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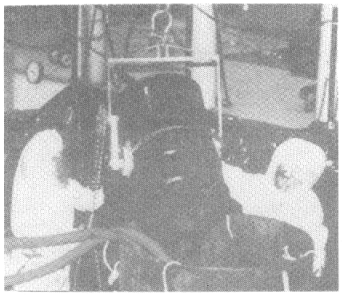

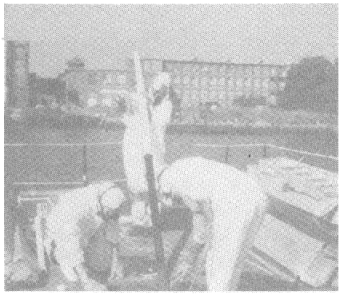

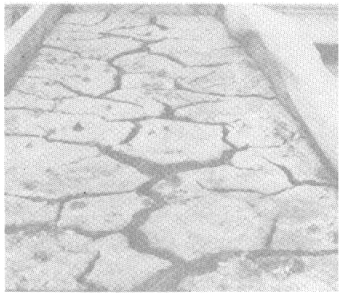

ENVIRONMENTAL LABORATORY

TECHNICAL REPORT EL-88-15

NEW BEDFORD HARBOR SUPERFUND PROJECT, ACUSHNET RIVER ESTUARY ENGINEERING FEASIBILITY STUDY OF DREDGING AND DREDGED MATERIAL DISPOSAL ALTERNATIVES

Report 6

LABORATORY TESTING FOR SUBAQUEOUS CAPPING

by

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Environmental Laboratory

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U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

October 1988

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The thickness of capping material needed to chemically sequester the polychlorinated biphenyl (PCB)-contaminated New Bedford Harbor sediment from the overlying water column and aquatic biota was assessed in a small-scale predictive test. Changes in the overlying water concentrations of dissolved oxygen, ammonium-nitrogen, and orthophosphate-phosphorus were monitored following isolation of the water column from the atmosphere by placing a 4-cm layer of mineral oil on the water surface. The chemical tracers (ammonium-nitrogen and orthophosphate-phosphorus) were selected for their mobility under anaerobic conditions, ease of measurement, and generally high concentrations in contaminated dredged material compared with clean sediments. The chemical tracers were used to evaluate the efficiency of the capping material in preventing transfer of contaminants from New Bedford Harbor sediment into the overlying water column. Chemical analysis of the water column overlying the

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35-cm cap treatment showed that the cap treatment was effective in preventing the ammonium-nitrogen and orthophosphate-phosphorus from reaching the overlying water column.

A verification test was conducted to substantiate results obtained in the predictive test. This was accomplished by running the small-scale units containing New Bedford Harbor sediment capped with the 35 cm of capping material shown to be effective in the predictive test. The water column was analyzed for PCBs. Results of the verification test substantiated the results obtained in the predictive test. The 35-cm cap treatment not only prevented the movement of the inorganic chemical tracers (ammonium-nitrogen and orthophosphate-phosphorus) but also prevented the movement of PCB contaminants.

PREFACE

This study was conducted as a part of the Acushnet River Estuary Engineering Feasibility Study (EFS) of Dredging and Dredged Material Disposal Alternatives. The US Army Corps of Engineers (USACE) performed the EFS for the US Environmental Protection Agency (USEPA), Region 1, as a component of the comprehensive USEPA Feasibility Study for the New Bedford Harbor Superfund Site, New Bedford, MA. This report, Report 6 of a series, was prepared by the US Army Engineer Waterways Experiment Station (WES) in cooperation with the New England Division (NED), USACE. Coordination and management support was provided by the Omaha District, USACE, and dredging program coordination was provided by the Dredging Division, USACE. The study was conducted between January 87 and July 1987.

Project manager for the USEPA was Mr. Frank Ciavattieri. The NED project managers were Messrs. Mark J. Otis and Alan Randall. Omaha District project managers were Messrs. Kevin Mayberry and William Bonneau. Project managers for the WES were Messrs. Norman R. Francingues, Jr., and Daniel E. Averett.

The report was prepared by Mr. Thomas C. Sturgis and Dr. Douglas Gunnison of the Aquatic Processes and Effects Group (APEG), Ecosystem Research and Simulation Division (ERSD), Environmental Laboratory (EL), WES. Chemical analyses for the study were performed by the Analytical Laboratory Group (ALG), Environmental Engineering Division (EED), EL, under the supervision of Ms. Ann Strong, Chief, ALG, and Dr. Raymond L. Montgomery, Chief, EED. The report was edited by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

This study was conducted under the general supervision of Dr. Thomas L. Hart, Chief, APEG; Mr. Donald L. Robey, Chief, ERSD; and Dr. John Harrison, Chief, EL.

COL Dwayne G. Lee, EN, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
gallons (US liquid)	3.785412	cubic decimetres
miles (US statute)	1.609347	kilometres

NEW BEDFORD HARBOR SUPERFUND PROJECT, ACUSHNET RIVER ESTUARY ENGINEERING FEASIBILITY STUDY OF DREDGING AND DREDGED MATERIAL DISPOSAL ALTERNATIVES

LABORATORY TESTING FOR SUBAQUEOUS CAPPING

PART I: INTRODUCTION

1. In August 1984, the US Environmental Protection Agency (USEPA) reported on the Feasibility Study of Remedial Action Alternatives for the Upper Acushnet River Estuary above the Coggeshall Street Bridge, New Bedford, MA (NUS Corporation 1984). The USEPA received extensive comments on the proposed remedial action alternatives from other Federal, state, and local officials, potentially responsible parties, and individuals. Responding to these comments, the USEPA chose to conduct additional studies to better define available cleanup methods. Because dredging was associated with all of the removal alternatives, the USEPA requested the Nation's dredging expert, the US Army Corps of Engineers (USACE), to conduct an Engineering Feasibility Study (EFS) of dredging and disposal alternatives. A major emphasis of the EFS was placed on evaluating the potential for contaminant releases from both dredging and disposal operations.

2. The technical phase of the EFS was completed in March 1988. However, as part of Task 8 of the EFS, the results of the study were compiled in a series of 12 reports, listed below.

a. Report 1, "Study Overview."

b. Report 2, "Sediment and Contaminant Hydraulic Transport Investigations."

c. Report 3, "Characterization and Elutriate Testing of Acushnet River Estuary Sediment."

d. Report 4, "Surface Runoff Quality Evaluation for Confined Disposal."

e. Report 5, "Evaluation of Leachate Quality."

f. Report 6, "Laboratory Testing for Subaqueous Capping."

g. Report 7, "Settling and Chemical Clarification Tests."

h. Report 8, "Compatibility of Liner Systems with New Bedford Harbor Dredged Material Contaminants."

i. Report 9, "Laboratory-Scale Application of Solidification/ Stabilization Technology."

j. Report 10, "Evaluation of Dredging and Dredging Control Technologies."

k. Report 11, "Evaluation of Conceptual Dredging and Disposal Alternatives."

l. Report 12, "Executive Summary."

This report is Report 6 of the series. The results of this study were obtained from conducting EFS Task 6, element 5 (see Report 1).

Background

3. Industrial and municipal waste released into the Acushnet River Estuary and harbor areas adjacent to New Bedford, MA, has contaminated the bottom sediments with organic chemicals, principally chlorinated hydrocarbons, and with heavy metals. Polychlorinated biphenyl (PCB) concentrations in the percent levels have been detected in sediments in the upper estuary region of the harbor (USEPA 1983, NUS Corporation 1984). Studies conducted by the State of Massachusetts and the USEPA during the 1970s and 1980s led to New Bedford Harbor being proposed in 1982 to the National Priorities List of the Nation's worst hazardous waste sites. Thus, the New Bedford Harbor site was designated a Federal Superfund site and became eligible for Federal cleanup funds (see Report 1).

4. A disposal option being considered for the upper harbor project is contained aquatic disposal (CAD). The CAD concept can be categorized as a controlled, accurate, subaqueous placement of dredged material; sequestering of contaminated material from the aquatic environment by some type of covering or cap; and monitoring once the cap is emplaced. Figure 1 is a schematic diagram of a CAD, in which lateral control or confinement is desired during placement of the dredged material. This confinement can be accomplished by use of an existing depression, preexcavation of a CAD cell, or construction of one or more submerged dikes or berms. In the shallow Acushnet River Estuary, preexcavation of the CAD cell will be necessary (see Report 11). One of the principal design decisions in a CAD operation is the nature and thickness of the capping material to be placed over the contaminated dredged material in the CAD cell. The capping material provides the isolation necessary to prevent or reduce the diffusion of substances from the underlying contaminated

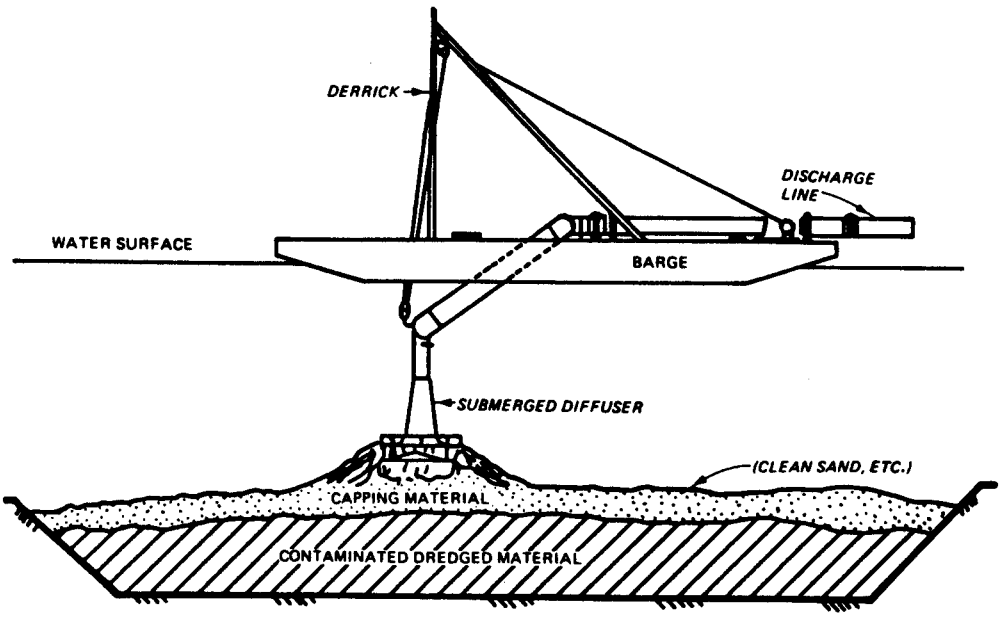

Figure 1. Schematic diagram of contained aquatic disposal of contaminated dredged material

dredged material into the overlying water column and prevents direct contact between the aquatic biota and the contaminated material.

5. A prime concern about the acceptability of capping as a disposal method is its efficiency in isolating contaminated dredged material from the water and from both pelagic and benthic biota. Much work has addressed this concern (Brannon et al. 1985, 1986; Gunnison et al. 1986, 1987; Palermo et al., in preparation). In these studies, the effectiveness of capping in chemically and biologically isolating a contaminated sediment from the overlying water column was examined using a two-step process that involved small- and large-scale testing units. Small-scale predictive tests were used to assess the cap thickness needed to chemically isolate a contaminated dredged material by following changes in dissolved oxygen (DO), ammonium-nitrogen, and orthophosphate-phosphorus in the overlying water column.

6. Dissolved oxygen depletion in the water column would normally not be a problem in an open-water disposal environment due to mixing and reaeration of the water column. However, DO depletion can be used as a tracer for determining the effectiveness of a cap in isolating an underlying contaminated dredged material having a demand exceeding that of the capping material. Most contaminated dredged material exerts an oxygen demand on the overlying water

column that exceeds oxygen demands normally exerted by uncontaminated sediment. To effectively seal a contaminated dredged material, the cap must be thick enough to prevent the migration of oxygen-demanding materials into the overlying water column. If these materials are able to diffuse through the cap layer, their presence in the water column will cause a DO depletion rate that exceeds that of the cap material alone.

7. Large-scale laboratory tests were used to determine the relationship of cap thickness to the effectiveness of capping in preventing movement of contaminants into the biota; to determine the effect of bioturbation on the effectiveness of capping; and to validate results that were obtained in the small-scale predictive test. Results from these studies indicated that the small-scale predictive test can be used to determine cap thickness needed to chemically isolate a contaminated sediment from the overlying water column and aquatic biota.

Objective

8. The objective of this study was to provide guidance on the thickness of capping material in a CAD cell that will chemically isolate contaminated New Bedford Harbor sediment from the overlying water column and biota.

PART II: MATERIALS AND METHODS

Sediment Collection

9. A 55-gal* drum of capping material was obtained by placing an 18-ft casing through the top 11 ft of sediment near location grid G-30 (Figure 2). The top 3 ft of expected contaminated material was forced out of the casing by jetting water into the material and allowing it to flow over the top of the casing. The material below the 3 ft of assumed contaminated material was then collected. The sediment was transported to shore by buckets, placed in 55-gal drums located in an insulated truck, and transported 50 miles to a refrigerated truck. The capping material was then transported by refrigerated truck to the US Army Engineer Waterways Experiment Station (WES) in Vicksburg, MS. Upon arrival at the WES, the capping material was composited and mixed using a motorized mixer. After mixing, the capping material was returned to the drum and stored at 20° C.

10. Collection and compositing of the contaminated sediment is described in Report 3. The contaminated sediment was a composited sample collected from four locations in the estuary and represented the midrange sediment PCB concentration of the estuary.

11. Particle size analyses were conducted on contaminated sediment and capping material according to methods in Engineer Manual 1110-2-1906 (USACE 1970).

Small-Scale Predictive Test

12. The effectiveness of capping in chemically isolating contaminated New Bedford Harbor sediment from the overlying water column was investigated using small-scale (22.6-ℓ) test units (Figure 3). The rationale for the predictive test is as follows. A cap thickness that is effective in preventing the movement of the soluble tracers ammonium-nitrogen and orthophosphate-phosphorus will also be effective in preventing the movement of PCBs that are

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

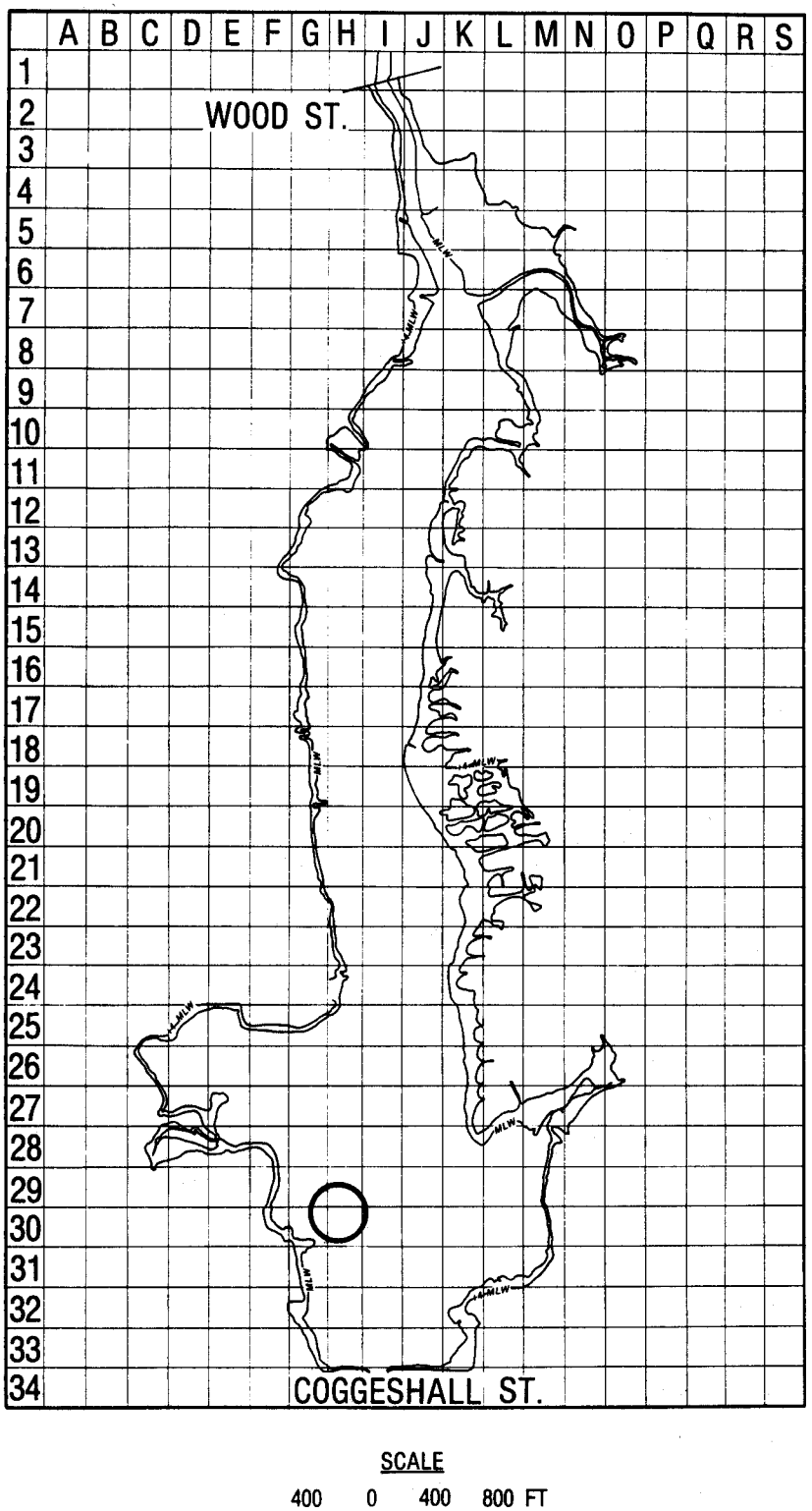

Figure 2. Capping material sample location

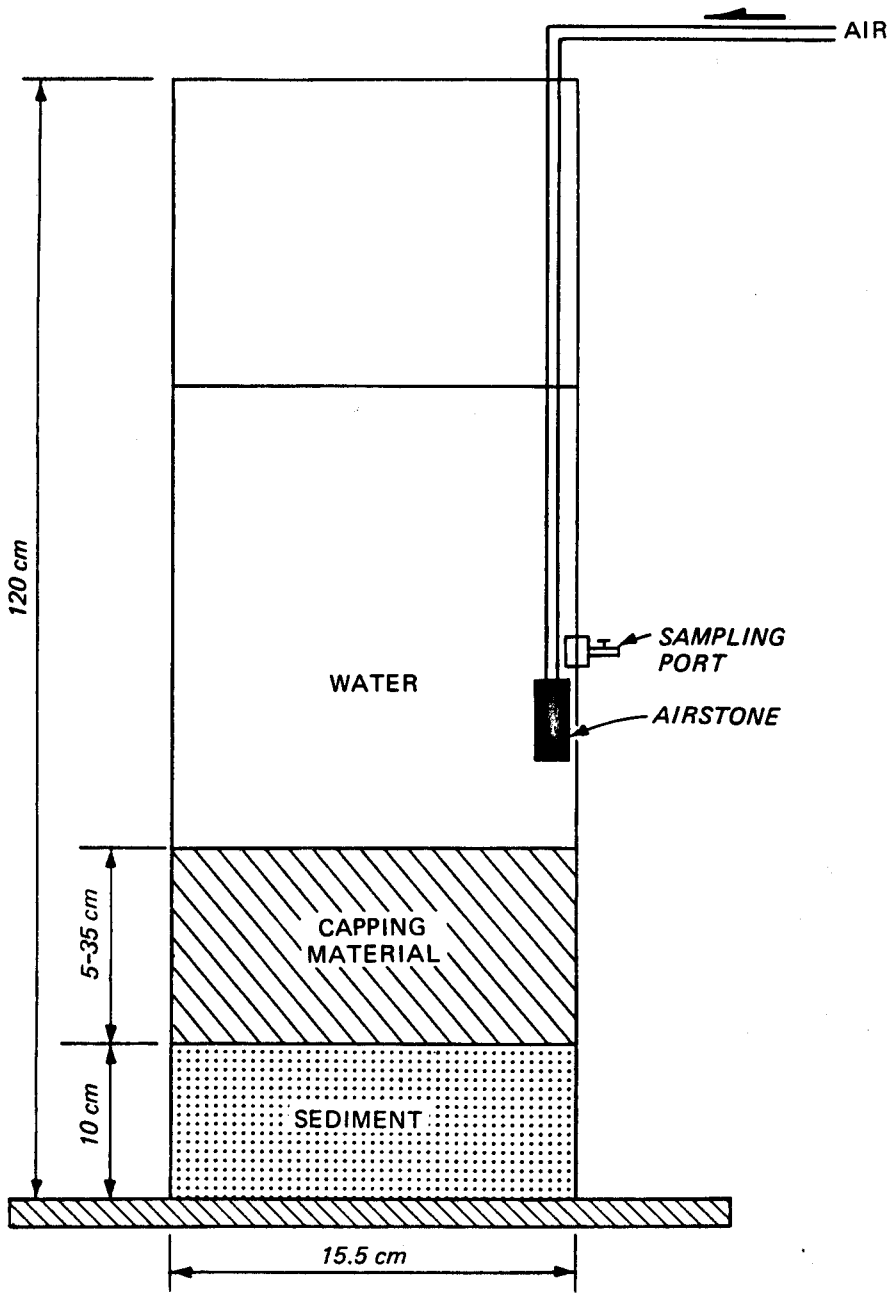

Figure 3. Small-scale test unit with aeration system

strongly adsorbed by sediment. In addition, the behavior of soluble reduced inorganic species (e.g., arsenic) will also be similar to the tracers.

13. The thickness of cap material needed to isolate contaminated sediment from the overlying water column was evaluated by following changes in DO depletion, ammonium-nitrogen, and orthophosphate-phosphorus. The design and sediment-loading arrangement of an individual unit are shown in Figure 3.

This experiment was conducted in triplicate for each control and cap thickness in a controlled environment where the temperature was regulated at 20° ± 0.5° C. A 10-cm-thick layer of New Bedford Harbor sediment was placed into the bottom of the small-scale unit; to this was added the cap material and 10 ℓ of artificial seawater having a salinity of 35 ppt. Cap thicknesses tested in this study were 5, 15, and 35 cm. Uncapped contaminated sediment and capping material alone were used as controls.

14. All experimental treatments were initially aerated by slowly bubbling air through the water column for 3 days to ensure DO saturation (within ±0.5 mg/ℓ). Aeration was accomplished by using an airstone attached to tygon tubing, with the free end of the tubing connected to an aquarium pump. The airstone was lowered into the water column to a depth of 15 cm above the sediment. After 3 days of aeration, the airstone was removed, and a plunger and mineral oil were added (Figure 4). The plunger was used for daily mixing to prevent the establishment of concentration gradients in the water column by ensuring a well-mixed column. The mineral oil was used to seal the surface of the water column from contact with the atmosphere so that anaerobic conditions would develop. Water samples were taken immediately after aeration for initial DO determination. Dissolved oxygen was then measured daily in the overlying water column of all treatments. Comparisons were made between the DO depletion rates of the controls and those of the capped treatments. Dissolved oxygen was determined with the azide modification of the Winkler Method as described in Standard Methods (American Public Health Association 1986).

15. Water samples to be analyzed for ammonium-nitrogen and orthophosphate-phosphorus (relatively mobile compounds that are released under anaerobic conditions) were initially taken when the DO was totally depleted (day 0) and subsequently on days 4, 11, 14, and 18. These water samples were cleared of particulate matter by passage through a 0.45-μm membrane filter under a nitrogen atmosphere and then preserved by acidification with concentrated HCl to pH 2, followed by immediate freezing and storage at 4° C. Ammonium-nitrogen and orthophosphate-phosphorus were determined using a Technicon Autoanalyzer II, in accordance with procedures recommended by Ballinger (1979).

16. The predictive test is used to determine cap thickness needed to obtain a chemical seal of the contaminated sediment from the overlying water column. However, the influence of burrowing organisms on cap efficiency is

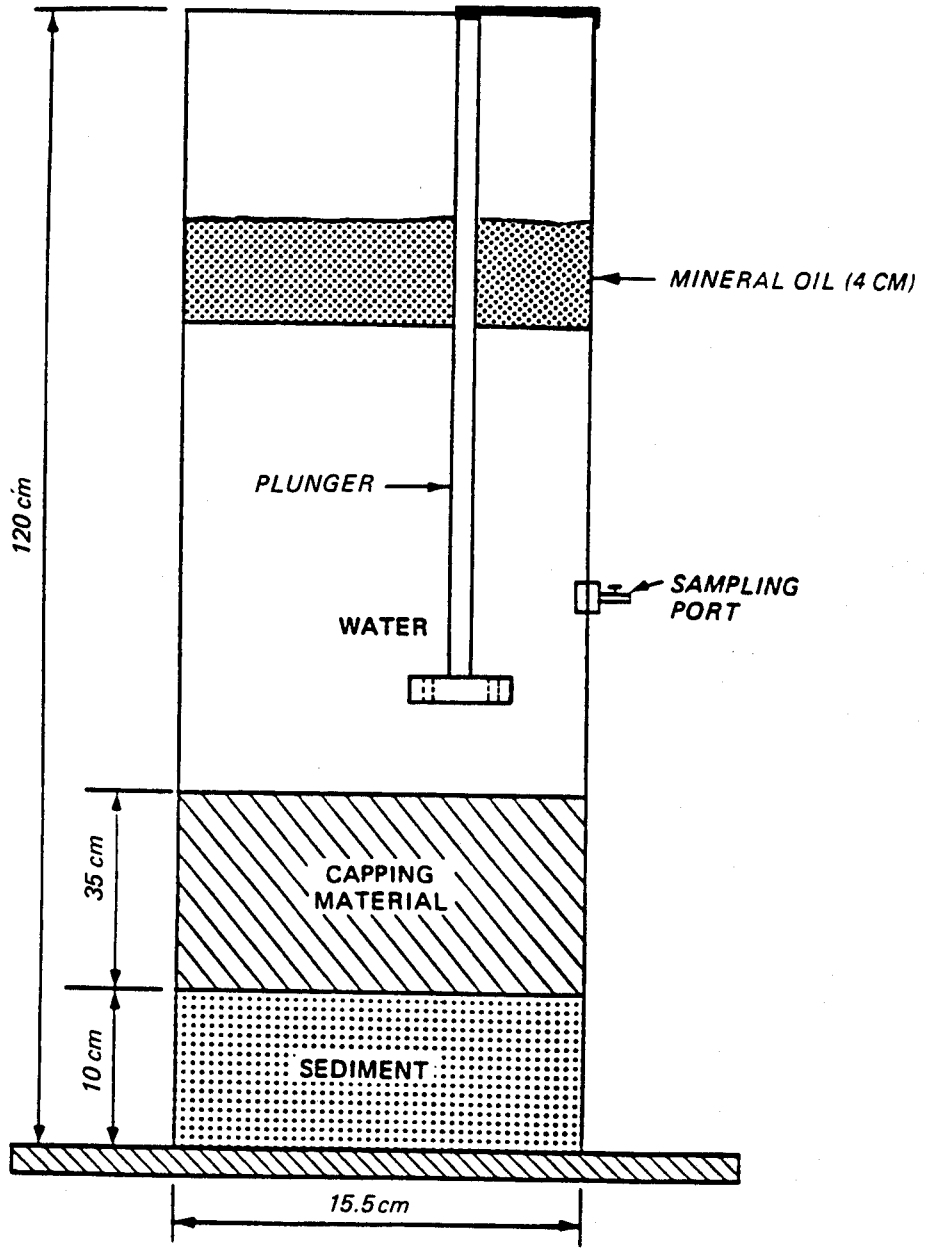

Figure 4. Small-scale test unit with plunger and mineral oil

not addressed in the laboratory using the predictive test. The equation developed under the Long-Term Effects of Dredging Operations research program is recommended for use to ensure complete cap integrity from both chemical and biological viewpoints (Gunnison et al. 1987).

Verification Test

17. A verification test using additional small-scale units was performed to substantiate results obtained with tracers in the predictive test. In the verification test, water samples were analyzed for selected PCBs. This test was conducted in triplicate in a controlled environment where the temperature was regulated at 20° ± 0.5° C. The design and sediment-loading arrangement of individual units were the same as in the routine predictive test procedure (Figure 3). The 35-cm cap thickness was tested in this study. Uncapped contaminated sediment and capping material alone were used as controls.

18. The test units were allowed to equilibrate for 3 days while being aerated. After 3 days of aeration, the airstone was removed. Unlike the predictive test, the mineral oil and plunger were not added to the experimental units. The PCBs would sorb to the mineral oil and plunger, consequently decreasing the PCB concentrations in the water column and giving erroneous results. The plunger was used to mix the water column but was not left suspended in the water column as in the small-scale predictive test. Water samples for PCB analysis were obtained at the end of 30 days. A 30-day period was selected because previous work had shown this to be long enough for soluble contaminants to appear in the water column (Brannon et al. 1985, 1986; Gunnison et al. 1986; Palermo et al., in preparation). The samples were placed in 3.8-ℓ glass jars that had been hexane washed and dried at 105° C for 24 hr. The PCB concentrations were determined following soxhlet extraction with a 50-50 hexane-acetone solution for 16 hr, sulfuric acid cleanup, and quantification with a dual electron capture detector HP 5880 gas chromatograph.

Analysis Methods

19. Means and standard errors were determined for each parameter within a treatment. The Duncan Multiple Range Test was used to determine the statistical significance of differences between treatments. Statements of significance made in the text refer to the 5-percent level ($p < 0.05$) or less.

PART III: RESULTS

Small-Scale Predictive Test

Sediment characterization

20. The contaminated sediment was classified as a dark gray sandy organic silt sediment, whereas the capping material was classified as a clay organic silt sediment.

21. The concentration of PCB aroclors (1242 and 1254) and congeners (Table 1) was significantly higher in the contaminated sediment than in the capping material ($p < 0.05$). The PCB congener concentrations in the capping material were each less than 1.0 µg/g. The total PCB concentration in the capping material was 8.4 µg/g, considerably less than the total PCB concentration (2,167 µg/g) in the contaminated sediment.

22. PCB Aroclors 1242 and 1254 and congeners 2,4'-dichlorobiphenyl, 2,4,4'-trichlorobiphenyl, 2,2',3,5-tetrachlorobiphenyl, 2,2',4,6-tetrachlorobiphenyl, and 2,2'5,5'-tetrachlorobiphenyl constituted the largest fractions of PCBs in the contaminated sediment (Table 1). Since these constituents were much higher in the contaminated sediment than the capping material, they were assessed in the verification test.

Dissolved oxygen depletion rates

23. The dissolved oxygen depletion rates of the capping material (504 ± 44 $mg/m^2/day$) were not significantly different ($p < 0.05$) from those of the contaminated sediment (500 ± 64 $mg/m^2/day$). This condition precluded the use of DO depletion as an indicator of cap effectiveness.

Nutrient release rates

24. Ammonium-nitrogen. Ammonium-nitrogen release rates to the overlying water, derived by performing linear regression analysis of mass release per unit area (milligrams per square metre) versus time, are presented as a function of cap thickness in Figure 5. Rates plotted are the means and standard deviations of three replicates. The 5-cm cap thickness reduced the ammonium-nitrogen release rates by 19 percent from those observed with uncapped New Bedford sediment. The 5- and 15-cm cap treatments proved to be ineffective in chemically isolating contaminated sediment from the water column, in that the ammonium-nitrogen releases from those treatments were significantly higher ($p < 0.05$) than those observed from the control. However, the

Table 1

Sediment PCB Concentration*

Analysis	PCB Concentration	
	Contaminated Sediment (Triplicate)	Capping Material (Single)
Aroclors		
PCB 1016	<50.00 (±0.00)	<0.002
PCB 1221	<50.00 (±0.00)	<0.002
PCB 1232	<50.00 (±0.00)	<0.002
PCB 1242	807.00 (±106.00)	5.300
PCB 1248	<50.00 (±0.00)	<0.002
PCB 1254	662.00 (±107.00)	3.500
PCB 1260	<50.00 (±0.00)	<0.002
Congeners		
2,4-Dichlorobiphenyl	<1.00 (±0.00)	0.004
2,4'-Dichlorobiphenyl	165.00 (±3.00)	0.620
2,4,4'-Trichlorobiphenyl	153.00 (±5.00)	0.810
2,2',3,5-Tetrachlorobiphenyl	84.00 (±3.00)	0.280
2,2',4,5'-Tetrachlorobiphenyl	28.00 (±0.85)	0.070
2,2',4,6-Tetrachlorobiphenyl	153.00 (±5.00)	0.910
2,2',5,5'-Tetrachlorobiphenyl	173.00 (±4.50)	0.510
2,3',4',5-Tetrachlorobiphenyl	59.20 (±3.20)	0.430
3,3'4,4'-Tetrachlorobiphenyl	<1.00 (±0.00)	0.720
2,2',3,3'4-Pentachlorobiphenyl	<1.00 (±0.00)	0.180
2,2',3,4,5'-Pentachlorobiphenyl	<1.00 (±0.00)	0.180
2,2',3',4,5-Pentachlorobiphenyl	27.90 (±1.10)	0.720
2,2',4',5,5'-Pentachlorobiphenyl	71.00 (±4.00)	0.420
2,3,3',4,4-Pentachlorobiphenyl	<1.00 (±0.00)	0.470
2,3',4,4',5-Pentachlorobiphenyl	29.60 (±1.00)	0.300
2,2',3,3',6,6-Hexachlorobiphenyl	17.10 (±0.50)	0.055
2,2',3,4,4',5'-Hexachlorobiphenyl	25.00 (±0.40)	0.250
2,2',3,4,5,6-Hexachlorobiphenyl	<1.00 (±0.00)	0.690
2,2',4,4',5,5'-Hexachlorobiphenyl	57.00 (±3.00)	0.730
2,2',4,4',6,6'-Hexachlorobiphenyl	<1.00 (±0.00)	0.070
2,3',4,4',5,5',-Hexachlorobiphenyl	<1.00 (±0.00)	0.032
2,2',3,4,4',5,5'-Heptachlorobiphenyl	7.90 (±1.60)	0.076
2,2',3,4,5,5',6-Heptachlorobiphenyl	<1.00 (±0.00)	0.013
Total PCBs	2,167.00 (±57.70)	8.400

* Expressed in micrograms per gram of sediment (± standard error).

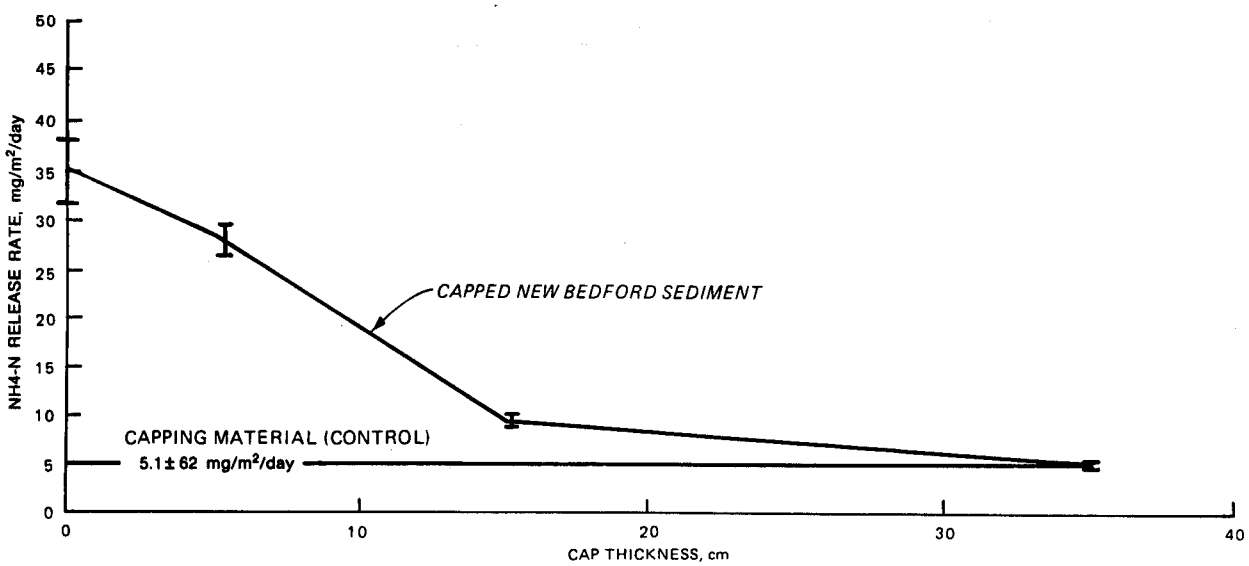

Figure 5. Effect of cap thickness on ammonium-nitrogen release rate

ammonium-nitrogen release rates above the 35-cm cap were not significantly different ($p < 0.05$) from those of the capping material. This indicated that with a cap thickness of 35 cm, the contaminated New Bedford Harbor sediment was not exerting any influence on the overlying water column.

25. Orthophosphate-phosphorus. Orthophosphate-phosphorus release rates to the overlying water, derived in the same manner as for ammonium-nitrogen, are shown in Figure 6. Water column analysis revealed that 35 cm of capping material served as an effective chemical seal in reducing the release of orthophosphate-phosphorus into the overlying water column. Based on these data, a cap thickness of 35 cm resulted in a 99-percent reduction in the orthophosphate-phosphorus release rate. Capping treatments of 5- and 15-cm depths were ineffective in isolating contaminated New Bedford Harbor sediment from the overlying water column. The release rates from these treatments were significantly different ($p < 0.05$) from those observed from the capping material, indicating an ineffective seal.

Verification Test

26. The PCB aroclor and isomer concentrations (Table 2) in the water column above the capped sediment (35 cm) did not significantly differ ($p < 0.05$) from their respective concentrations in the water column overlying

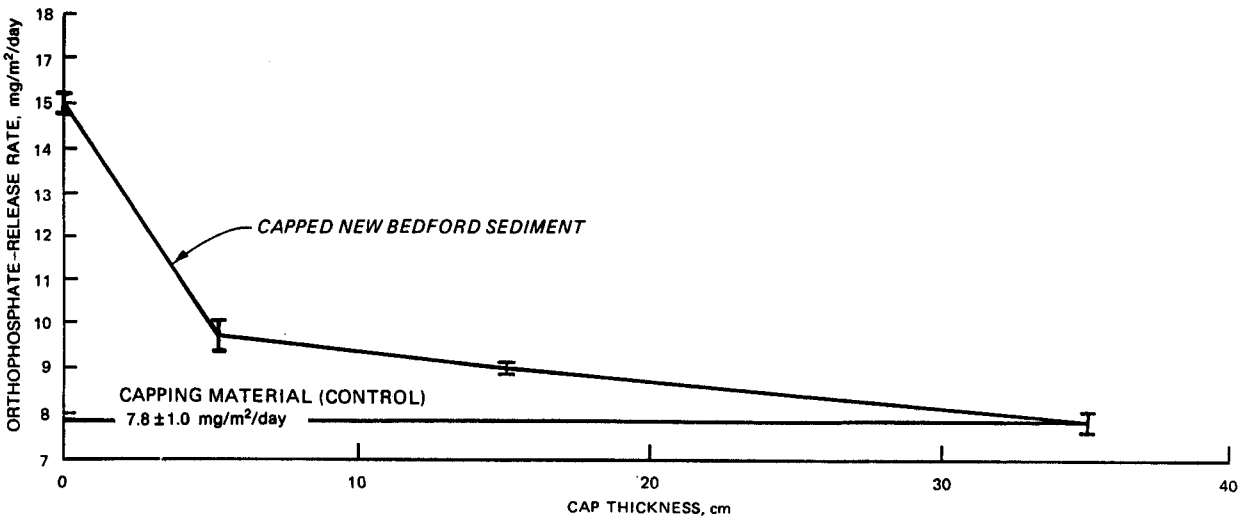

Figure 6. Effect of cap thickness on orthophosphate-phosphorus release rate

the capping material alone (control). Therefore, the PCBs detected in the overlying water column of the capped treatment could be attributed to the capping material, rather than to the contaminated New Bedford Harbor sediment.

27. The results from the verification test substantiated results obtained in the small-scale predictive test. The results indicated that a 35-cm cap thickness, which was effective in preventing the release of the ammonium-nitrogen and orthophosphate-phosphorus tracers, was also effective in preventing the movement of PCBs into the overlying water column.

Table 2

Results of Verification Test Showing Water Column PCB Concentration*

Following 30 Days of Incubation

Analysis	Capping Material	NB**	NB+35†
	Aroclors		
PCB 1016	<0.0002 (±0.0000)	<0.0002 (±0.0000)	<0.0002 (±0.0000)
PCB 1221	<0.0002 (±0.0000)	<0.0002 (±0.0000)	<0.0002 (±0.0000)
PCB 1232	<0.0002 (±0.0000)	<0.0002 (±0.0000)	<0.0002 (±0.0000)
PCB 1242	<0.0002 (±0.0000)	0.0040 (±0.0015)	0.0003 (±0.0002)
PCB 1248	<0.0002 (±0.0000)	<0.0002 (±0.0000)	<0.0002 (±0.0000)
PCB 1254	0.0002 (±0.0003)	0.0016 (±0.0004)	0.0002 (±0.0001)
PCB 1260	<0.0002 (±0.0000)	<0.0002 (±0.0000)	<0.0002 (±0.0000)
	Congeners		
2,4-Dichlorobiphenyl	<0.00001 (±0.00000)	<0.00001 (±0.00000)	<0.00001 (±0.00000)
2,4'-Dichlorobiphenyl	↓	0.00020 (±0.00003)	↓
2,4,4'-Trichlorobiphenyl		0.00100 (±0.00003)	
2,2',3,5-Tetrachlorobiphenyl		0.00020 (±0.00006)	
2,2',4,5'-Tetrachlorobiphenyl		0.00009 (±0.00003)	
2,2',4,6-Tetrachlorobiphenyl		0.00100 (±0.00030)	
2,2',5,5'-Tetrachlorobiphenyl		0.00050 (±0.00010)	
2,3',4',5-Tetrachlorobiphenyl		0.00010 (±0.00002)	
3,3'4,4'-Tetrachlorobiphenyl		0.00020 (±0.00005)	
2,2',3,3'4-Pentachlorobiphenyl		0.00002 (±0.00001)	
2,2',3,4,5'-Pentachlorobiphenyl		0.00004 (±0.00000)	
2,2',3',4,5-Pentachlorobiphenyl		0.00005 (±0.00002)	

(Continued)

* Expressed in micrograms per litre (± standard error).
** New Bedford Harbor sediment only.
† New Bedford Harbor contaminated sediment + 35-cm cap.

Table 2 (Concluded)

Analysis	Capping Material	NB	NB+35
		Congeners (Continued)	
2,2',4',5,5'-Pentachlorobiphenyl	<0.00001 (±0.00000)	0.00010 (±0.00002)	<0.00001 (±0.00000)
2,3,3',4,4-Pentachlorobiphenyl		0.00007 (±0.00004)	
2,3',4,4',5'-Pentachlorobiphenyl		0.00007 (±0.00001)	
2,2',3,3',6,6-Hexachlorobiphenyl		0.00004 (±0.00002)	
2,2',3,4,4',5'-Hexachlorobiphenyl		0.00004 (±0.00001)	
2,2',3,4,5,6-Hexachlorobiphenyl		0.00004 (±0.00002)	
2,2',4,4',5,5'-Hexachlorobiphenyl		0.00009 (±0.00005)	
2,2',4,4',6,6'-Hexachlorobiphenyl		0.00001 (±0.00003)	
2,3',4,4',5,5',-Hexachlorobiphenyl		<0.00001 (±0.00000)	
2,2',3,4,4',5,5'-Heptachlorobiphenyl		<0.00001 (±0.00000)	
2,2',3,4,5,5',6-Heptachlorobiphenyl		<0.00001 (±0.00000)	
Total PCBs		0.00500 (±0.00008)	

PART IV: SUMMARY AND DISCUSSION

28. The results from the small-scale predictive tests indicated that the capping material is effective in isolating contaminated New Bedford Harbor sediment from the overlying water column. Increasing the cap thickness from 5 to 35 cm increasingly prevented the release of ammonium-nitrogen and orthophosphate-phosphorus from the underlying contaminated New Bedford Harbor sediment into the water. The ability to significantly decrease the movement of these reduced inorganic chemical constituents is an indicator of cap effectiveness (Brannon et al. 1985, 1986; Gunnison et al. 1986; Palermo et al., in preparation). A cap thickness that is effective in preventing the movement of these inorganic constituents will also be effective in preventing the movement of organic contaminants that are strongly bound to sediment (e.g., polynuclear aromatic hydrocarbons, petroleum hydrocarbons, and PCBs), as was demonstrated in this study. In addition, when soluble reduced inorganic species (e.g., arsenic) are of concern, the behavior of these materials should also be similar to the tracers.

29. Data from these tests show that a cap thickness of 35 cm is an effective seal to chemically isolate New Bedford Harbor contaminated sediment from the overlying water column. The estimated thickness is for a chemical seal only and does not include allowances for bioturbation. The importance of bioturbation by burrowing aquatic organisms to the mobility of contaminants cannot be overstated. In addition to the possible disruption (breaching) of a thin cap that can result when organisms actively work the surface sediment, there is the problem of direct exposure of burrowing organisms to the underlying contaminated sediment.

30. The thickness needed to prevent breaching of cap integrity through bioturbation can be obtained indirectly from a number of sources. For example, the benthic biota of US coastal and freshwater areas has been fairly well examined, and the depth to which benthic organisms burrow should be available from regional authorities on these animals. It has been suggested that most of the organisms found in the New Bedford area will not burrow deeper than 20 cm.* However, *Squilla*, which was detected in the outer harbor, burrows to

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* Personal Communication, 1987, Russ Bellmer, US Army Engineer Division, New England, Waltham, MA.

a depth of 410 cm during winter months.* Normally, the depth which the deepest burrowing organism in the region reaches is used as a safety margin to prevent breaching of cap integrity through bioturbation.

31. In developing a final recommendation for the thickness of cap material required to prevent breaching, it is necessary to consider the frequencies of occurrence as well as the burrowing depths of most of the organisms in the area. Most of the organisms in the inner harbor area burrow to depths no greater than 20 cm. The thickness needed to biologically and chemically sequester contaminated New Bedford Harbor sediment from the overlying water is determined by the sum of the thickness needed for a chemical seal (35 cm) plus the 20-cm allowance for bioturbation (total, 55 cm). If it is necessary to ensure cap integrity against *Squilla*, an organism whose existence and prevalence in the inner harbor area has not been demonstrated, the required cap thickness would be 445 cm.

32. The estimated thickness of 55 cm does not allow for hydrodynamic forces that may cause scouring and resuspension of cap material. Procedures to predict and offset the effects of hydrodynamic processes require engineering considerations. In addition, since capping is still considered an experimental procedure, the site should be monitored once the cap has been emplaced. Further discussion of capping-related concerns is provided in Environmental Laboratory (1987), Truitt (1987a,b), and Palermo et al. (in preparation).

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* Personal Communication, 1987, Cheryl Butman, Woods Hole Oceanographic Institution, Cambridge, MA.

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