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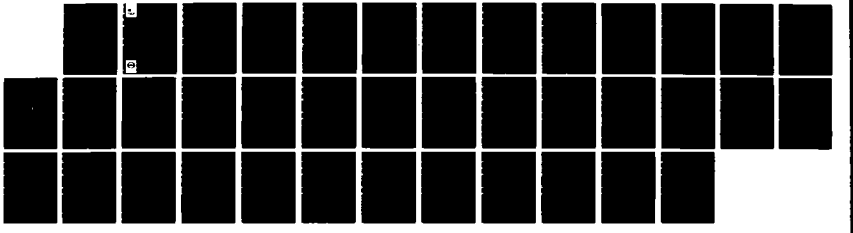

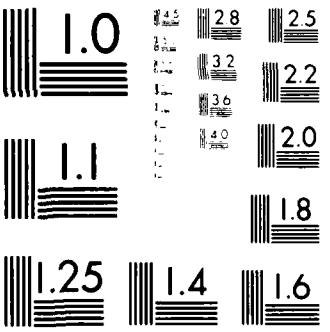

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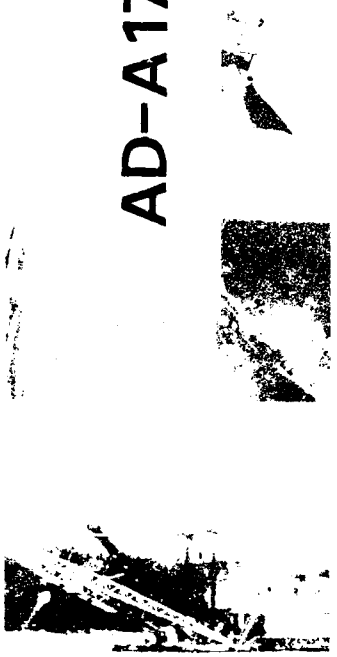

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EFFECTIVENESS OF CAPPING IN ISOLATING DUTCH KILLS SEDIMENT FROM BIOTA AND THE OVERLYING WATER

by

James M. Brannon, Ronald E. Hoeppel, Thomas C. Sturgis, Issac Smith, Jr., Douglas Gunnison

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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The effectiveness of capping in chemically and biologically isolating contaminated dredged material was investigated using large- (250 ℓ) and small- (22.6 ℓ) scale laboratory reactor units. The ability of Buttermilk Channel cap materials to isolate contaminated dredged material was assessed in the large reactor units by following the movement of chemical contaminants and microbial spores contained in the capped dredged material into the overlying water column

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and by monitoring the biological uptake of chemical contaminants by clams and polychaetes. The depth of cap material needed to chemically isolate contaminated dredged material was assessed in the small-scale reactor units. Changes in overlying water concentrations of dissolved oxygen (DO), ammonium nitrogen (NH_4^+-N), manganese, and orthophosphate were monitored following isolation of the water column from air by placing a 4-cm layer of mineral oil on the surface. The constituents analyzed were selected due to their mobility under anaerobic conditions, ease of measurement, and generally high concentrations in contaminated dredged material compared to clean cap materials.

Buttermilk Channel cap material was evaluated for its efficiency in preventing transfer of contaminants from Dutch Kills sediment into the overlying water column and biota. In the presence of bioturbating polychaetes (*Nereis virens*) at densities of 100 large animals per square metre, a 50-cm cap of Buttermilk Channel sediments in the large chamber experiment was effective in preventing the transfer of chemical constituents to the overlying water and nonburrowing biota. Chemical analysis of polychaete tissue and visual observation showed that the polychaetes penetrated both the 10-cm and 50-cm caps of Buttermilk Channel sediments.

Mercenaria in experimental units with a 10-cm cap (with polychaetes) showed significantly increased total trichlorobiphenyl body burdens following 40 days of exposure compared to *Mercenaria* in units with Buttermilk Channel cap material. It should be noted that the apparent uptake of total trichlorobiphenyls by *Mercenaria* in treatments with a 10-cm cap (with polychaetes) may have been due to chance or organism differences in that treatment. No significant difference was found between uptake of total trichlorobiphenyls by *Mercenaria* exposed to Buttermilk Channel and uncapped Dutch Kills sediment. These results indicate that a 50-cm cap and a 10-cm cap of Buttermilk Channel sediment, even when penetrated by organisms, are effective in preventing the transfer of chemical constituents to the overlying water and biota during a 40-day experiment. Microbial spores, which are not subject to the same adsorption reactions as dissolved chemicals, were found in higher numbers in the water column of experimental units with either 10-cm or 50-cm caps compared with Buttermilk Channel cap material alone. The number of spores in the water column of all treatments, however, tended to decrease steadily over time.

PREFACE

This study was sponsored by the US Army Engineer District, New York. The work was conducted by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., under the direction of Dr. John Harrison, Chief of EL, and under the general supervision of Dr. Thomas L. Hart, Chief of the Aquatic Processes and Effects Group, and Mr. Donald L. Robey, Chief of the Ecosystem Research and Simulation Division (ERSD).

This study was conducted by Drs. James M. Brannon and Douglas Gunnison and Messrs. Ronald E. Hoeppel, Thomas C. Sturgis, and Issac Smith, Jr., all of ERSD. The New York District project manager was Mr. James Mansky.

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CONTENTS

EFFECTIVENESS OF CAPPING IN ISOLATING DUTCH KILLS SEDIMENT FROM BIOTA AND THE OVERLYING WATER

PART I: INTRODUCTION

1. Capping contaminated dredged material with noncontaminated dredged material to reduce the ecological impact of contaminated dredged material in open water is a procedure that has been utilized by the New England Division and the New York District of the US Army Corps of Engineers. Monitoring of capped disposal sites has shown that capping is technically feasible and that the caps are stable under normal tidal and wave conditions (O'Conner and O'Conner 1983; Science Applications, Inc. (SAI) 1982). The efficacy of capping in isolating contaminants in dredged material from overlying water and from pelagic and benthic biota is unknown (O'Conner and O'Conner 1983). In the New York Bight, a mussel bioaccumulation study at the capping site indicated low body burdens that could have been due to bioconcentration of contaminants from ambient water as much as from the nearby sediments (O'Conner and O'Conner 1983). In Long Island Sound, mussels were also suspended in the water column at the sand- and silt-capped sites of the Stanford-Norwalk capping project. Concentrations of cobalt, copper, mercury, zinc, and vanadium fluctuated in the mussels over time, but these changes were thought to be unrelated to the caps because no differences in spatial concentration were detected (Morton and Kemp 1980). Contaminants that organisms encounter and bioaccumulate in the water column can originate from sources other than dredged material. Therefore, determining the ability of caps to isolate contaminated dredged material from the water column has proven to be a difficult field problem (Morton and Kemp 1980, O'Conner and O'Conner 1983).

2. The objective of this study was to evaluate the effectiveness of capping in isolating Dutch Kills sediment from organisms and the water column. Testing required under Public Law 92-532 has revealed that the potential for ecological harm exists in Dutch Kills sediment. Based on these results, ocean disposal of this material has been prohibited. The present study was therefore conducted to assess the effectiveness of capping in chemically and biologically isolating Dutch Kills sediment.

PART II: MATERIALS AND METHODS

Sediment Acquisition

3. Sediment samples were obtained from the Dutch Kills and Buttermilk Channel areas of New York Harbor by personnel from the New York District on 20 January 1983 using a 1.5-cu-yd clamshell dredge. Five 208-ℓ steel barrels of sediment were obtained from each site. Samples were then placed in a refrigerated truck and transported to the US Army Engineer Waterways Experiment Station (WES). Upon arrival at WES, contents of the five barrels of Dutch Kills sediment and five barrels of Buttermilk Channel sediment were separately composited and mixed, then returned to the barrels for storage at 4°C.

Large Reactor Unit Experiments

4. Laboratory studies to assess the medium-term (40 days) effectiveness of Buttermilk Channel sediment in isolating Dutch Kills sediment were conducted in a controlled environment chamber maintained at 20° ± 0.5°C using modified 250-ℓ flow-through reactor units (Figure 1) described in detail by Gunnison et al. (1980). These chambers are 121 cm in height and measure 46 cm on a side. Modifications included sealing of sampling ports with Plexiglas, removal of the mixing pump from the system, and provision for constant aeration of the water column. With the exception of the control units, to which only Buttermilk Channel sediment was added, 17 cm of Dutch Kills sediment was first placed on the bottom of each reactor unit. This sediment was then capped with either 10 cm or 50 cm of Buttermilk Channel sediment. Sixty litres of artificial seawater at 20 ppt, prepared from Tri S™ artificial sea salts, was then added as gently as possible to each reactor unit and allowed to equilibrate with aeration for 14 days. A 14-day equilibration time was selected to allow initial compaction to occur and material suspended during water addition to settle. At the end of this equilibration/consolidation period, flow-through of artificial seawater was initiated at a rate of 1.2 ℓ/hr. At this flow rate, 50 percent of the overlying water was replaced every 36 hr (Sprague 1969). Aeration ensured constant mixing of water in the reactor units.

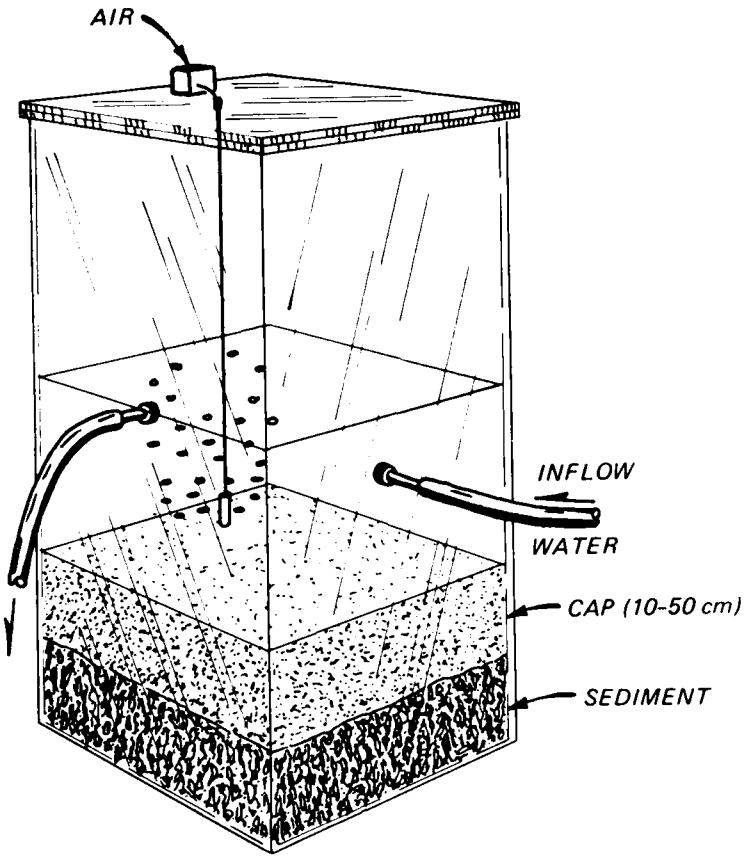

Figure 1. Large reactor units

5. Clam (*Mercenaria mercenaria*) were selected to determine if contaminants were moving through the cap and into the water column. Polychaetes (*Nereis virens*) were used to assess the effect of capping on contaminant bioaccumulation in infaunal organisms and to provide a source of bioturbation. Clams were obtained from Multi-Aquaculture Systems, Inc., Amagansett, New York, and polychaetes from the Maine Bait Co., New Castle, Maine. All animals were acclimated to test conditions in the laboratory for at least 1 week prior to being added to the reactor units.

6. Following 4 days of flow-through operation in the reactor units, clams and polychaetes were added to various units as shown in Table 1. There were three replicates of each experimental treatment. Forty-two clams in baskets were suspended in the water column 5 cm above the sediment surface in all reactor units. Twenty-one polychaetes ($100/m^2$) were added to each reactor unit designated to receive polychaetes. Concurrent with addition of clams and

polychaetes to the reactor units, subsamples were removed from the holding tanks for initial chemical characterization. Clams were immediately frozen; divided into subsamples for polychlorinated biphenyls (PCB), polyaromatic hydrocarbons (PAH), and metals analysis; removed from their shells; and then placed in glass (PCB and PAH) or plastic (metals) containers and maintained frozen until analysis. Polychaetes were depurated for 24 hr in water identical to that in the reactor units to remove sediment and food from their gut. They were then divided into subsamples for PCB, PAH, and metals analysis, placed in appropriate glass (PCB, PAH) or plastic (metals) containers, and maintained frozen until analyzed. Twenty-one clams were removed from each reactor unit at 10- and 40-day intervals and handled in the same manner as described for initial clam samples. At the end of 40 days, polychaetes were removed from the sediment, then depurated and prepared for analysis in the same manner described for initial polychaete samples. Polychaetes in each reactor unit were fed 2 g of ground tetramin each week during the experiment. Clams in each reactor unit were fed 6 g (wet weight) of green marine algae twice weekly. The algae were grown in the media given in US Environmental Protection Agency (USEPA) (1978, pp 43 and 44).

7. Water samples were obtained at the end of 40 days for subsequent chemical analyses. Samples to be used for PCB and PAH analyses were placed in 3.8-ℓ glass jars which had been hexane washed and dried at 105°C for 24 hr. Samples for metal analyses were filtered through 0.45-μm pore size membrane filters. The first 100 ml of filtrate was discarded. The subsequent filtrate was acidified to pH 1 with concentrated HNO_3. Water samples were analyzed for cadmium, copper, lead, and zinc using a Perkin-Elmer Model 2100 heated graphite atomizer and a Perkin-Elmer Model 503 atomic absorption spectrophotometer. Mercury was determined using a Perkin-Elmer Model 503 atomic adsorption unit coupled to a Perkin-Elmer MHS-10 hydride generator. Unfiltered water samples were analyzed for total suspended solids using the method of Ballinger (1979).

8. Water, tissue, and sediment samples were analyzed for ten PCB isomer groups: total monochlorobiphenyls through total decachlorobiphenyls. Isomer group concentrations were determined following Soxhlet extraction, H_2SO_4 cleanup, and quantification in an electron capture detector gas chromatograph. Thirty compounds comprising the PAH family (Table 2) were also determined in water and tissue samples. In sediments, all PAHs in Table 2, except single ring compounds because of evaporative losses during the extraction procedures,

were determined. Samples were Soxhlet extracted overnight with benzene: methanol. The aromatic hydrocarbon fraction was then separated using silica gel chromatography, concentrated, and subjected to capillary gas chromatographic analyses on a Hewlett Packard 5840A gas chromatograph equipped with a flame ionization detector. Individual compounds were quantified using analytical standards and an internal standard. Lipid concentrations were determined on each tissue sample (Food and Drug Administration (FDA) 1977). Heavy metal concentrations in water, tissue, and sediment samples were analyzed using atomic absorption spectroscopy following appropriate sample digestion procedures (Ballinger 1979).

9. Total organic carbon (TOC) in sediment samples was determined by dry combustion (Allison 1965). Sediment particle-size distribution was determined using the method of Patrick (1958).

Microbiological Studies

Sediment analyses

10. The Dutch Kills dredged material and Buttermilk Channel capping material were assayed for (a) total viable, aerobic, and heterotrophic bacteria; (b) total coliform (TC) bacteria; (c) fecal coliform (FC) bacteria; (d) *Salmonella* spp. (Salmonellae); and (e) *Clostridium perfringens*. Identification of isolates from the fecal coliform and salmonellae assays was performed by biochemical testing.

11. Total heterotrophic bacteria were enumerated by the pour plate method on Standard Methods agar incubated at 25°C for 72 hr. The TC and FC bacteria concentrations were determined by the five-tube most probable number (MPN) method using lauryl sultate tryptose broth for the presumptive tests. Confirmations for TC and FC were conducted with brilliant green lactose bile broth incubated at 35° ± 1°C and EC broth incubated at 45° ± 0.5°C, respectively, according to Standard Methods (American Public Health Association (APHA) 1980). Sediment concentrations of salmonellae were assessed by the five-tube MPN method using selenite cystine and tetrathionate broths for enrichment, brilliant green and bismuth sulfite agar plates for isolation, and triple sugar iron (TSI) agar slants for primary biochemical screening (FDA 1978). All potentially positive isolates from EC broth (FC testing) and TSI slants (salmonellae) were identified using API-20E biochemical test strips

(Analytab Products, Division of Ayerst Laboratories, Plainview, N.Y.). *Clostridium perfringens* was enumerated in the sediment by the membrane filter (mCP) method of Bisson and Cabelli (1979) using the shake, sonication, and settling procedures previously developed and evaluated for marine sediment (Emerson and Cabelli 1982; Emerson 1982).

12. Representative wet weight sediment aliquots were diluted serially with 0.01 M phosphate-buffered saline for all assays except the mCP. A 0.1 percent peptone water diluent was used in the mCP testing using the supernatant from each sediment suspension, following a 10-min settling period, as the initial dilution.

Water analyses

13. Water samples from each previously described large reactor unit were also monitored for viable *Clostridium perfringens* spore densities using the mCP method of Bisson and Cabelli (1979). One-tenth percent peptone water was used as the buffer solution, and incubation of mCP plates was at 44° ± 0.5°C for 18 to 20 hr. Water samples were assayed 2 hr before adding clams and polychaetes, and 6, 15, 28, 37, and 41 days after addition of these organisms.

Small Reactor Unit Experiments

14. The ability of capping material to chemically seal contaminated dredged sediment containing relatively mobile and oxygen-demanding constituents from the overlying water was determined in 22.6-ℓ, cylindrical, Plexiglas leaching columns (Figure 2). These experiments were conducted in a controlled environment chamber where the temperature was regulated at 20° ± 0.5°C. The design and loading arrangement of an individual column are shown in Figure 2.

15. All experimental treatments were initially aerated for 3 days to ensure dissolved oxygen saturation by slowly bubbling air through the water column. At the end of 3 days, the aeration apparatus was removed and a layer of mineral oil (4 cm) added to seal the surface of the water column from the atmosphere. Water samples were taken initially and at regular intervals for 21 days or until the measured dissolved oxygen concentration was depleted. The overlying water was manually mixed daily with a Plexiglas stirring plunger that was suspended between the sediment and the mineral oil layer. All experiments were conducted in triplicate.

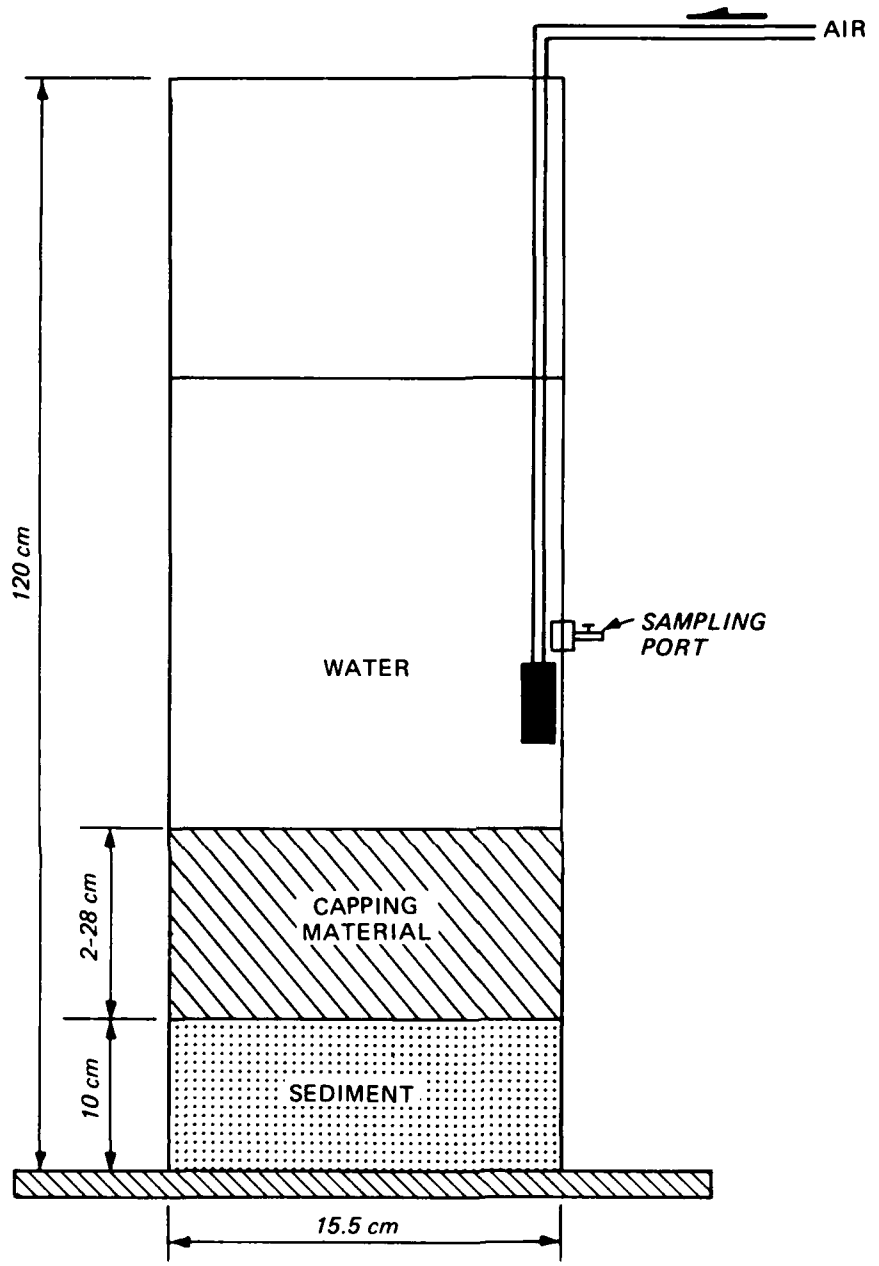

Figure 2. Small reactor units

16. Dissolved oxygen was measured in samples collected by permitting water to flow gently from a reactor unit sampling port into a standard biochemical oxygen demand (BOD) bottle. Dissolved oxygen was determined with the azide modification of the Winkler method as described in Standard Methods (APHA 1980).

17. Samples to be analyzed for ammonium nitrogen, orthophosphate, and manganese were cleared of particulate matter by passage through a 0.45-μm membrane filter under a nitrogen atmosphere. Manganese samples were preserved by acidification to pH 1 with concentrated HCl. Metal concentrations were determined using direct flame aspiration with a Perkin-Elmer Model 306 atomic absorption spectrophotometer. Samples for ammonium nitrogen and orthophosphate analyses were preserved by acidification with concentrated HCl to pH 2 and immediate freezing and storage at -4°C. Ammonium nitrogen and orthophosphate concentrations were determined using a Technicon Autoanalyzer II, in accordance with procedures recommended by the USEPA (Ballinger 1979).

Analysis of Results

18. Means and standard errors were determined for each parameter within a treatment. To determine the statistical significance of differences between means, t-tests were conducted. Statements of significance made in the text refer to the 5-percent level or less.

PART III: RESULTS AND DISCUSSION

Sediment Chemical Characterization

19. Sediment from Dutch Kills was more contaminated with PCBs than the capping sediment from Buttermilk Channel (Table 3). Total PCB concentration in Dutch Kills sediment was 17.7 µg/g dry weight compared to 1.0 µg/g dry weight in Buttermilk Channel sediments. Total hexachlorobiphenyl constituted the largest fraction of PCBs in both Dutch Kills (40.7 percent) and Buttermilk Channel (26.3 percent) sediments.

20. Both sediments contained PAH compounds (Table 4). Benzothiophene was, however, present only in Dutch Kills sediment. Benzothiophene should therefore be a potentially useful tracer compound for this study.

21. Dutch Kills sediment contained higher levels of heavy metals compared to Buttermilk Channel sediment, with the exception of mercury which was similar in both sediments (Table 5). Dutch Kills sediment also contained higher amounts of TOC and differed in texture (i.e. more silt and less clay) from Buttermilk Channel sediment.

Large Reactor Unit Experiments

Contaminant release and uptake

22. Concentration values for selected contaminants were determined in water, clams, and polychaetes to assess the ability of 10- and 50-cm Buttermilk Channel caps to isolate Dutch Kills dredged material. The clams and polychaetes did not suffer excessive mortality in the reactor units; 95 percent or more of the animals added initially to the experimental units survived until sampled and used for tissue analyses.

23. Water column. Heavy metal (Table 6) and PCB isomer group (Table 7) concentrations in the water column above capped sediments did not significantly differ from their respective concentrations in the Buttermilk Channel water column. Replicate samples for PAHs in the water column were composited to obtain greater sensitivity. Even using these techniques, concentrations of PAHs in the water column for all treatments were below the detection limit of 1 nanogram/ℓ.

24. In these water column data, it is especially noteworthy that heptachlorobiphenyls and octachlorobiphenyls, which were present in the Dutch Kills sediments at levels much greater than the Buttermilk Channel sediment, were present in water overlying Dutch Kills sediment but were not detected in any of the capped treatments (Table 7). This indicates that the Buttermilk Channel cap prevented water column contamination attributable to Dutch Kills sediment.

25. *Mercenaria.* All tissue concentrations of PCB and PAH were normalized to lipid concentration to facilitate comparison with data being generated in ongoing studies at WES. Concentrations can be converted to a whole body basis by dividing the lipid normalized concentration by 100, then multiplying by percent lipids. Average percent lipids for each treatment and organism can be found in Appendix Table A1.

26. Heavy metal concentrations in *Mercenaria* tissue did not significantly exceed that of Buttermilk Channel cap material in any of the treatments (Table 8). The presence or absence of polychaetes had no impact on *Mercenaria* heavy metal tissue concentrations.

27. PAH concentrations in clams did not significantly exceed those observed in Buttermilk Channel cap material for any of the capped treatments (Table 9). Concentrations of PAHs were generally lower, however, in treatments without polychaetes at the 10-day sampling. This was probably due to increased suspended material early in the study in the water column of treatments containing polychaetes. The addition of polychaetes to reactor units will cause increased suspended solids in the early part of such capping studies (Brannon, unpublished data). At this time, polychaetes were observed to be most active, resulting in suspended material that can act as a source of contamination to the exposure water (McFarland, unpublished data). After 40 days of exposure, the presence of polychaetes in the sediments did not significantly affect PAH concentrations in *Mercenaria* tissue. Total suspended solid concentrations in the water column at day 40 did not differ among treatments (Table A2). Benzothiophene could not be used as a tracer because no uptake of this compound by *Mercenaria* was observed.

28. Tissue concentrations of total trichlorobiphenyls in clams normalized to organism lipid content were significantly higher after 40 days in capped (10 cm) sediment with polychaetes than in Buttermilk Channel cap material (Table 10). However, the uptake observed may have been due to chance or

to organism differences in the 10-cm cap (with polychaetes) treatment. There was no significant difference between total trichlorobiphenyl concentrations in the Buttermilk Channel and uncapped Dutch Kills sediment treatments. In addition, there was close agreement, except for the 10-cm cap (with polychaetes), between 40-day total trichlorobiphenyl *Mercenaria* concentrations in all treatments. There were no significant differences in PCB uptake between Buttermilk Channel cap material and either of the 50-cm cap treatments (with or without polychaetes).

29. These results indicated that the 10-cm cap (with polychaetes) was generally effective in isolating Dutch Kills dredged material from the *Mercenaria*. Only total trichlorobiphenyls could have been present in higher concentrations than in Buttermilk Channel in the 10-cm cap (with polychaetes) treatment. The 50-cm cap, even with polychaetes present, effectively isolated the Dutch Kills sediment from *Mercenaria*.

30. To compare contaminant uptake by *Rangia* and *Mercenaria*, *Rangia* were exposed for 10 days in some treatments concurrently with *Mercenaria* by suspending them in the same baskets. Tissue concentrations of heavy metals in *Rangia* and *Mercenaria* were generally similar, with the exception of mercury (Table 11). Concentrations of total PCB in *Mercenaria* exposed to Dutch Kills sediment was 55 ± 18 µg/g compared with 54 ± 17 in *Rangia*. PCB concentrations in tissue are lipid normalized. These results indicate that much of the data being obtained in concurrent capping studies using the clam *Rangia* will be comparable to data obtained in this study. *Rangia* were not analyzed for PAHs due to sample size limitations.

31. Polychaetes. Significant bioaccumulation of heavy metals by polychaetes in capped and uncapped Dutch Kills sediments over levels observed in Buttermilk Channel sediments was not noted in any treatment (Table 12).

32. *Nereis* accumulated significantly higher concentrations of total hexachlorobiphenyl in uncapped Dutch Kills compared to Buttermilk Channel sediments (Table 13). The presence of a 10-cm cap prevented significant bioaccumulation of total hexachlorobiphenyl in *Nereis*.

33. Examination of sediment PAH data in Table 4 indicated that benzothiophene was present in Dutch Kills sediment but was not found in Buttermilk Channel sediment. As shown in Table 14, benzothiophene was not detected in

polychaetes exposed to Buttermilk Channel sediment, but was found in polychaetes in both the 10-cm and 50-cm cap treatments. No other PAH compound or groups of compounds were significantly bioaccumulated by *Nereis* over levels observed in *Nereis* in Buttermilk Channel sediments. PAH data for *Nereis* are summarized in Table A3.

34. Bioaccumulation results indicate that the polychaetes penetrated both the 10-cm and 50-cm caps. These results were supported by observations during retrieval for analyses that the worms had reached the Dutch Kills sediment through both the 10-cm and 50-cm caps. Cap breaching by the polychaetes offers contaminants in the Dutch Kills sediment an easier path into the overlying water than if the cap remained unbreached. Even when breached, however, the water column, clam, and polychaete data indicate that both the 10-cm and 50-cm caps generally prevented the movement of contaminants into the water column or organisms. Only with total trichlorobiphenyls in clams and benzothiophene in worms was significant bioaccumulation observed from capped Dutch Kills sediment. Findings of the bioaccumulation portion of the study are summarized in Table 15.

Microbial releases

35. Total viable aerobic, heterotrophic bacteria in the Dutch Kills sediment averaged 1.9×10^5 per gram wet sediment (6.0×10^5/g dry), while the Buttermilk Channel cap sediment displayed a comparable wet sediment value of 1.8×10^5 per gram (3.6×10^5/g dry weight). These numbers are one to three orders of magnitude lower than in oxidized sediments (Alexander 1977), but were not unexpected for a highly reduced, contaminated sediment.

36. The TC and FC MPN assays indicated very low viable levels of these fecal contamination indicator bacteria. Estimated TC and FC numbers for the Dutch Kills sediment were 17 per 10 g wet sediment (55/10 g dry) and 5 per 10 g wet sediment (16/10 dry), respectively. The Buttermilk Channel cap material also showed very low TC and FC counts, namely, 130 per 10 g wet sediment (220/10 g dry) and 49 per 10 g wet sediment (80/10 g dry), respectively. These low numbers, especially for FC, are typical for highly reduced subsurface marine sediments (Attwell and Colwell 1981). A previous study of indicator bacteria in core samples from Long Island Sound and adjacent harbor areas indicated that TC and FC bacteria are seldom found at elevated numbers below the uppermost layer of fine-grained, fecal-contaminated marine sediments (Babinchak et al. 1977a). Also, the sediment was stored for several weeks

prior to sampling; this could result in declining TC and FC counts (Babinchak et al. 1977b). Biochemical testing indicated that most of the FC isolates were *Citrobacter freundii*, a member of the FC bacterial group.

37. Assays for *Salmonella* species and other pathogenic members of the salmonellae all proved negative. The MPN tables thus indicated numbers of less than two viable cells per gram wet sediment. The median ratio of salmonellae to FC in freshwater muds is about 1:14,000 (Van Donsel and Geldreich 1971), and the die-off of both is more rapid in marine versus freshwater environments (Mitchell 1968). Biochemical testing of isolates indicated that none were even closely related to the salmonellae group. The main isolate identified was *Pseudomonas putrefaciens*.

38. The *Clostridium perfringens* membrane filter (mCP) assays of the Dutch Kills sediment indicated very high numbers of viable cells and/or spores. The mCP test gave an average enumeration of 2.88×10^5 per gram wet sediment (1.01×10^6/g dry sediment). *Clostridium perfringens* is a fecal pollution indicator and pathogenic bacterium as well as a strict anaerobe (i.e., does not grow in an aerated water column). Therefore, monitoring of viable *C. perfringens* spore densities in the aerated water column of the test chambers serves to evaluate the movement of resistant bacteria and very small particles through the different thicknesses of the Buttermilk Channel cap covering Dutch Kills sediment. Endospores of clostridia are generally less than 1 μm in diameter, smaller than most bacteria and clay-sized particles. The results of water column mCP monitoring are shown in Table 16. These data indicate that bioturbation by the large polychaete *Nereis virens* caused breaching of both the 10-cm and 50-cm Buttermilk Channel caps between days 6 and 37.

39. There was a large amount of variability associated with both the microbial and bioaccumulation data. This is similar to the bioaccumulation variability observed in the data of Rubinstein, Lores, and Gregory (1983) from aquaria containing *Nereis virens*, *Mercenaria mercenaria*, and *Palaemonetes pugio*. It is highly probable that much of the variability observed represents differences in exposure conditions caused by polychaete activity among chambers. For example, spore counts showed that one of the three chambers with a 50-cm cap and polychaetes suffered major breaching by day 15, while the remaining chambers did not. The impact of polychaetes on spore counts can be

appreciated by comparing the data (Table 16) for 10-cm and 50-cm caps with and without polychaetes.

40. Even though the caps were penetrated by the polychaetes, the presence of a 10-cm cap was sufficient to cause a twofold to threefold lower spore count than in chambers containing uncapped Dutch Kills sediment. This indicates that even a shallow cap which has been subjected to bioturbation can reduce the impact of contaminated sediment on the overlying water.

41. It is important to emphasize that the bioturbation in this study may have been more severe than normally encountered in the New York area. Rhoads, McCall, and Yingst (1978) reported that polychaetes observed recolonizing a dredged material disposal site in Long Island Sound were *Streblospio benedicti*, *Capitella capitata*, and *Nephtys incisa*. Of these polychaete species, *Nephtys*, at 50 mm, was the longest measured. For *Nephtys*, an increase in worm size has been shown to produce a corresponding increase in burrow length and depth (Davis and Miller 1979, Davis 1980). The data of Davis (1980) showed that the largest 1- to 2-year-old *Nephtys* (0.6 g wet weight) burrowed to a depth of approximately 8 cm. The *Nereis virens* used in this study are among the largest of the polychaete species and often measure up to 450 mm in length (Arnold 1968). The *Nereis* used in this study were generally 300 mm or longer, and burrowed to much greater depths (at least 50 cm) than do smaller polychaete species. Bioturbation was therefore much greater than would be expected of the polychaete assemblage in the ocean disposal areas in the New York area.

42. Microbial spores and chemical constituents may not behave in a similar manner in sediments. Davis (1980) demonstrated that the burrow wall of *Nephtys* adsorbed soluble copper as a function of copper concentration and sediment wall organic content. Microbial spores are of the same size as very fine clay particles, and there is no reason to expect them to be adsorbed to sediments in the same manner or degree as for chemical constituents (Bitton and Marshall 1980).

43. During the course of the experiment, a thick growth of filamentous fungi developed at the sediment-water interface. Such growth will also occur to some degree in the natural environment. Therefore, the initial geotechnical measurement for determining stability of fine-grained sediments may be pertinent only for the dredging and disposal phases of a capping operation;

long-term stability of these sediments may be greater than such testing indicates.

Small Reactor Unit Experiments

Water column oxygen depletion

44. Small reactor unit experiments were conducted to determine the depth of cap necessary to chemically isolate Dutch Kills sediment from the water column. Dissolved oxygen depletion in the water column would not be a problem in an open water environment because of mixing and reaeration. Dissolved oxygen depletion, however, does serve as a good tracer for determining how effectively a cap can isolate dredged material such as Dutch Kills that possess a high oxygen demand.

45. The effect of the buttermilk cap depth on dissolved oxygen depletion rate in the overlying water is shown in Figure 3. Oxygen depletion rates

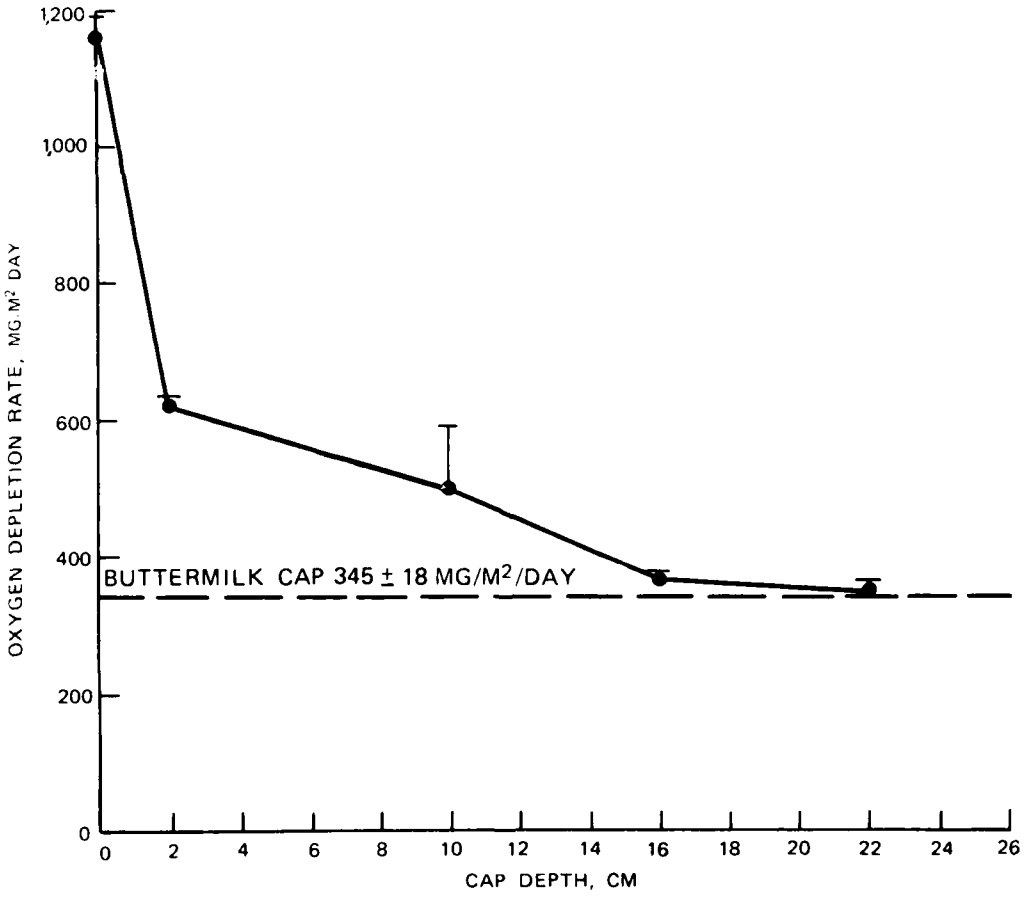

Figure 3. Effect of Buttermilk Channel cap depth on overlying water oxygen demand

were derived by performing linear regression analyses of mass uptake or release per unit area (milligrams per square metre) versus time. Rates plotted are the mean and standard deviation of three replicates. Figure 3 shows that the 2-cm cap resulted in a large (46 percent) decrease in oxygen depletion rate. Following this initial decrease, oxygen depletion rate decreases were linearly related ($r = 0.97$, $p < 0.05$) to cap depth until a cap depth of 22 cm was reached. At this point, oxygen depletion rates of the capped Dutch Kills sediment were not significantly different from that of the Buttermilk controls.

Nutrient and metal release rates

46. Ammonium nitrogen (NH_4^+-N) release rates to the overlying water, derived in the same manner as oxygen depletion rates, are presented as a function of cap depth in Figure 4. The 2-cm cap depth reduces the NH_4^+-N release rate by 18 percent from that observed with uncapped Dutch kills sediment. The NH_4^+-N release rates decreased linearly ($r = 0.97$, $p < 0.05$) until a cap depth of 22 cm was reached. At this point, NH_4^+-N release rates of the capped Dutch Kills sediment were not significantly different from that of Buttermilk Channel sediments.

47. The phosphorus release rates of the uncapped Dutch Kills sediment (41 ± 3 mg/m^2/day) were not significantly different from that of the Buttermilk Channel cap material (42 ± 1 mg/m^2/day). This precluded any evaluation of the effectiveness of capping on phosphorus release. A similar situation was encountered with manganese release; uncapped Dutch Kills sediment had a manganese release rate of 1.58 ± 0.09 mg/m^2/day compared to 1.52 ± 0.00 mg/m^2/day in Buttermilk Channel sediments.

48. These results demonstrate that a cap over Dutch Kills sediment exerts a considerable influence on sediment-water interactions. After a cap depth of 22 cm was reached, Dutch Kills sediment no longer affected oxygen depletion and NH_4^+-N release rates to the overlying water. In the absence of cap disruption, 22 cm of Buttermilk sediment adequately isolated the overlying water column from soluble, oxygen-demanding constituents and NH_4^+-N contained in the Dutch Kills sediment. This 22-cm depth is the depth required to obtain a chemical seal in the absence of bioturbation.

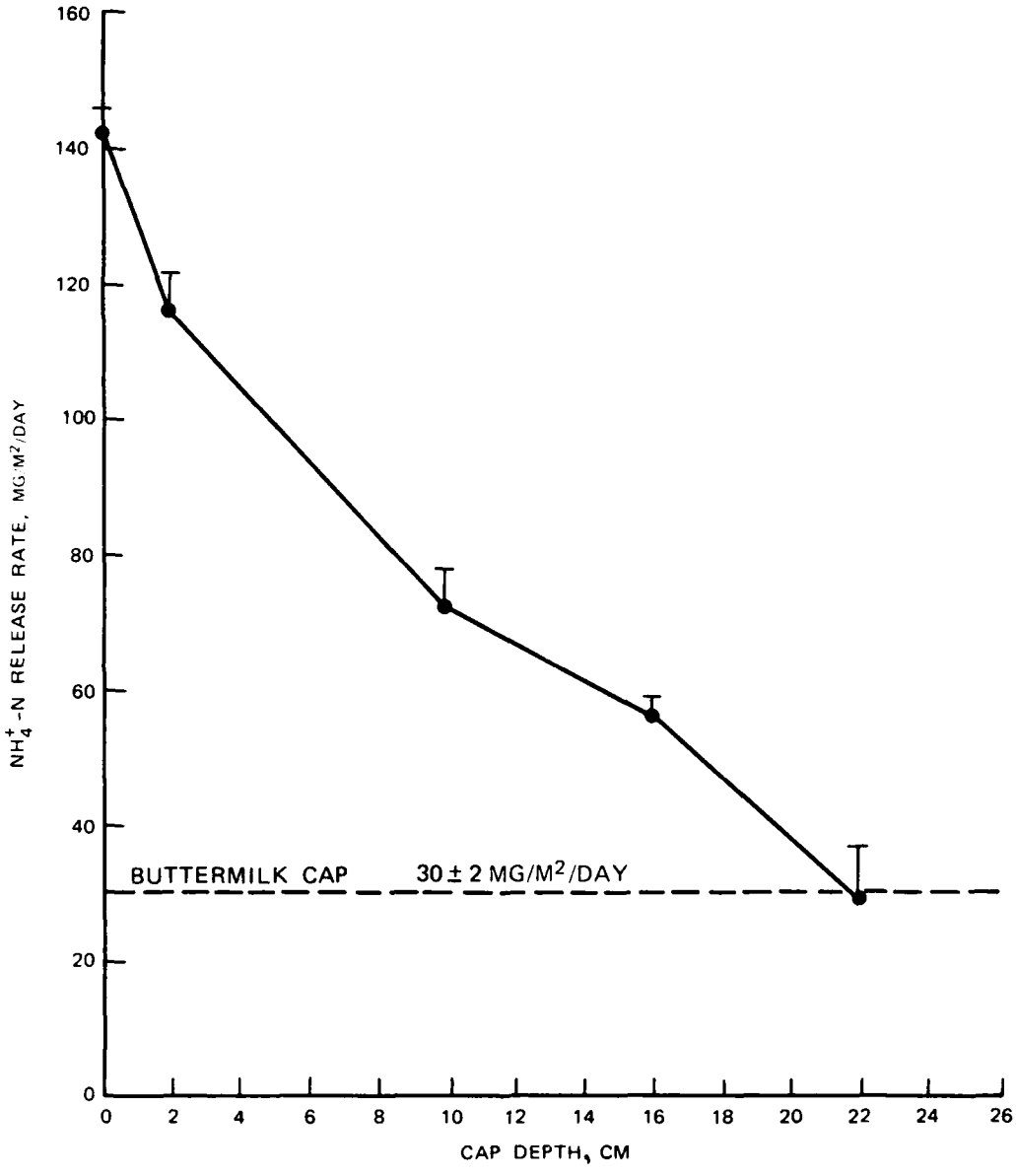

Figure 4. Effect of Buttermilk Channel cap depth on ammonium nitrogen release rates

PART IV: SUMMARY AND CONCLUSIONS

49. In the small reactor units, analyses of dissolved oxygen and NH_4^+-N in the overlying water revealed that increasing cap depths prevented the transfer of dissolved constituents to the overlying water. For Dutch Kills sediment with a Buttermilk Channel sediment cap, this was found to occur at a cap depth of 22 cm for both dissolved oxygen and NH_4^+-N. Release rates of manganese and phosphorus did not differ between Dutch Kills and Buttermilk Channel sediments.

50. Water column microbial results and chemical analyses of polychaete tissue showed that *Nereis* penetrated both the 10-cm and 50-cm caps. This resulted in bioturbation that was probably more severe than generally encountered in New York area ocean disposal sites. The normal polychaete assemblage in Long Island Sound or New York Bight should only burrow to a depth of 8 to 10 cm, although large individuals may burrow deeper.

51. Under the severe bioturbation conditions of this study (100 large polychaetes per square metre), neither *Mercenaria* body burdens nor water column concentrations of PCBs, PAHs, or heavy metals showed a significant increase compared with cap material alone in experimental units with a 50-cm cap. At the end of 40 days, however, *Mercenaria* in experimental units with a 10-cm cap (with polychaetes) showed significantly increased total trichlorobiphenyl body burdens compared with *Mercenaria* in units with Buttermilk Channel cap material. It should be noted that the apparent uptake of total trichlorobiphenyls by *Mercenaria* in treatments with a 10-cm cap (with polychaetes) may have been due to chance or organism differences in that treatment. No significant difference was found between uptake of total trichlorobiphenyls by *Mercenaria* exposed to Buttermilk Channel and uncapped Dutch Kills sediment. These results indicate that a 50-cm cap and possibly a 10-cm cap of Buttermilk Channel sediment, even when penetrated by organisms, are effective in preventing the transfer of chemical constituents to the overlying water and biota during a 40-da xperiment. Microbial spores, which are not subject to the same adsorption reactions as dissolved chemicals, were found in higher numbers in the water column of experimental units with 50-cm caps compared with Buttermilk Channel cap material alone. The number of spores in the water column of all treatments, however, tended to decrease steadily over time.

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Table 1

Experimental Setup for Dutch Kills Sediment with Buttermilk Channel

Treatment	Animals in Reactor Unit	
	Polychaetes	Suspended clams
Control (Buttermilk Channel)	X	X
10-cm cap	X	X
10-cm cap		X
50-cm cap	X	X
50-cm cap		X
Dutch Kills	X	X

Table 2

Polyaromatic Hydrocarbon Compounds Determined in Water and Tissue Samples

Single Ring Compounds	Two Ring Compounds
Ethyl - Benzene	Naphthalene
M - Xylene	Benzothiophene
O - Xylene	2-Methylnaphthalene
Isopropylbenzene	1-Methylnaphthalene
1-Ethyl-4-Methylbenzene	Biphenyl
1,2,4-Trimethylbenzene	2,6-Dimethylnaphthalene
Secbutylbenzene	2,3,6-Trimethylnaphthalene
1-Methyl-4-Isoprophylbenzene	
1-3-Dimethyl-5-Ethylbenzene	**Four Ring Compounds**
1-2-Diethylbenzene	Pyrene
1-2-Dimethyl-4-Ethylbenzene	Chrysene
1,2,3,5-Tetramethylbenzene	
	Five Ring Compounds
Three Ring Compounds	Benzo (e) Pyrene
Fluorene	Benzo (a) Pyrene
Dibenzothiophene	Perylene
Phenanthrene	
Anthracene	
1-Methylphenanthrene	
Fluoranthene	

Table 3

Sediment PCB Concentrations

Isomer Group	Concentration in Indicated Sediment µg/g dry weight	
	Dutch Kills	Buttermilk Channel Cap
Total monochlorobiphenyls	< 0.5	< 0.5
Total dichlorobiphenyls	1.7	0.11
Total trichlorobiphenyls	1.4	0.16
Total tetrachlorobiphenyls	2.8	0.22
Total pentachlorobiphenyls	2.8	0.12
Total hexachlorobiphenyls	7.2	0.26
Total heptachlorobiphenyls	0.83	0.01
Total octachlorobiphenyls	0.80	0.04
Total nonachlorobiphenyls	0.13	0.04
Total decachlorobiphenyls	0.04	0.03
Total PCBs	17.7	1.0

Table 4

Sediment PAH Concentrations

Parameter	Concentration in Indicated Sediment µg/g sediment dry weight	
	Dutch Kills	Buttermilk Channel
Naphthalene	2.7	7.8
Benzothiophene	7.4	ND*
2-Methylnaphthalene	14.5	9.2
1-Methylnaphthalene	12.5	11.6
Biphenyl	5.8	2.4
2,6-Dimethylnaphthalene	25.0	11.6
2,3,6-Trimethylnaphthalene	26.3	7.9
Fluorene	16.9	13.8
Dibenzothiophene	113.0	34.6
Phenanthrene	107.0	92.8
Anthracene	101.0	78.3
1-Methylphenanthrene	116.0	62.7
Fluoranthene	262.0	228.4
Pyrene	75.0	152.4
Chrysene	32.7	136.1
Benzo (e) Pyrene	74.2	55.8
Benzo (a) Pyrene	48.0	146.7
Perylene	17.4	42.7
Total	106.0	110.0

* ND = Not Detected (detection limit = 0.5 ng/g).

Table 5

Heavy Metal Concentrations and Selected Sediment Physical Characteristics

Sediment	Metal Concentration, µg/g (dry weight)					TOC, %	Texture, % Sand:Silt:Clay
	Cd	Cu	Pb	Zn	Hg		
Dutch Kills	134	1754	1175	2460	4.0	14.0	24:76:0
Buttermilk Channel cap	2.3	274	416	760	5.1	4.3	34:37:29

Table 6

Water Column Metal Concentrations (µg/ℓ ± SE*) in the Dutch Kills Capping Study Following 40 Days of Incubation

Treatment	Cd	Cu	Pb	Zn
Buttermilk Channel	1.8 ± 0.87	2.7 ± 0.99	10 ± 1.7	<50
Dutch Kills	1.4 ± 0.82	6.0 ± 2.5	30 ± 32	<50
10-cm cap	0.2 ± 0.16	2.0 ± 0.82	9 ± 1.6	<50
10-cm cap**	0.8 ± 0.49	3.0 ± 1.6	10 ± 2.5	80 ± 25
50-cm cap	0.3 ± 0.41	4.0 ± 2.5	10 ± 1.6	<50
50-cm cap**	0.7 ± 0.16	5.0 ± 0.82	7 ± 2.5	<50
Inflow water	0.5	5.0	9.0	<50

* SE = Standard error.
** Polychaetes present.

Table 7

Water Column PCB Concentration Following 40 Days of Incubation

Parameter	Concentration at Indicated Treatment, µg/ℓ ± SE						
	Inflow Water	Buttermilk Cap	Dutch Kills	10-cm Cap	10-cm Cap*	50-cm Cap	50-cm Cap*
Total monochlorobiphenyl	2.1	4.9 ± 1.2	3.3 ± 0.5	2.9 ± 0.0	3.8 ± 0.8	2.9 ± 0.70	4.0 ± 0.40
Total dichlorobiphenyl	2.1	10.1 ± 4.9	22 ± 4.0	7.4 ± 3.5	5.1 ± 4.5	0.73 ± 0.19	11.1 ± 5.4
Total trichlorobiphenyl	0.46	0.32 ± 0.13	0.18 ± 0.02	0.36 ± 0.27	0.64 ± 0.28	0.94 ± 0.14	0.46 ± 0.27
Total tetrachlorobiphenyl	0.09	0.04 ± 0.02	0.06 ± 0.02	0.03 ± 0.01	0.06 ± 0.03	0.04 ± 0.01	0.04 ± 0.02
Total pentachlorobiphenyl	<0.01	0.02 ± 0.01	0.02 ± 0.04	0.01 ± 0.01	0.02 ± 0.01	<0.01	0.04 ± 0.02
Total hexachlorobiphenyl	0.02	0.01 ± 0.0	0.06 ± 0.03	<0.01	<0.01	<0.01	<0.01
Total heptachlorobiphenyl	<0.01	<0.01	0.01 ± 0.01	<0.01	<0.01	<0.01	<0.01
Total octachlorobiphenyl	0.01	<0.01	0.03 ± 0.02	<0.01	<0.01	<0.01	<0.01
Total nonachlorobiphenyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total decachlorobiphenyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total PCB	4.8	15.5 ± 5.9	25.7 ± 4.3	10.7 ± 3.2	9.6 ± 3.9	4.7 ± 0.69	15.6 ± 4.7

* Polychaetes present.

Table 8

Heavy Metal Concentration in *Mercenaria* Tissue at 10 and 40 Days

Parameter	Concentration at Indicated Treatment, µg/g dry weight ± SE											
	Buttermilk (Cap)		Dutch Kills		10-cm Cap		10-cm Cap*		50-cm Cap		50-cm Cap*	
	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days
Cadmium	1.67 ± 0.08	1.16 ± 0.36	1.28 ± 0.08	1.98 ± 0.24	1.37 ± 0.28	1.88 ± 0.17	1.46 ± 0.22	2.01 ± 0.12	1.47 ± 0.25	1.77 ± 0.3	1.46 ± 0.15	1.51 ± 0.04
Copper	27.1 ± 2.45	24.4 ± 0.4	24.4 ± 0.4	26.4 ± 0.99	27.6 ± 5.29	31.1 ± 6.58	24.9 ± 3.73	25.7 ± 2.68	23.6 ± 3.92	29.8 ± 1.19	24.5 ± 4.42	26.0 ± 2.31
Lead	4.04 ± 0.49	10.7 ± 2.6	10.7 ± 2.6	6.77 ± 1.00	2.45 ± 1.88	8.31 ± 3.81	3.74 ± 1.53	7.69 ± 2.06	4.50 ± 1.04	5.18 ± 0.49	3.77 ± 1.16	6.9 ± 1.03
Zinc	98.5 ± 12.4	118 ± 13.5	118 ± 13.5	99.1 ± 11.9	82.0 ± 10.0	116 ± 18.6	114 ± 15.8	105 ± 10.5	111 ± 11.5	102 ± 17.9	116 ± 10.7	108 ± 7.06
Mercury	0.164 ± 0.003	0.08 ± 0.14	0.08 ± 0.05	0.25 ± 0.13	0.23 ± 0.03	0.30 ± 0.17	0.205 ± 0.030	0.17 ± 0.17	0.258 ± 0.050	0.41 ± 0.22	0.118 ± 0.06	0.31 ± 0.17

* Polychaetes present.

Table 9

PAH Concentration (Normalized to Lipid Concentration)

in *Mercenaria* Tissue at 10 and 40 Days

Parameters	Concentration at Indicated Treatment, µg/g lipid ± SE											
	Buttermilk (Cap)		Dutch Kills		10-cm (Cap)		10-cm* (Cap)		50-cm (Cap)		50-cm* (Cap)	
	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days
Single ring compounds	15 ± 12	53 ± 21	18 ± 8.5	87 ± 41	7.0 ± 2.5	215 ± 207	7.3 ± 2.1	23 ± 5.4	12 ± 2.3	30 ± 18	4.7 ± 2.5	45 ± 22
Double ring compounds	3.3 ± 1.2	12 ± 7.0	4.2 ± 1.7	5.0 ± 3.6	1.3 ± 1.0	16 ± 9.5	4.6 ± 2.0	6.3 ± 3.2	5.4 ± 3.5	0.5 ± 0.3	4.0 ± 3.1	6.8 ± 5.6
Triple ring compounds	178 ± 75	92 ± 52	137 ± 31	58 ± 23	1.2 ± 2.0	307 ± 161	155 ± 56	35 ± 11	9.1 ± 4.6	42 ± 16	143 ± 33	97 ± 5.6
Four ring compounds	215 ± 77	187 ± 86	158 ± 54	89 ± 33	19 ± 3.2	495 ± 314	183 ± 59	82 ± 21	13 ± 7.8	78 ± 40	139 ± 23	200 ± 72
Five ring compounds	44 ± 17	75 ± 43	90 ± 87	11 ± 0.3	1.7 ± 0.3	107 ± 47	32 ± 13	23 ± 21	2.0 ± 1.5	50 ± 22	30 ± 1.7	44 ± 6.1
Total PAHs	456 ± 184	418 ± 183	321 ± 85	250 ± 106	41 ± 6.6	1171 ± 564	383 ± 130	171 ± 35	39 ± 15	182 ± 60	320 ± 63	389 ± 112

* Polychaetes present.

Table 10

PCB Concentration (Normalized to Lipid Concentration)

in *Mercenaria* Tissue at 10 and 40 Days

Parameter	Concentration at Indicated Treatment µg/g lipid ± SE											
	Buttermilk (Cap)		Dutch Kills		10-cm (Cap)		10-cm* Cap		50-cm Cap		50-cm* Cap	
	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days	10 Days	40 Days
Total monochlorobiphenyl	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.05	<0.05	<0.05
Total dichlorobiphenyl	<0.01	83 ± 83	<0.01	10 ± 10	<0.01	15 ± 18	<0.01	42 ± 14	<0.01	31 ± 6.9	<0.01	94 ± 79
Total trichlorobiphenyl	13 ± 4.6	5.0 ± 5.0	3 ± 2.9	16 ± 3.5	2 ± 1.7	15 ± 18	13 ± 4.0	31 ± 7*	2 ± 1.7	27 ± 10	3 ± 2.3	19 ± 19
Total pentachlorobiphenyl	50 ± 3.5	44 ± 6.0	48 ± 13.3	46 ± 9.2	42 ± 8.1	69 ± 40	42 ± 6.9	48 ± 4.6	33 ± 5.2	45 ± 2.9	23 ± 0.8	42 ± 15
Total hexachlorobiphenyl	0.1 ± 0.1	<0.01	4 ± 4	<0.01	10 ± 1.2	<0.01	5 ± 2.3	0.01	8 ± 1.7	<0.01	5 ± 0.8	<0.01
Total heptachlorobiphenyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total octachlorobiphenyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total nonachlorobiphenyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total decachlorobiphenyl	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total PCB	73 ± 8.1	132 ± 94	55 ± 10.4	72 ± 11.1	54 ± 6.7	99 ± 31	60 ± 12	121 ± 12	43 ± 6.9	103 ± 13	31 ± 3.5	155 ± 43

* Polychaetes present.

** = Significantly ($P < 0.05$) higher than Buttermilk Channel cap.

Table 11

Heavy Metal Concentrations in *Rangia* and *Mercenaria* After 10 Days of Exposure

Metal	Concentration in Buttermilk (Cap), µg/g dry weight ± SE		Concentration in 10-cm Cap with Polychaetes, µg/g dry weight ± SE	
	Rangia	*Mercenaria*	*Rangia*	*Mercenaria*
Cd	0.9 ± 0.12	1.67 ± 0.08	1.1 ± 0.21	1.5 ± 0.22
Cu	32.5 ± 3.6	27.1 ± 2.5	32.6 ± 2.2	25. ± 3.7
Pb	2.8 ± 0.13	4.1 ± 0.5	3.6 ± 0.14	3.7 ± 1.5
Zn	63.2 ± 2.1	98.5 ± 12.4	68.3 ± 2.8	114 ± 16
Hg	1.5 ± 0.25	0.16 ± .003	1.2 ± 0.04	0.21 ± 0.03

Table 12

Heavy Metal Concentrations in *Nereis* Tissue Following 40 Days of Exposure

Parameter	Concentration at Indicated Treatment, µg/g dry weight			
	Buttermilk (Cap)	Dutch Kills	10-cm Cap	50-cm Cap
Cadimum	0.58 ± 0.09	1.89 ± 0.49	1.32 ± 0.47	0.94 ± 0.33
Copper	23.8 ± 2.62	25.9 ± 5.66	24.8 ± 0.97	24.13 ± 2.02
Lead	2.85 ± 0.54	2.35 ± 0.23	3.61 ± 0.65	2.87 ± 0.22
Zinc	93.1 ± 12.1	113 ± 32.0	91.8 ± 6.78	102 ± 12.0
Mercury	<0.02	<0.02	<0.02	<0.02

Table 13

PCB Concentration (Normalized to Lipid Concentration) in *Nereis* Tissue

Parameters	Concentration at Indicated Treatment, µg/g lipid ± SE			
	Buttermilk Cap	Dutch Kills	10-cm Cap	50-cm Cap
Total monochlorobiphenyl	<0.5	<0.5	<0.5	<0.5
Total dichlorobiphenyl	12 ± 1.0	12 ± 4.4	16 ± 2.1	11 ± 2.2
Total trichlorobiphenyl	36 ± 16	14 ± 1.9	26 ± 10.2	30 ± 3.5
Total tetrachlorobiphenyl	9.6 ± 1.1	16 ± 4.0	14 ± 3.8	11 ± 2.9
Total pentachlorobiphenyl	5.3 ± 2.3	16 ± 4.0	11 ± 4.0	8.6 ± 4.3
Total hexachlorobiphenyl	14 ± 7.0	49 ± 12*	35 ± 11	21 ± 14
Total heptachlorobiphenyl	1.0 ± 1.0	4.0 ± 1.8	6.0 ± 1.8	2.1 ± 2.1
Total octachlorobiphenyl	5.9 ± 1.5	10 ± 2.5	11.6 ± 1.8	5.3 ± 2.7
Total nonachlorobiphenyl	<0.01	<0.01	<0.01	<0.01
Total decachlorobiphenyl	<0.01	<0.01	<0.01	<0.01
Total PCB	84 ± 20	121 ± 28	120 ± 32	89 ± 28

* Significantly ($P < 0.05$) higher than Buttermilk Channel cap.

Table 14

Benzothiophene Concentration in *Nereis* Tissue (μg/g)

Following 40 Days of Exposure

Buttermilk (Cap)	Dutch Kills	10-cm Cap	50-cm Cap
Not detected*	0.53 ± 0.54	0.20 ± 0.20	0.33 ± 0.26

Note: Tissue concentrations are lipid normalized.
* Detection limit = 0.5 ng/g.

Table 15

Summary of Bioaccumulation Results Following

40 Days of Exposure

Animal	Chemical Parameter		
	PCB	PAH	Metals
Mercenaria	Significant accumulation of trichlorobiphenyls in 10-cm cap with polychaetes.* No accumulation in 50-cm cap	No accumulation	No accumulation
Nereis	No accumulation	Significant accumulation of benzothiophene	No accumulation

* These results may have been due to chance or to organism differences. There was no significant difference in *Mercenaria* total trichlorobiphenyl concentration between Buttermilk Channel and uncapped Dutch Kills sediment treatments.

Table 16

Clostridium perfringens Bacterial Spore Counts in Chamber Water Samples

Treatment	Count at Indicated Day, No./100 ml ± SE				
	Day 6	Day 15	Day 28	Day 37	Day 41*
Buttermilk Cap + polychaete worms	240 ± 14.5	110 ± 10.4	150 ± 60.1	75 ± 4.8	40
Dutch Kills + polychaete worms	1340 ± 185.**	575 ± 170.8**	555 ± 82.3**	250 ± 30.9**	290
10-cm Buttermilk Cap/Dutch Kills	45 ± 32.5	20 ± 15.2	22 ± 13.8	15 ± 10.5	18
10-cm Buttermilk Cap/Dutch Kills + polychaete worms	265 ± 13.6	250 ± 18.8**	295 ± 42.5	180 ± 88.8	87
50-cm Buttermilk Cap/Dutch Kills	9 ± 2.6	13 ± 6.0	16 ± 4.6	4 ± 2.2	5
50-cm Buttermilk Cap/Dutch Kills + polychaete worms	250 ± 19.2	200 ± 60.2	210 ± 6.7	180 ± 16.4**	130
Influent waters	0	0	0	0	1

* Composites of three replicate chambers.

** Counts significantly higher than those of the Buttermilk cap material.

APPENDIX A: TISSUE, WATER AND MICROBIAL RESULTS

Table A1

Percent Lipids (Wet Weight) in *Mercenaria* and *Nereis* Tissue

Treatment	*Mercenaria*		*Nereis*
	10 Days	40 Days	40 Days
Buttermilk	0.15	0.07	1.09
Dutch Kills	0.80	0.10	1.19
10-cm cap	0.16	0.08	
10-cm cap + polychaetes	0.17	0.15	0.89
50-cm cap	0.16	0.14	
50-cm cap + polychaetes	0.15	0.12	1.20

Table A2

Total Suspended Solids Concentration in the Water Column at 40 Days

Treatment	Concentration, mg/ℓ ± SE*
Buttermilk	12 ± 5
Dutch Kills	15 ± 1
10-cm cap	16 ± 7
10-cm cap + polychaetes	12 ± 5
50-cm cap	13 ± 6
50-cm cap + polychaetes	14 ± 1

* SE = Standard error.

Table A3

Polyaromatic Hydrocarbon (PAH) Concentration (Normalized to Lipid Concentration) in *Nereis* Tissue (µg/g lipid ± SE) Following 40 Days of Exposure

Parameter	Buttermilk (Cap)	Dutch Kills	10-cm Cap	50-cm Cap
Single ring compounds	35 ± 26	49 ± 62	34 ± 16	35 ± 42
Double ring compounds	2.6 ± 0.15	12.1 ± 2.0	7.0 ± 5.2	3.2 ± 1.3
Three ring compounds	89 ± 47	50 ± 21	177 ± 122	97 ± 74
Four ring compounds	104 ± 49	29 ± 13	105 ± 24	84 ± 40
Five ring compounds	62 ± 51	27 ± 10	62 ± 15	72 ± 61
Total PAHs	393 ± 120	166 ± 92	333 ± 28	291 ± 143

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