioned above, the depositional history of Black Rock and New Haven material was complicated by the approximately 3,000 m^3 of Black Rock Harbor material deposited after the cap material was in place (Figure 2-8).

REMOTS® surveys as late as 1986 continued to show a dominance of Stage I

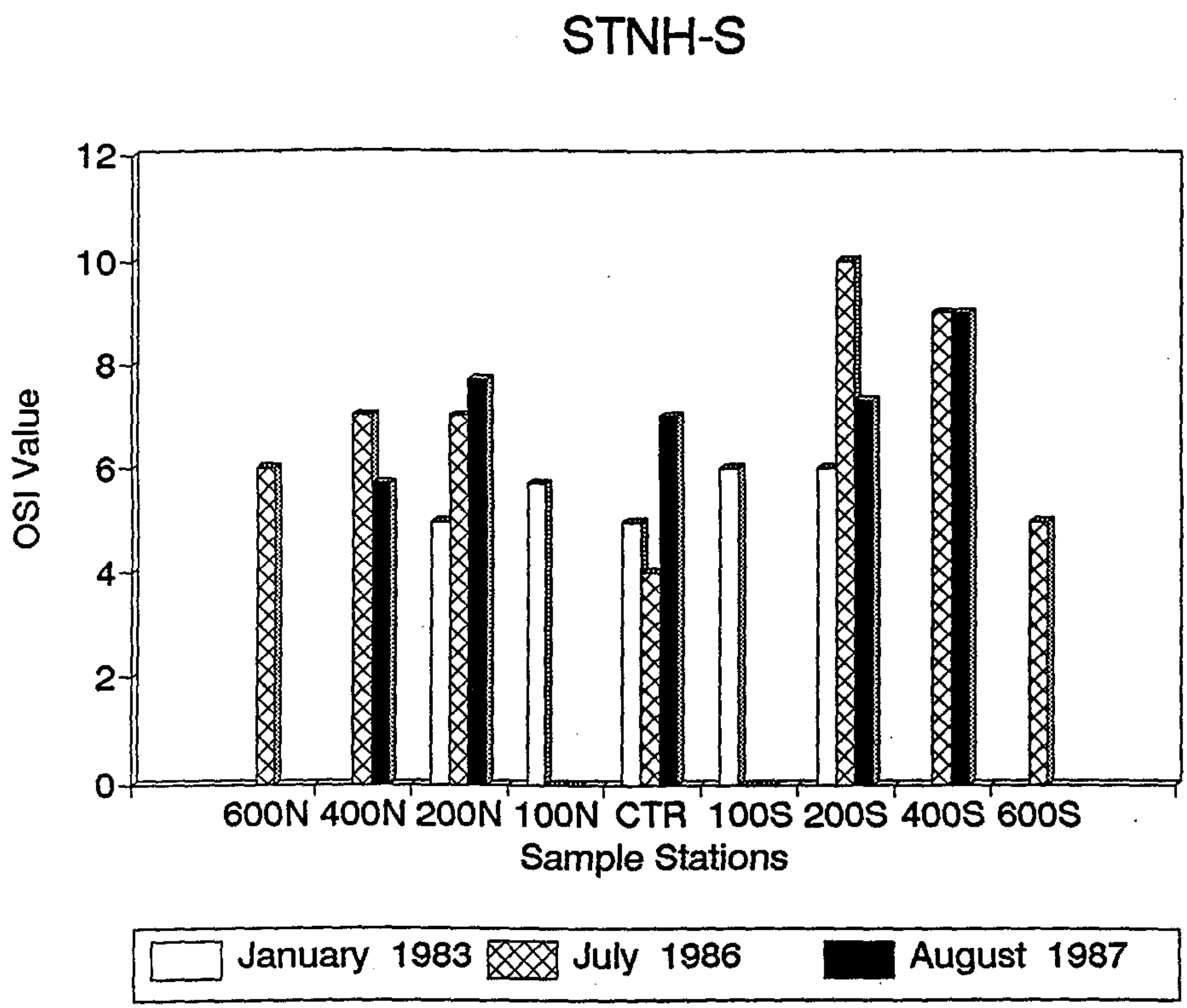


Figure 3-7. The evolution of Organism-Sediment Indices (OSI) at Stamford-New Haven South

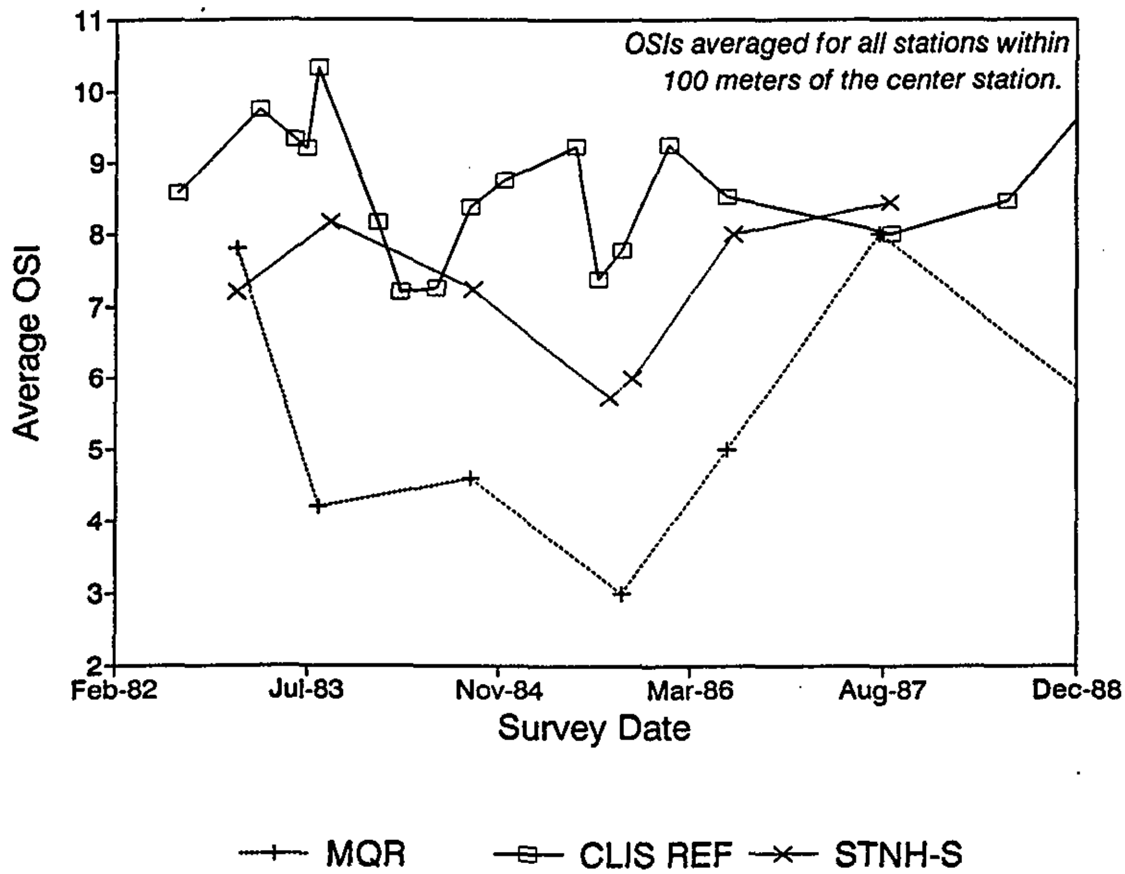


Figure 3-8. Time-series summary of OSI values at STNH-S and MQR as compared to the CLIS reference station

species on the three-year-old cap, with OSI values ranging between 2 and 9 (Figure 3-8). Hurricane Gloria had an impact on biological communities at CLIS (especially FVP). By the 1987 survey, Stage I organisms still dominated, with Stage III beginning to appear at depth. Associated OSI values increased slightly but remained lower than those found concurrently at Cap Sites 1 and 2, formed at the same time and with the same material as MQR (Figure 3-8; SAIC 1990a,b). After the 1987 survey, benthic conditions at MQR again regressed, as will be discussed in more detail below.

The cause of the evident differences in recolonization rates at MQR was not clear. Because these differences were not apparent prior to the disposal of the Black Rock/New Haven material, it seems likely that the recolonization difficulties were related to this disposal operation. Seasonal hypoxic events in Central Long Island Sound may also have contributed to the slow recovery of MQR (SAIC 1989).

Black Rock material was also disposed at the experimental Field Verification Program mound (FVP) during the spring of 1983. This mound was left uncapped for comparison to the capped mound projects. The apparently healthy response of the uncapped FVP mound in comparison to MQR is particularly interesting. REMOTS® surveys conducted prior to disposal at the FVP location in August 1982 showed OSI values between 9 and 11, suggesting conditions essentially similar to those at the established FVP reference area (Figure 3-9). The placement of the Black Rock sediments in May-June 1983 significantly reduced the mean OSI value for the FVP stations in the postdisposal June 1983 REMOTS® survey, consistent with the anoxic, nearly azoic nature of these sediments (Johnson et al. 1981). REMOTS® surveys from July 1983 to December 1984 showed a gradual and significant increase in mean OSI values for the aggregate of stations; values approached those observed during the predisposal survey for both the pooled reference and FVP stations (Figure 3-9).

Relatively healthy benthic conditions continued, as indicated by later REMOTS® surveys of FVP. August 1987 OSI values at FVP stations ranged from 7.3 to 10, with the exception of the center station, which had an OSI value as low as 4.7. Reference station OSI values were only slightly higher, ranging from 8 to 11. Successional stages at FVP were dominated by Stage III organisms; Stage I organisms, although present, were clearly secondary in concentration. These latter conditions were essentially similar to those observed at the STNH capped mounds, despite the evident differences in deposit age, and suggested that habitat quality at the FVP deposit, an uncapped mound, was generally better than that at MQR. Sediment chemistry results for FVP sediments are within the lower contaminant range of Black Rock material (Section 3.3). Diver observations, core descriptions, and geotechnical measurements (see below) indicated that the surface material at FVP was coarse black silt with much higher density than typical Black Rock material.

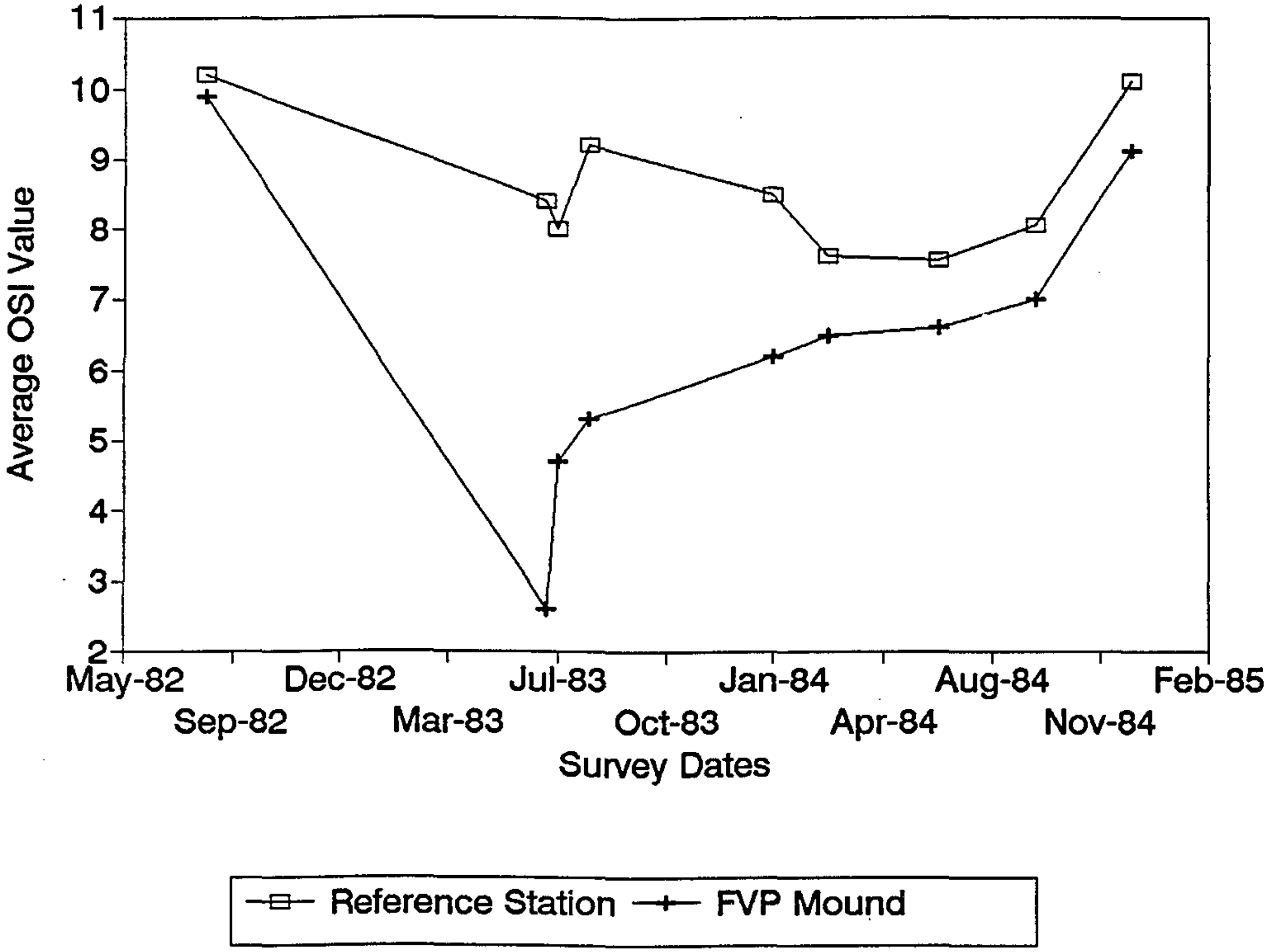


Figure 3-9. Mean Organism-Sediment Indices (OSI) calculated for FVP mound stations and CLIS reference stations from August 1982 (predisposal) to December 1984

The 1987 REMOTS® surveys of MQR and FVP indicated that both mounds had recovered from the effects of Hurricane Gloria and were resuming normal recolonization (Figure 3-10). More recently, a 1991 reconnaissance survey of older capped mounds showed that benthic recolonization at MQR had again regressed since the 1987 sampling, even relative to FVP. The median OSIs were significantly lower than the three reference stations. The June 1991 monitoring survey results triggered a management response according to the tiered approach (Germano et al. 1994). An amphipod bioassay was conducted to test the toxicity potential of the MQR sediments. Percent survival rates for amphipods exposed to MQR sediments ranged from 10 to 45%, as compared with control station survival rates from 75 to 100% (Murray 1992).

Sediment chemistry and coring results have subsequently shown that capping material at MQR contained organic contaminants in relatively high concentrations and could have contributed to the slow recolonization following disposal of the Black Rock/New Haven Harbor sediments (Section 3.3.3). However, the drastic drop in benthic conditions as measured by REMOTS® parameters in the 1991 survey was probably caused by physical disturbance. The combination of poor capping material at MQR and potential episodes of physical disturbance has forced management action. Although a subsequent REMOTS® survey in the summer of 1992 indicated improving benthic conditions, amphipod bioassay and sediment chemistry results were used to recommend recapping according to tiered monitoring protocols (Germano et al. 1994).

3.2.4 Bioaccumulation

Although the REMOTS® surveys provide a rapid evaluation of recolonization and biological activities, they cannot be used to measure contaminant levels in sediments or organisms. When used in a tiered monitoring approach, the results of REMOTS® analysis might trigger direct investigations of sediment chemistry or bioaccumulation (Germano et al. 1994). For instance, if a survey indicated that a previously healthy surface had areas devoid of macrofauna, the first step would be to look for evidence of physical disturbance (erosion, trawling). If this was not the case, one tiered approach would be to collect vertical cores to look for contaminant migration from the mound and conduct bioassays on the sediments. If contaminants and toxicity were found in surface sediments, bioaccumulation studies could help determine if surrounding communities were affected. Because the preponderance of biological and chemical evidence has indicated that capped mounds are recolonized quickly and have moderate to low levels of contaminants in the surface sediments, there were few instances where bioaccumulation was measured.

At present, only one monitoring cruise in August 1986 has been completed where body burden concentrations have been established for *Nephtys incisa* (Stage III

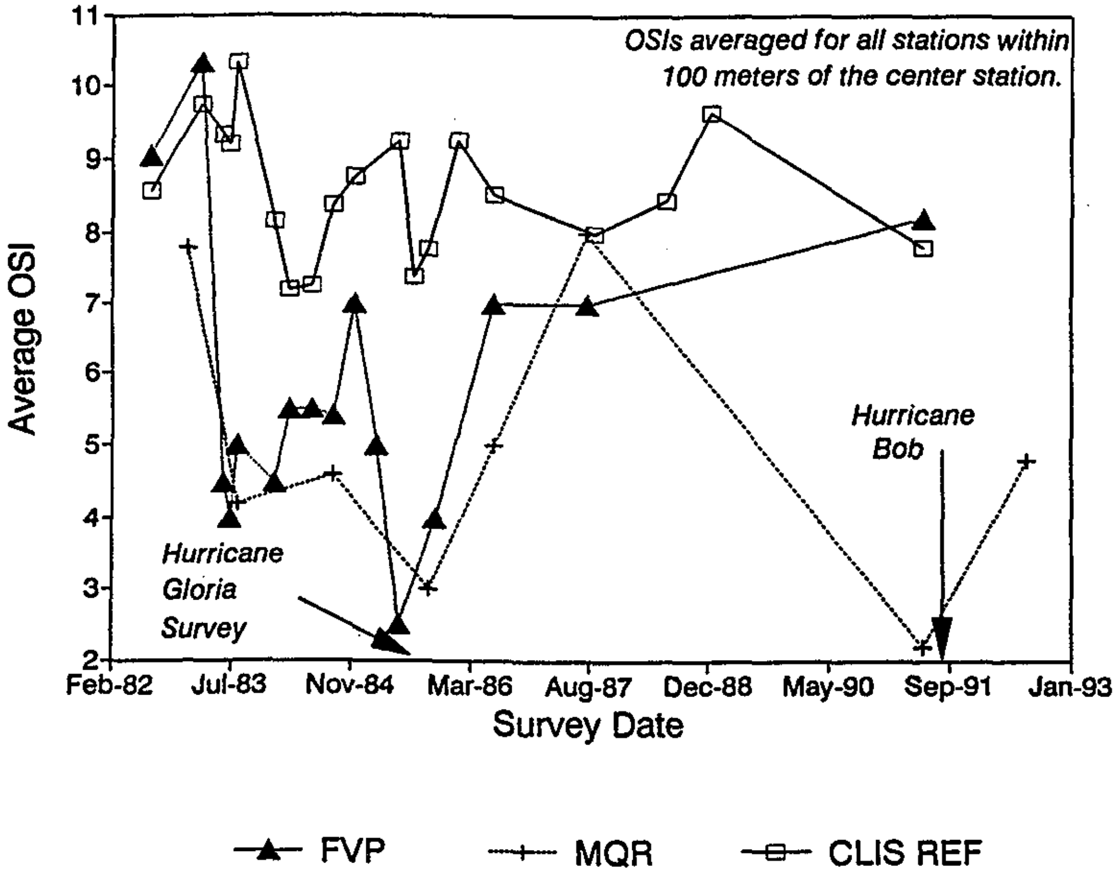


Figure 3-10. Average OSI values measured at FVP, MQR, and the CLIS reference station from 1982 to the present

species) collected at capped mounds (Table 3-1). At MQR and FVP, Cr and Cu levels were elevated above reference values both in surface sediments and in the tissue of the polychaetes. These results suggested some correlation between sediment contaminant levels and bioaccumulation. The similarity between sediment and body burden values for MQR and FVP also suggested that inorganic contaminants were not responsible for the observed slow recolonization rates at MQR (SAIC 1990a). These values are comparable to results from other body burden analyses from the former CLIS reference station and FVP (Munns et al. 1989).

In contrast, elevated concentrations of Cr, Cu, and Zn in *Nephtys* at STNH-N did not correspond with elevated sediment levels of these three metals. All other evidence has suggested that the sand cap at STNH-N has been effective in physically isolating or diluting the metal concentrations in the surface sediments (Fredette et al. 1992). It is important to note that the metal levels measured in these worms are still low relative to results from urban estuaries in the United States and Europe (Reish et al. 1981, Long and Morgan 1990). The data are clearly not adequate to make conclusive statements regarding the sources of contaminants measured in biological communities collected from capped dredged material mounds.

Experiments on bioaccumulation of contaminants in Stage I organisms (very small polychaetes and amphipods) would facilitate interpretation of anomalous recolonization responses. If a capped mound is apparently unhealthy, it may be very difficult to collect sufficient quantities of Stage III species to conduct the analyses. Successful measurement of contaminant body burdens in Stage I species would help determine whether or not an apparently normal recolonization rate and a dense Stage I community are synonymous with acceptable environmental quality. Techniques are in development for improving efficiency of collection of Stage I organisms for conducting such experiments (Rhoads et al. 1994).

3.2.5 Biological Monitoring: Conclusions

The methods of biological monitoring have varied since the conception of DAMOS. Since 1982, biological monitoring has emphasized REMOTS® technology. All methods have confirmed and expanded on many of the physical monitoring results:

- No data from the early biological monitoring approaches (caged mussels, body burden analyses) suggested that contaminant signals were related to the capped mounds.
- REMOTS® data have allowed the quantification of recolonization rates and the overall biotic health of a capped mound.
- Monitoring at MQR included initial REMOTS® studies followed by bioassay analyses, and this "response" monitoring was

Table 3-1

Trace Metals in Body Tissues of *Nephtys* Collected at CLIS, August 1986

	(μg/g wet weight)							
Station	As	Cd	Cr	Cu	Fe	Hg	Pb	Zn
Reference 1	4.0	0.14	0.03	2.6	99	0.02	0.58	26
Reference 2	3.8	0.18	0.05	3.5	124	0.01	0.63	32
Reference 3	2.9	0.09	0.03	2.7	91	0.04	0.49	26
Mean	3.6	0.14	0.04	2.9	105	0.02	0.07	28
±STD	0.6	0.05	0.01	0.5	17	0.02	0.07	3
STNH-N 1	0.10	0.19	0.1	4.0	54	0.02	0.22	38
STNH-N 2	0.11	0.14	0.08	3.3	51	0.05	0.18	30
STNH-N 3	0.12	0.17	0.09	3.8	67	0.03	0.21	35
Mean	0.11	0.17	0.09	3.8	67	0.03	0.21	35
±STD	0.01	0.03	0.01	0.4	28	0.02	0.03	4
FVP 1	2.6	0.12	0.08	6.4	50	0.02	1.2	27
FVP 2	2.9	0.14	0.14	8.2	72	0.02	1.4	29
FVP 3	2.8	0.14	0.35	7.0	99	0.03	1.2	23
Mean	2.8	0.13	0.19	7.2	74	0.02	1.3	26
±STD	0.2	0.01	0.14	0.9	25	0.01	0.1	3
MQR 1	2.6	0.18	0.12	5.6	103	0.02	1.6	33
MQR 2	3.6	0.18	0.2	5.6	135	0.02	1.7	34
MQR 3	1.6	0.14	0.19	4.2	115	<.008	1.6	29
Mean	2.6	0.17	0.17	5.1	118	---	1.6	32
±STD	1.0	0.02	0.04	0.8	16	---	0.1	3
CLIS-86 1	0.17	0.3	2.6	19	1690	0.02	5.1	30

--- = Not applicable.

incorporated and expanded as a tiered monitoring program (Germano et al. 1994).

- REMOTS® data have shown that, in general, disposal activities do not prevent the reestablishment of normal benthic conditions.

3.3 Chemical Characteristics

Capping of dredged material was initiated to isolate sediments contaminated with inorganic (heavy metals) and organic constituents from the environment designated for disposal. In marine environments, metals and most organic chemicals are usually strongly bound to particulates. The particles that dominate waters and surface sediments in coastal areas are a complex mixture of dead plant and animal matter, clay particles, and living microorganisms. These "organic-mineral aggregates" provide complexation sites for the chemicals carried by rivers, rain, and wind into coastal waters. Once chemicals are bound to particles, their fate is frequently determined by the movement and deposition of the particles.

Many compounds are cycled through marine sediments, and most of this activity is biologically mediated. Organic compounds and metals used as nutrients are actively mobilized and chemically modified by the feeding, burrowing, and oxygenation of surface sediments (Aller 1978, 1980). Other compounds are sorbed passively by organisms and can move through the food chain. Because the contaminated dredged material in capped mounds is assumed to be isolated from biological activity, it has also been assumed that the contaminants are not mobile. Unlike terrestrial landfills, subaqueous capped mounds do not experience leaching from ground water movement. For this reason, chemical monitoring has been limited to "assurance" monitoring, i.e., routine analyses of surface sediments to assess contaminant levels.

The geochemical processes within marine sediments are complex and strongly influenced by biological activity, pore water mobility, and availability of oxygen. Although no detailed studies of geochemical processes within capped mounds have ever been conducted, the extensive surveys of contaminant levels in surface sediments strongly support the assumption that subsurface contaminants are not reaching the surface.

3.3.1 Methods

In the evaluation of chemical characteristics of capped mounds to determine whether or not capping was successful in isolating contaminants, the DAMOS Program has emphasized monitoring of the composition of surface sediments forming the cap layer. Smith-McIntyre grab samples have been analyzed on an intermittent basis since the beginning of the program (Appendix C). The results of these analyses are stored within the DAMOS database.

The contaminants of concern which were routinely measured in the beginning of the DAMOS Program were primarily heavy metals and hydrocarbons such as oil and grease. In the following discussion the comparisons stem from these measurements, although it is important to recognize that, as research continues, more information is available on the toxicity of various compounds. In recent years, data have been collected on additional contaminants such as PAHs, PCBs, and pesticides, which pose distinct ecological and potential human health risks.

Most of the sediment samples were obtained using a 0.1-m^2 Smith-McIntyre mechanical grab sampler. On maximum penetration, expected for most of the fine-grained dredged material, this sampler will extract a sediment section extending to approximately 25 cm below the sediment-water interface. Typically, subsamples of this section are obtained using individual sections of plexiglass core liner approximately 6.5 cm in diameter and 10 cm in length (e.g., SAIC 1990a). In the early years of the program, similar cylindrical plastic tubes were used by divers to directly sample the surface of the capped disposal mound for subsequent chemical analysis (Morton et al. 1984b).

Sediment chemical analyses have been conducted by the NED laboratories. The quality of laboratory data was assessed primarily by its reproducibility. In general, each station was sampled three times, but the variation between sets of data is not consistent. Considering the variable composition of dredged material, the majority of scatter between three replicate points may reflect the true nature of the sediment. For example, if three samples were taken at a station which has only a thin cover of a particular type of sediment, the three sample results could show a mix of the types of sediment present. In the ensuing discussion, data which are presented are station averages. This averaging serves to "smooth" the relative concentrations at each station.

The CLIS reference station has been sampled repeatedly since the beginning of the DAMOS Program. A measure of data precision was obtained by comparing measurements of samples taken at different times (Section 3.3.3). In general, the reference values have been consistent.

3.3.2 Surface Sediment Geochemical Model

A model was developed to describe the changing chemistry of surface sediment collected at a station during different phases of capped mound development (Figure 3-11). Before disposal, measured concentrations of contaminants should be within the range of reference station values (1 on Figure 3-11). After mound sediment deposition, the concentration levels should increase to within the range of those values measured in the source harbors (2). With the deposition of the cap, the contaminant concentrations of the surface sediments should decrease (3). The amount of this decrease is again dependent upon the chemistry of the source area. Sand caps will tend to have lower contaminant concentrations than silt caps because most contaminant species are associated with the fine-grained fraction. Cap contaminant

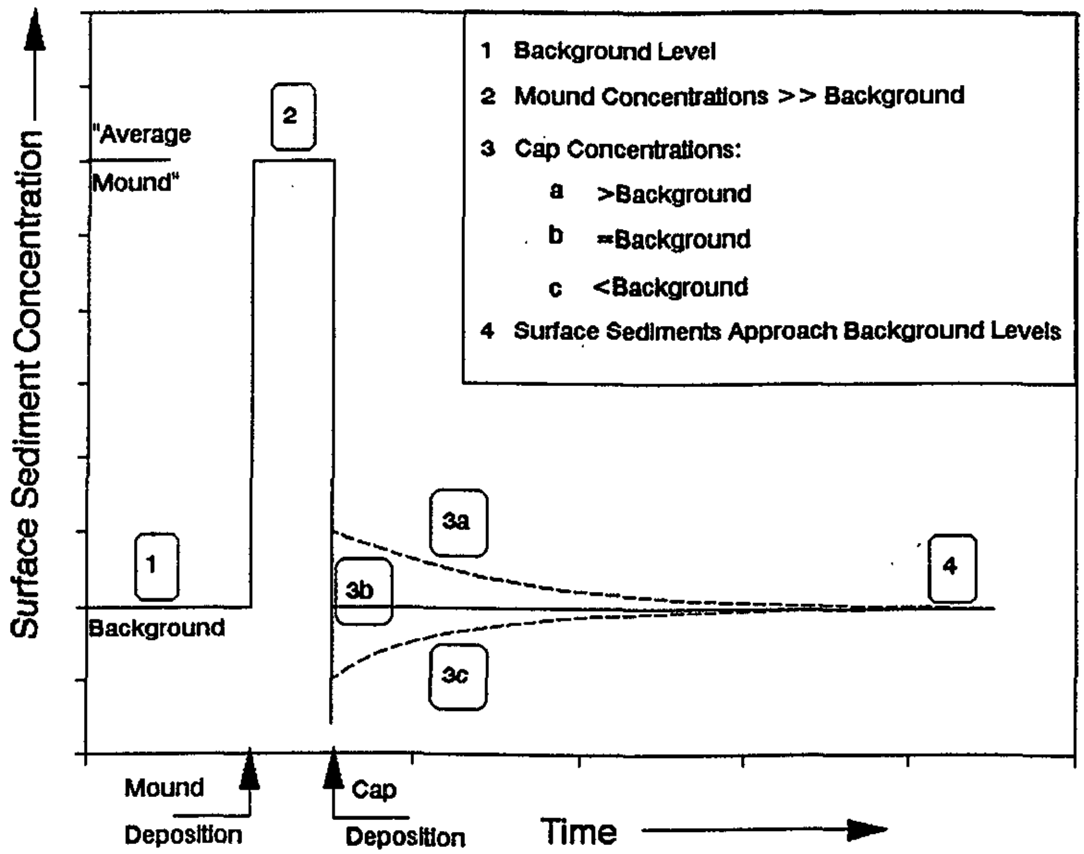


Figure 3-11. Geochemical model for capping of contaminated sediments

concentrations may also be slightly higher than reference values. Finally, surface concentrations are expected to equilibrate as ambient sediments are deposited over time and mixed with the cap surface until background levels are once again established (4).

Chemistry data from STNH-N and STNH-S show that capping of disposal mounds has effectively produced a "layer cake" effect such that lower concentrations of contaminants are measured in surface sediments overlying contaminated dredged material. Time-series data along E-W and N-S transects are available for each depositional phase of the STNH capped mounds. These data provide a representative picture of the change in surface chemistry during the period of dredged material deposition, and serve to test the geochemical model. Sediment copper (Cu) levels at STNH-N will be used to demonstrate the variation in chemical concentrations. In general, metals and oil and grease vary in a similar fashion; specific differences in particular analytes are discussed in the section that follows.

In May 1979, after formation of the mound of Stamford material, Cu concentrations of surface sediments were three to six times higher than in March before disposal (Figure 3-12). By June, after placement of the sand cap from New Haven harbor, surface Cu concentrations near the center of STNH-N decreased to below reference levels. These results are not surprising considering the lithology of the capping material at STNH-N; sand tends to have lower metal concentrations than clay-rich silt because many clay minerals contain metals in the natural environment. At the margin of the capped mound, Cu concentrations were in the range of background levels. By early August, the Cu concentrations near the center of STNH-N began to increase, as predicted by the geochemical model. Eventually, surficial mixing of cap sediments with ambient sediments and deposition of local-source silt onto the capped mound should result in the reestablishment of background contaminant concentrations (Figure 3-12).

The depositional, and therefore chemical, history at STNH-S is more complex. As with STNH-N, the contaminant load of the surface sediments increased with mound deposition, then decreased with cap deposition. The silt cap effectively reduced the contaminant concentrations in surface sediments to near or slightly above reference levels.

A series of contour plots of Cu during each depositional phase at STNH-S demonstrate the evolution of that capped mound. The presence of relatively higher Cu levels 200 m south of the center following cap deposition agrees with the detection of thin cap cover noted in bathymetric profile analyses (Figure 3-13; Morton and Karp 1980). Results of the August 1979 survey indicated an increase of contaminant levels to the west of STNH-S, suggesting mixing of Stamford and New Haven sediments, or an errant barge disposal (Figure 3-13). This increase was flagged, and plans for the

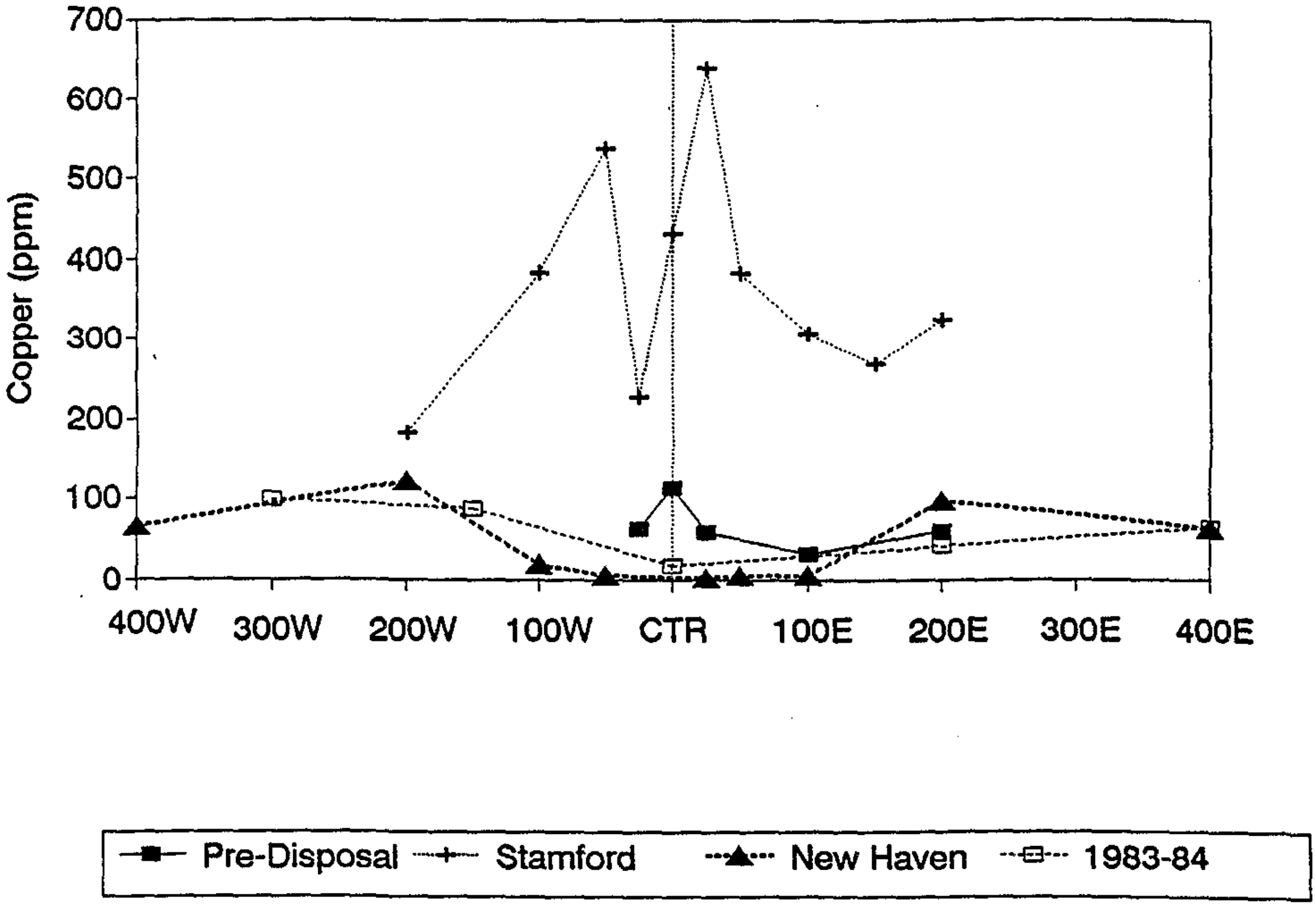


Figure 3-12. Copper concentrations of surface sediment samples collected at Stamford-New Haven North after each phase of disposal

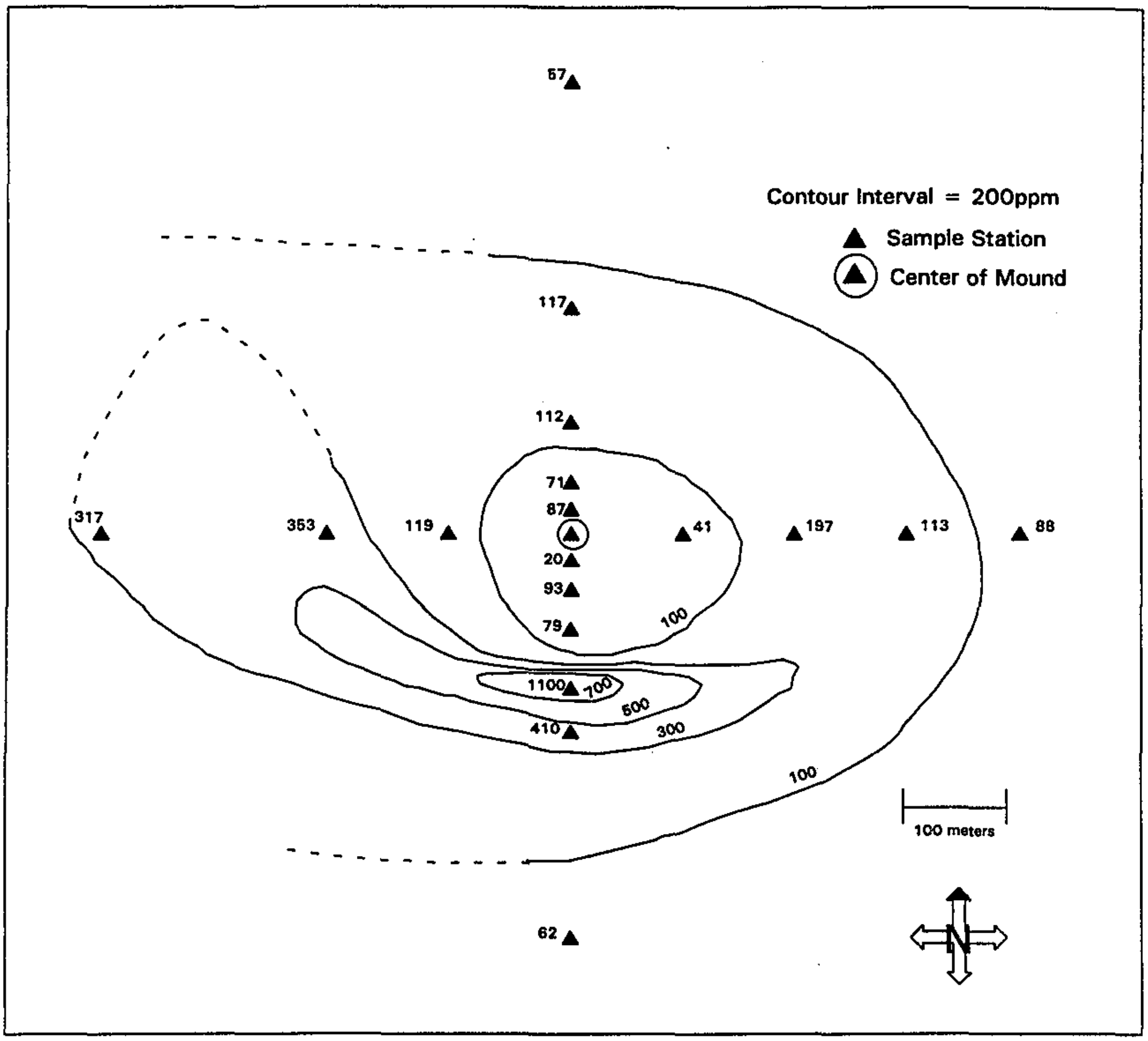


Figure 3-13. Copper concentration (ppm) contours measured at Stamford-New Haven South in August 1979

placement of additional cap material at STNH-S during the spring of 1980 included coverage of the south and west areas of the cap (Morton and Karp 1980).

The next bathymetric survey (in association with sediment sampling) at STNH-S occurred in November 1979, primarily to measure the effect of the 6,000 m^3 of Stamford material which had been deposited in the preceding month. The bathymetric survey indicated an apparent large loss of material (see Section 3.1.3). To confirm this unexpected result, and because of the passage of Hurricane David in early September, an additional survey at both STNH-N and STNH-S was conducted in December 1979.

The chemical results of both the November and December surveys showed a shift of Stamford-range contaminant levels from the south and west of STNH-S to the center (Figure 3-14). The increase at the top was most likely due to the September-October deposition of Stamford material. It is unlikely that this increase could be due to stripping off of cap material, or mixing of Stamford and New Haven, during Hurricane David. Cores taken within 60 m of the center of STNH-S in 1990 showed a minimum of 1.5 m of New Haven material above the mound/cap interface (Section 4.0).

The reasons for the decrease of contaminant levels at the stations west and south of the center between August 1979 and November 1979 are unclear. One possibility is that surficial New Haven cap material from the center was transported to the flanks as a result of Hurricane David. Geotechnical modeling has suggested that much of the reduction in STNH-S contaminant concentrations could have been due to consolidation. This conclusion does not discount the possibility of minor surficial (cap) reworking and/or slumping.

Following the deposition of 110,000 m^3 of New Haven capping material in the spring of 1980 at STNH-S, contaminant concentrations returned to reference levels everywhere on the capped mound. Subsequent sampling through 1986 has shown no substantial increase in surface contaminants; concentrations have remained near background at STNH-S and continue to approach background at STNH-N. These data support the model described above which predicts that, barring physical disturbance or pore water migration and precipitation, surface sediment contaminant values should remain equivalent to those measured at the reference station (Figure 3-11).

3.3.3 The Chemistry of Dredged Material

The attempt to classify sediment by the "amount" of contamination is limited by our knowledge of the effects of bioaccumulation and associated mortality rates, as well as pathways to human consumption, for any given element or compound. In comparing the tables of cap and mound characteristics (Tables 2-1 and 2-3), it is apparent that there are no "indicator" species of contamination for the early CLIS projects. For example,

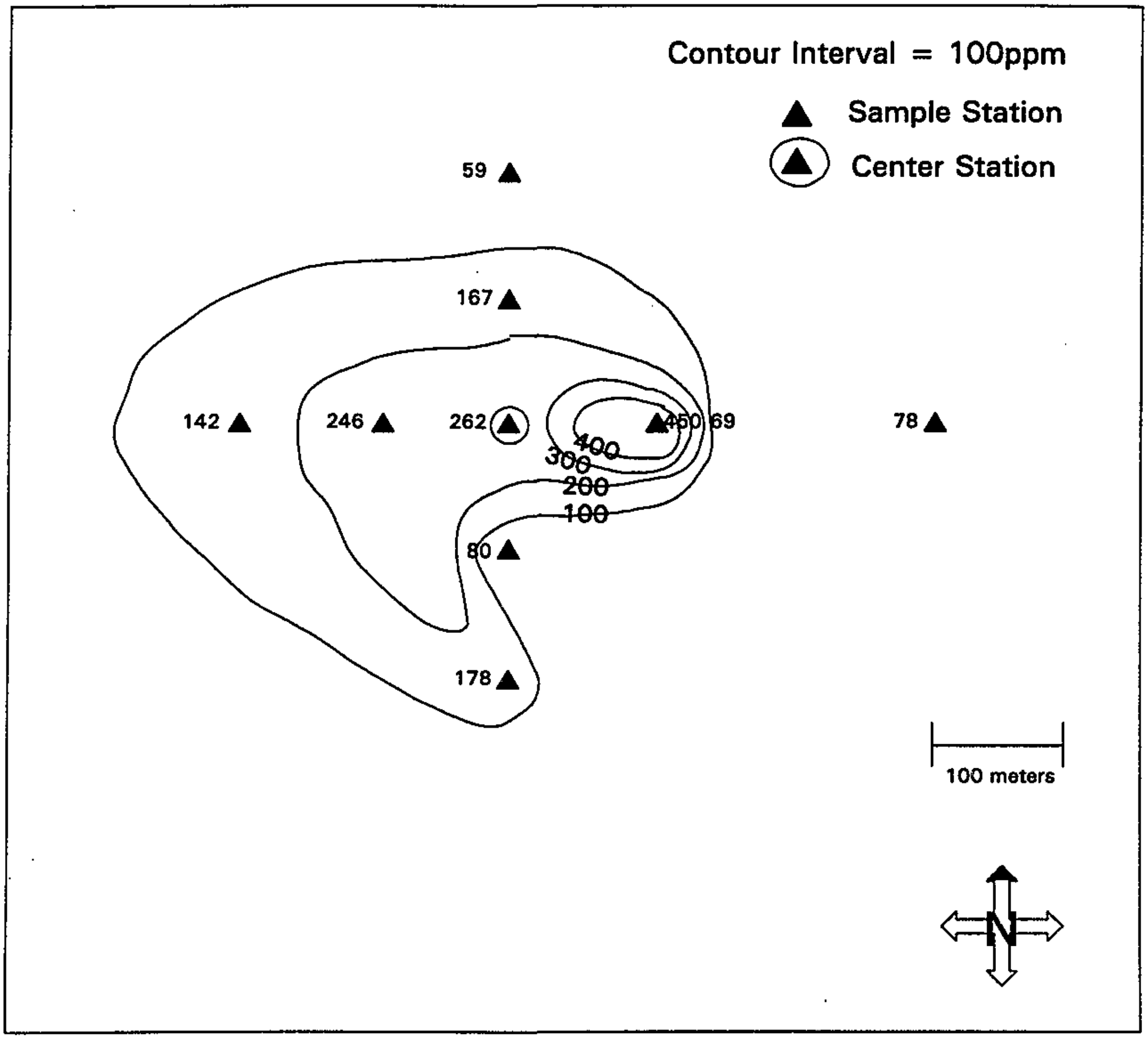


Figure 3-14. Copper concentration contours measured at Stamford-New Haven South in November-December 1979

Mill River sediments, which are relatively high in many metals (especially Hg and Cd), have a very low oil and grease component. There is little difference in arsenic concentrations between mound and cap sediments from these areas. Based on metal analyses, sediments from Quinnipiac River, as already discussed, were originally intended as capping material for Mill River sediments, but actually contain a high enough percentage of volatile solids to be considered highly contaminated. Finally, except for Hg, the contaminant concentrations of Norwalk cap and mound sediments are within the ranges of most of the other cap sediments. Therefore, any discussion of the contaminant concentrations in dredged sediments must be considered relative, and does not specifically address how detrimental a particular sediment is to the biota, or what the synergistic effects of different contaminants may be.

Theoretically, any capped mound will consist of three components, or end members: moderately to highly contaminated mound material, relatively uncontaminated capping material, and background, or ambient, material. Any sediment sampled, during either the formation or monitoring phase, will contain one or more of these three components. If each one has a distinct chemical signature, any random sample can be distinguished as being mound, cap, or background material, or a composite of two or more components.

There are six source areas of dredged sediments for the NED projects discussed in this report. Sources of mound material (more contaminated sediments) include Stamford Harbor (ST), Norwalk Harbor (highly contaminated), Mill River, and Black Rock Harbor (BR). Capped sediments were commonly derived from New Haven Harbor (NH). Quinnipiac River sediments were used for the first cap at MQR, and low to moderately contaminated sediments from Norwalk Harbor were used for capping material at NOR.

Surface sediments sampled in the source harbors appeared to have relatively uniform sediment textures but highly variable contaminant levels (Tables 2-1 and 2-3). Despite the widely varying ranges of contaminant levels in both mound and capping material, several distinct characteristics permit more detailed analysis of the sediment grab samples. For example, New Haven sand, which constitutes the cap at both STNH-N and CS-2 and is represented by sample FD-7 from New Haven Harbor, contains concentrations of metal and organic contaminants that are markedly lower than either background levels of concentrations in other New Haven materials (Figure 3-15). The chemical and physical properties of the sand cap make this material clearly distinguishable from the mound material as seen in sediment cores (Section 4.0). Surface sediments at both MQR and CS-1 have the highest ranges of contaminants measured in capping material, as represented by sample FD-5 taken in New Haven Harbor (Figure 3-15).

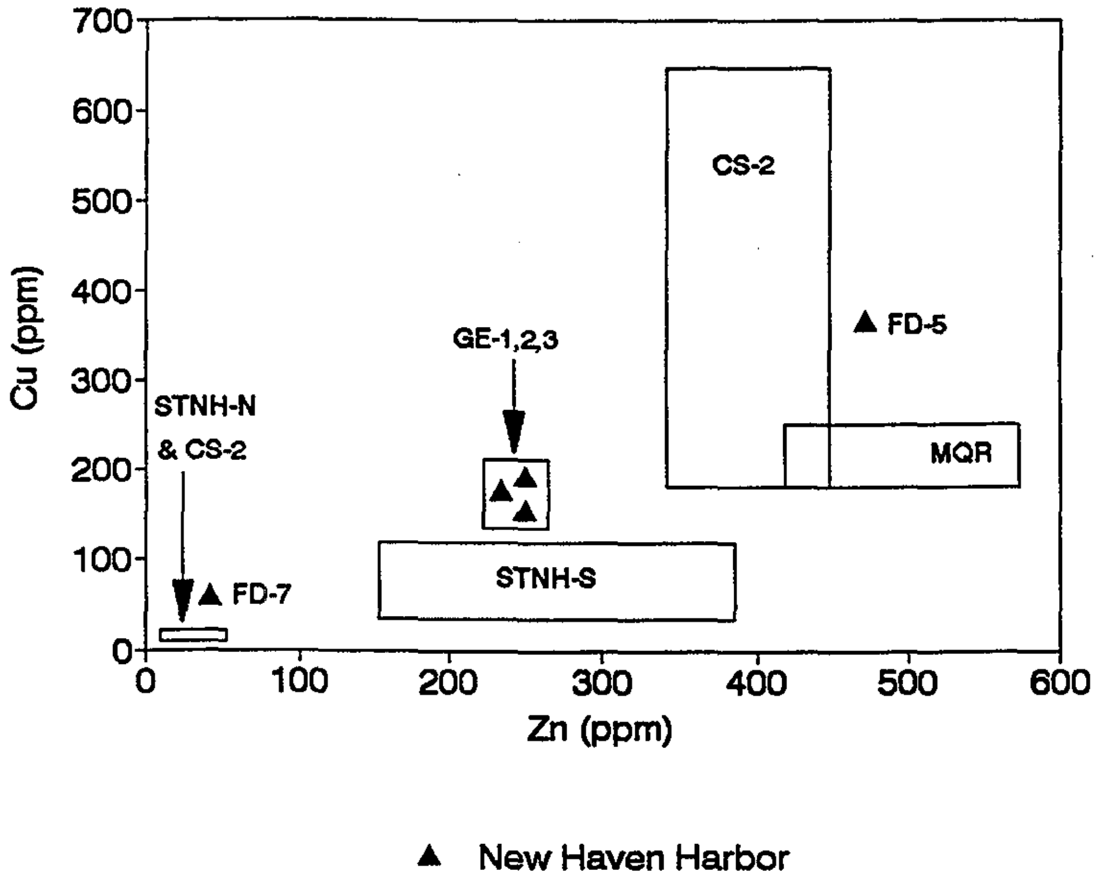


Figure 3-15. Zinc and Cu concentrations of samples collected from New Haven Harbor (NH), and New Haven cap material sampled from CLIS capped mounds

Metal analyses performed by the NED laboratory (using EPA methods) have been the most common suite of analyses for both the dredged material source areas and surface grab samples from the capped mounds. The replicability of NED analyses can be shown by the summary of reference station data (Figure 3-16). The use of the historical record of sediment chemistry samples collected during the DAMOS Program is a technique which can be employed both to track the development of a capped mound and to trace the sources of the material years after it was deposited (Section 4.0).

For example, the four sources of the MQR mound (Mill and Quinnipiac Rivers, Black Rock, and New Haven Harbors) were sampled before each phase of disposal, as were the sediments from the disposal area itself (Figures 3-17 and 3-18). These data indicated that Cd concentrations of Quinnipiac River sediments, as measured by the NED laboratory, were higher than those of the Mill River (Figure 3-17). One distinct characteristic of the mound sediments is the relatively high Cu concentrations of Black Rock Harbor sediments. As mentioned in Section 4.0, these characteristics are useful in distinguishing source material in cores taken through several capped mounds.

Sediment samples taken from the surface of the MQR mound after deposition of Mill and Quinnipiac River dredged material show the record of surface chemistry (Figure 3-19). Again, Cd concentrations of post-Quinnipiac River dredging are relatively higher than the Mill River sediments. Surface sediment grab samples taken since deposition of both Black Rock Harbor and New Haven Harbor sediments have indicated stable and relatively low trace metal concentrations since cap deposition (Figure 3-19).

Chemical data from MQR source areas were normalized to Cu in order to form "fields" of concentrations of sediments from different source areas. Black Rock Harbor samples, due to excessive Cu concentrations, form a relatively discrete field (Figure 3-20A). Although there is some separation of Mill and Quinnipiac River fields due to the relative enrichment of Cd in Quinnipiac sediments, New Haven Harbor sediments bridge the gap between these two fields. The fact that New Haven Harbor data overlap with both the Mill and Quinnipiac River data is not surprising since New Haven Harbor is a depository for sediments from both of these rivers (Figure 2-6).

Recently, MQR was cored in order to determine the chemical nature of the capping material, and to test the hypothesis that Black Rock Harbor material was concentrated at the top of the capped mound. Results were plotted with these source data and showed that most of the cap material at MQR has metal concentrations within the range found in upper New Haven/lower Quinnipiac River sediments (Figure 3-20B; Murray 1992).

Coring results from MQR do not support the contention that the slow biological recovery at MQR was due to the

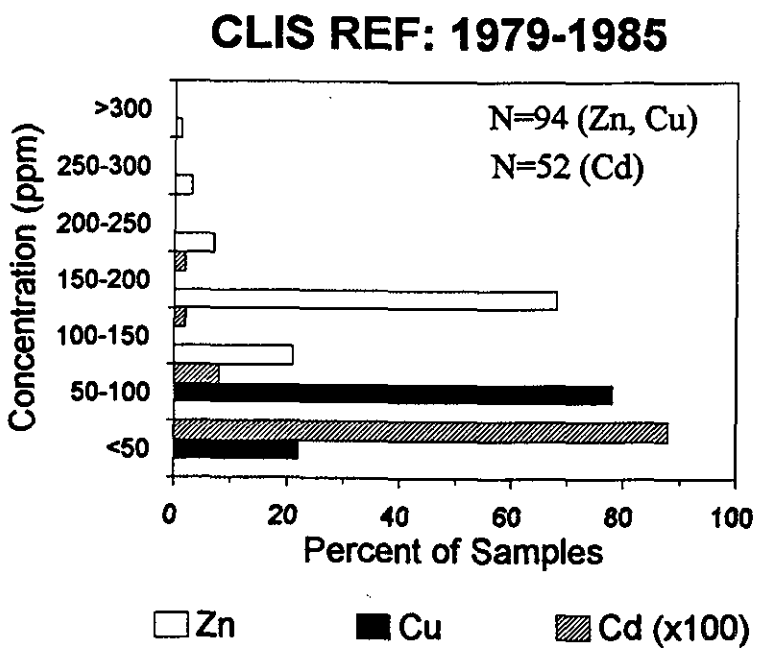
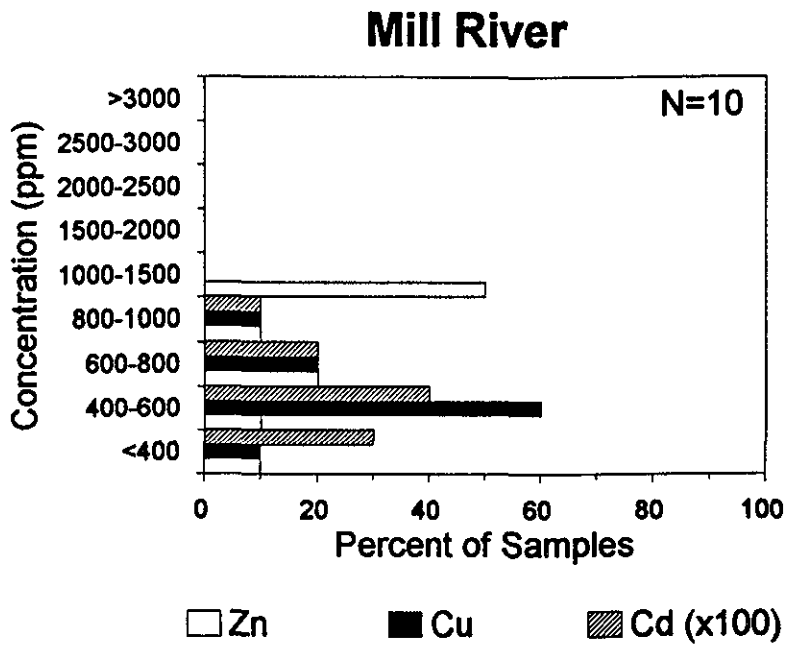


Figure 3-16. Trace metal (Zn, Cu, Cd) concentration frequency distribution of samples from the CLIS reference station, cumulated over the years 1979-1985. Note units and change of scale relative to Figures 3-17 and 3-18.



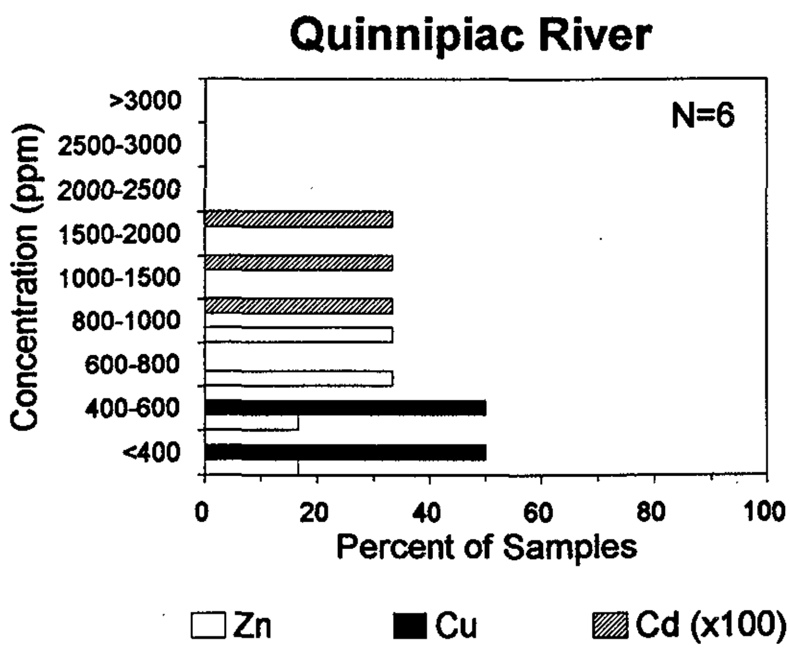


Figure 3-17. Trace metal (Zn, Cu, Cd) concentration frequency distribution of samples from the Mill and Quinnipiac Rivers

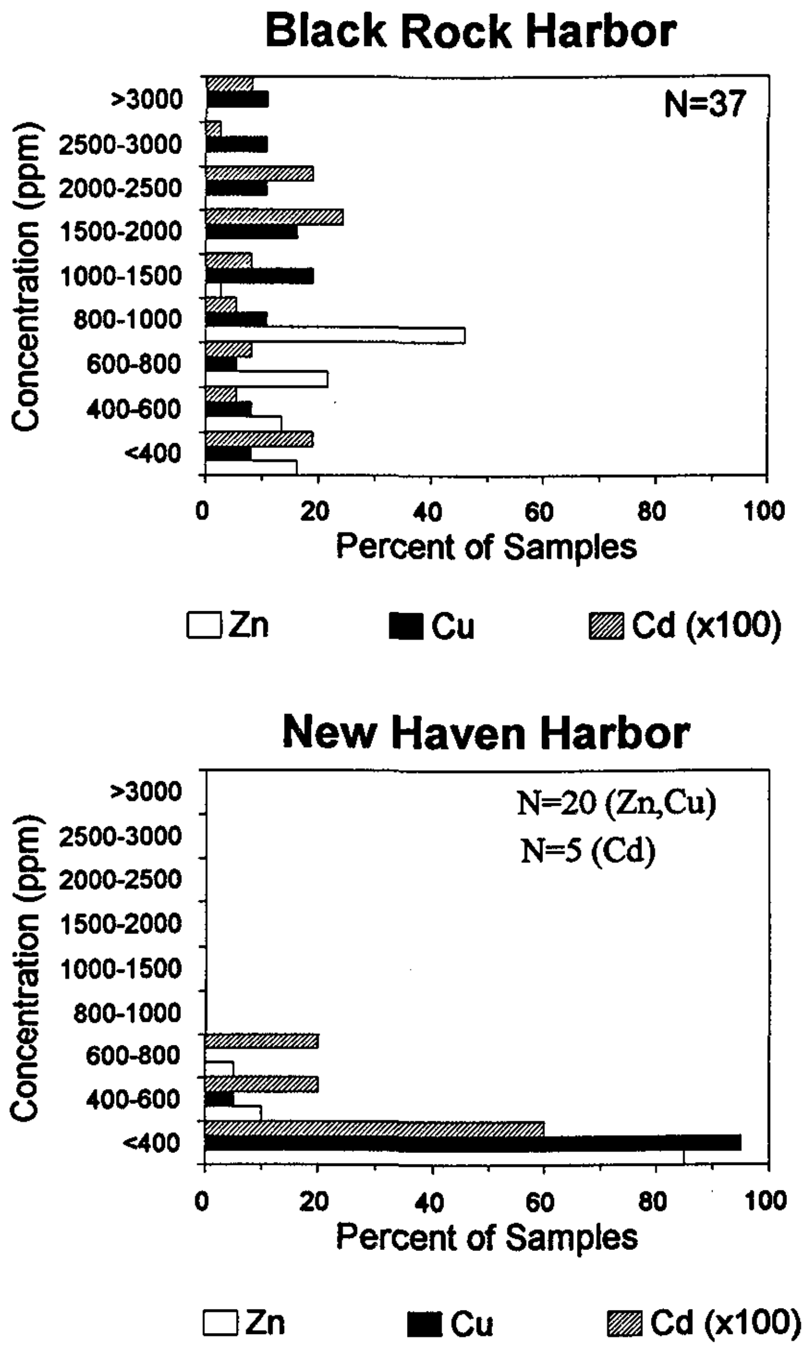


Figure 3-18. Trace metal (Zn, Cu, Cd) concentration frequency distribution of samples from Black Rock and New Haven Harbors

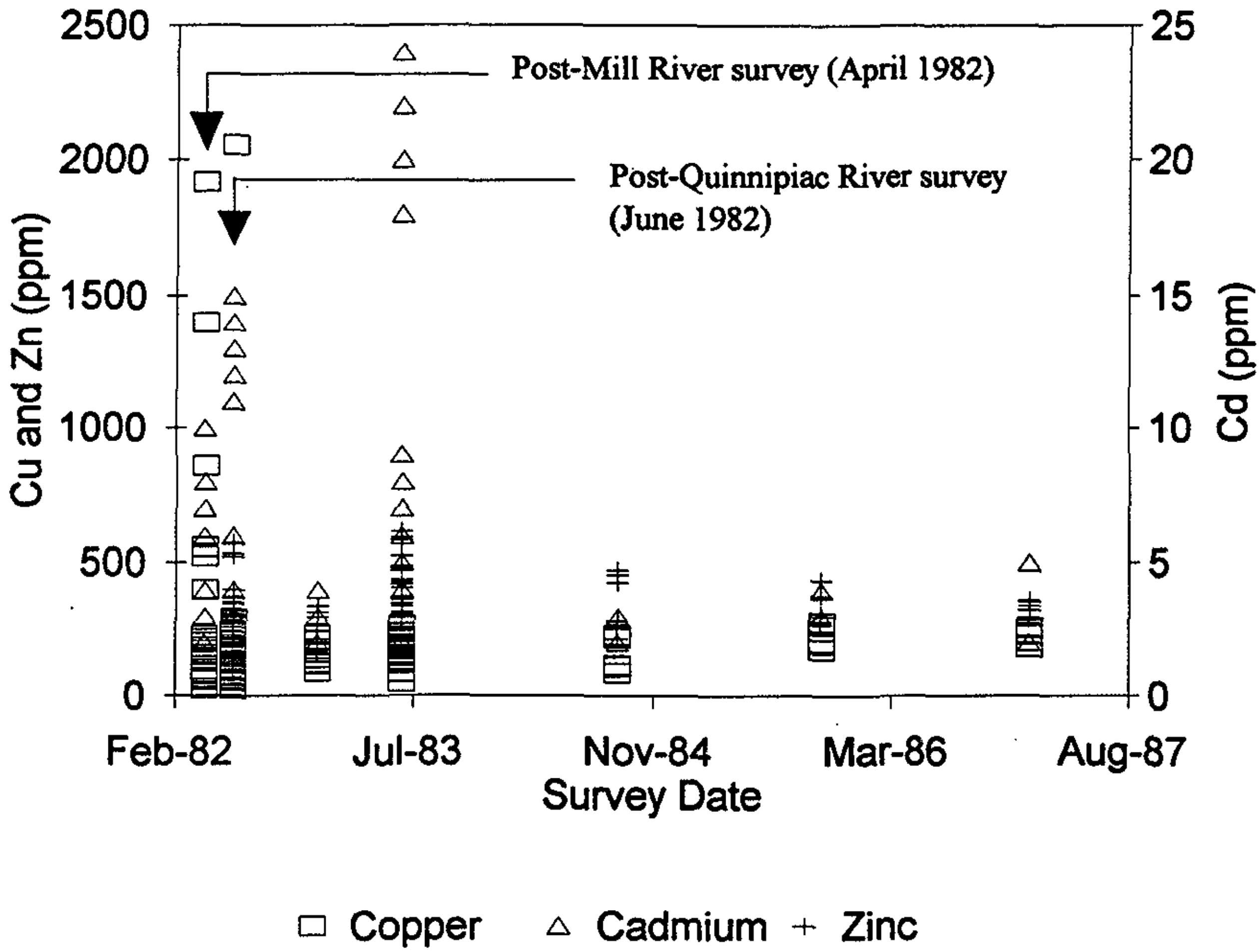


Figure 3-19. Trace metal data from surface grabs collected from MQR during successive stages of formation

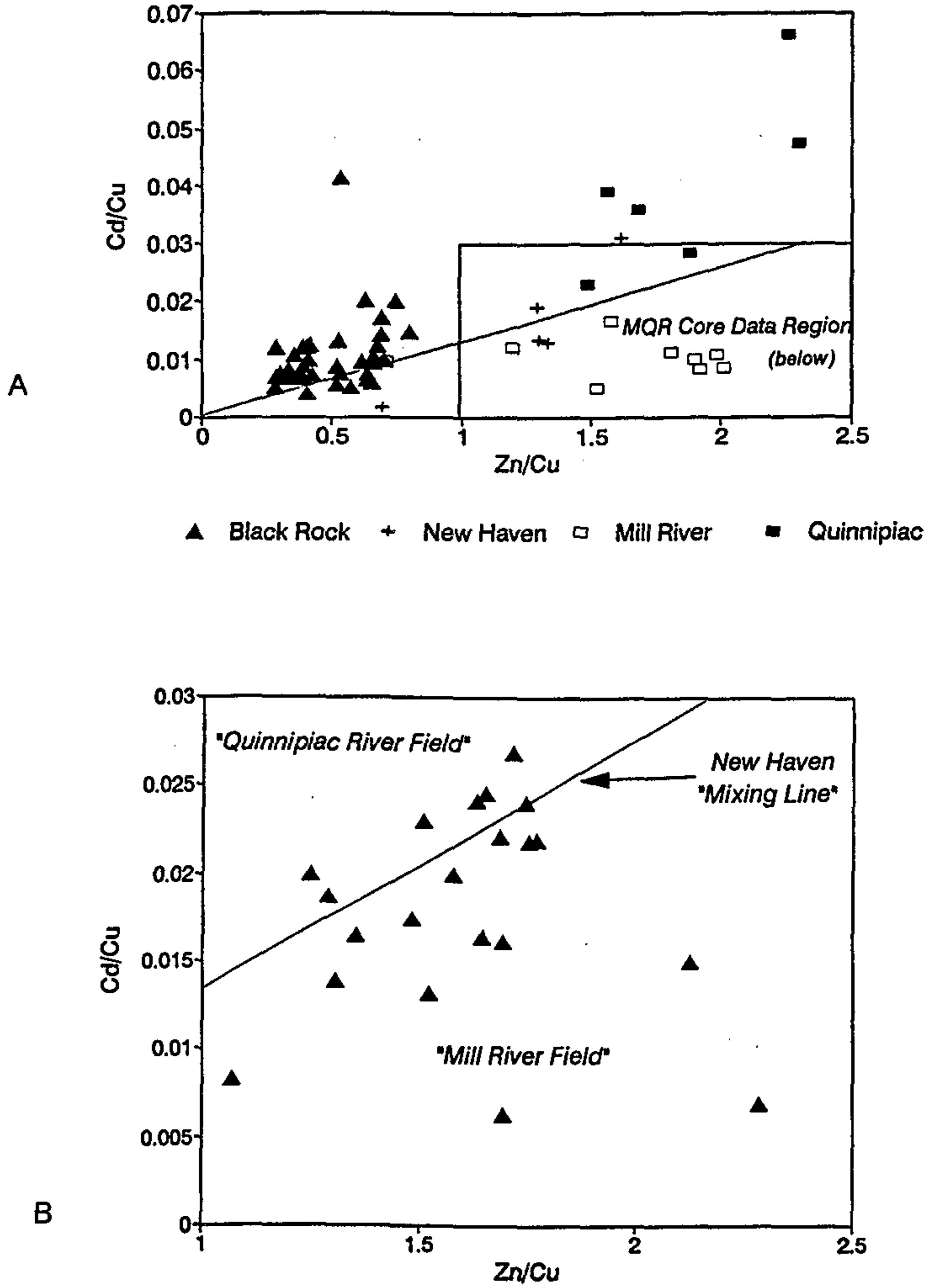


Figure 3-20. Zinc and Cd concentrations normalized to Cu for (A) MQR source areas and (B) MQR core samples

presence of Black Rock material. Rather, the sediment chemistry record at MQR supports the historical disposal barge record that a large volume of New Haven material was disposed at MQR, potentially from the upper reaches of the harbor which is affected by Mill and Quinnipiac River effluent sediments. MQR core samples were also analyzed for organic contaminants (e.g., PAHs); results indicated that concentrations were high enough to have been a factor in the slow biological recolonization monitored there (Murray 1992).

3.3.4 Chemical Monitoring: Conclusions

Sampling and analyzing surface sediments of capped mounds is not a routine part of DAMOS monitoring, but has been incorporated as part of the tiered approach developed for DAMOS (Germano et al. 1994). A historical review of chemistry data reveals the following:

- Monitoring the surface chemistry of capped mounds has shown that chemical analyses can be used to track the distribution of dredged sediments and aid in cap placement.
- Surface sediment samples from capped mounds have shown relatively low concentrations of measured contaminants after dredged material disposal.
- Initial chemical characterization of the source material, both mound and cap, is important.
- Further work is in progress on accurate and efficient methods to characterize and classify contaminated sediments.
- Management decisions for capping projects, especially in the choice of material for use as caps, should be based on complete information from the source area and should rely on the most current classifications of contaminated sediments.

4.0 CAPPED MOUND CORING INVESTIGATION

Despite the lack of evidence of cap failure, questions concerning the chemical integrity of mounds have persisted. Previous investigations of capped mounds have suggested that there is a distinct physical and chemical boundary between mound and cap. Coring investigations of an experimentally capped mound at the New York Bight Mud Dumpsite revealed that the sand-mud interface was distinct visually and could be recovered with vibracoring operations (Bokuniewicz 1989). Grain size analysis of cores showed that the transition from sand to mud occurred over a distance of less than a few centimeters. Preliminary chemistry results of vertical core studies of sand-capped mounds in the Duwamish waterway supported the conclusion that the mound and cap material formed a sharp, relatively unmixed interface (Truitt 1986).

A coring investigation was initiated in 1990 to revisit three of the capped mounds located at CLIS (STNH-N, STNH-S, and CS-2). The initial assumptions of this investigation were that the caps should have relatively low levels of contaminants and should be visually and chemically distinct from the underlying contaminated material. The guiding hypotheses were: (1) if the interface was distinct visually, then the mound material has been physically isolated, and (2) if the interface was distinct chemically, then the mound material has been chemically isolated by the capping operation. If chemical gradients existed in the cap, then contaminants may have migrated from mound to cap.

It is important to note that there was no independent criterion for distinguishing the cap/mound interface. Distinct interfaces were discernible, but there is no conclusive method of determining the original interface between the mound and the cap. For management purposes, this distinction is not crucial as long as the contaminants remain isolated from the biotic communities. However, information concerning the fine-scale distribution of sediments and contaminants within historical capped mounds can be used to evaluate the assumptions behind the design of capped mounds and to guide future investigations and capping operations.

Capped mounds were cored in roughly cross-shaped sampling arrays (CS-2, Figure 2-10; STNH-N, Figure 3-3; STNH-S, Figure 4-1) located away from the peak heights in an attempt to sample three distinct (cap, mound, and base) layers from each capped mound. Cores were named according to their location: e.g., a core taken from the center of the capped mound was identified as CTR; a core taken from 80 m north of the center station was identified as 80N. Sediment samples were analyzed for Cd, Cu, and Zn, as well as for total recoverable petroleum hydrocarbons (TRPHs) and grain size. One core from each capped mound was analyzed for pesticides and PCBs, and three cores from each capped mound were analyzed for PAHs.

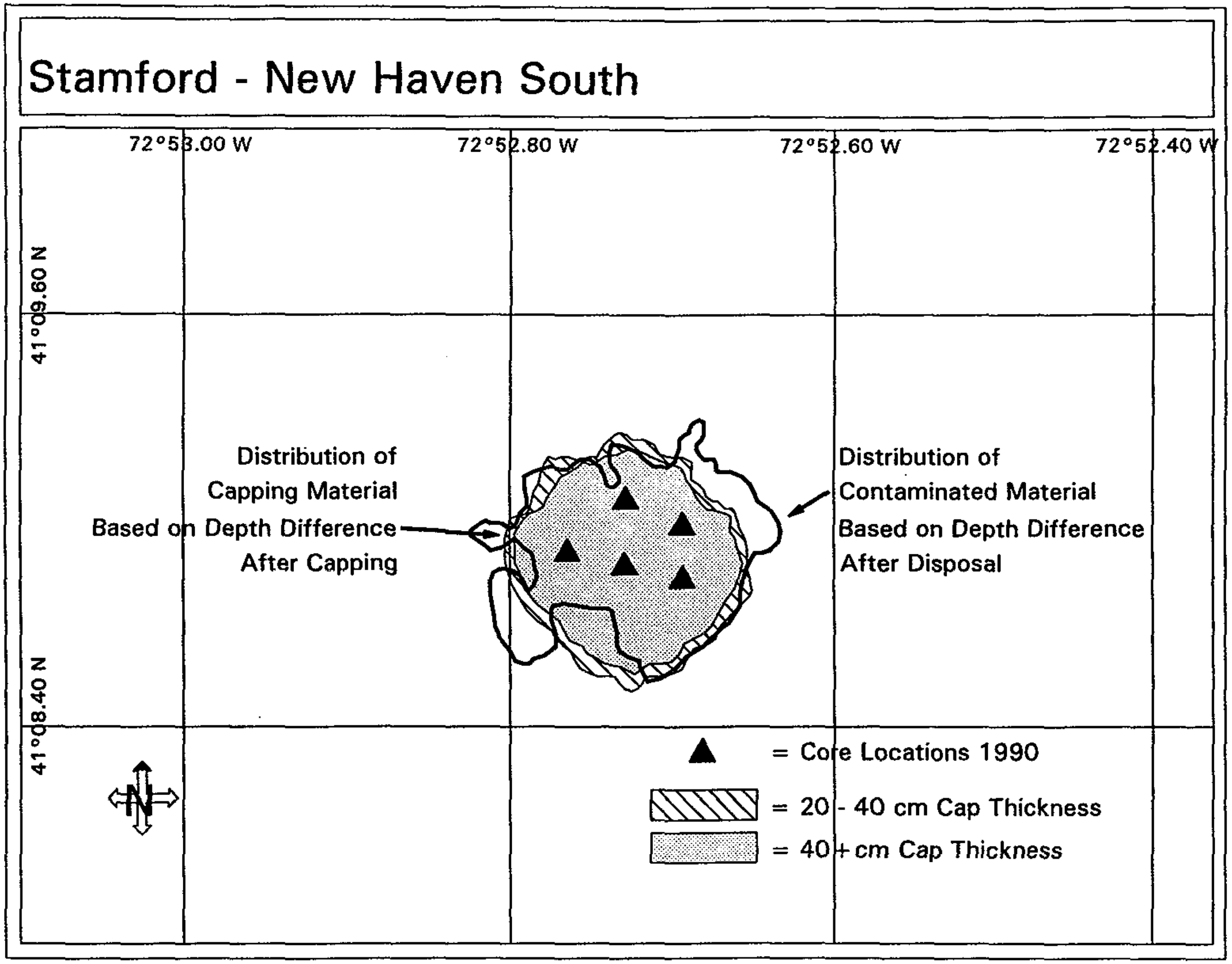


Figure 4-1. Distribution of dredged material at STNH-S (adapted from Fredette et al. 1992)

4.1 Results of the Coring Investigation

Both CS-2 and STNH-N had sand caps; based on previous studies, the visual interface between cap and mound was expected to be more obvious than in cores from STNH-S, which had a silt cap. At STNH-N, the coarse-grained cap (sand and shells) was fairly uniform in texture (some bands of shell hash) and had low levels of contaminants (Figure 4-2). There was a sharp visual transition from the cap to the mound sediments in all of the cores except 40W. The mound sediments were relatively uniform in texture (black organic silt) with high levels of contaminants.

In comparison to STNH-N, the cap material at CS-2 was variable in sediment texture (sand, shell, and silt) and contaminant loading (Figure 4-3). Based on chemical results, it is apparent that mound material was recovered only at 80NE and CTR, even though it was described as being present at 40E. The visual transition from the cap to the mound was not as obvious as at STNH-N. The zone of transition at 80NE appeared to extend over 30 cm, and the transition in contaminant levels occurred within the bottom of a sand layer which had been defined visually as cap material. The mound material was also variable in texture (shell and silt) and contaminant loading.

At STNH-S, the cap material was highly variable in sediment texture (Figure 4-4). The visual appearance was one of very distinct bands of high organic (black) and low organic (grey) silt and clay. The contaminant loading was moderate and variable. Despite this variability, the visual and chemical transition to mound material was distinct. Again, it is apparent from the visual descriptions and the chemical results that mound material was recovered only in two cores: 60NE and CTR. STNH-S received a large amount of cohesive cap material which formed a relatively thick layer on top of the mound. Despite success in taking long cores, most of the material recovered was cap material. The mound material contained high levels of contaminants and a uniform texture of dry, black organic silt. In this case (in contrast to STNH-N and CS-2), the variability of the cap material made it distinctive and recognizable, and the uniformity of the mound material made it easier to distinguish.

4.2 Geochemistry of CLIS Cores

The hypothesis that the contaminants are chemically isolated is dependent, in our model, on the lack of chemical gradients in the sediment samples. This hypothesis is constrained largely by sampling. Samples were taken every 20 cm in order to avoid bias introduced by field interpretation of a boundary. In some cases, the sample boundary did happen to coincide with a visual boundary. However, if a sample was taken in a transition zone, it is impossible to distinguish whether an intermediate level of contamination resulted from an actual gradient in the sediment (which may indicate remobilization of contaminants) or

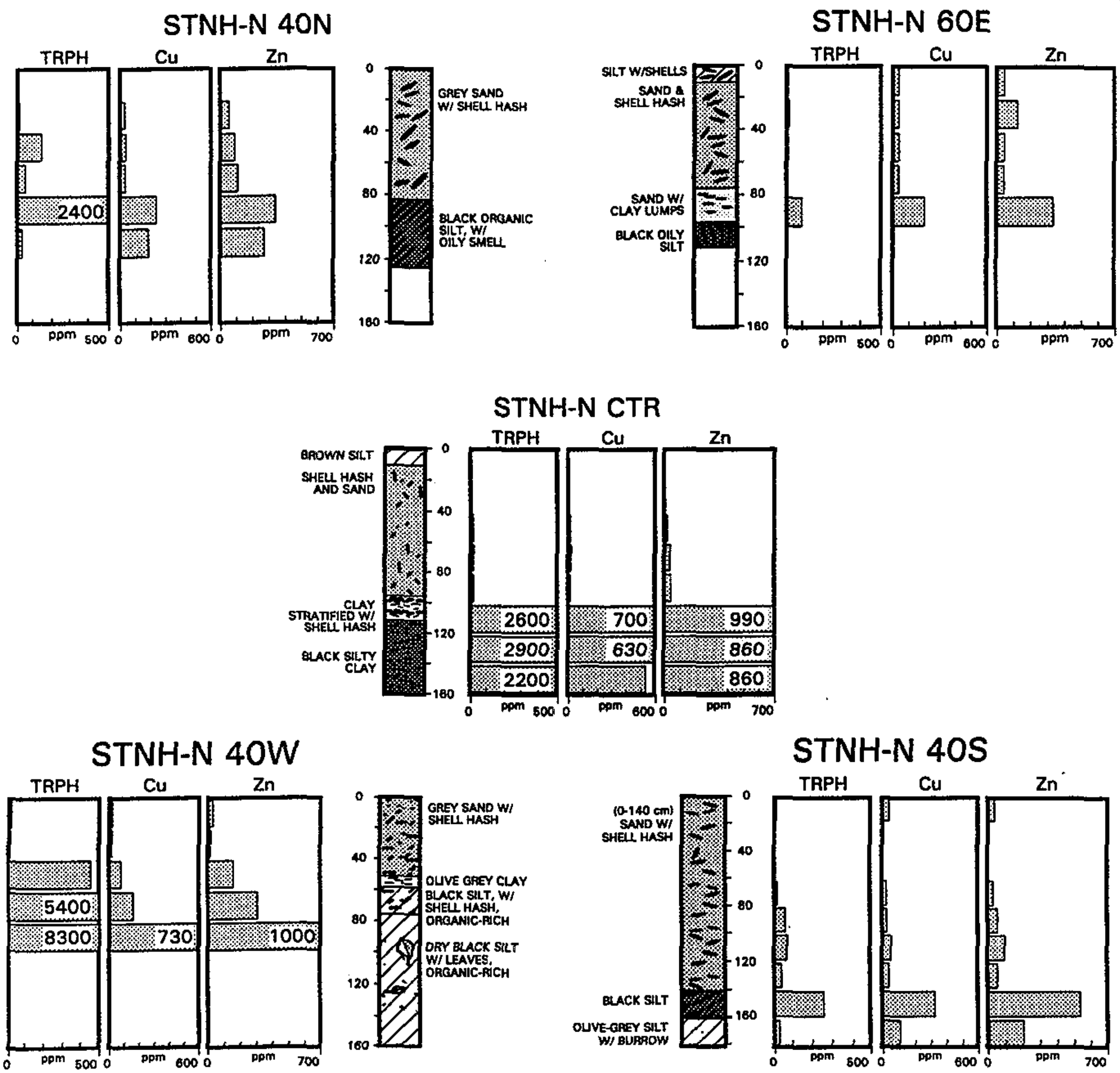


Figure 4-2. Visual core descriptions and selected chemical results of cores recovered from Stamford-New Haven North (adapted from Fredette et al. 1992)

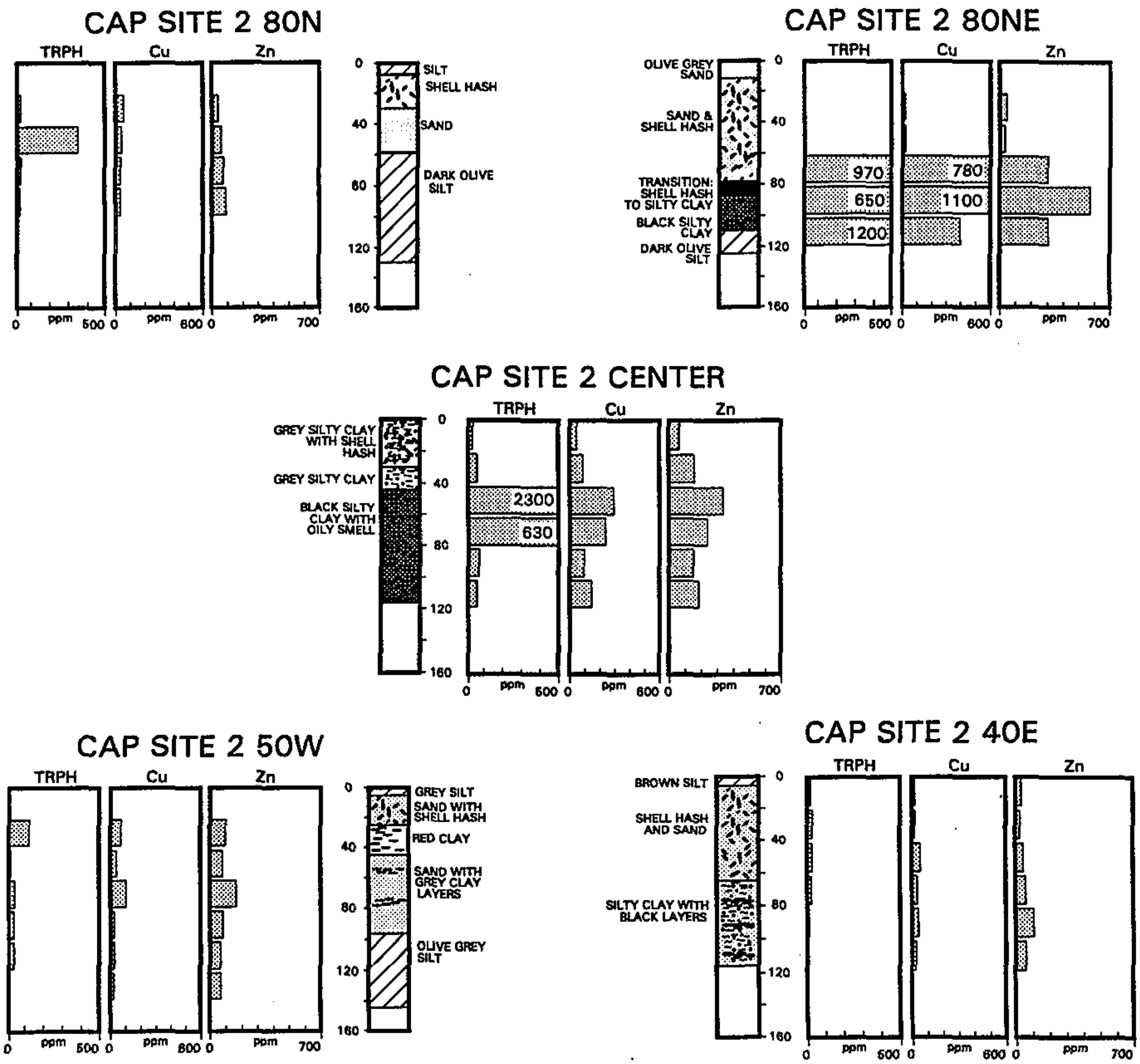


Figure 4-3. Visual core descriptions and selected chemical results of cores recovered from Cap Site 2 (adapted from Fredette et al. 1992)

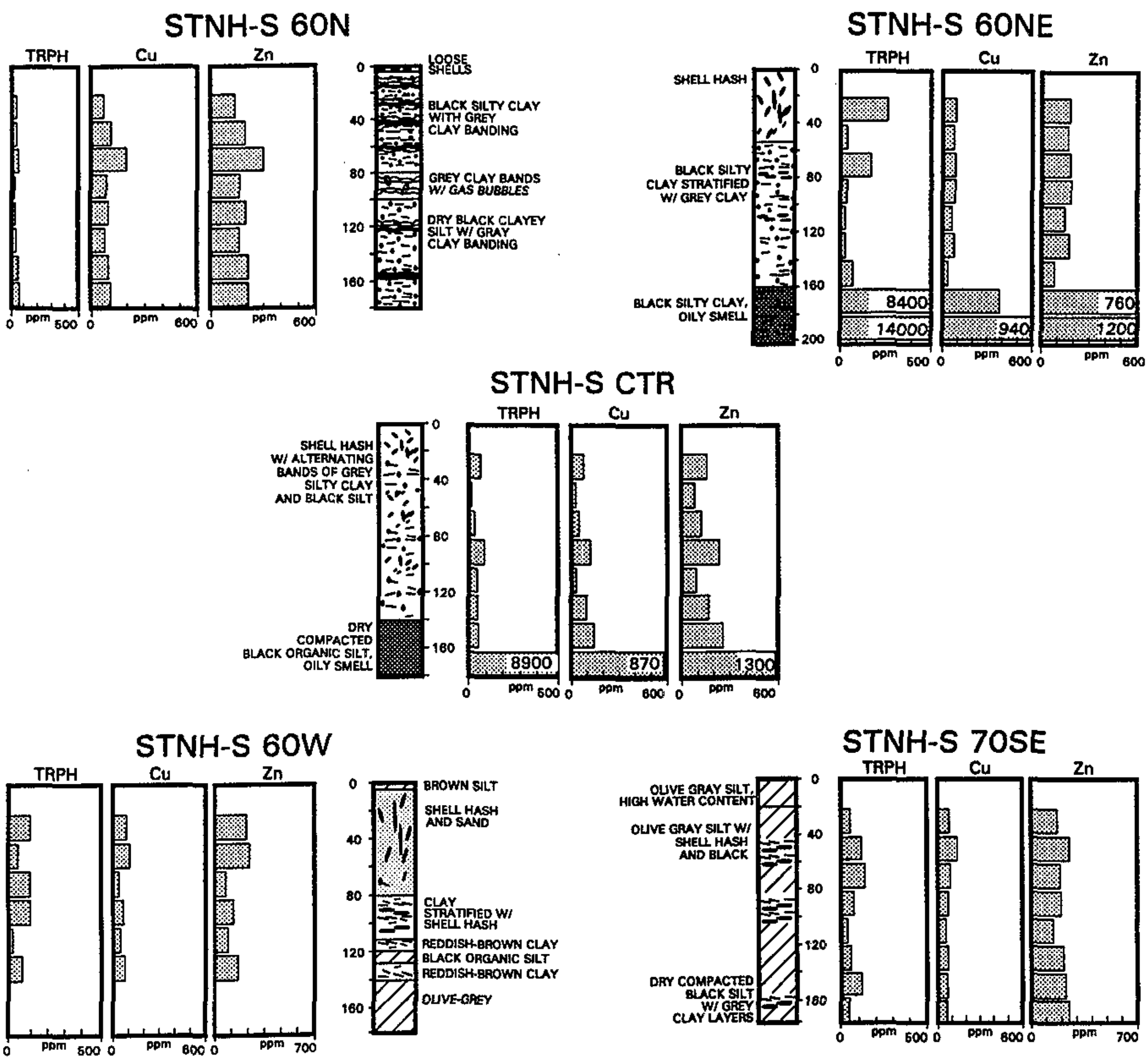


Figure 4-4. Visual core descriptions and selected chemical results of cores recovered from Stamford-New Haven South (adapted from Fredette et al. 1992)

from artificial mixing of a sharp chemical boundary.

Statistical analyses were conducted to document the presence or absence of a sharp chemical boundary between sample intervals (Appendix D). Initially a principal components analysis (PCA) was conducted to reduce the large number of chemical analytes to a smaller, more workable number of uncorrelated variables (PCA axes). Each PCA axis represents a set of analytes which covary. Scores from the PCA axes were then examined for the presence of a sharp chemical boundary. Regression analysis was conducted between the PCA axes and a set of dummy variables, each of which simulated a sharp boundary at a different depth interval. A single sharp chemical boundary was considered present when the R^2 value for a PCA axis and a dummy variable was close to 1. In addition, PCA axis scores for each depth interval were plotted to confirm the regression results.

Three different principal components analyses were conducted in this study. The first was run on all of the samples and included only those analytes sampled in all cores (three metals and TRPH). The second was run on nine of the cores which were sampled for three metals, TRPH, and PAHs. The third was conducted on only three cores and included all of the analytes. From these analyses, sharp boundaries were found for some cores using PCA axes generated from metal and TRPH data. The results showed that metals and TRPH are the best boundary indicators for the cores examined. The frequency distribution of the PCA R^2 values resulted in a bimodal distribution of values less than 0.5 and greater than 0.9. This division is convenient for using the PCA analyses to describe the relative presence (>0.9) or absence (<0.5) of a boundary between sample intervals. R^2 values for several of these PCA axes and their dummy variables are presented in the following discussion.

Data from STNH-N, which had the most visually obvious cap and mound distinction, also resulted in well-correlated statistical boundaries. Metal data from STNH-N showed a dual concentration pattern between relatively low and higher values (Figure 4-5); the higher values were within the Stamford ranges, although there was quite a bit of overlap between Stamford and New Haven metal concentrations. R^2 values for the cap/mound boundary documented in visual core descriptions were 0.984 at CTR, 0.989 at 60E, and 0.915 at 40N.

The only evidence for chemical gradients at STNH-N was at 40W, where the visual and chemical interface between cap and mound was unclear. The increase in contaminant values from 40 to 100 cm in the 40W core was coincident with the described variability in texture. This coincidence was noted commonly in this coring investigation and is discussed more fully below. The greatest R^2 value occurred at 80 cm (0.879), which indicated that mound material was indeed found below that point. Organic chemical data, in general, agreed with the metal data at STNH-N. An exception was a peak of

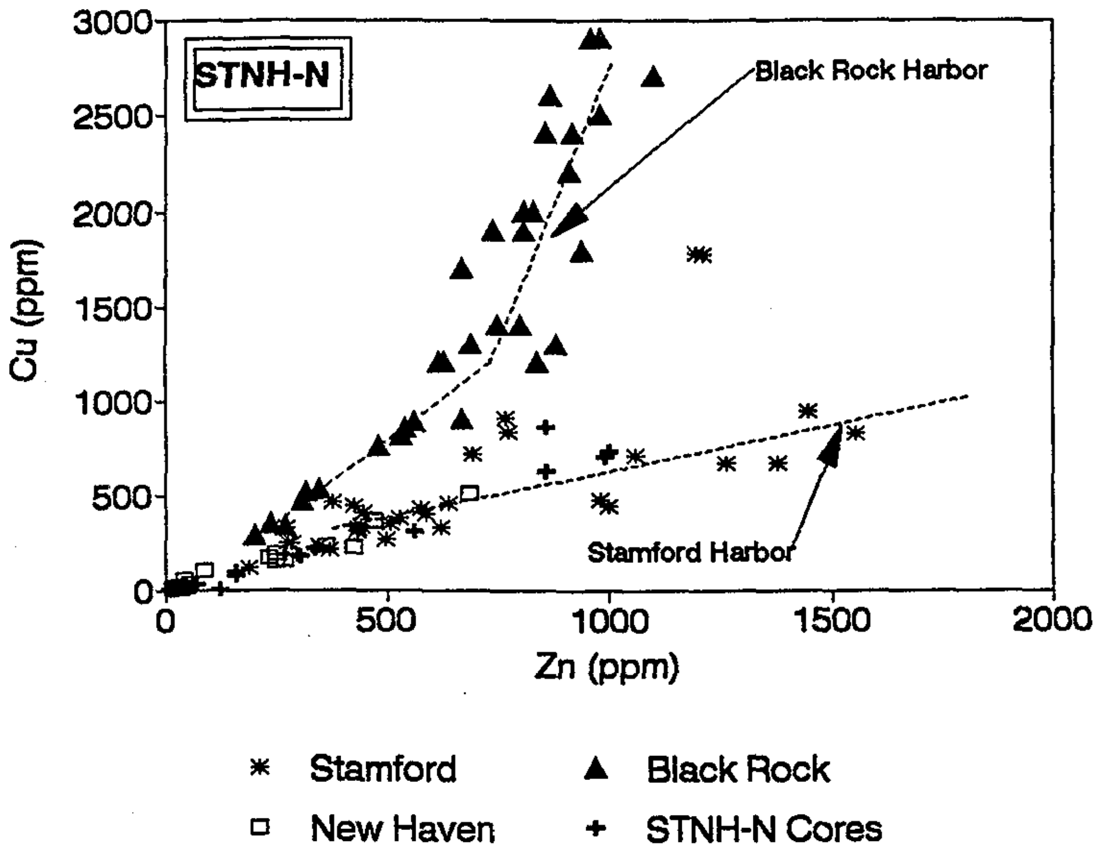


Figure 4-5. Zinc and Cu concentrations of sediments from Stamford, Black Rock, and New Haven Harbors, and core samples from Stamford-New Haven North

some of the PAHs, pesticides, and TRPHs (40N from 40 to 60 cm) that was well within the cap sediments (Figure 4-2), although these compounds were low or below detection levels in the interval between 40 and 60 cm and the top of the mound material. This suggested either that there had been lateral movement of organic contaminants without accompanying movement of metals or, more likely, that the New Haven dredged material had patches of relatively contaminated sediments.

Three of the five cores taken at CS-2 (80N, 50W, and 40E) did not penetrate mound material and had correspondingly low chemical contaminant concentrations. As at STNH-N, these low concentrations were indicative of the sand material used as a cap at both CS-2 and STNH-N. A relatively high R^2 value of 0.800 occurred at the 60-cm interval of 80N. This was coincident with the boundary between base and cap (Figure 4-3) and was due to the base material having higher values of vanadium (V) and Zn and a peak of TRPHs in the 40-60 cm interval. The hydrocarbon peak in apparent cap material again testified to the chemical variability of dredged material. The results at 80N indicated that cap material was deposited where there was no mound material, with little or no mixing of cap and base sediments.

The highest R^2 value at CS-2 occurred at 80NE, but not where the boundary was visually located. The statistical (chemical) boundary occurred at 60 cm (0.965) whereas the visual boundary occurred at approximately 80 cm. This difference may be an artifact of sampling because the visual dredged material interval occurred in a narrow band (20 cm) between cap and base. However, there is a possibility of mixing of, or migration from, that 20-cm interval.

The CTR station at CS-2 was the most problematic. PCA analyses showed no boundary with an R^2 greater than 0.7, even though there was a visual distinction between shell hash and black mud described as mound material (Figure 4-3). The contaminant values at the CTR station fell between the ranges measured for normal CS-2 cap material and for sediment from Black Rock Harbor where the mound material was obtained (Figure 4-6). These intermediate values extended throughout most of the core (20-120 cm), although no distinctive Black Rock material was recovered at CTR.

The intermediate contaminant values of samples recovered at CS-2 CTR could represent a remnant of mixing of cap and mound, evidence of contaminant mobilization, or an isolated pile of more contaminated New Haven sediment. Mixing was unlikely since this core was taken at the center of the capped mound where the cap presumably is thickest, and no evidence of mound material was found at three of the other five core locations. If the intermediate contaminant values were a result of chemical migration from mound to cap, an additional explanation for the isolated occurrence at the CTR station (i.e., no similar intermediate values were measured at CS-2 80NE) is required. The

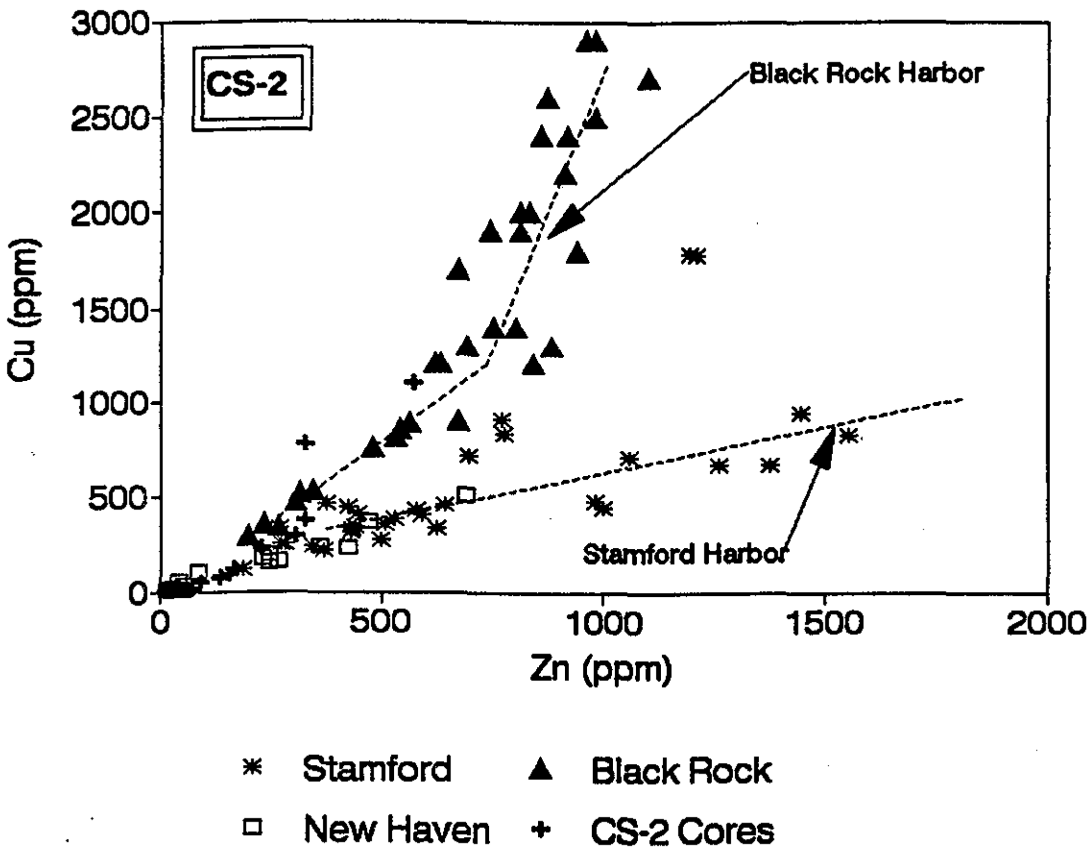


Figure 4-6. Zinc and Cu concentrations of sediments from Stamford, Black Rock, and New Haven Harbors, and core samples from Cap Site 2

most realistic possibility is that the material recovered at CS-2 CTR was New Haven cap material. The concentrations of contaminants were within the ranges of New Haven dredged material disposed elsewhere (e.g., Cap Site 1, Mill-Quinnipiac River).

One of the original concerns about the success of the capping project was that a silt cap would make cap/mound distinction difficult. However, cores from STNH-S showed very clear chemical and visual boundaries (Figure 4-4). Both metal and organic data show a bimodal distribution between the three samples taken from areas in the core documented in the visual core descriptions as being mound material of sediments from Stamford, Black Rock, and New Haven Harbors, and core samples from Cap Site 2 (160-200 cm at 60NE and 160-180 at CTR) and cap material (Figures 4-7). R^2 values are 0.841 at 60NE and 0.993 at CTR. This suggests that silt caps are just as effective at containing contaminants and may cause even less disturbance than sand caps deposited on silt.

4.3 Dredging Effects on Sediment Texture

The uniform texture and contaminant levels within the STNH-N cap may be, in part, due to the use of a hopper dredge (hydraulic) to collect and dispose of the coarse material from outer New Haven Harbor. STNH-N was deliberately constructed with a coarse cap, and the hopper dredge was used to produce an even coverage of material. During the hydraulic dredging process, the sediment texture is destroyed, and the pore waters and sediments (with adsorbed contaminants) are well mixed (Bohlen 1990). Sediments deposited using this dredging method might meet the general assumptions that cap material should have relatively low and uniform contaminant loading and texture (cap at STNH-N) and be distinct from the mound material, which would be expected to have relatively high and variable contaminant loading and texture.

A clamshell dredge (mechanical) was used for both the mound and cap at CS-2, the cap at STNH-S, and the mound at STNH-N. If there is any stratification or variation in texture and contaminant loading within the original deposit, mounds and caps formed with this type of dredging should not be expected to meet the general assumption of uniform contaminant loading and texture. If the original deposit is relatively uniform in texture or contaminant loading, the process of clamshell dredging may preserve this uniformity in mounds or caps (mound at STNH-S).

Applying this awareness of dredging processes to the data leads to a new set of hypotheses. With clamshell dredging, some of the stratification, texture, and contaminant distribution from the original deposit may be preserved and observed in long cores taken from disposal mounds and caps. Based on results from a grab sampling study, Morton and Karp (1980) suggested that localized heterogeneity in

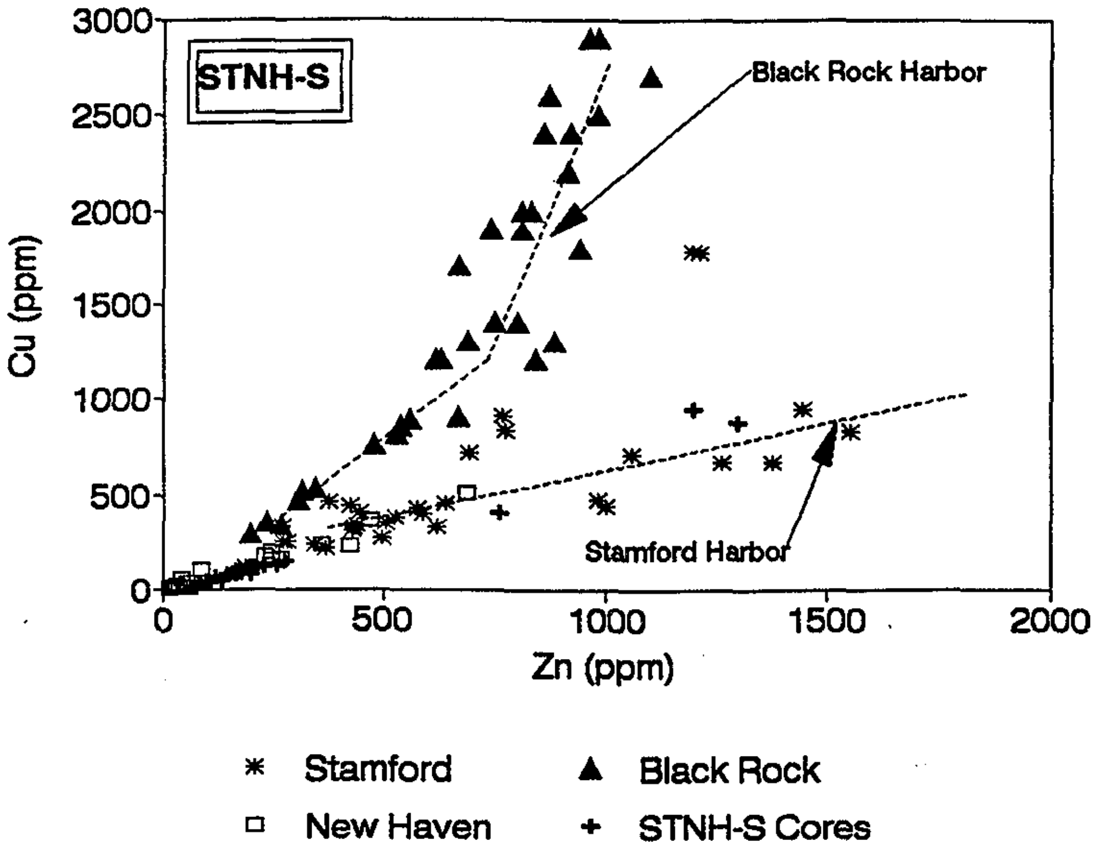


Figure 4-7. Zinc and Cu concentrations of sediments from Stamford, Black Rock, and New Haven Harbors, and core samples from Stamford-New Haven South

contaminant loading might be diagnostic of dredged material.

Since both the cap and the mound are composed of dredged material, any certainty that the interface between the cap and the mound will be distinct and easily recognizable visually or chemically is reduced. There may be several interfaces between successive barge loads. If the top of the disposal pile happens to contain the low end of the range of contaminants (i.e., deeper or coarser dredged material), and the first barge load of cap material happens to have the high range for this material (i.e., surface or finer dredged material), the interface may appear to be blurred or mixed. Therefore, it may be impossible to distinguish inherent variability from variability due to mixing during the disposal process.

For example, at CS-2 the transition area within core 80NE could be interpreted as a result of limited mixing of materials between the cap and the mound during deposition. However, it seems more likely that the top of CS-2 around this core originally consisted of a mixture of sand and shell which was mistaken for cap material. The potential for incorporation of coarse, relatively clean material into the mound material during the dredging operation is relatively high, given the nature of clamshell dredging operations. These results suggest that variation in contaminant levels within horizons and correlation of contaminants with sediment texture are not necessarily diagnostic criteria. Without further evidence to distinguish the cause, both conditions could result from mixing of cap and mound materials during disposal, from preservation of variability introduced during dredging, or from a combination of the two.

The criterion that is most likely to influence management decisions is the presence or absence of gradients of contaminants within the cap. Given the processes that govern the deposition of the dredged material, gradients would not be expected unless the contaminants were able to migrate from higher concentrations in the mound material up through the cap toward the lower concentrations at the sediment-water interface. If this hypothesis is the most crucial, future sampling of cores taken from capped mounds should target testing for the presence of chemical gradients. The absence of a correlation between sediment texture and contaminant levels would also be an indicator that contaminant mobilization may have taken place. This effort, while not practical for individual disposal projects, could be implemented as part of an organized research effort. If there is no evidence of gradients, or there is strong correlation between contaminant concentration and sediment texture, there may be no cause for further investigation. If evidence of gradients does exist, pore water sampling could confirm or exclude the hypothesis of contaminant mobilization and potential availability to the benthic ecosystem.

4.4 Capped Mound Coring Study: Conclusions

The coring investigation at CLIS was conducted to test several of the hypotheses formulated during the experimental capping projects at CLIS. Results indicated that

- Cores showed very clear chemical and visual boundaries, presumably between original mound and cap material;

- Silt caps deposited on silt mounds are apparently just as effective at containing contaminants as sand caps deposited on silt; and silt caps deposited on silt mounds may cause less disturbance than sand-on-silt;

- Clamshell dredging may preserve some of the stratification, texture, and contaminant distribution from the original deposit.

5.0 SUMMARY AND RECOMMENDATIONS

Based on monitoring results from the capped dredged material disposal mounds in the DAMOS Program, there has been no evidence of physical or chemical breaching of the cap. The history of DAMOS illustrates that capping is a viable method of contaminated dredged material management. Capping success depends on several factors that have been learned through experience over the course of the DAMOS Program. Quality control during every phase of capped mound formation is essential, as is effective monitoring.

The first capped mound projects, both Stamford-New Haven North and South (STNH-N and STNH-S) and Cap Site 2 (CS-2) were clearly the most successful of the early capped mounds. Bathymetric and REMOTS® data showed them to be thickly covered with capping material from the center to the flanks. Successful point-dumping of mound material and subsequent strategic placement of capping material at the top and flanks of the mound were accomplished with both a taut-wired, moored buoy and accurate navigational controls.

Long-term stability of the capped mounds has been tested during at least 12 years of monitoring and the passage of three hurricanes. There is some evidence that STNH-S may have experienced some erosion as a result of Hurricane David in 1979, although the hurricane's passage was coincident with the predicted exponential compaction phase. Additionally, recent coring data showed that a thick (at least 1.4 m) cap remained at this, and other, cored mounds. However, it is recommended that capping operations be planned to avoid peak storm periods so there is time for natural settlement and compaction.

Generally, Long Island Sound capped mounds have continued to show normal biological recolonization rates in subsequent monitoring. Sediment chemistry data showed that, after capping, surface sediment contaminants were at or below background concentrations. Recent coring data showed sharp visual and chemical boundaries in many of the cores.

More significantly, examination of the historical record of capped mounds that were not as successful provides equally important information for dredged material managers. For example, accurate placement of dredged sediments is less reliable without the use of both a taut-wired, moored buoy and precise navigation (partial offset of cap and mound occurred at CS-1 due to the lack of these two controls).

The Mill-Quinnipiac Rivers mound (MQR) provided perhaps the best evidence for the need to control operational factors and to monitor these mounds effectively. More recently, the MQR mound was used to test the tiered monitoring approach developed for DAMOS. Biological monitoring at MQR showed abnormal recolonization rates relative to the other CLIS sites. The disposal episodes, including sediments from the Mill and

Quinnipiac Rivers, and Black Rock and New Haven Harbors, were not conducted in distinct phases of mound and cap deposition. Also, recent coring data suggest that the cap material at MQR was mischaracterized. Both of these factors may have affected the observed recolonization rate at MQR.

The recent coring investigation at CLIS provided further evidence that caps are effective at isolating contaminants. Chemical and lithological data showed clear boundaries between cap and mound material in most of the recovered cores. Coring results also indicated that the dredging method used can affect the resulting heterogeneity of both the cap and mound deposits. Clamshell-dredged deposits, in particular, retained the sediment texture and chemical character of the pre-dredged sediment.

This historical review of the early years of capping and subsequent monitoring provides a checklist of recommendations for a successful capping project.

Pre-Operational Planning:

- Characterize the sediments which are proposed for disposal (this may include sediment chemistry and bioassay and/or bioaccumulation data); and classify the sediments using the best available information.
- Estimate the volumes of material to be disposed.
- Conduct site surveys, and choose a disposal area with lesser or no vulnerability to natural or anthropogenic (i.e., trawling) erosion.
- Schedule dredging and disposal operations so that mound and cap are completed well before the storm season to allow for consolidation and surface stabilization, to insure that the cap material can be disposed as soon as possible after mound material.

Disposal Operations:

- Use both precise navigational techniques and a taut-wired buoy for disposal of both cap and mound sediments.
- Point-dump mound material by directing the barge to unload as near to the buoy as possible.
- Dispose a portion of the cap sediments along the radius of the contaminated mound sediments.
- Maintain the pre-operational plan for mound deposition followed by cap deposition.
- Keep complete records of all disposal operations.

Monitoring:

- Monitor the surface contours of the capped mound to document any physical breaching or alteration.

- Compare the recolonization status of the benthic ecosystem on the surface of the capped mound to reference sites.

- Sample the capped mound, and analyze for contaminants of concern as updated methods and geochemical data for contaminated marine sediments become available.

- Develop a response program, similar to the Tiered Monitoring Program for DAMOS (Germano et al. 1994), for any problems that become apparent during monitoring.

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APPENDIX A

DAMOS Capping Model

DAMOS CAPPING MODEL

BACKGROUND

At present, the primary management tool used by the New England Division (NED) of the US Army Corps of Engineers in dealing with the disposal of contaminated dredged material in the marine environment is capping. Several capping experiments have been conducted in Long Island Sound to confirm and demonstrate the viability of this alternative to upland disposal of contaminated dredged material. In order to better manage the disposal of contaminated dredged material and the subsequent capping, regulators at NED required a simple model that could predict the configuration of a disposal mound and help estimate the amount of clean material needed to adequately cap the mound. Although models predicting the behavior of disposed dredged material already existed (Koh and Chang 1973, Brandsma and Divoky 1976), the level of complexity and the amount of information required to run them precluded their frequent use by managers. To provide a model that could be useful incorporating the theory and processes used in the above models, the DAMOS Capping Model was developed.

THEORY

The DAMOS Capping Model is based on two published reports (Koh and Chang 1973, Brandsma and Divoky 1976) dealing with the subject of dredged material disposal. These reports contain a complete mathematical description of the models operations and include extensive equations and formulas that will not be repeated here. Koh and Chang (1973) included of models describing the dilution and transport of dredged material under several discharge conditions:

1. simple overboard dumping;

2. jet discharged;

3. discharge into barge wake.

Brandsma & Divoky (1976) included descriptions of the first two cases above but also considered a number of different receiving water conditions typical of estuaries such as:

1. strongly stratified/salt wedge conditions;

2. two layer flow;

3. partially mixed estuary (vertically);

4. completely mixed estuary (vertically).

Both reports described the process of material settling to the bottom in distinct phases. The first phase, called **convective descent**, describes the dilution due to the momentum induced mixing resulting from the relative motion between the disposed material and receiving water. The second phase, called **dynamic collapse**, occurs when the material encounters a density gradient which, if strong enough, may prevent the material from settling further. Bottom encounter is a special case of the strong gradient and is the situation considered in the present capping model. The Koh and Chang (1973) report further considers a long-term passive dispersion/diffusion process for those cases when settling may be inhabited by a sufficiently strong density gradient in the water column.

DESCRIPTION OF CAPPING MODEL

In the present model, the goal was to draw on the work presented in the above reports and provide a management tool that would not require the user to have overly extensive background data, in the form of input parameters, to estimate the mound configuration of a hypothetical disposal project. As an example, while the models described above require input of the density gradient in the water column, this variable is not normally known at the time of the disposal operation and, therefore, a uniform density was assumed. This led to the conclusion that dumped material will eventually reach the bottom and the only gradient encountered will be the bottom. The model was also designed to run on any PC-compatible computer with a math coprocessor.

The phases of disposal, therefore, which were considered in the DAMOS Capping Model are the convective descent and bottom encounter. The two referenced reports derived essentially the same equations describing the phases with the exception of the expression for the velocity of the centroid of the collapsing cloud. The Brandsma and Divoky (1976) equations were used because they were thought to avoid numerical difficulties inherent in the Koh and Chang scheme.

There were many coefficients that occurred in the equations which are not normally measured and represented uncertainly in the model. In all cases, the recommended values from the above reports were used and the user is not required to input them. If the user has data that indicate different values for some of the coefficients, he may enter them into the model by editing the file DREDGE.D. This file, which contains model coefficients as well as fall velocities, *in situ* densities, and entrainment factors, is read each time the model is run. DREDGE.D may be edited with any word processor which will produce a pure ASCII text file.

The relationships which comprise the model form a system of simultaneous differential equations for each of the two phases considered. These are solved using a forth order Rung-Kutta scheme. There are three differential equations in the connective descent phase representing conservation of mass, momentum, and buoyancy. The above reports also include conservation of vorticity and solid particles; however, in the absence of a vertical density gradient, the change in vorticity reduces to zero. Koh and Chang (1973) argued that settling of particles from a falling cloud may be ignored as long as the cloud and particles are going in the same direction. During the dynamic collapse phase, the number of simultaneous differential equations was increased to eight. In addition to the conservation of mass and buoyancy, there were four equations for the conservation of solid particles (one for each grain size class considered for the capping model), one for the rate of change of the tip of the cloud expanding on the bottom, and one for the dynamic formation of the sediment cloud as a slice of a half and ellipsoid. The initial conditions for the convective descent phase were estimated from barge dimensions, while conditions for the dynamic collapse are estimated from values at the last step of the connective descent phase.

Based on the considerations described above the capping model was designed to allow input of the important parameters available to the user. The input screens of the model list the parameters needed by the user to operate the model. These include:

- material properties;
- material volume;
- *in situ* bulk density;
- radius of operations;
- physical oceanographic parameters.

The geotechnical properties of the dredged material are usually supplied by the permittee along with the estimated volume of material to be dredged and the approximate size of the individual scow. The *in situ* bulk density of the sediment to be dredged is required to convert the volume of the material to mass to insure the conservation of mass all the way to the disposal point. The *in situ* densities can range from 1300-1600 kg/m^3. The radius of operations can be estimated by the user based on past performance by the dredging contractors, whether a taut-moored buoy is in place and whether the barge and scow are actually stopped at the buoy prior to disposal. The physical oceanographic parameters are very general descriptions of the disposal site location. The ambient water density is assumed to be constant throughout the entire water column. Because the model assumes that no density gradient occurs to prevent the dredged material from reaching the bottom, this value has little effect on the results of the model. An average sigma-t value for Long Island Sound is around 20. The depth of the site is very important to these results, however, because it controls the time required for the material to reach the bottom and, subsequently, this time period affects the size of the material "cloud" upon impact with the bottom. The mean bottom current does not significantly affect the results of the model at the depths normally encountered in New England because the descent time is so short. Any offset of the material during descent due to currents would be small.

Another consideration for the present model was that the impact of multiple dumps of material should be estimated. In order to accomplish this, a scheme for randomly placing the barge within the user-input radius of operations was developed. The capping model incorporates two mathematical random number generators. The first generates a uniform random variate within the range 0.0 to 1.0. The second random variate generator uses the first and produces a normally distributed variate with zero mean and unit internal clock to initiate the random number generators. Two different algorithms for calculating the position were run to determine which was most representative of actual conditions. The first generated positions whereby any point within the radius of operations is a likely as any other (Figure 1a), while the second distributed positions uniformly along a radius from the center operation (Figure 1b). These algorithms were run for a large number (e.g. 2500) of calculated dump positions and plotted. In Figure 1a, any dump position is as likely as any other. This pattern was obtained by generating a north coordinate and a corresponding east coordinate uniformly distributed within the radius of operations. If the resulting distance from the center of operations was greater than the radius of operations, the position was rejected. The process was repeated until a satisfactory position was returned. This distribution of disposal locations is used for capping operations to provide an even layer of cap material over the entire radius of operations. The pattern in Figure 1b was obtained by generating a radial distance uniformly distributed from zero and the radius of operations. An azimuth is generated uniformly between zero and 360 degrees. The resulting position is guaranteed to be located within the radius of operations. However, the pattern is considerably center-weighted which most likely simulates the positions of scows during normal disposal operations. The watch circle of the disposal buoy would allow scows to sometimes occupy the center of the disposal area. Because the scow operators are attempting to occupy a position as close to the center as possible, the center-weighed distribution seems appropriate.

The model output is presented in the form of a two or four page report (depending on whether the run is capping or disposal) and is generally based on the sum of many barge loads of material distributed in space as described above. Figure 2 shows the distribution of a typical single load of disposed material in shallow water (<100 meters) for which this model is designed. It can be seen that the distribution of material is flat near the center of the mound. This is because in the shallower depths, there is not enough time for the receiving water to penetrate into the center of the load of material and dilute the sediment concentration. The overall guassian appearance, which is typical of a multiple-barge load operation, is due to the smoothing effect of many mounds located at different positions and overlapping.

In addition to the user inputs provided during the model operation, several coefficients and factors are provided in the text file **DREDGE.D** and can be changed if better values are obtained. The entrainment, apparent mass, drag, and skin friction coefficients, as well as the fall velocities, were obtained from Koh and Chang (1973). The *in situ* densities at the disposal site (set at an average of 1400 kg/m^3) can be changed to reflect results from previous dredged material disposal operations. The entrainment factors (H-FCT and C-FCT) represent the amount of water added to the scow during dredging operations, with the hopper dredge entraining more then the clamshell dredge. In order to allow the user to expand the scale of the grid printouts for cases where the cap material may extend beyond the edge of a grid defined by a small disposal run, P-FCT can be increased. Finally, if the attached printer does not support graphics, the centerline plots can be eliminated from the output be entering **NO** on the last line of the file.

The most recent addition on the DAMOS Capping Model is the estimation of erosion at a disposal mound. The EPA Equation Workbook Scientific Protocol for Ocean Disposal Site Designation was used to develop algorithms for indicating the amount of loss of sediment at a disposal mound over a fixed period of time. The overall sediment transport rate was determined from the mean net bottom drift and the wave-induced bottom velocity. Methods are presented to predict the frequency of storms capable of resuspending sediment at a disposal site. Using these equations, however, resulted in large losses of material over short periods of time that were unrepresentative of the mounds studied under the DAMOS program. These inconsistencies seemed to be the direct result of the volumetric sediment transport rate versus mean flow relationship used in the Equation Workbook.

SUMMARY

The present version of the DAMOS Capping Model adequately provides the tool needed by managers at NED to predict the configuration of a disposal mound and estimate the amount of capping material required to isolate any containments in that mound. Assumptions made in developing this model were necessary to reduce the input parameters required of the user and, therefore, to facilitate its use on any PC-compatible computer. As more accurate information is obtained from tightly controlled disposal operations and mass balance experiments, the model may be refined to better reflect these results.

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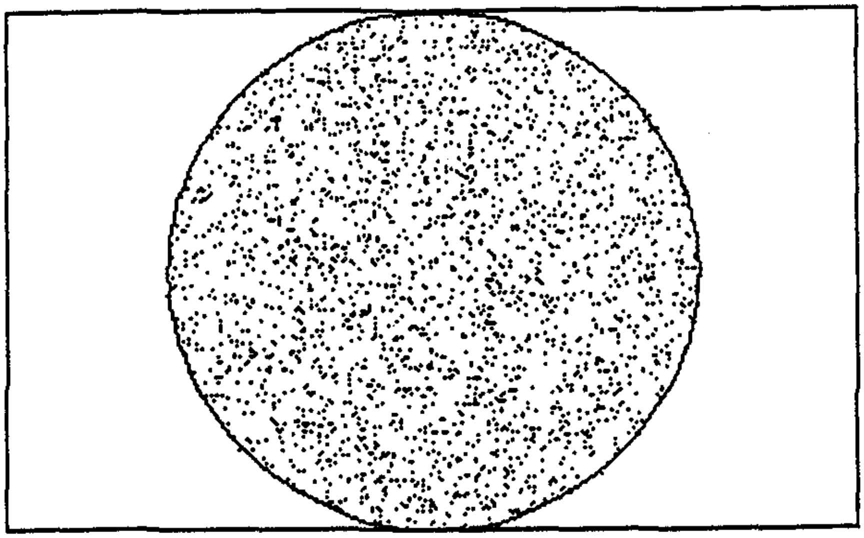
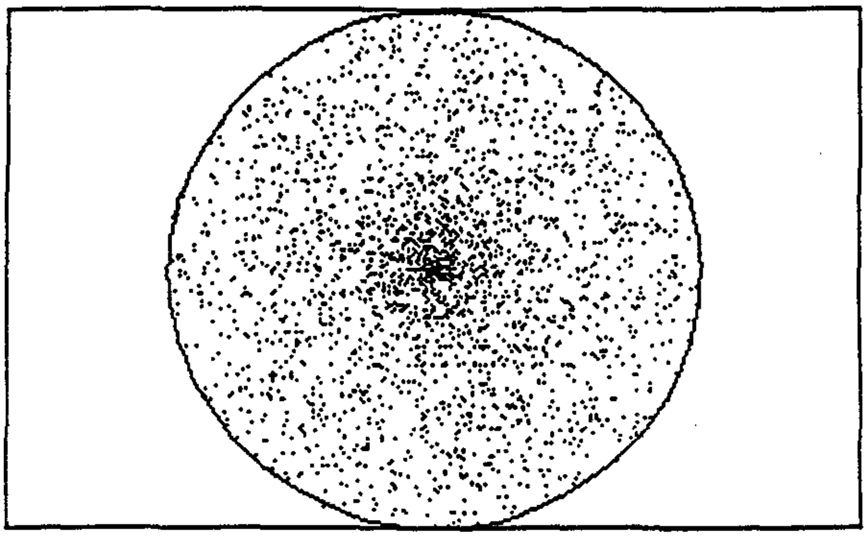


A. Uniform disposal pattern.



B. Uniform pattern along a radius.

Figure 1. Results of algorithms to produce a random distribution of barge dump loads. Circle represents radius of operations.

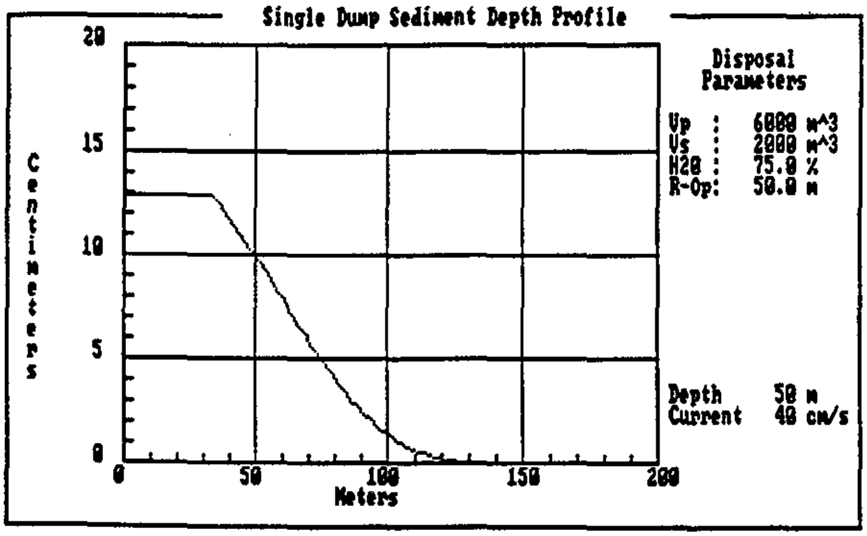


Figure 2. Single barge load disposal mound profile.

APPENDIX B

STNH Disposal Monitoring Plan

DISPOSAL MONITORING PLAN
STAMFORD-NEW HAVEN HARBOR MAINTENANCE DREDGING

SUMMARY

The New England Division of the Corps of Engineers will conduct maintenance dredging of the Stamford and New Haven channels during the spring of 1979. This will involve the removal of 76,000 yd^3 of fine-grained material from Stamford, 169,000 yd^3 of lithologically similar but cleaner material from New Haven and 65,000 yd^3 of sand from New Haven. Since Stamford spoils have higher concentrations of heavy metal contaminants than the New Haven material a disposal plan has been devised to cover the Stamford material with that dredged from New Haven. Disposal of spoil from both harbors will take place sequentially in the Central Long Island Sound disposal area. A monitoring study for this operation has been designed to address the potential environmental impacts resulting from disposal and evaluate the effectiveness of the capping operation.

The consultants employed by the Corps of Engineers view this project as an opportunity to address some questions relative to the suitability of capping as an operational procedure. The Stamford material will be disposed of at two points to provide for comparisons between sand and mud capping procedures. One deposit will be covered with fine-grained materials dredged from inner New Haven Harbor, and the other pile will be covered with sand from the outer channel of New Haven Harbor. The monitoring program will address the physical aspects of the capping operation, and evaluate its effect on the biological community.

Physical measurements will assess the effectiveness of capping fine-grained contaminated spoils with both fine and coarse grained material. The success of the capping procedure must be defined by a determination of the extent to which covering of contaminated spoils has been accomplished and therefore requires an ability to distinguish between spoils from both locations. Such a determination may be extremely difficult, particularly where spoils of similar lithology are concerned. Several approaches to this problem will be used including comparison of bathymetric data obtained prior to disposal, after disposal of Stamford spoil and after disposal of New Haven spoil to ascertain the distribution of material and to measure volumes of spoil present at the disposal points. Divers will obtain cores from specific stations established on a logarithmic sample spacing. The cores will be used to measure heavy metal contents for determination of contaminated/versus clean spoil distribution. Visual observations of the bottom and measurement if spoil thickness will be made at each of these stations.

Biological monitoring will examine the effectiveness of sand versus mud capping in preventing burrowing organisms from contacting buried containments. The body burden of species colonizing the mud and sand-capped mounds and species from the natural bottom surrounding the disposal sites will be compared. The program will include characterization of body burden relative to (1) life history of the organism i.e., pioneering (group 1) versus stable (group 3) species; (2) heavy metal concentration or, if possible, pollutant flux in the sediment; and (3) the effects of exposure to pollutants over an extended period of time. A

program to study transfer and concentration at higher levels in the food chain will be introduced if significant body burdens are encountered.

DISPOSAL OPERATIONS PROCEDURES

Several requirements must be imposed in the disposal operation to enhance the probability of successful data acquisition. Most of these requirements are designed to increase the precision of disposal (and therefore the potential for successful capping) because the volumes of material under consideration in this project are so small. Prior to initiation of dredging, two buoys will be installed at the points designated for disposal. The buoys will be set on taut-wired moorings which will restrict their motion to radii of less than 10 meters. Disposal will occur 25 meters south of these buoys. The tug will bring the scow alongside whenever possible and disposal will always occur with the scow headed against the current. If the scow must remain underway due to weather condition, the dump will be made in two passes with the scow dumping the inside sections on one pass and fore and aft compartments on the second pass. Two-thirds of the Stamford material will be dumped south of the south buoy. The remainder will be dumped south of the north buoy.

All of the mud from New Haven will be dumped at the south site using the same disposal procedures upon completion of the Stamford portion of the project. The sand from New Haven will be dredged and similarly dumped south of the north buoy to complete the project.

PHYSICAL AND CHEMICAL MEASUREMENTS

Bathymetric surveys will be made using a state of the art Bathymetric Data Acquisition System (BDAS) to determine condition, spoil distribution following disposal of Stamford material, spoil distribution following disposal of New Haven material and subsequent changes in distribution with time. Surveys will be made prior to initiation of dredging with 25 meter lane spacing over 600 x 600 meter areas centered at the designated disposal points. The surveys will provide baseline data for calculations used for the construction of spoil distribution charts and volume determinations. Future surveys will be run over the same transects used to develop the baseline data with a horizontal precision of $\pm$5 meters, and vertical profiles will be measured to ascertain the presence of spoil material. Contour charts and depth difference charts will be developed after each survey to determine the location and thickness of spoil deposits, and volume calculations will be made to determine the amount of spoil material at the disposal locations.

The 24 kHz fathometer system employed by the BDAS system will be supplemented by a dual frequency fathometer utilizing both a 300 kHz transducer for precision surface determination, and a 7.5 kHz transducer for sub-bottom penetration. This system may be particularly useful in measuring the coverage of spoils on the sand pile but may have restricted use in evaluating the mud capping.

The bathymetric data will provide important information on the areal distribution of spoils and will be the only information to ascertain the volumes of material present. These data will also provide information as to where sampling should be conducted to obtain samples of organisms living on the spoils. The bathymetric data will not yield information on whether clean spoils have been capped, intermixed with or displaced underlying material. The resolution of acoustic data is not sufficient to delineate the margins of the spoil mounds. *In situ* observation and samples taken by divers will supplement the remote measurements.

The major problem associated with diver operations is navigation control. Limited visibility and the lack of undersea to surface communications hamper diving studies in New England waters, interfering with precision or replicate sampling procedures. This problem will be solved by using microwave navigation equipment to deploy a wire on the bottom. The wire will be 400 meters long and centered 25 meters south of the disposal buoy designated for the mud-capped pile. This wire will be oriented east-west and will have polypropylene line spliced at specific distances from the middle to designate sample locations based on a logarithmic distribution.

These sample locations will be spaced at distances of 25, 29, 36, 47, 64, 92, 136, and 206 meters from the middle of the wire. At each location a calibrated stake will be installed to anchor the wire and provide a means of measuring sediment accumulation.

Two additional stations near the ends of the wire will be sampled by spot dives as controlled by the navigation system. At these distances changes in the distribution of spoils should be minimal and precise replication of sample stations less important.

An acoustic release and pinger will be placed at the 206 meter station and divers will start at this location and swim towards the center. At each station three 20 cm cores will be obtained for heavy metal analysis; visual observations of the sediment stakes will be obtained and photographs taken.

The wire itself may act as a measure of spread of the spoils inasmuch as the margin of the mound may be identified by the proportion of the wire that is covered. The stakes and the polypropylene line should enable divers to ascertain sample locations as they approach the disposal point location despite cover of the wire.

Sampling and analysis for metal content of the cores obtained by the divers appears to be the most definitive approach to determining the extent of coverage, intermixing, or displacement of Stamford spoils by New Haven material.

Grab samples for chemical analysis taken from on board ship will be obtained at distances farther removed form the disposal points.

Twenty eight separate diver stations at the mud-capped site will require at least two days to sample because of distances that must be travelled and restrictions on bottom time in repetitive dives. Fewer samples should be required at the sand site to define the sediment cover because of the small amount of materials involved and their sharp lithological differences.

A single wire marking an E-W transect across the sand pile will be deployed with four stations at 25, 30, 40, and 60 meters on each side of the center. Two other stations at distances of 100 m from the disposal point will be sampled with spot dives. Three cores and all other observations made at the mud-capped pile will be made for each station at this site as well. Remote sampling will also be obtained for comparisons and background data.

Additional physical and chemical monitoring will be continued on a semiannual basis as part of the ongoing DAMOS program. Detailed bathymetric surveys will be continued to assess long term changes in spoil distribution and diver obtained samples will be repeated at a reduced number of stations depending on the effectiveness of capping obtained. Any future changes in the monitoring program would also be a function of the results of this study.

BIOLOGICAL MONITORING

The major thrust of the biological monitoring program will be the study of body burdens of species colonizing the spoil mounds and the surrounding sea floor. During the first year following disposal of the dredge spoil, samples will be taken monthly from April through October to obtain sufficient numbers of animals to obtain heavy metal body burdens from both spoil mounds and the surrounding bottom. It is anticipated that the baseline data obtained in March 1979 will consist primarily of stable, deep burrowing, long-lived species with few opportunistic group 1 individuals. An epibenthic sled will be used to attempt to obtain sufficient samples of these species for analysis. This device cannot be used, however, on the spoil mounds.

Smith-McIntyre grab samples will be taken after disposal to obtain organisms from the spoil mounds. There will be periods where group 1 or group 3 species may be rare on the disposal mounds and, consequently, insufficient biomass may be available for analysis. This is a natural function of the repopulation process and cannot be avoided. Samples will be sieved on board in order to insure sufficient biomass whenever possible.

The organisms obtained from the disposal mounds and surrounding bottom will be categorized into group 1, 2, or 3 species and body burden analysis will be done on a species by species basis or, if insufficient numbers are available, within similar groups. Comparison of body burdens between the occupants of the deposits and natural bottom, between species groups, and relative background levels will be made. Box cores of both spoils mounds and the bottom will be made in August to determine the extent of burrowing and to measure the flux of pollutants into the water column. Problems may occur in determining the net flux of the mud-capped mound if sample to sample variability is high. Additional cores to evaluate flux of heavy metals will also be made at the completion of the disposal operation in October.

The second year of monitoring will repeat the sampling procedures of the first year on a bimonthly basis, stressing the body burden of group 3 species and evaluating the effect of bioturbation of the effective protection of the capping material. Studies of contaminant uptake of higher trophic forms feeding on the infauna of the disposal mounds will be preformed if required, depending on the results of the body burden measurements.

Additional studies relative to the biological effects of the disposal operation will include the maintenance of a mussel cage on the vicinity of the disposal locations to monitor uptake of contaminants from suspended material, and installation of a lobster trawl immediately east of the disposal area to evaluate changes in the catch that may result from the disposal operation.

Data and results of the monitoring program will be made available to the consultants as soon as possible and presented to the public in report format. A summary of the first year's work should be available ton final form by December 1979. Subsequent work will be published as part of the DAMOS reporting procedures.

APPENDIX C

DAMOS Activity Matrix and List of DAMOS Contributions

APPENDIX C
Explanatory Notes

The following matrices summarize DAMOS activities at the CLIS disposal mounds discussed in the text. The matrices are listed according to the initial disposal date.

Several sediment grab studies have been conducted through the DAMOS Program. These have been summarized into three categories:

- Physical: Sediment description and/or grain size analyses.
- Chemical: Chemical analyses of sediments for organic and/or inorganic constituents.
- Benthic: Includes both benthic community and body burden (tissue chemical analyses) studies.

Some notes on Additional Studies:

- Diver observations often include bottom photographs.
- Coring studies usually incorporate physical and/or chemical sediment analyses.
- Descriptions for many special studies (e.g., DAISY, mussel cages) can be found within the text.

DAMOS Contributions are published by the New England Division (NED) of the U.S. Army Corps of Engineers. DAMOS Contributions listed in the Activity Matrix provide additional information for each survey. A list of published DAMOS Contributions follow the Activity Matrix.

The following Activity Matrix reference notes have not yet been published:

(1) DAMOS Annual Report, 1985-1990. SAIC Report No. SAIC-91/7610 & C97. Submitted.

(2) Monitoring Cruise at the Central Long Island Sound Disposal Site, June 1991. SAIC Report No. SAIC-92/7621 & C100. Submitted.

(3) Murray, 1992 (see References).

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE								
Stamford - New Haven South (STNH-S)								
DATE	PURPOSE OF SURVEY	BATHYMETRY		REMOTS®	SEDIMENT GRAB STUDIES			ADDITIONAL STUDIES	CONTRIBUTION NUMBERS
		Size[1]	Lane[2]	# of Stations	Physical	Chemical	Benthic		
1/79	Pre-Disposal	600	25				●	Side Scan survey	1,17
3/79	Interim Stamford	600	25		●	●	●		1,17
4/79	Post-Stamford	600	25			●			3,11,17
6/79	Interim Capping	575	25		●	●		Coring, Diver observations	5,11,17
8/79	Post-Capping	575	25		●	●	●	Diver observations	6,13,46
11/79	Post-Hurricane David	575	25		●	●			7,11,17,46
12/79	Post-Hurricane David					●	●		17,46
4/80	Interim Capping	500	25		●	●	●	Mussel cages (20,22)	12,13,14,17
6/80	Post-Capping	800	25						17
9/80	Monitoring	800	25		●	●	●		17,46
1/81	Monitoring	800	25		●	●			17,46
1/82	Monitoring	800	25			●		Diver observations	46

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE									
Stamford - New Haven South (STNH-S)									
DATE	**PURPOSE OF SURVEY**	**BATHYMETRY**		**REMOTS®**	**SEDIMENT GRAB STUDIES**			**ADDITIONAL STUDIES**	**CONTRIBUTION NUMBERS**
		Size[1]	**Lane[2]**	**# of Stations**	**Physical**	**Chemical**	**Benthic**		
8/82	Monitoring	800	25		●	●			46
12/82	Monitoring	800	25		●	●		Diver observations	46
1/83	Monitoring			11					46
8/83	Monitoring	All of CLIS	50	11	●	●			29,46
4/84	Post-Storm	800	25				●		46
9/84	Monitoring	All of CLIS	50	11	●	●		Coring	46,57
8/85	Monitoring	800	25	17				Diver observations	57
10/85	Post-Hurricane Gloria	800	25						57,63
11/85	Post-Hurricane Gloria			10	●	●			57,63
7/86	Monitoring	800	25	17				Coring	63,(1)
8/87	Monitoring			19				CTD/Dissolved oxygen	68,(1)
7/90	Investigation							Coring	This Volume

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE								
Stamford - New Haven North (STNH-N)								
DATE	PURPOSE OF SURVEY	BATHYMETRY		REMOTS®	SEDIMENT GRAB STUDIES			ADDITIONAL STUDIES	CONTRIBUTION NUMBERS
		Size[1]	Lane[2]	# of Stations	Physical	Chemical	Benthic		
3/79	Pre-Disposal	600	25		●	●	●		1,17
4/79	Interim Stamford					●			1,17
5/79	Post-Stamford	600	25		●	●	●	Diver observations	4,11,17
6/79	Interim Capping	575	25		●	●		Coring, Diver observations	5,11,17
8/79	Post-Capping	575	25		●	●	●	Diver observations, Erosion stakes	6,17,46
11/79	Post-Hurricane David	600	25						7,46
4/80	Monitoring	600	25		●	●	●	Mussel cages (20,22)	13,14,17,20,24
9/80	Monitoring	600	25		●	●			17,46
1/81	Monitoring	600	25		●	●	●		17,46
1/82	Monitoring	600	25		●	●		Diver observations	46
2/82	Monitoring						●		46
8/82	Monitoring	800	25		●	●			46

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE									
Stamford - New Haven North (STNH-N)									
DATE	PURPOSE OF SURVEY	BATHYMETRY		REMOTS®	SEDIMENT GRAB STUDIES			ADDITIONAL STUDIES	CONTRIBUTION NUMBERS
		Size[1]	Lane[2]	# of Stations	Physical	Chemical	Benthic		
12/82	Monitoring	800	25		●	●		Diver observations	46
1/83	Monitoring			9					46
8/83	Monitoring	All of CLIS	50	9	●	●			29,46
4/84	Post-Storm	800	25						46
9/84	Monitoring	All of CLIS	50	9	●	●			46,57
8/85	Monitoring	800	25	17				Diver observations	57
10/85	Post-Hurricane Gloria	800	25						57
11/85	Post-Hurricane Gloria			10	●	●			57
7/86	Monitoring	800	25	17	●	●	●	Coring	63,(1)
7/90	Investigation							Coring	This Volume

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE									
Norwalk (NOR)									
DATE	PURPOSE OF SURVEY	BATHYMETRY		REMOTS®	SEDIMENT GRAB STUDIES			ADDITIONAL STUDIES	CONTRIBUTION NUMBERS
		Size[1]	Lane[2]	# of Stations	Physical	Chemical	Benthic		
4/80	Pre-Disposal	700	25		●	●	●	Diver observations, Mussel cages (20,22)	13,14,17,24
6/80	Interim Disposal	700	25					Diver observations	14,17
9/80	Interim Disposal	720	25						17
1/81	Interim Disposal	800	25		●	●	●		17,46
4/81	Post-Disposal	800	25		●	●		Diver observations	15,46
8/81	Post-Capping	800	25		●	●	●		24,46
1/82	Monitoring	800	25		●	●	●		46
8/82	Monitoring				●	●	●		46
12/82	Monitoring	800	25		●	●			46
1/83	Monitoring			9			●		46
8/83	Monitoring	All of CLIS	50		●	●			29,46
9/84	Monitoring	All of CLIS	50	9	●	●			46,57

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE									
Norwalk (NOR)									
DATE	PURPOSE OF SURVEY	BATHYMETRY		REMOTS®	SEDIMENT GRAB STUDIES			ADDITIONAL STUDIES	CONTRIBUTION NUMBERS
		Size[1]	Lane[2]	# of Stations	Physical	Chemical	Benthic		
8/85	Monitoring	800	25	17					57
7/86	Monitoring	800	25	17	●	●			63,(1)

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE								
Mill - Quinnipiac River (MQR)								
DATE	PURPOSE OF SURVEY	BATHYMETRY		REMOTS®	SEDIMENT GRAB STUDIES			ADDITIONAL STUDIES	CONTRIBUTION NUMBERS
		Size[1]	Lane[2]	# of Stations	Physical	Chemical	Benthic		
3/82	Pre-Disposal	800	25		●	●		Diver observations	25,46
4/82	Post-Mill River	800	25		●	●		Side Scan survey, Diver observations	25,46
6/82	Post-Quinnipiac River	800	25		●	●			25,38,46
8/82	Post-Disposal	800	25						25,38,46
9/82	Post-Disposal							Diver observations	25,46
12/82	Pre-Black Rock/New Haven Harbors	800	25		●	●		Diver observations	25,38,46
1/83	Pre-Black Rock/New Haven Harbors			13					46
5/83	Interim Capping	800	25		●				25,29,38,46
6/83	Post-Capping				●	●			38,46
8/83	Post-Capping	All of CLIS	50	13					29,46,57
9/84	Post-Storm	All of CLIS	50	13	●	●			46,57

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE									
Mill - Quinnipiac River (MQR)									
DATE	PURPOSE OF SURVEY	BATHYMETRY		REMOTS®	SEDIMENT GRAB STUDIES			ADDITIONAL STUDIES	CONTRIBUTION NUMBERS
		Size[1]	Lane[2]	# of Stations	Physical	Chemical	Benthic		
8/85	Monitoring	800	25	12					57
10/85	Post-Hurricane Gloria	800	25	10					57
7/86	Monitoring	800	25	17	●	●	●	Coring	63,(1)
8/87	Monitoring			21	●			CTD/Dissolved oxygen	68
6/91	Monitoring			13					(2)
8/91	Investigation							Coring	(3)
12/91	Monitoring				●	●			(3)
8/92	Monitoring			21					In preparation

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE								
Field Verification Program (FVP)								
DATE	**PURPOSE OF SURVEY**	**BATHYMETRY**		**REMOTS®**	**SEDIMENT GRAB STUDIES**			**ADDITIONAL STUDIES**	**CONTRIBUTION NUMBERS**
		Size[1]	**Lane[2]**	**# of Stations**	**Physical**	**Chemical**	**Benthic**		
3/82	Baseline				●	●		Depth profiles	23,25,38
4/82	Baseline	800	25					DAISY, *Side Scan survey*	23,25,38
6/82	Baseline				●	●		Side Scan survey, Diver observations	25,38
8/82	Baseline			51				Diver observations	23,32,38
12/82	Pre-Disposal	800	25					Diver observations, Water column sampling	25,38
2/83	Pre-Disposal							*Mussel cages*	25
4/83	Interim	800	25						25,46
5/83	Post-Disposal	800	25	72	●			Water column sampling, Side Scan survey	25,46
6/83	Post-Disposal	800	25	34				Coring	38,46
7/83	Post-Disposal	800	25	14					29,32,38
8/83	Post-Disposal	800	25	20				DAISY	29,32
9/83	Post-Disposal				●	●		EPA sampling	38

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE								
Field Verification Program (FVP)								
DATE	PURPOSE OF SURVEY	BATHYMETRY		REMOTS®	SEDIMENT GRAB STUDIES			ADDITIONAL STUDIES	CONTRIBUTION NUMBERS
		Size[1]	Lane[2]	# of Stations	Physical	Chemical	Benthic		
3/84	Monitoring	800	25						46
4/84	Post-Storm	800	25						46
9/84	Post-Storm	All of CLIS	50		●	●			46
3/85	Monitoring	800	25	21					47,52
6/85	Monitoring			21					49,52
8/85	Monitoring	All of CLIS	50					Diver observations	57
10/85	Post-Hurricane Gloria	800	25	21					52
7/86	Monitoring	800	25	21	●	●	●	Coring	63
8/87	Monitoring			21			●	CTD/Dissolved oxygen	68
6/91	Monitoring			13					(2)

1 Length of survey lane in meters   2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE									
CAP SITE 1 (CS-1)									
DATE	**PURPOSE OF SURVEY**	**BATHYMETRY**		**REMOTS®**	**SEDIMENT GRAB STUDIES**			**ADDITIONAL STUDIES**	**CONTRIBUTION NUMBERS**
		Size[1]	**Lane[2]**	**# of Stations**	**Physical**	**Chemical**	**Benthic**		
4/83	Pre-Disposal	800	25	11	●	●		Side Scan survey, Diver observations	25,32,38,46
4/83	Post-Black Rock Harbor	800	25					Density probe, Diving observations	25,29,32,38,46
6/83	Post-Capping	800	25	29	●	●		Side Scan survey, Erosion stakes	32,38,46
7/83	Post-Capping							Side Scan survey, Coring	33,38,46
8/83	Monitoring	800	25	11					29,32,38
10/83	Monitoring							Density probe	29,32,33,38
4/84	Post-Storm	800	25						46
9/84	Post-Storm	All of CLIS	50	11	●	●			46,57
8/85	Monitoring	800	25	17				Diver observations	57
10/85	Post-Hurricane Gloria	800	25	10					54,57
7/86	Monitoring	800	25	17	●	●	●	Coring	63,(1)
7/87	CLIS-86 Survey		25						68

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE									
CAP SITE 1 (CS-1)									
DATE	**PURPOSE OF SURVEY**	**BATHYMETRY**		**REMOTS®**	**SEDIMENT GRAB STUDIES**			**ADDITIONAL STUDIES**	**CONTRIBUTION NUMBERS**
		Size[1]	**Lane[2]**	**# of Stations**	**Physical**	**Chemical**	**Benthic**		
7/88	CLIS-86 Survey		25						72
6/91	Monitoring			13					(2)

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE									
CAP SITE 2 (CS-2)									
DATE	**PURPOSE OF SURVEY**	**BATHYMETRY**		**REMOTS®**	**SEDIMENT GRAB STUDIES**			**ADDITIONAL STUDIES**	**CONTRIBUTION NUMBERS**
		Size[1]	**Lane[2]**	**# of Stations**	**Physical**	**Chemical**	**Benthic**		
4/83	Pre-Disposal	800	25	11	●			Diver observations	25,32,38,46
4/83	Interim	800	25					Density probe	25,32,38,46
5/83	Interim				●			Side Scan survey	25,38
6/83	Post-Capping	800	25	29	●	●		Side Scan survey, Diver observations	29,32,38,46
7/83	Post-Capping							Side Scan survey, Coring	33,38
8/83	Monitoring	800	25	11				Diver observations	29,32,38,46
10/83	Monitoring							Density probe	29,32,33,38
4/84	Post-Storm	800	25						46
9/84	Post-Storm	All of CLIS	50	11	●	●			46,57
8/85	Monitoring	800	25	17				Side Scan survey, Diver observations	57
10/85	Post-Hurricane Gloria	800	25	10					57
7/86	Monitoring	800	25	17	●	●	●	Coring	63(1)

1 Length of survey lane in meters 2 Lane spacing in meters

DAMOS ACTIVITY MATRIX FOR CAPPED MOUNDS AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE								
CAP SITE 2 (CS-2)								
DATE	**PURPOSE OF SURVEY**	**BATHYMETRY**		**REMOTS®**	**SEDIMENT GRAB STUDIES**			**ADDITIONAL STUDIES**	**CONTRIBUTION NUMBERS**
		Size[1]	**Lane[2]**	**# of Stations**	**Physical**	**Chemical**	**Benthic**		
7/87	CLIS-86 Survey		25		●				68
7/88	CLIS-86 Survey		25						72
7/90	Investigation							Coring	This Volume

1 Length of survey lane in meters 2 Lane spacing in meters

LIST OF DAMOS CONTRIBUTIONS
(through 12/94)

NUMBER	TITLE	DATE
No. 1	Stamford/ New Haven Disposal Operation Monitoring Survey Report - Baseline Surveys	1979
No. 2	Stamford/New Haven Disposal Operation Monitoring Survey Report - 20,000 yd^3 Increment	1979
No. 3	Stamford/New Haven Disposal Operation Monitoring Survey Report - 50,000 yd^3 Southern Site, 10,000 yd^3 Northern Site	1979
No. 4	Stamford/ New Haven Disposal Operation Monitoring Survey Report-Completion of Stamford Disposal	1979
No. 5	Stamford/New Haven Disposal Operation Monitoring Survey Report-Post Disposal Surveys	1979
No. 6	Stamford/ New Haven Disposal Operation Monitoring Survey Report-Post Disposal Monitoring	1979
No. 7	Stamford/New Haven Disposal Operation Monitoring Survey Report	1980
No. 8	Management and Monitoring of Dredge Spoil and Capping Procedures in Central Long Island Sound	1980
No. 9	Chronological Records of *In Situ* Physical and Biological Conditions Obtained by Diver Survey at CLIS and New London	1980
No. 10	Changes in the Levels of PCB's in *Mytilus edulis* Associated with Dredge Spoil Material	1980
No. 11	"Capping" Procedures as an Alternative Technique to Isolate Contaminated Dredge Material in the Marine Environment	1980
No. 12	Precision Disposal Operations Using a Computerized LORAN-C System	1980

NUMBER	TITLE	DATE
No. 13	Disposal Area Monitoring System Progress Report March 15- May 15, 1980	1980
No. 14	Disposal Area Monitoring System Progress Report May 15 - July 30, 1980	1980
No. 15	Precision Bathymetry, Diving Observations and Sediment Description - Norwalk Disposal Area Operation Monitoring Survey Reports Post Disposal Surveys, April 1981	1981
No. 16	Deployment of Dredged Material Disposal Buoys at the Central Long Island Sound and Western Long Island Sound Disposal Sites	1982
No. 17	Disposal Area Monitoring System Annual Report, 1980	1980
No. 18	Interim Survey of Western Long Island Sound III Disposal Site	1982
No. 19	Baseline Survey of the Proposed WLIS III Dredged Material Disposal Site	1982
No. 20	Damos Mussel Watch Program: Histological Studies of Mussels from Dredged Material Disposal Sites	1984
No. 21	Mussel Watch Program - New London Disposal Site Monitoring Projects - 1977-1979	1982
No. 22	DAMOS Mussel Watch Program: Monitoring of the "Capping" Procedure Using *Mytilus edulis* at the Central Long Island Sound Disposal Site; 1980-81	1982
No. 23	Site Selection and Baseline Surveys of the Black Rock Disposal Site for the Field Verification Program	1982
No. 24	A Study of the Benthic Macrofauna at the CLIS Disposal Site	1983

NUMBER	TITLE	DATE
No. 25	Status Report, Disposal Operations at the Central Long Island Sound Disposal Site	1983
No. 26	Application of LORAN-C Control System to Disposal Operations at the Boston Foul Ground	1983
No. 27	Summary of Measurements made at the WLIS III Disposal Site	1983
No. 28	Interim Report on the Concentration of Trace Metals in *Mytilus edulis* Deployed at the Western Long Island Sound Disposal Site	1983
No. 29	DAMOS Cruise Report, August - September 1983	1983
No. 30	OSV Antelope Cruise Report - June, 1983	1984
No. 31	Wave Climate, Green Harbor, Massachusetts (Green Harbor No. 1)	1983
Nos. 32, 33 & 34	Combined into No. 38	
No. 35	Post-Disposal Survey of the WLIS III Disposal Site; August - September, 1983	1984
No. 36	A Feasibility Study of the Disposal of Dredged Material at Morris Cove, New Haven Harbor	1984
No. 37	Wave Climate, Green Harbor, Massachusetts (Green Harbor No. 2)	1984
No. 38	Results of Monitoring Studies at Cap Sites No. 1, No. 2, and the FVP Site in Central Long Island Sound and a Classification Scheme for the Management Capping Procedures	1984
No. 39	Sediment Characterization - NLON Disposal Site; March - April, 1984	1984

NUMBER	TITLE	DATE
No. 40	Wave Climate, Green Harbor, Massachusetts (Green Harbor No. 3)	1984
No. 41	Dredged Material Disposal Operations at the Boston Foul Ground; June 1982 - February 1983	1984
No. 42	Evaluation of the Effectiveness of Dredging on the Kennebec River	1984
No. 43	Mussel Watch: Eastern Long Island Sound Disposal Site and Portland Disposal Site Monitoring Projects	1984
No. 44	Baseline and Post-Disposal Surveys at the WLIS III "B" Disposal Site	1984
No. 45	Rhode Island and Southeastern Massachusetts Dredging Needs Survey, 1985-1995	1984
No. 46	Disposal Area Monitoring (DAMOS) Annual Report, 1984	1984
	Volume I, Section I. Overview of the DAMOS Program	
	Volume I, Section II. Critique of DAMOS Program	
	Volume II, Part A. Central Long Island Sound Previous Studies	
	Volume II, Part B. Central Long Island Sound Ongoing Surveys	
	Volume II, Part C. Field Verification Program (FVP)	
	Volume II, Part D. Field Verification Program (FVP) Monitoring Surveys	
	Volume III, Part A. Western Long Island Sound Disposal Area	
	Volume III, Part B. New London Disposal Area Rhode Island	

NUMBER	TITLE		DATE
	Volume III, Part C.	Foul Area Cape Arundel Disposal Area Portland Disposal Area Rockland Disposal Area	
	Volume IV, Part A.	Development of the DAMOS Database Management System	
	Volume IV, Part B.	Mass Balance Calculations	
		Measurements of Geotechnical Properties at the Central Long Island Sound Disposal Site	
		Submersible and ROV Surveys at Deep Water Disposal Sites in New England	
		Green Harbor Wave Climate	
No. 47	Field Verification Program Monitoring Cruise on 19 March 1985		1985
No. 48	Standard Operating Procedure Manual for DAMOS Monitoring Activities Volume I and Volume II		1985
No. 49	Field Verification Program Monitoring Cruise on 26 June, 1985		1985
No. 50	Distribution of Dredged Material at the Rockland Disposal Site, May 1985		1988
No. 51	DAMOS - Mussel Watch, Western Long Island Sound Disposal Site Monitoring Project, 1985		1987
No. 52	Monitoring Surveys at the Field Verification Program (FVP) Disposal Site in 1985		1988
No. 53	Combined into No. 60		
No. 54	Combined into No. 57		

NUMBER	TITLE	DATE
No. 55	Monitoring Surveys at the Western Long Island Sound Disposal Site, August and October 1985	1988
No. 56	Response to Comments Generated as a Result of the DAMOS Symposium (January, 1985)	1989
No. 57	1985 Monitoring Surveys at the Central Long Island Sound Disposal Site: An Assessment of Impacts from Disposal and Hurricane Gloria	1989
No. 58	Buzzards Bay Disposal Site - Literature Review	1989
No. 59	A Synthesis of REMOTS Results Collected at the FVP Disposal Site (incorporated into "Impact of Open-water Disposal of Black Rock Harbor Dredged Material on Benthic recolonization at the FVP Site, "WES, Tech. Rep. D-87-4)	1987
No. 60	Monitoring Surveys at the New London Disposal Site, August 1985 - July 1986	1989
No. 61	Seasonal Monitoring Cruise at the Central Long Island Sound Disposal Site, July 1986	1987
No. 62	Determination of Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans in FVP Sediment Samples	1988
No. 63	Monitoring Cruise at Central Long Island Sound Disposal Site, July 1986	1990
No. 64	Monitoring Surveys at the Foul Area Disposal Site, February 1987	1988
No. 65	unpublished - data sheets	
No. 66	Monitoring Cruise at the New London Disposal Site, July 1986	1990

NUMBER	TITLE	DATE
No. 67	Monitoring Cruise at the Cape Arundel Disposal Site, October 1987	1990
No. 68	Monitoring Cruise at the Central Long Island Sound Disposal Site, August and September 1987	1990
No. 69	SOP Manuals I & II	1988
No. 70	Bathymetric Survey at the Cornfield Shoals Disposal Site, July 1987	1990
No. 71	Capping Survey at the New London Disposal Site, February 3, 1989	1990
No. 72	Monitoring Cruise at the Central Long Island Sound Disposal Site, July 1988	1990
No. 73	Monitoring Cruise at the Massachusetts Bay Disposal Site November 1988 - January 1989	1990
No. 74	Monitoring Cruise at the Western Long Island Sound Disposal Site, November 1987	1990
No. 75	Analysis of Sediment Chemistry and Body Burden Data Obtained at the Massachusetts Bay Disposal Site, October 1987	1990
No. 76	Monitoring Cruise at the Western Long Island Sound Disposal Site, July 1988	1990
No. 77	Monitoring Cruise at the New London Disposal Site, August 1988	1990
No. 78	Monitoring Cruise at the Portland Disposal Site, January 1989	1990
Index	Index of SR-Reports	1990
Index	Index of DAMOS Contributions	1990

NUMBER	TITLE	DATE
No. 79	Preliminary Field Operations in Support of Disposal Site Designation in the Rhode Island Sound Region	1990
No. 80	Buzzards Bay Disposal Site Baseline Study, March 1990	1991
No. 81	Monitoring Cruise at the Saco Bay Disposal Site, May 1990	1991
No. 82	Monitoring Cruise at the Cape Arundel Disposal Site, May 1990	1991
No. 83	Monitoring Surveys at the Rockland Disposal Site, July 1989	1992
No. 84	Monitoring Cruise at the Cape Cod Canal Disposal Site and Springhill Beach Site March 1990-April 1990	1993
No. 85	Monitoring Cruise at the New London Disposal Site, June-July 1990	1993
No. 86	An Investigation of Techniques Suitable for Field Extraction of Spionid and Capitellid Polychaetes for Bioaccumulation Testing	1994
No. 87	An Integrated, Tiered Approach to Monitoring and Management of Dredged Material Disposal Sites in the New England Region	1994
No. 88	Analysis of the Contribution of Dredged Material to Sediment and Contaminant Fluxes in Long Island Sound	1994
No. 89	DAMOS Capping Model Verification	1994
No. 90	Monitoring Cruise at the Cornfield Shoals Disposal Site July 1990	1994
No. 91	Chemical Analyses of Sediment Sampling at the Massachusetts Bay Disposal Site, 5-7 June 1989	1994
No. 92	Monitoring Cruise at the Massachusetts Bay Disposal Site, August 1990	1994

APPENDIX D

PCA Variable and Regression Calculations

PCA VARIABLE AND REGRESSION CALCULATIONS

Example: STNHS 60NE

I. PCA VARIABLES AND AXIS CALCULATIONS

TABLE 1. CORRELATION MATRIX

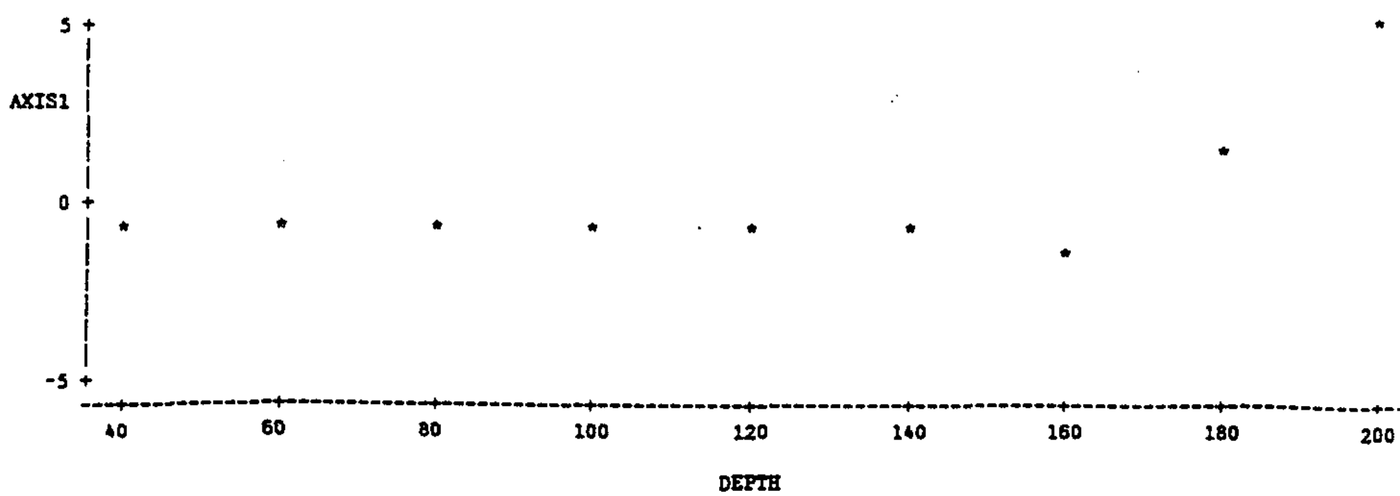
	Cd	Cu	Zn	TRPH
Cd	1.0000	0.9892	0.9547	0.9535
Cu	0.9892	1.0000	0.9843	0.9769
Zn	0.9547	0.9843	1.0000	0.9955
TRPH	0.9535	0.9769	0.9955	1.0000

TABLE 2. FACTOR PATTERN

	AXIS1
Cd	0.98330
Cu	0.99673
Zn	0.99275
TRPH	0.99058

TABLE 3. VARIABLES AND AXIS SCORES

CORE	LAYER	DEPTH	Cd	Cu	Zn	TRPH	AXIS1
60NE	2	40	5.7	120	200	260	-0.83095
60NE	3	60	5.8	99	180	25	-0.91245
60NE	4	80	6.9	110	194	180	-0.80978
60NE	5	100	5.8	110	200	25	-0.86678
60NE	6	120	7.2	79	148	16	-0.92717
60NE	7	140	6.3	94	170	16	-0.91266
60NE	8	160	5.9	30	83	87	-1.15040
60NE	9	180	15.0	410	760	8400	1.63571
60NE	10	200	39.0	940	1200	14000	4.77448



II. REGRESSION ANALYSES: BOUNDARY VARIABLES

OBS	CORE	LAYER	DEPTH	D1	D2	D3	D4	D5	D6	D7	D8	D9
1	60NE	2	40	1	0	0	0	0	0	0	0	0
2	60NE	3	60	1	1	0	0	0	0	0	0	0
3	60NE	4	80	1	1	1	0	0	0	0	0	0
4	60NE	5	100	1	1	1	1	0	0	0	0	0
5	60NE	6	120	1	1	1	1	1	0	0	0	0
6	60NE	7	140	1	1	1	1	1	1	0	0	0
7	60NE	8	160	1	1	1	1	1	1	1	0	0
8	60NE	9	180	1	1	1	1	1	1	1	1	0
9	60NE	10	200	1	1	1	1	1	1	1	1	1

III. REGRESSION ANALYSES: REGRESSION MODELS

N = 9 Regression Models for Dependent Variable: D2

Number in Model	R-square	C(p)	Variables in Model
1	0.02472477	1.00354	AXIS1
1	0.00057488	1.15220	AXIS2
2	0.02529965	3.00000	AXIS1 AXIS2

N = 9 Regression Models for Dependent Variable: D3

Number in Model	R-square	C(p)	Variables in Model
1	0.06219233	1.00008	AXIS1
1	0.00001293	1.39791	AXIS2
2	0.06220526	3.00000	AXIS1 AXIS2

N = 9 Regression Models for Dependent Variable: D4

Number in Model	R-square	C(p)	Variables in Model
1	0.10374338	1.03291	AXIS1
1	0.00488950	1.69832	AXIS2
2	0.10863288	3.00000	AXIS1 AXIS2

N = 9 Regression Models for Dependent Variable: D5

Number in Model	R-square	C(p)	Variables in Model
1	0.16752643	1.03625	AXIS1
1	0.00499914	2.21473	AXIS2
2	0.17252557	3.00000	AXIS1 AXIS2

N = 9 Regression Models for Dependent Variable: D6

Number in Model	R-square	C(p)	Variables in Model
1	0.27067486	1.32746	AXIS1
1	0.03774374	3.34831	AXIS2
2	0.30841861	3.00000	AXIS1 AXIS2

N = 9 Regression Models for Dependent Variable: D7

Number in Model	R-square	C(p)	Variables in Model
1	0.44028859	1.85519	AXIS1
1	0.06982407	6.38253	AXIS2
2	0.51011266	3.00000	AXIS1 AXIS2

N = 9 Regression Models for Dependent Variable: D8

Number in Model	R-square	C(p)	Variables in Model
1	0.84079001	99.30506	AXIS1
1	0.15005166	551.83634	AXIS2
2	0.99084167	3.00000	AXIS1 AXIS2

N = 9 Regression Models for Dependent Variable: D9

Number in Model	R-square	C(p)	Variables in Model
1	0.81627259	224.05757	AXIS1
1	0.17891480	1019	AXIS2
2	0.99178249	3.00000	AXIS1 AXIS2