ASSESSMENT OF THE ENVIRONMENTAL IMPACTS OF THE HART-MILLER ISLAND CONTAINMENT FACILITY

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FOREWORD

Maryland Department of Natural Resources seeks to preserve, protect and enhance the living resources of the state. Working in partnership with the citizens of Maryland, this worthwhile goal will become a reality. This publication provides information that will increase your understanding of how DNR strives to reach that goal through its many diverse programs.

John R. Griffin
Secretary
Maryland Department of Natural Resources

EXECUTIVE SUMMARY

The Hart-Miller Island Containment Facility (HMI) was designed to receive dredged material from navigation channel maintenance and improvement activities in Baltimore Harbor and its approaches. The facility is located in the Chesapeake Bay at the mouth of Back River, to the northeast of Baltimore Harbor. Construction of the facility was completed in 1983. Operation of the facility has continued from that time through the present, which coincides with the termination of the eleventh year of the exterior monitoring activities.

The exterior monitoring program for HMI was developed in response to special condition (d) of the State Wetlands License No. 72-127(R). That condition required that "water quality and biota in the facility area be frequently and comprehensively monitored under the supervision of the Department of Natural Resources (DNR)." Results from the monitoring is used to observe chronic changes from baseline environmental conditions in the area surrounding HMI. The information is available to guide decisions regarding operational changes and/or the implementation of remedial actions, if necessary. Past exterior monitoring efforts have investigated the sedimentary environment and biota near the facility. Fish and crab population studies were discontinued after the fifth monitoring year due to the ineffectiveness of using the information as a monitoring tool. The current monitoring program is divided into four major projects: 1) Scientific Coordination and Data Management; 2) Sedimentary Environment (physical and chemical analysis); 3) Benthic Study (population trends); 4) Analytical Services (chemical analysis of sediments and biota).

The eleventh monitoring year was a continuation of the sediment and biotic studies conducted in previous years. The construction of HMI resulted in the direct loss of approximately 1100 acres of estuarine aquatic habitat within the limits of the diked area. Two significant changes to the sedimentary environment around the perimeter of HMI have been observed during the past ten years of monitoring. A fluid mud layer was observed to extend from 525 to 1090 yards from the limits of the facility. The fluid mud was attributed to construction of the HMI perimeter dike. Changes in the benthic biota accompanied the occurrence of the fluid mud layer. However, recovery of the benthic population was observed in subsequent years.

An enrichment of zinc in the sediment near spillway #1 of the facility was documented in the eighth monitoring year. Monitoring stations around HMI were modified in the ninth monitoring year to further investigate the zinc concentrations in the sediments and the effects on the aquatic biota. Observations during the ninth year indicated that zinc levels increased in response to the rate of release of effluent from the dike.

Higher than expected zinc concentrations persisted in the vicinity of the dike through the eleventh monitoring year. The results from the 3-D hydrodynamic modelling effort previously reported in the tenth monitoring year was utilized to explain the structure of the zinc distribution in the sediments surrounding HMI as observed during the eleventh monitoring year. The chemistry of the sediments and effluent released from the dike has also been concluded to influence the distribution of the zinc enriched sediments.

Benthic populations observed at stations in the zinc enriched areas did not appear to differ from the populations observed at the original nearfield and reference stations. Also, concentrations of zinc in benthos samples at the zinc enriched stations were not observed to be significantly different in comparison to the other monitoring stations. Monitoring at the stations added in response to the zinc enrichment continued through the eleventh monitoring year.

PROJECT I: SCIENTIFIC COORDINATION AND DATA MANAGEMENT

As in previous years, the scientific coordination and data management activities were conducted by the Tidewater Administration of DNR. This oversight is consistent with the requirements of the special conditions of the State Wetlands License for HMI. Through coordination of the scientific investigation, DNR participates directly in the continued assessment of environmental impacts associated with the operation of HMI over the long term.

Liason and coordination between the agencies responsible for on-site management, operations, monitoring, sampling, and oversight programs associated with HMI were maintained through the eleventh monitoring year. Data produced by sampling efforts during the eleventh year were archived in the long term data base maintained by the Chesapeake Bay Research and Monitoring Division of the Tidewater Administration.

PROJECT II: SEDIMENTARY ENVIRONMENT

The Coastal and Estuarine Geology Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Containment Facility (HMI) for more than a decade. In a separate effort, the program's staff has also documented the erosional and depositional changes along the recreational beach between Hart and Miller Islands. The results of these two studies during the eleventh year of monitoring are presented in this report.

Sedimentary Environment

In April 1989, during the eighth monitoring year, an area of zinc (Zn) enrichment was detected southeast of spillway #1. In response to that discovery, the scope of monitoring was expanded to include a greater number of samples distributed over a wider area. That sampling scheme remained in effect throughout the eleventh year.

Surficial bottom sediments sampled during two cruises, in November 1991 and April 1992, were analyzed for grain size composition and trace metal content. This year, a different analytical method was used to determine trace metal concentrations. Previously, metals were analyzed using a lithium metaborate fusion technique, followed by standard flame or furnace atomic absorption spectrophotometry. The new analytical protocol involves a microwave digestion technique, followed by analysis on an inductively coupled argon plasma spectrometer. Analyses of standard reference materials using the two techniques showed that the new method resulted in improved accuracy and precision.

The grain size distribution of exterior bottom sediments - presented as percent sand and clay:mud ratios - was similar to last year's findings and consistent with earlier post-discharge periods. The distribution of sand around the facility has remained largely unchanged since November 1988. The typical seasonal pattern in the distribution of the fine (mud) fraction - coarsening over the summer and fining over the winter - was also evident again this year. This indicates that, hydrodynamically, the depositional environment around the facility was somewhat quieter between the November 1991 and April 1992 cruises than it had been prior to the November 1991 cruise.

Since the initial detection of Zn enrichment, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, higher than expected Zn levels persisted through the eleventh monitoring year in the vicinity of the dike. In previous reports, elevated Zn levels were associated with low flow releases of effluent from the facility. Results obtained from a 3-D hydrodynamic model of the upper Chesapeake Bay explain the structure of the plume of material found in exterior sediments, but not why Zn levels increase after periods of low flow discharge from the dike. However, the chemistry of the effluent released from the dike does seem to account for this association. Metal levels in ponded water increase due to leaching of metals from the sediment in the dike, through a process analogous to acid mine drainage. The maximum Zn loading due to leaching occurs at releases between 0.3-10 million gallons/day (MGD). At higher discharge rates, flushing with large volumes of water effectively dilutes Zn loadings in the effluent and, consequently, precludes Zn enrichment in the surrounding bottom sediments.

Continued monitoring is recommended. During the dewatering phase of operations, exposure of dredged material to the air is likely to result in the mobilization of metals associated with those sediments. Higher metal levels in the effluent may very well increase metal loadings to exterior bottom sediments, particularly if discharge rates are low. Future monitoring will be needed to detect such effects. Monitoring will also be valuable in assessing the effectiveness of any amelioration protocol implemented to counteract the effects of exposing the contained dredged material to the atmosphere.

Beach Erosion Study

In accordance with previous recommendations, the recreational beach was replenished in April 1991, immediately prior to this study year (May 1991 - May 1992). Approximately 14,700 yd^3 (11,240 m^3) of clean, medium-grained sand, dredged from an approach channel to Baltimore Harbor and stockpiled at the facility, was distributed in front of the existing wave-cut escarpment, from station 28+00 to the northern end of the beach. Beach renourishment widened the foreshore and reduced the slope of the beach. Since replenishment, both shoreline position and the foreshore profile have changed.

The beach is composed of three distinct segments, each distinguishable by a unique beach form. The southernmost segment, south of profile 28+00, is most stable, with minor erosion on the upper beach face. The lower beach face accretes as sediments derived from the northern end of the beach are transported southward via longshore currents and deposited. Deposition will continue along this reach as long as there is a source of sand and wind-driven waves approach from the proper angle. The central beach, from 30+00 to 44+00, is transitional in nature. Along the upper beach face and nearshore, below datum, erosion predominates. Sediments eroded from the upper beach face accrete along the lower beach face. The northern beach, from 48+00 to 49+00, is erosional along its entire length. Shoreline retreat is most evident at 49+00, where the profile has eroded to its pre-nourishment configuration.

Monitoring of the recreational beach should continue, to assess any future erosional damage. If erosion becomes severe enough to endanger the public or the integrity of the dike, the shoreline should be replenished with sand. Periodic renourishment of the beach with a coarser sand will slow erosion. The shoreline developed during the April 1991 beach nourishment project is the baseline against which future beach conditions will be referenced. If the shoreline retreats or the profile form erodes to pre-nourishment conditions, then immediate action should be taken to restore the beach.

PROJECT III: BIOTA

Benthic invertebrate populations in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI) in the upper Chesapeake Bay were monitored for the eleventh consecutive year in order to examine any potential effects from the operation of the HMI facility on these bottom-dwelling organisms. Organisms living close to the containment dike (referred to as the nearfield stations) either within the sediments (infaunal) or upon the concrete and wooden pilings (epifaunal) were collected along with organisms living at some distance from the containment facility (referred to as reference stations) in December 1991 and April and August 1992.

The infaunal samples were collected with a 0.05 m^2 Ponar grab and washed on a 0.5 mm mesh screen. The epifaunal samples were scraped from the pilings, that support a series of piers which surround HMI, with a specially designed scraping apparatus. Seventeen infaunal stations were sampled on each cruise (8 nearfield/experimental stations, S1-S8; 5 reference stations HM7, 9, 16, 22, 26) and four stations which were added over the course of the 9th year study in areas which had been reported by the sedimentary group from the Maryland Geological Survey to have sediments which were substantially enriched in zinc (referred to as zinc-enriched, and numbered as G5, G25, G84, HM12). The various infaunal stations have sediments of varying compositions and include, silt-clay stations, oyster shell stations and sand substrate stations. A total of 35 species were collected from these seventeen infaunal stations. The most abundant species were the worms, *Scolecolepides viridis* and *Heteromastus filiformis*; the crustaceans, *Leptocheirus plumulosus*, *Balanus improvisus* and *Cyathura polite*; and the clams, *Rangia cuneata* and *Macoma balthica*.

Species diversity (H') values were evaluated at each of the infaunal stations for the three sampling periods. The highest diversity value (4.482) was obtained for the Back River station HM26, in April 1992. The lowest diversity value (0.725) also occurred in April at one of the nearfield stations, S1. For the three sampling dates, the overall highest diversity values (with only three stations under 2.5 and seven greater than 3.0) occurred in August and the lowest overall diversity occurred in April 1992.

The length-frequency distributions of the clams, *Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli* were examined at the nearfield, reference, and zinc-enriched stations and there was good correspondence in terms of numbers of clams present and the relative size groupings for the three sampling dates. *Rangia cuneata* continues to be the most abundant species for all three groups of stations, followed by *Macoma balthica*, and *Macoma mitchelli* remains the least abundant of the 3 predominant clam species.

Cluster analysis of the stations over the three sampling periods continues to associate stations primarily in response to sediment type. Variations in recruitment at the different stations explain why some specific stations did not form tight groupings. The clusters were again consistent with studies from previous years and did not indicate any unusual groupings resulting directly from HMI. Rank analysis of differences in the mean abundances of eleven selected species at stations with silt/clay substrates indicated significant differences for the combined nearfield and reference stations in December, April and August and the nearfield stations in December and April. No significant differences in means for the combined zinc-enriched and reference stations or for the zinc-enriched or reference stations occurred for any of the sampling periods.

Epifaunal populations were similar to those observed in previous years. Samples were collected at two depths (about 3 feet/1 meter and 6-8 feet/2-3 meters, dependent on the station depth); the lower depth is well below the winter ice scour zone. The epifaunal populations persisted throughout the year at all of the locations on the pilings. The epifaunal populations at both the nearfield and reference stations were very similar over all three sampling periods and as previously reported the crustacean, *Corophium lacustre*, was one of the most abundant organisms present at both the reference and nearfield stations at all sampling periods. The encrusting mosslike bryozoan, *Victorella pavida*, was the second most frequently observed species on the pilings, in August, but in December and April, the worm, *Polydora* was the more abundant species.

The results of the current monitoring effort once again suggest that only localized and temporary effects on the benthic organisms result from HMI. These effects are limited primarily to the area where dredged materials are brought in by the barges to the facility and they are believed to be caused by some scouring of the bottom through the activity of the barges and tug boats. Discharge of effluent from the facility has occurred over the past few sampling years and to date no adverse effects on the benthic populations have been observed. In response to the zinc-enrichment findings, of the Maryland Geological Survey group, we added four benthic infaunal stations in the zinc-enriched areas, during the 9th year of sampling. During this the third year of sampling for these zinc-enriched stations, these stations do not appear to differ in any distinct manner from the original nearfield and reference epifaunal stations.

Continued monitoring of the benthic populations in the area is strongly recommended in order to continue to follow any potential changes associated with the existence and operation of the Hart-Miller Island Dredged Material Containment Facility.

ADDENDUM (TOXICITY ASSESSMENT OF SEDIMENTS)

During the eleventh monitoring year, toxicity tests were conducted to provide direct, quantifiable information on the biological effects of sediment-associated contaminants. The study was initiated in response to the observation of enriched levels of zinc reported in the surficial sediments during the eighth monitoring year. There was concern that the biological impacts of the zinc enrichment may not be fully accounted for through the chemical and benthic community analysis.

Several interpretations were developed from the results of the toxicity testing. In the amphipod sediment toxicity test, the mortality of test organisms in the test sediments was attributed to interactions between indigenous species in the samples. Mortality due to chemical toxicity would be expected to be manifested as higher mortality occuring in test than reference sediments. However, a difference between the test and reference sediments was not observed. Results of the Microtox bacterial luminescence assay of sediment porewater indicated no toxicity associated with porewater from the sediment samples. This result further supported the conclusion that mortality of the test species in the amphipod toxicity tests was due to interspecific interactions with indigenous species in the test samples, not chemical toxicity.

ANALYTICAL SERVICES (INTERPRETATION OF THE ANALYSIS OF ORGANIC CONTAMINANTS AND METALS)

The results from the quantitative analysis of organic contaminants and metals produced some observable differences from previous years. Chromium was not detected in the biota from any site. Also, there were no detectable contaminants in any sample of benthos. Overall, there have been no obvious trends in the observed differences in contaminant concentrations spatially among stations or temporally from the eighth to the eleventh monitoring years. Similiar to the tenth year, nickel concentrations in benthos near HMI were higher than concentrations found in other coastal U.S. waters. Copper and zinc concentrations in benthos samples were not atypical of other areas of the Chesapeake Bay, though they are high compared to the NOAA Mussel Watch data.

RECOMMENDATIONS

The HMI exterior monitoring program should be continued to assess impacts to the aquatic environment surrounding the facility. Close interaction between the monitoring researchers, the managers of the facility, and the participants on the Technical Review Committee should be maintained to ensure that the program is adapted to meet future changes in operations or relevant findings of concern. Updating and maintenance of the long term data base should also be continued.

Specific recommendations resulting from the exterior monitoring activities during the eleventh monitoring year are presented below.

1) Continued monitoring of the metals concentrations in the sediments surrounding the HMI facility is needed to detect the effects of metals released from the contained dredged materials as they are dewatered. The monitoring will be valuable in assessing the effectiveness of proposed ameliorations protocol implemented to counteract the effects of exposing the contained materials to the atmosphere, thereby potentially reducing pH and mobilizing associated metals.

2) Monitoring of the recreational beach should continue to assess any future erosional damage. If erosional damage is documented, the shoreline should be replenished with sand. Periodic renourishment of the beach with coarser sand may slow erosion.

3) The infaunal and epifaunal populations should continue to be sampled at the established locations along with the more recently added zinc-enriched areas during the continued period of active operation of the HMI facility.

4) Station locations and sampling techniques should be maintained as close as possible to the last few years to eliminate sampling variations and permit rapid recognition of the effects from the HMI facility.

5) Sampling protocols for analysis of potential contaminants should be better standardized to further concordance between the sediment and biota monitoring. Stations for sediment contaminant analyses should be the same as those for benthos sediment analyses.

6) Considerations should be given to transect sampling strategy, extending away from the facility in several directions to provide a better assessment of any contamination stemming from the HMI facility.

7) The analysis of iron and manganese in tissues should be dropped because they are not providing useful insights into the impacts from the HMI facility. The project should add additional trace metals of toxicological concern or direct analysis of these metals to additional numerical or spatial coverage.

8) The number of target analytes should be decreased because several of the analytes are not likely to be associated with the sediments in the facility, as past monitoring has now corroborated. Organic contaminants which could be dropped include aldrin and endrin.

9) Sampling of biota should be standardized with respect to the age of the organisms in order to reduce variability and facilitate the detection of interstation differences in contaminant burdens. Normalization of organic contaminant burdens to lipid weight should also be considered.

10) If sediment toxiciity testing is repeated, the sediments should be sieved prior to analysis to reduce the confounding effects of these organisms on the test results. Sieving the sediments may cause the alteration of the physical and chemical properties of the sediment but the benefits of eliminating the organisms outweighs the potential alteration of sediment toxicity.

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DEFINITION OF TERMS

Amphipod - a large group usually - an order of crustaceans - comprising the beach fleas and related forms - being mainly of small size with laterally compressed body, four anterior pairs of thoracic limbs directed forward - and three posterior pairs directed backward - and upward - the thoracic limbs bearing gills-aquatic in fresh or salt water.

Bathymetric - Referring to contours of depth below the water's surface.

Benthos - The bottom of a sea or lake. The organisms living on sea or lake bottoms.

Bioaccumulation - The accumulation of foreign substances, particularly toxic contaminants, within the tissues of organisms. Results from chronic exposure to contaminated food or habitats.

Biogenic - Resulting from the activity of living organisms. For example, bivalve shells are biogenic minerals.

Biometrics - The statistical study of biological data.

Biota - The animal and plant life of a region.

Bioturbation - Mixing of sediments by the burrowing and feeding activities of sediment-dwelling organisms. This disturbs the normal, layered patterns of sediment accumulation.

Brackish - Salty, though less saline than sea water.

Bryozoan - Small phylum of aquatic animals that reproduce by budding - that usually form branching, flat or mosslike colonies -permanently attached on stones or seaweed and enclosed by an external cuticle soft and gelatinous or rigid and chitinous or calcareous - that consist of complex zooids (polyps) each having alimentary canal with separate mouth and anus.

Dendrogram - A branching diagrammatic representation of the interrelations of a group of items sharing some common factors (as of natural groups connected by ancestral forms).

Desiccation - The act of drying thoroughly; exhausting or depriving of moisture.

Diversity index - A statistical measure that incorporates information on the number of species present in a habitat with the abundance of each species. A low diversity index suggests that the habitat has been stressed or disturbed.

Dominant (species) - Designating an organism or a group of organisms which, by their size and numbers or both, determine the character of a community.

Dredge - Any of various machines equipped with scooping or suction devices used in deepening harbors and waterways and in underwater mining.

Effluent - Something that flows out or forth; an outflow or discharge of waste, as from a sewer.

Enrichment factor - A method of normalizing geochemical data to a reference material, which partially corrects for variation due to grain size.

Epifauna - Benthic animals living on the surface of bottom material.

Flocculate - An agglomeration of particles bound by electrostatic forces.

Flocculent - Having a fluffy or wooly appearance.

Gas chromatography - A method of chemical analysis in which a sample is vaporized and diffused along with a carrier gas through a liquid or solid adsorbent for differential adsorption. A detector records separate peaks as various compounds are released (eluted) from the column.

Gyre - The term used to decribe a circular or spiral motion.

Hydrodynamics - Term referring to the study of the dynamics of fluids in motion.

Hydrography - The scientific description and analysis of the physical conditions, boundaries, flow, and related characteristics of oceans, rivers, lakes, and other surface waters.

Hydroid - Order of Hydrozoan coelenterates - comprising forms that alternate a well developed asexual polyp generation with a generation of free medusa or of an abortive medusoid reproductive structure on the polyps - resembling a polyp.

Infauna - Benthic animals living in bottom material.

Littoral - Of or pertaining to the seashore, especially the region between the highest and lowest levels of spring tides.

Mean low water - The average water level at low tide.

Radiograph - An image produced on a radiosensitive surface, such as a photographic film, by radiation other than visible light, especially by x-rays passed through an object or by photographing a fluoroscopic image.

Revetment - A facing, as of masonry, used to support an embankment.

Salinity - The concentration of salt in a solution. Full strength seawater has a salinity of about 35 parts per thousand (ppt or o/oo).

Sediment - That which settles to the bottom, as in a flask or lake.

Seine - A large fishing net made to hang vertically in the water by weights at the lower edge and floats on the top.

Spawn - To produce and deposit eggs, with reference to aquatic animals.

Spectrophotometer - An instrument used in chemical analysis to measure the intensity of color in a solution.

Spillway - A channel for an overflow of water.

Substrate - A surface on which a plant or animal grows or is attached.

Supernatant - The clear fluid over a sediment or precipitate.

Surficial - The top, or surface, layer of sediment.

Trace metal - A metal that occurs in minute quantities in a substance.

Trawl - A large, tapered fishing net of flattened conical shape, towed along the sea bottom. To catch fish by means of a trawl.

INTRODUCTION

The Hart-Miller Island Containment Facility monitoring program was established to determine the effects of the facility on the surrounding environment. The program was launched in 1981 so that environmental data for pre-construction and pre-operational conditions could be compared with the data collected during operation of the facility. The Eleventh *Annual Interpretive Report* presents the results of the environmental monitoring of the Hart-Miller Island Containment Facility from August 1991 through August 1992.

Description of the containment facility

The site is environmentally and economically important to Maryland and the Chesapeake Bay region. The State of Maryland contracted for the construction of a diked area at Hart and Miller Islands during 1981-1983, and the facility was completed in 1983. It was designed to receive 52 million cubic yards (mcy) of dredged material, including contaminated material from Baltimore Harbor. The most signficant portion of dredged material placed in the facility was generated from the deepening of the Baltimore Harbor and its approach channels to 50 feet. Once the facility is filled, it will be converted to a permanent wildlife and recreational area.

The dike is 28' (18' + a 10' perimeter dike) above mean low water and encloses an area of 1,140 acres. It was constructed from sand deposits within and underlying the enclosure. Presumably, the fine sands and silts from the dredged material will fill the pores between the sand grains, forming a semi-permeable dike wall. The Bay-side face is riprapped with stone over filter cloth. The typical side slopes are 3:1 (three horizontal to one vertical) on the exposed outside face, 5:1 on the inside and 20:1 along the recreational beach on the Back River side. The completed dike is approximately 29,000' long and contains 5,800 cubic yards of stone. The facility is divided into North and South containment cells by an interior dike approximately 4,300' long.

Dredged Material Disposal

The sources of dredged material received is listed by project in Table 1.

The material dredged in 1983 and 1984 was composed of mostly 42' channel maintenance (3.9 mcy) and facility maintenance (188,000 cyds). One additional project was deposited in the facility in 1984, Dundalk Marine Terminal (500,000 cyds).

Material dredged in 1985, totaling 3.7 mcy, was deposited in the north cell. Of the 7.5 mcy of dredged material disposed in 1986, 3.7 mcy was deposited into the north cell and 3.8 mcy in the South Cell. The disposed volumes shown in the table for 1985 represent the entire 1985 and 1986 dredging seasons (April 1985 through September 1985 and June 1986 through January 1987, respectively).

The major 1986 dredging task was to remove material from the main shipping channel to maintain a working depth of 42'. The other projects listed for that year were mainly to remove dredged material allowing shipping companies to make better use of the 42' deep channel. Since the beginning of the project to deepen the channel to 50', shipping companies have been dredging their access channels to make better use of the 50' channel depth. The 50' contract No.1 represents the first of two contracts to increase the Maryland shipping channel to a depth of 50'. The addition of the dredged material from these projects produced a sufficient quantity of supernatant. This resulted in a discharge from spillway #1 during the seventh monitoring year, beginning on October 25, 1986. Monitoring of the discharge is required to fulfill the State Discharge Permit Number 91-DP-2294.

The 1987 disposal operations included projects from the Inner Harbor area: Seagirt Marine terminal, Amstar, and the Bethlehem Steel Shipyard. The operations also included the removal of 125,000 ft^3 of material from the Hart-Miller north unloading pier to allow access to the north pier. The first contract of the 50' channel project totaled 9.9 mcy and 54,000 ft^3 of material that was used to relocate utilities related to the 50' channel.

The 1988 disposal operations included projects from the Inner Harbor, including Baltimore Gas & Electric Company, Canton waterfront, CSX coal pier, and Toyota. The operations included disposals from the maintenance of the 42' channel along with 6.2 mcy of material from the 50' channel project.

The 1989 operations included disposals from CSX, Consolidated Coal, and Seagirt marine terminal. These operations also included 6.3 mcy of dredged material from the 50' channel project contract No. 2.

The 1990 dredging operations included dredging projects from the Inner Harbor, including Seagirt Marine terminal, Curtis Bay Coal and Allied Signal in addition to 6,500 yd^3 from Baltimore County dredging projects. Sediments dredged during the Allied Signal project were rich in Cr concentrations. The year's dredging activities also included 9.5 mcy from the 50' channel project, contract No. 2.

The largest fraction of material discharged into the facility during 1991 was generated from the maintenance of the 50' channel. Significant quantities were also produced from the 42 foot channel maintenance, East Alco, and Bulk Stevedores.

During 1992 the dredging operations to maintain the 42 foot channel provided the largest fraction of dredged material discharged into the facility. Hobelmann Port and Dundalk Marine Terminal dredging activities also produced significant quantities.

TABLE 1
DISPOSAL OPERATIONS

YEAR DISPOSED	PROJECT NAME	CUT QUANTITY (Cubic Yards)
1983	Hart-Miller Personnel Pier	24,000
1984	Hart-Miller South Unloading Facility	164,000
1984	Dundalk Marine Terminal	500,000
1984	42' Channel Maintenance and Brewerton Eastern Extension	3,908,000
	TOTAL 1984	4,596,000
1985	42' Channel Maintenance	3,145,000
1985	Bethlehem Steel	596,000
	TOTAL 1985	3,741,000
1986	42' Channel Maintenance	7,000,000
1986	Eastern Avenue Bridge	18,000
1986	Canton-Seagirt	500,000
1986	South Locust Point	185,000
1986	Hess Oil	7,200
1986	Bethlehem Steel Ore Pier	5,250
1986	Rukert Terminal	166,632
	TOTAL 1986	7,731,082
1987	Seagirt	2,617,000
1987	Eastern Avenue Bridge	22,000
1987	Aquarium Pier 4	5,763
1987	HMI North Unloading facility	125,000
1987	Amstar	28,170
1987	Bethlehem Steel Shipyard	378,461
1987	50-ft Contract #1	9,900,000
1987	50-ft Channel Utilities	54,000
	TOTAL 1987	13,130,394
1988	Seagirt	
1988	Baltimore Gas and Electric	1,833,000

Table 1 (Cont.)

1988	Brandon Shore/Wagner pt.	18,464
1988	Canton Waterfront	2,500
1988	CSX Coal Ore Pier	28,030
1988	Clinton Street	1,000
1988	Toyota (MD Shipbuilding)	70,000
1988	50-ft Contract #1	6,212,230
1988	42-ft Channel Maintenance Brewerton, Swann Point	125,000
	TOTAL 1988	8,342,724
1989	50' Channel Contract No. 2	6,300,000
1989	CSX	25,000
1989	Consolidation Coal Sales	235,000
1989	MPA Seagirt	43,000
	TOTAL 1989	6,603,000
1990	Fifty-Foot Channel, Contract II	9,450,000
1990	Allied-Signal	131,000
1990	Curtis Bay Coal	62,000
1990	Baltimore County	2,000
1990	Consolidated Coal	13,000
	TOTAL 1990	9,658,000
1991	Baltimore County	59,000
1991	Consolidated Coal	9,000
1991	East Alco & Chesapeake Bulk Stevedores	299,000
1991	Fifty-foot Federal Maintenance	1,600,000
1991	Lady Maryland Marina & Inner Harbor	28,000
1991	Forty-two Foot Federal Maintenance	1,400,000
	TOTAL 1991	4,995,000
1992	Forty-two Foot Federal Maintenance	580,000
1992	Dundalk Marine Terminal	131,000
1992	Hobelmann Port	195,000
1992	North Locust Point	49,000
	TOTAL 1992	955,000
	Grand Total* (cubic yards)	59,156,200

* Through December 1992

SUMMARY OF MONITORING PROGRAMS

The State determined, as prescribed in authorizing permits for the facility, that there was a need for "a comprehensive environmental monitoring program for the Hart-Miller Containment Facility prior, during, and following commencement of operations." Responsibility for the monitoring was assigned to the Water Resources Administration. The monitoring program is divided into two complementary portions: (a) monitoring to ensure compliance with federal and state laws; and (b) monitoring for environmental impacts. The operational permits requiring monitoring were issued by the Maryland Department of the Environment (MDE) (formerly Maryland Department of Health and Mental Hygiene (DHMH)) and the Water Resources Administration (WRA) of the Department of Natural Resources (Dept. of Trans. et. al., 1979). The Maryland Environmental Service (MES) is responsible for monitoring water quality within the diked area.

This report describes studies designed to assess any impacts to the biota and sediments exterior to the dike. This assessment is performed under a separate agreement between the Maryland Department of Natural Resources and the Maryland Port Administration. Coordination was maintained among all agencies having roles in site management, operations, monitoring, sampling and oversight programs related to the Hart-Miller Island Facility, primarily through periodic meetings with the Technical Review Committee. Four projects have been implemented to assess the environmental effects of construction and operation of the facility. These include the following:

1) Project I: Scientific Coordination and Data Management [conducted by the Tidewater Administration of the Maryland Department of Natural Resources];

2) Project II: Sedimentary Environment, including beach erosion studies and assessment of the sedimentary environment surrounding the HMI facility [conducted by the Maryland Geological Survey];

3) Project III: Biota, focusing on benthic macroinvertebrates and including interpretation of the analysis of contaminants conducted in Project IV [conducted by the University of Maryland];

4) Project IV: Analytical Services, focusing on the analysis of organic contaminants and metals in the sediments and biota [conducted by the Maryland Environmental Service].

CONTINUING ASSESSMENT OF THE ENVIRONMENTAL IMPACTS OF CONSTRUCTION AND OPERATION OF THE HART MILLER ISLAND CONTAINMENT FACILITY

Project I

SCIENTIFIC COORDINATION AND DATA MANAGEMENT ELEVENTH YEAR INTERPRETIVE REPORT

(November 1991 - October 1992)

BY
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Development and implementation of a monitoring program which is sufficiently sensitive to the environmental effects of dredged material containment at Hart-Miller Island continues to be a complex and difficult undertaking. The environmental monitoring activities have evolved over the eleven years of the project. Ongoing studies have included physical and chemical characterization of sediments and population studies of benthos and finfish. Baseline data on water column nutrients and productivity, submerged aquatic vegetation, trace metals and organic contaminants were included in the first and second Interpretive Reports (Cronin et al., 1981-1983). Bathymetric studies were completed in the first three monitoring years to identify pre- and post-construction changes in currents and erosion. Fish population studies were conducted in the first five monitoring years, these studies were discontinued thereafter.

Scientific planning, review, and coordination of the monitoring activity are provided by Tidewater Administration. Sampling procedures, data analysis, and future directions of the program are discussed with the principal investigators at quarterly meetings of the Technical Review Committee. Descriptions of any changes in sampling methods are included in the individual project quarterly reports that follow. Compilation, editing, technical review, and printing of the Interpretive and Data Reports are the responsibilities of the Tidewater Administration.

During the first eleven years of the environmental assessment program, data collected by the Department of Natural Resources and research institutions were stored in the Tidewater Administration's "Resource Monitoring Data Storage System." The IBM-OS File/SAS Data Base is used for computer storage and analysis of data. The data are also stored on a VAX 8600 computer in a SAS file format. The Tidewater Administration staff assumes responsibility for the long-term storage of data related to the exterior monitoring program. Permanent storage of the data in a readily accessible form provides a continuous, documented record of baselines and trends in biota, sediments and contaminant levels. Data from the 1991-1992 monitoring year are included in the Eleventh Year Data Report, which is compiled and printed separately from the Interpretive Report. The data is standardized using Resource Monitoring Data Storage (RMDSS) formats. The codes are documented in the manual to the Resource Monitoring System produced by the Tidewater Administration, Chesapeake Bay Research and Monitoring Division (Tidewater Admin., 1989).

Recommendations

It is imperative that good lines of communication be maintained between the monitoring scientists and the managers of Hart Miller Island, so that both groups can benefit from any information acquired through the monitoring surveys they conduct. The assessment of impact should include consideration of direct, indirect, and cumulative effects from the operation and maintenance of the HMI facility. It is therefore recommended that the Technical Advisory Committee continue to meet quarterly through the year. Future exterior monitoring efforts should be designed relative to the following: 1) the operating characteristics of the facility; 2) information derived from the 3-D hydrodynamic model developed for use in the vicinity of HMI; 3) the results of the data collection from the NPDES monitoring and previous exterior monitoring efforts; and 4) new and pertinent information introduced to the Technical Advisory Committee.

The Continuing State Assessment of the Environmental Impacts of Construction and Operation of the Hart-Miller Island Containment Facility

Project II

SEDIMENTARY ENVIRONMENT
ELEVENTH YEAR INTERPRETIVE REPORT
(November 1991 - October 1992)

Part 1: Sedimentary Environment
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Part 2: Beach Erosion Study
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July 1994

PART 1: SEDIMENTARY ENVIRONMENT

INTRODUCTION

Since 1981, the Maryland Geological Survey (MGS) has monitored the sedimentary environment in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI). HMI is a man-made enclosure in northern Chesapeake Bay named for the two natural islands that form part of its western perimeter (Fig. 1-1). The oblong structure, designed specifically to contain material dredged from Baltimore Harbor and its approach channels, was constructed of sediment dredged from the area that is now the dike interior. The physical and geochemical properties of the older, "pristine" sediment used in dike construction differed from those of modern sediments accumulating around the island. Likewise, material dredged from shipping channels and deposited inside the dike also differs from recently deposited sediments outside the facility. Much of the material generated by channel deepening is fine-grained and enriched in trace metals and organic constituents. These differences in sediment properties have allowed the detection of changes attributable to construction and operation of the dike.

PREVIOUS WORK

Events in the history of the containment facility can be meaningfully grouped into the following periods:

1. preconstruction (Summer 1981 and earlier)
2. construction (Fall 1981 - Winter 1983)
3. post-construction
    a. pre-discharge (Spring 1984 - Fall 1986)
    b. post-discharge (Fall 1986 - present).

The nature of the sedimentary environment prior to and during dike construction has been well-documented in previous reports (Kerhin *et al.*, 1982a, 1982b; Wells and Kerhin, 1983; Wells *et al.*, 1984; Wells and Kerhin, 1985). This work established a baseline against which changes due to operation of the dike could be measured. The most notable effect of dike construction on the surrounding sedimentary environment was the deposition of a thick, light gray to pink layer of "fluid mud" immediately southeast of the facility. This layer is still evident in a few cores, although the uppermost sections of the layer have been bioturbated (reworked by bottom-dwelling organisms) and, in places, eroded.

For a number of years after the dike began operating, no major effects were observed on the surrounding sedimentary environment. Then, in April 1989, more than two years after the first release of effluent from the dike, anomalously high zinc

(Zn) values were detected in samples collected near spillway #1 (Hennessee *et al.*, 1990b). Zn levels rose from the regional average enrichment factor of 3.2 to 5.5. Effluent discharged during normal operation of the dike was thought to be the probable source of excess Zn accumulating in the sediments. A flow net developed from preliminary results of a 3-D hydrodynamic model (Johnson *et al.*, 1989) showed that the enriched area should only be affected by low flows from spillway #1 (<5 million gallons/day (MGD). Daily discharge records kept by the Maryland Environmental Service (MES) indicated that, prior to Fall 1989, comparatively high flow conditions prevailed at spillway #1. After that, much lower volumes of effluent were released. This period of low flow immediately preceded the detection of higher Zn levels in samples collected south of the spillway.

Since the initial detection of Zn enrichment, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, higher than expected Zn levels persisted through the tenth monitoring year in the vicinity of the dike (Hennessee and Hill, 1993).

DIKE OPERATIONS

Certain activities associated with the operation of the containment facility have a direct impact on the exterior sedimentary environment. Local Bay floor sediments appear to be sensitive, physically and geochemically, to the release of effluent from the dike. Events or operational decisions that affect the quality or quantity of effluent discharged from the dike may account for some of the changes in exterior sediment properties observed over time. For this reason, dike operations during the periods preceding each of the eleventh year cruises are chronicled below. Information was extracted from two *Operations Reports* prepared by MES, covering the periods April 1, 1991 - September 30, 1991, and October 1, 1991 - March 31, 1992.

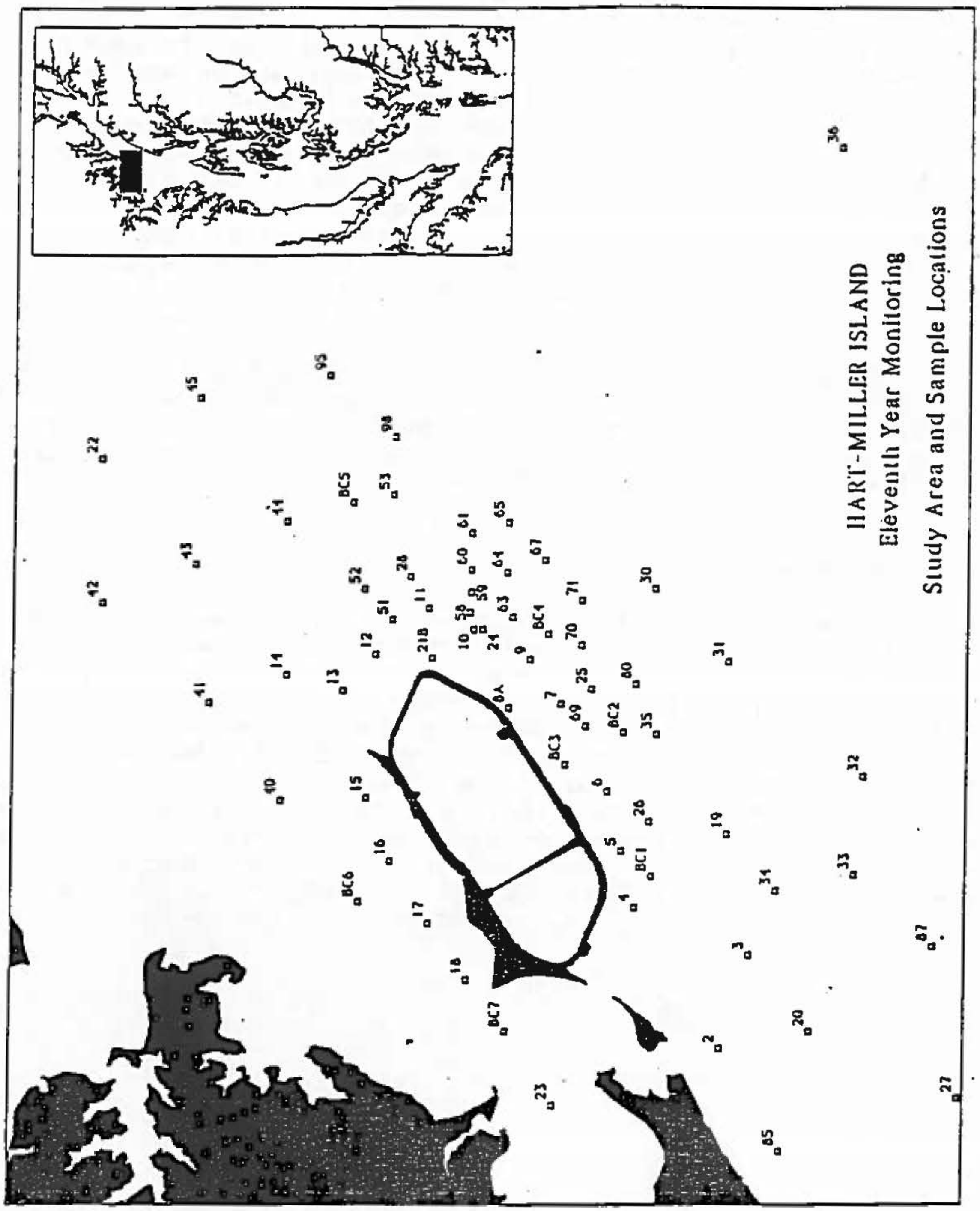


Figure 1-1: The Hart-Miller Island containment facility and vicinity, with locations of the surficial sediment and core stations sampled during the eleventh year of exterior monitoring.

November 1991

During the seven months preceding the November 1991 cruise (April 1991 - October 1991, inclusive), dredged material was placed in the north cell from early May 1991 through late August 1991. About 1.9 million cubic yards (MCY) of material, consisting mostly of silt and sand from the Fifty-Foot Federal Maintenance Project, was hydraulically inflowed. A much smaller volume of material (28,000 yd^3) was mechanically placed. Placement resumed in mid-October 1991 and continued beyond the date of the November 1991 cruise. No material has been deposited in the south cell since December 31, 1990, as stipulated by the wetlands license.

The main operational objective during the period was to minimize ponded water, even during periods of hydraulic inflow. Effluent was released from all five spillways. In terms of total volume discharged, spillways #1 and #2 in the north cell were by far the most active. Spillway #2 was the primary outfall structure during the first three months (April 1991 - June 1991) of the period, and spillway #1 during the last four months (July 1991 - October 1991). The switch from spillway #2 to spillway #1 occurred after spillway #2 became inundated with slurry from the inflow of material. Flow from the primary spillway averaged about 4 MGD over the period of greatest activity. Spillway #4 was active during April and May 1991, then closed in June 1991 when it, too, became inundated with slurry. It remained closed until September 1991. Discharge from south cell spillways #3 and #5 was intermittent and minimal, usually less than 1 MGD. Spillway #3 was the more active of the two.

The discharge permit issued by the Maryland Department of the Environment places limits on total suspended solids (TSS) in the effluent. Under the renewed permit issued in December 1992, limits no longer vary, depending on the remaining capacity of the dike. During the eleventh year, the dike was more than 85% filled, and the 1992 permit established the following TSS limits: monthly average ≤ 400 mg/l; daily maximum ≤ 800 mg/l. Spillways were closed on numerous occasions to ensure that TSS levels in the effluent remained in compliance with the discharge permit; no TSS violations occurred during the period.

Crust management programs implemented in both cells of the dike entailed establishing trenches along the cell perimeters. Desiccation of the south cell was hampered by a layer of clay deposited over much of the cell during the final months of the Fifty Foot Contract. The bearing capacity of the material was insufficient to support the weight of the trenching equipment, leaving much of the perimeter inaccessible. By September 1991, about half of the south cell perimeter (5,000 ft) had been trenched. In the north cell, about 6,000 ft of perimeter trenches had been installed, with four interior trenches along the north side of the cell between spillways #1 and #2.

April 1992

During the five months preceding the April 1992 cruise (November 1991 - March 1992, inclusive), about 2 MCY of material, generated by maintenance dredging of the 42 Foot Federal Maintenance Project and three smaller Baltimore Harbor projects, were hydraulically inflowed into the north cell. The material consisted mostly of silt. Placement occurred in two phases: mid-October 1991 to late November 1991 and late March 1992 to early April 1992.

Again, the primary operational objective throughout the period was to minimize the volume of ponded water. In the north cell, spillway #1 was the primary outfall structure. The spillway was open constantly during November and December 1991 and periodically thereafter. During the period, daily flow from the spillway averaged 5.4 MGD; maximum daily flow was 56 MGD in March 1992. Spillway #2 was closed for most of the period, discharging intermittently beginning in March 1992. Likewise, spillway #4 remained closed for most of the period, reopening in early April 1992. In the south cell, spillway #3 was open intermittently, discharging an average of about 1 MGD. Discharge from spillway #5 was intermittent and minimal, averaging 0.3 MGD.

The same TSS limits applied as in the period preceding the November 1991 cruise. Again, no TSS violations were reported.

Crust management efforts were concentrated in the south cell, where trench footage was extended to 13,000 ft. In the vicinity of the two south cell spillways, six interior trenches, each about 400 ft long, were established. Existing trenches in the north cell were maintained and deepened. They continued to function even though material was being inflowed into the cell.

OBJECTIVES

As in the past, the main objectives of the eleventh year study were (1) to measure specific physical and geochemical properties of near-surface sediments around HMI and (2) to assess detected changes in the sedimentary environment. Tracking the extent and persistence of the area of Zn enrichment was again of particular interest. Also, the source of Zn enrichment was reexamined in light of 21 computer runs of a 3-D hydrodynamic model simulating various flow conditions of the Susquehanna River and effluent releases from three of the HMI spillways.

METHODOLOGY

FIELD METHODS

The information presented in this report is based on analyses of samples collected on two cruises aboard the R/V Discovery during the eleventh year of monitoring. Sampling sites (Fig. 1-1) were located in the field by means of the LORAN-C navigational system. For the past nine years, the same LORAN X and Y time delays (TD's) have been used to locate the stations that were established during the initial phase of this project. The repeatability of LORAN-C navigation, that is, the ability to return to a location at which a navigation fix has previously been obtained, is affected primarily by seasonal and weather-related changes along the signal transmission path. Data recorded in 1982 from the U.S. Coast Guard Harbor Monitor at Yorktown, Virginia provide an approximate range of repeatable error. That year, variations in the X-lines amounted to 0.256 units and, in the Y-lines, 0.521 units. In the central Chesapeake Bay, one X-TD unit equals approximately 285 m (312 yd) and one Y-TD unit, 156 m (171 yd). Therefore, when a vessel reoccupies an established station in the Bay region, it should be within about 100 m (109 yd) of its original location (Halka, 1987). LORAN-C TD's were converted to "corrected" latitudes and longitudes (NAD 1927) using a computer program that incorporates the results of a LORAN-C calibration in Chesapeake Bay (Halka, 1987). The LORAN-C TD's, latitude, and longitude for each station are compiled in the *Eleventh Year Data Report.*

Surficial sediment samples were collected in November 1991 (Cruise 26) and April 1992 (Cruise 27). During the ninth year of monitoring, the number of sampling stations was doubled in response to the detection of abnormally high Zn levels in sediments near spillway #1 (Hennessee and Hill, 1992). The expanded sampling plan was retained throughout the eleventh year. In November 1991, 66 sites, including all of the box core (BC) stations, were occupied. In April 1992, 62 stations were revisited.

Undisturbed samples of the upper 8-10 cm of the sediments were obtained with a dip-galvanized Petersen sampler. At least one grab sample was collected at each station and split for textural and trace metal analyses. Triplicate grab samples were collected at eight stations (11, 12, 16, 24, 25, 28, BC3, and BC6) in November 1991 and at seven of those eight stations in April 1992. (Attempts to collect replicates at station 12 failed.) During the April cruise, additional grab samples were taken for organic contaminant analysis at nine stations (23, 24, 25, 28, 30, 34, 36, BC3, and BC6). Upon collection, each sediment sample was described lithologically and subsampled (see the *Eleventh Year Data Report*).

Sediment and trace metal subsamples were collected using plastic scoops rinsed with distilled water. These samples were taken several centimeters from the top, below the flocculent layer and away from the sides of the sampler, to avoid possible contamination by the grab sampler. They were placed in 18-oz "Whirl-Pak" bags. Samples designated for textural analysis were stored out of direct sunlight at ambient temperatures. Those intended for trace metal analysis were refrigerated and maintained at 4°C until processing.

Subsamples for organic analysis were collected with an aluminum scoop (also rinsed with distilled water), placed in pre-treated glass jars, and immediately refrigerated. They were delivered to MES, then transferred to a private laboratory for analysis.

In April 1992, gravity cores were collected at the seven BC stations and at stations 12 and 25 (Fig. 1-1). A Benthos gravity corer (Model #2171) fitted with clean cellulose acetate butyrate (CAB) liners, 6.7 cm in diameter, was used. Each core was cut and capped at the sediment-water interface, then refrigerated until it could be x-rayed and processed in the lab.

LABORATORY PROCEDURES

Radiographic Technique

Prior to processing, the upper 50 cm of each core were x-rayed at MGS, using a TORR-MED x-ray unit (x-ray settings: 90 kv, 5 mas, 30 sec). A negative x-ray image of the core was obtained by xeroradiographic processing. On a negative xeroradiograph, denser objects or materials, such as shells or sand, produce lighter images. Objects of lesser density permit easier penetration of x-rays and, therefore, appear as darker features. The xeroradiographs are reproduced in Appendix A.

Each core was then extruded, photographed, and described. Visual and radiographic observations of the cores are presented in the *Eleventh Year Data Report*. On the basis of these observations, sediment samples for textural and trace metal analyses were taken at selected intervals from each core.

Textural Analysis

In the laboratory, subsamples from both the surficial grabs and gravity cores were analyzed for water content and grain size composition (sand-silt-clay content). Water content was calculated as the percentage of the water weight to the total weight of the wet sediment:

$$Wc = \frac{Ww}{Wt} \times 100 \qquad (1)$$

where Wc = water content (%)
Ww = weight of water (g)
Wt = weight of wet sediment (g)

Water weight was determined by weighing approximately 25 g of the wet sample, drying the sediment at 105-110°C, and reweighing it. The difference between total wet weight (Wt) and dry weight equals water weight (Ww). Bulk density was also determined from water content measurements.

The relative proportions of sand, silt, and clay were determined using the sedimentological procedures described in Kerhin *et al.* (1988). The sediment samples were pre-treated with hydrochloric acid and hydrogen peroxide to remove carbonate and organic matter, respectively. Then the samples were wet sieved through a 62-μm mesh to separate the sand from the mud (silt plus clay) fraction. The finer fraction was analyzed using the pipette method to determine the silt and clay components (Blatt *et al.*, 1980). Each fraction was weighed; percent sand, silt, and clay were determined; and the sediments were categorized according to Pejrup's (1988) classification (Fig. 1-2).

Pejrup's diagram, developed specifically for estuarine sediments, is a tool for graphing a three-component system summing to 100%. Lines parallelling the side of the triangle opposite the sand apex indicate the percentage of sand. Each of the lines fanning out from the sand apex represents a constant clay:mud ratio (the proportion of clay in the mud, or fine, fraction). Class names consist of letter-Roman numeral combinations. Class D-II, for example, includes all samples with less than 10% sand and a clay:mud ratio between 0.50 and 0.80.

The primary advantage of Pejrup's classification system over other schemes is that the clay:mud ratio can be used as a simple indicator of hydrodynamic conditions during sedimentation. (Here, hydrodynamic conditions refer to the combined effect of current velocity, wave turbulence, and water depth.) The higher the clay:mud ratio, the quieter the depositional environment. Sand content cannot be similarly used as an indicator of depositional environment; however, it is well-suited to a rough textural classification of sediment.

Although the classification scheme is useful in reducing a three-component system to a single term, the arbitrarily defined boundaries separating classes sometimes create artificial differences between similar samples. Samples may be assigned to different categories, not because of marked differences in sand-silt-clay composition, but because they fall close to, but on opposite sides of, a class boundary. To avoid that problem, the results of grain size analysis are discussed in terms of percent sand and clay:mud ratios, not Pejrup's classes themselves.

PEJRUP'S DIAGRAM

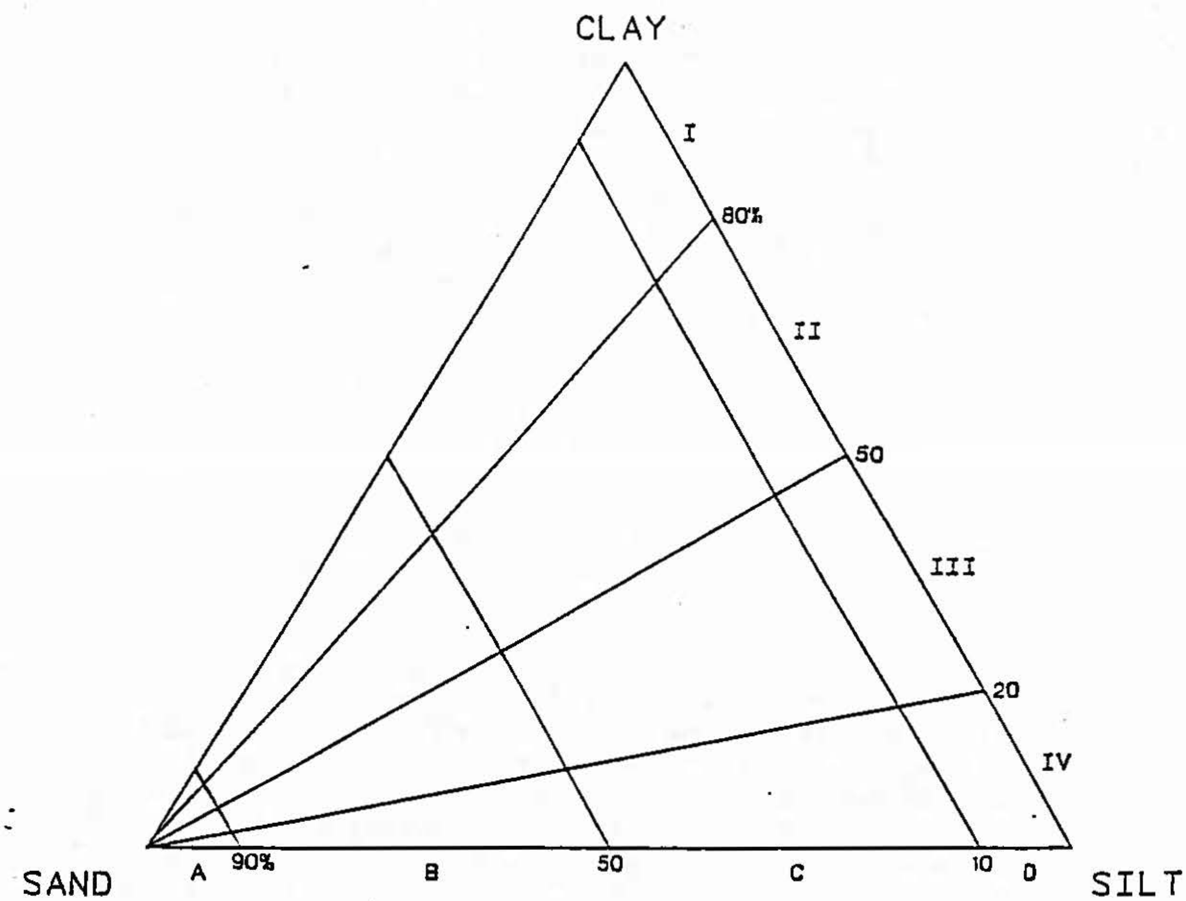


Figure 1-2: Pejrup's (1988) classification of sediment type.

Trace Metal Analysis

Sediment solids were analyzed for six trace metals - iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), and nickel (Ni). In previous monitoring years, these metals were analyzed using a lithium metaborate fusion technique, followed by standard flame (Fe, Mn, Zn) or furnace (Cr, Cu, Ni) atomic absorption (AA) spectrophotometry. This procedure, based on methods developed by Suhr and Ingamells (1966) for whole rock analysis, was refined specifically for the analysis of Chesapeake Bay sediments (Sinex *et al.*, 1980; Sinex and Helz, 1981; Cantillo, 1982). However, starting this year, a new analytical protocol was implemented. The new procedure uses a microwave digestion technique followed by analysis on an Inductively Coupled Argon Plasma Spectrometer (ICAP). This new protocol, modified from EPA Method #3051 (Soil Sample Digestion Procedure for Floyd Digestion Vessels), has many advantages over the previous method of analysis:

1. The samples are digested in sealed teflon bombs. This minimizes the loss of analyte due to volatilization. In addition, the temperature of the digestion is much lower, further reducing potential sample loss.

2. The samples are digested in strong acids only; flux and matrix modifiers are not required. This reduces potential contamination and minimizes blank corrections.

3. ICAP detection limits are generally equal to or significantly lower than those of comparable AA methods.

4. Samples can be analyzed more quickly with ICAP than with AA methods. With an AA, only one element can be analyzed at a time. This several-day process entails optimizing and calibrating for each element, followed by element analysis. The ICAP system analyzes all of the elements at one time, reducing the analytical time to a fraction of that required by AA. Additionally, the calibration range of the ICAP is significantly larger than that of the AA, reducing the number of dilutions required. This reduces the chance of contamination and error due to sample handling.

The MGS laboratory followed the steps below in handling and preparing trace metal samples:

1. Samples were homogenized in the "Whirl-Pak" bags in which they were stored and refrigerated (4°C).

2. Approximately 10 g of wet sample were transferred to Teflon evaporating dishes and dried overnight at 105-110°C.

3. Dried samples were hand-ground with an agate mortar and pestle, powdered in a ball mill, and stored in "Whirl-Pak" bags.

4. 0.5000 ± 0.0005 g of dried, ground sample was weighed and transferred to a Teflon digestion vessel.

5. 2.5 ml concentrated HNO_3 (trace metal grade), 7.5 ml concentrated HCl (trace metal grade), and 1 ml ultra-pure water were added to the Teflon vessel.

6. The vessel was capped with a Teflon seal, and the top was hand tightened. Between four and twelve vessels were placed in the microwave carousel. (Preparation blanks were made by using 0.5 ml of high purity water plus the acids used in Step 5.)

7. Samples were irradiated using programmed steps appropriate for the number of samples in the carousel. These steps were optimized based on pressure and percent power. The samples were brought to a temperature of 175°C in 5.5 minutes, then maintained between 175-180°C for 9.5 minutes. (The pressure during this time peaked at approximately 6 atm for most samples.)

8. Vessels were cooled to room temperature and uncapped. The contents were transferred to a 100 ml volumetric flask, and high purity water was added to bring the volume to 100 ml. The dissolved samples were transferred to polyethylene bottles and stored for analysis.

9. The sample was analyzed.

All surfaces that came into contact with the samples were acid washed (3 days 1:1 HNO_3; 3 days 1:1 HCl), rinsed six times in high purity water (less than 5 mega-ohms), and stored in high-purity water until use.

The dissolved samples were analyzed with a Jarrel-Ash AtomScan 25 sequential ICAP spectrometer using the method of bracketing standards (Van Loon, 1980). The instrumental parameters used to determine the solution concentrations were the recommended, standard ICAP conditions given in the Jarrel-Ash manuals, optimized using standard reference materials (SRM) from the National Institute of Standards and Technology (NIST) and the

National Research Council of Canada. Blanks were run every 12 samples, and SRM's were run five times every 24 samples.

Results of the analyses of three SRM's (NIST-SRM #1646 - Estuarine Sediment; NIST-SRM #2704 - Buffalo River Sediment; National Research Council of Canada #PACS-1 - Marine Sediment) are given in Table 1-1. Results obtained by the two methods are presented for comparison. The data show an overall increase in both accuracy and precision when comparing the microwave (μwave)/ICAP method to the fusion/AA method. The microwave/ICAP method has recoveries (accuracies) within ±5% for all of the metals analyzed, except Ni and Mn. Although poorer, the recoveries for these two metals are good. The poorer recoveries for Ni and Mn are due to the concentrations of these elements being near detection limits. For Mn, the SRM's have unrealistically low concentrations, compared to the samples around HMI. The Buffalo River SRM has the highest Mn content of the three, and the recovery of Mn for this SRM is excellent.

RESULTS AND DISCUSSION

SEDIMENT DISTRIBUTION

Since November 1983, sand-silt-clay percentages have been measured twice a year at 24 stations around HMI. The grain size composition of these sediments is depicted in ternary diagrams for five different sampling periods (Fig. 1-3). The first diagram (Fig. 1-3a) is typical of the post-construction, **pre-discharge** sediment distribution around the facility. The next four diagrams - all **post-discharge** - summarize tenth year (Fig. 1-3 b&c) and eleventh year (Fig. 1-3 d&e) findings. Related statistics are presented in Table 1-2.

Table 1-1: Results of MGS's analysis of three standard reference materials, showing the recovery of the certified metals of interest and comparing the fusion/AA technique to the microwave/ICAP technique.

Recovery (%)				
Metal	Method	NIST 1646	Buffalo River	PACS
Fe	Fusion/AA	96±3 (15)	97±1 (6)	94±2 (6)
	μwave/ICAP	97±4 (15)	97±2 (15)	94±3 (15)
Mn	Fusion/AA	98±3 (15)	106±4 (6)	102±2 (6)
	μwave/ICAP	85±6 (15)	102±4 (15)	79±5 (15)
Zn	Fusion/AA	93±2 (15)	98±2 (6)	102±4 (6)
	μwave/ICAP	87±1 (15)	96±1 (15)	98±2 (15)
Cu	Fusion/AA	105±6 (15)	93±2 (6)	81±9 (6)
	μwave/ICAP	93±5 (15)	100±4 (15)	100±2 (15)
Cr	Fusion/AA	114±9 (15)	116±5 (6)	116±5 (6)
	μwave/ICAP	102±4 (15)	98±5 (15)	95±4 (15)
Ni	Fusion/AA	84±16 (15)	84±2 (6)	79±4 (6)
	μwave/ICAP	86±9 (15)	88±9 (15)	84±8 (15)

(Note: Numbers in parentheses are the number of replicate analyses.)

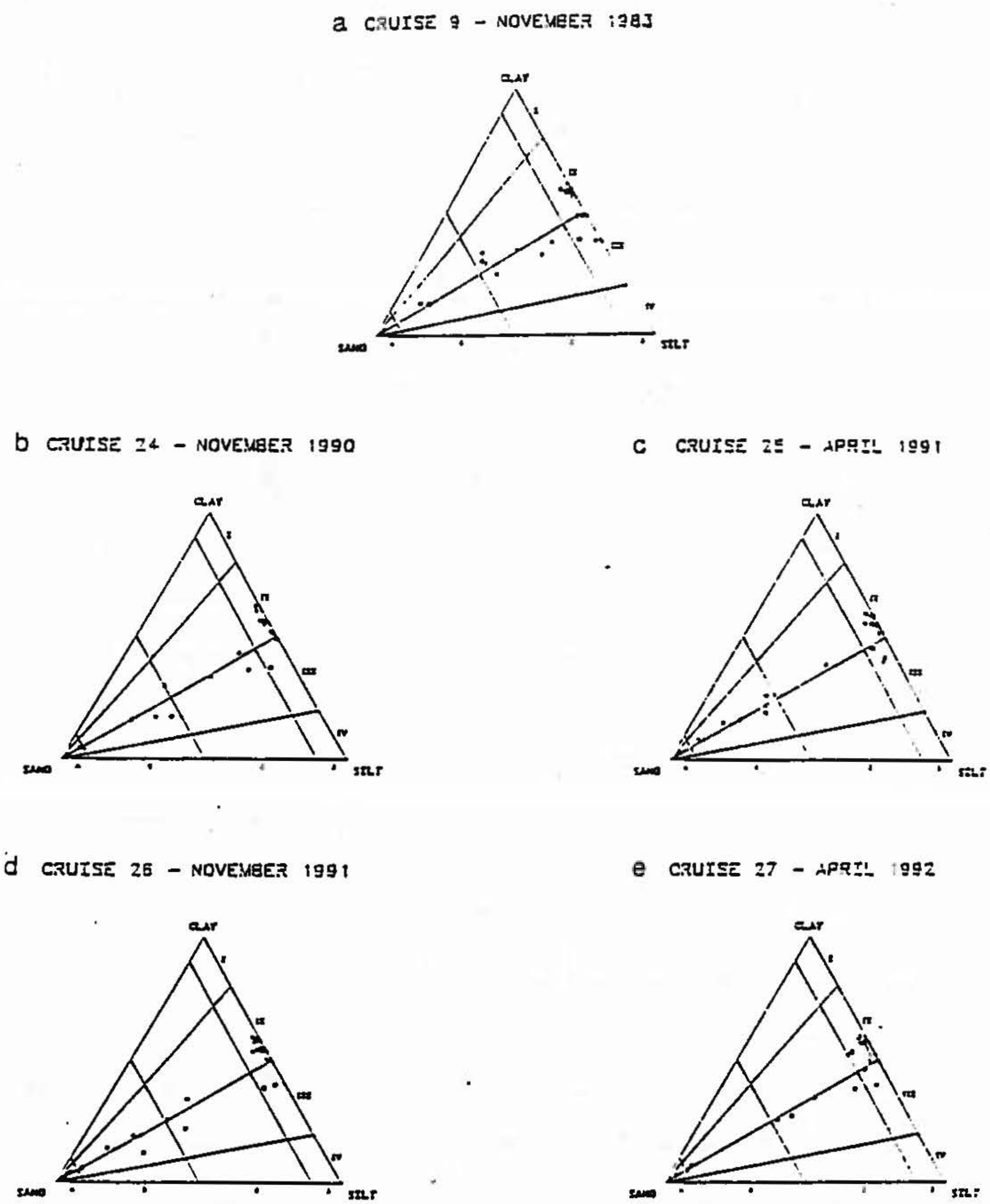


Figure 1-3: Sediment type of samples collected in (a) November 1983 (post-construction, pre-discharge), (b) November 1990, (c) April 1991, (d) November 1991, and (e) April 1992. The dashed line extending from the sand apex diagonally across each diagram represents the average clay:mud ratio for that sampling period.

Table 1-2: Summary statistics for five cruises, based on 24 continuously monitored stations around HMI.

Cruise	Date	Clay:mud ratio Range	Clay:mud ratio Average	% Sand Range	% Sand Average
9	11/83	0.39-0.63	0.54	0.33-97.34	26.40
24	11/90	0.33-0.63	0.51	0.58-98.36	33.45
25	4/91	0.43-0.78	0.56	0.27-95.92	34.87
26	11/91	0.34-0.61	0.53	0.95-98.05	34.97
27	4/92	0.42-0.61	0.54	1.27-97.75	34.79

For the 24 continuously monitored sampling locations, Figure 1-4 depicts percent sand and clay:mud ratios, averaged over all 24 stations, for all post-construction cruises. The vertical line indicating the first release of effluent in October 1986 separates pre- and post-discharge cruises.

During the pre-release period, the sand content of sediments increased systematically over time. Marked increases in percent sand occurred during the winter (between fall and spring cruises). Sand content then remained comparatively stable until the following fall, when another jump occurred. This pattern of steady, seasonal increases in sand content changed once discharging began. With a single, minor exception, sand percentages have remained above the maximum pre-discharge level of 31.4%. Initially, average sand content fluctuated between 31% and 35%, tending to decrease during the winter months (November to April) and increase during the summer (April to November). Recently, a new pattern has emerged. Beginning with the second cruise of the tenth year (Cruise 25 - April 1991), sand content has stabilized, remaining at about 35% through the eleventh monitoring year.

Average clay:mud ratios for the 24 stations also show distinctly different pre- and post-discharge patterns. Overall pre-discharge ratios varied over a relatively small range (0.52-0.56); no seasonal trend is evident. During the post-discharge period, ratios have varied over a wider range (0.49-0.57). A consistent seasonal pattern has developed and persisted through the eleventh year. The muddy fraction of the sediment becomes finer (more clay-rich) during the winter (between fall and spring cruises) and coarser during the summer.

Two sets of contour maps, based on the entire suite of samples, show the spatial distribution of sediment type during the tenth and eleventh monitoring years. Figures 1-5 and 1-6 depict percent sand; Figures 1-7 and 1-8, clay:mud ratios. Maps showing the distribution of sand are virtually identical for the four sampling periods. In fact, sand distribution has remained largely unchanged since November 1988. Lobes of sandy (>90%

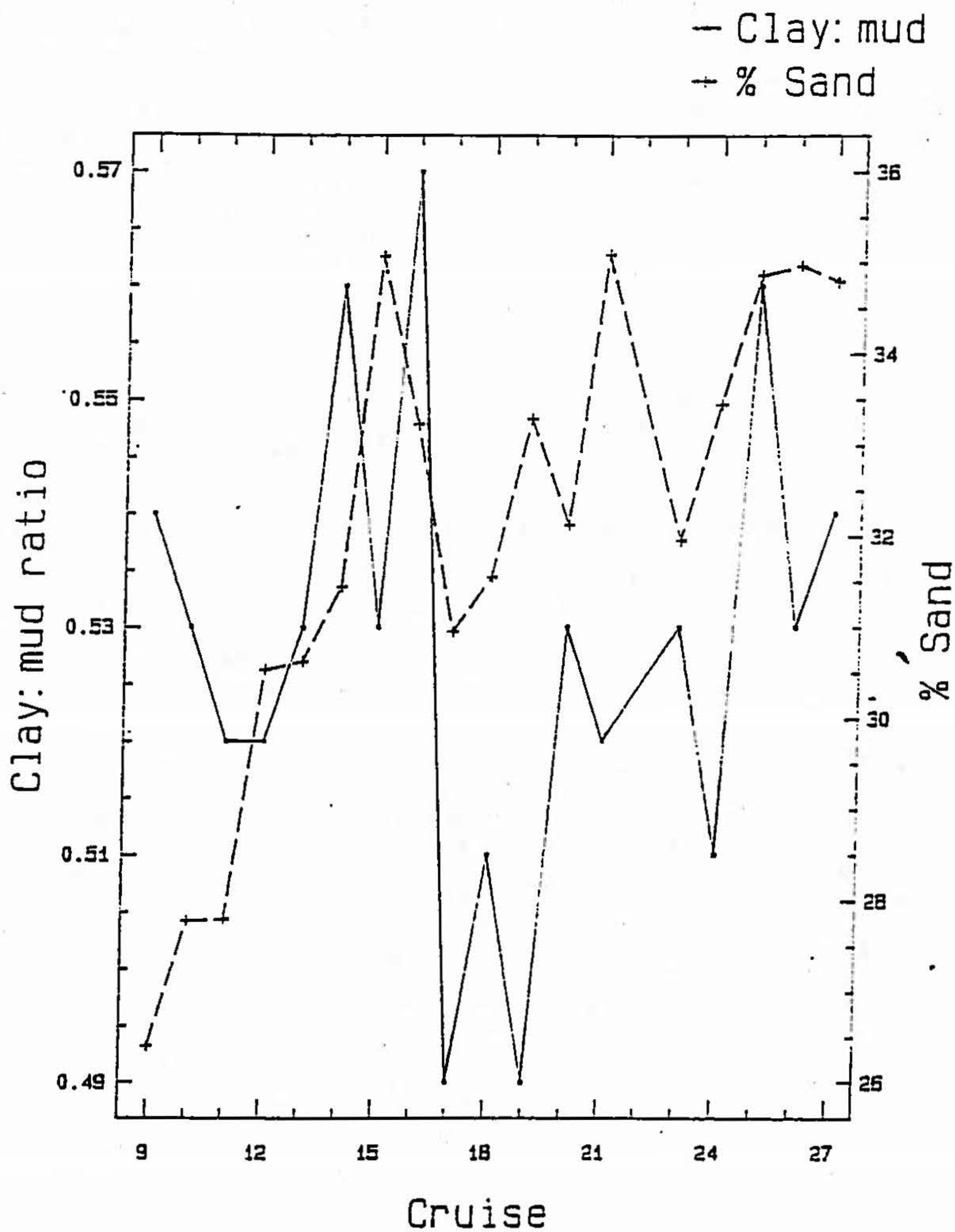


Figure 1-4: Average percent sand and clay:mud ratios, based on 24 continuously monitored stations, for all post-construction cruises through the eleventh year.

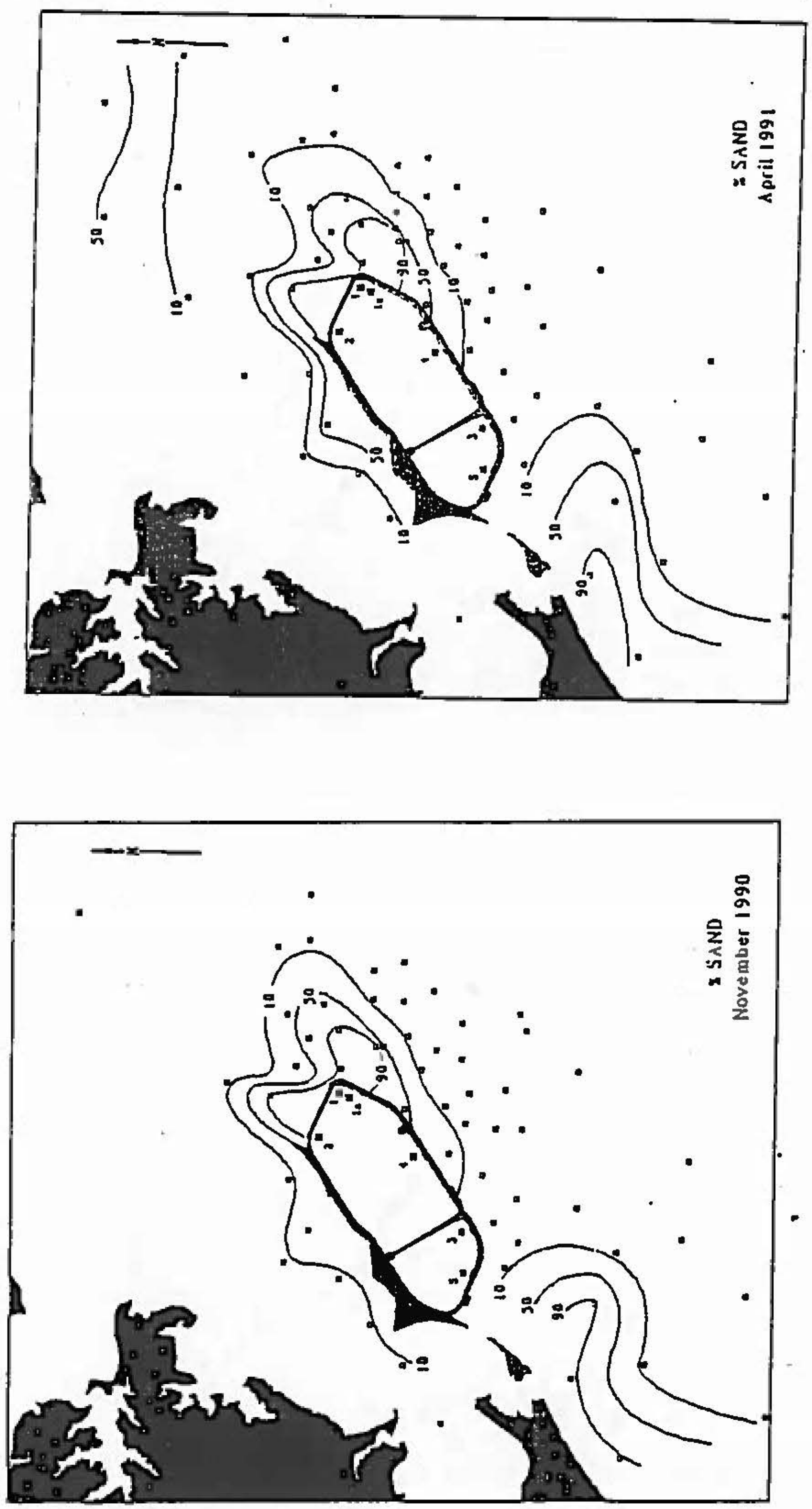
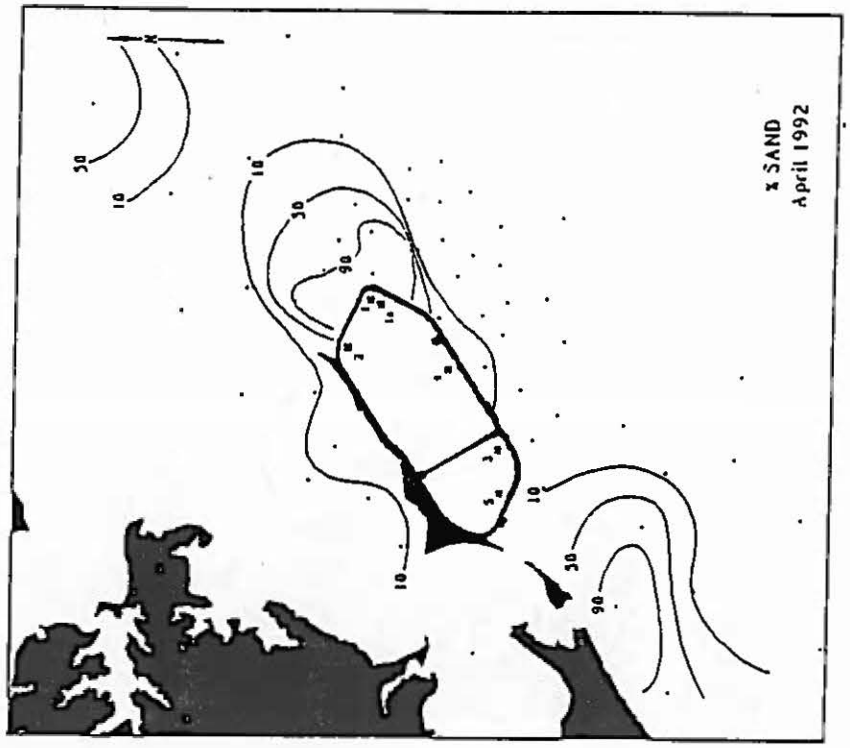


Figure 1-5: Distribution of percent sand - tenth year monitoring: (a) November 1990 and (b) April 1991.



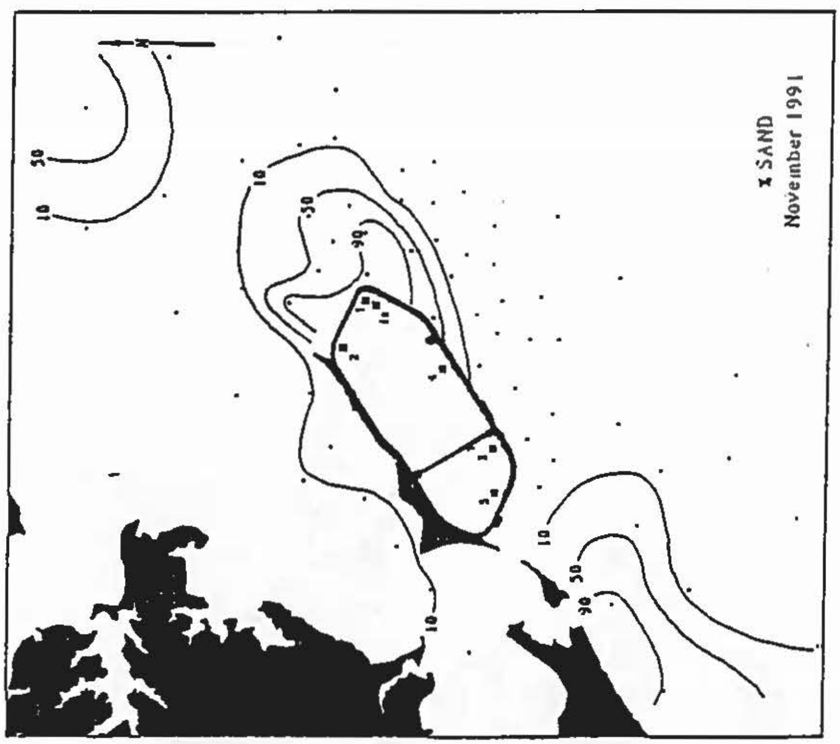


Figure 1-6: Distribution of percent sand - eleventh year monitoring: (a) November 1991 and (b) April 1992.

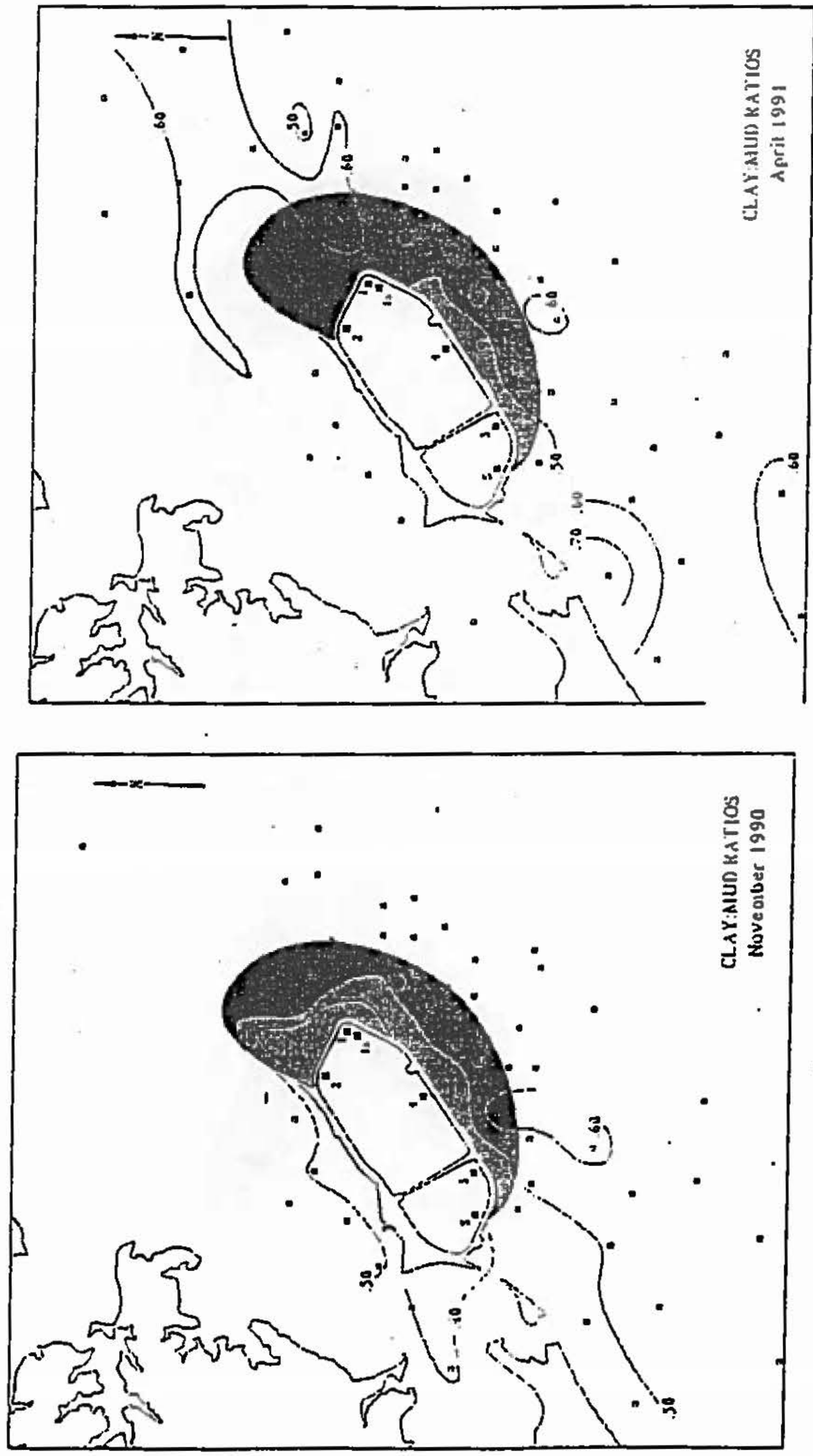


Figure 1-7: Distribution of clay:mud ratios - tenth year monitoring: (a) November 1990 and (b) April 1991.

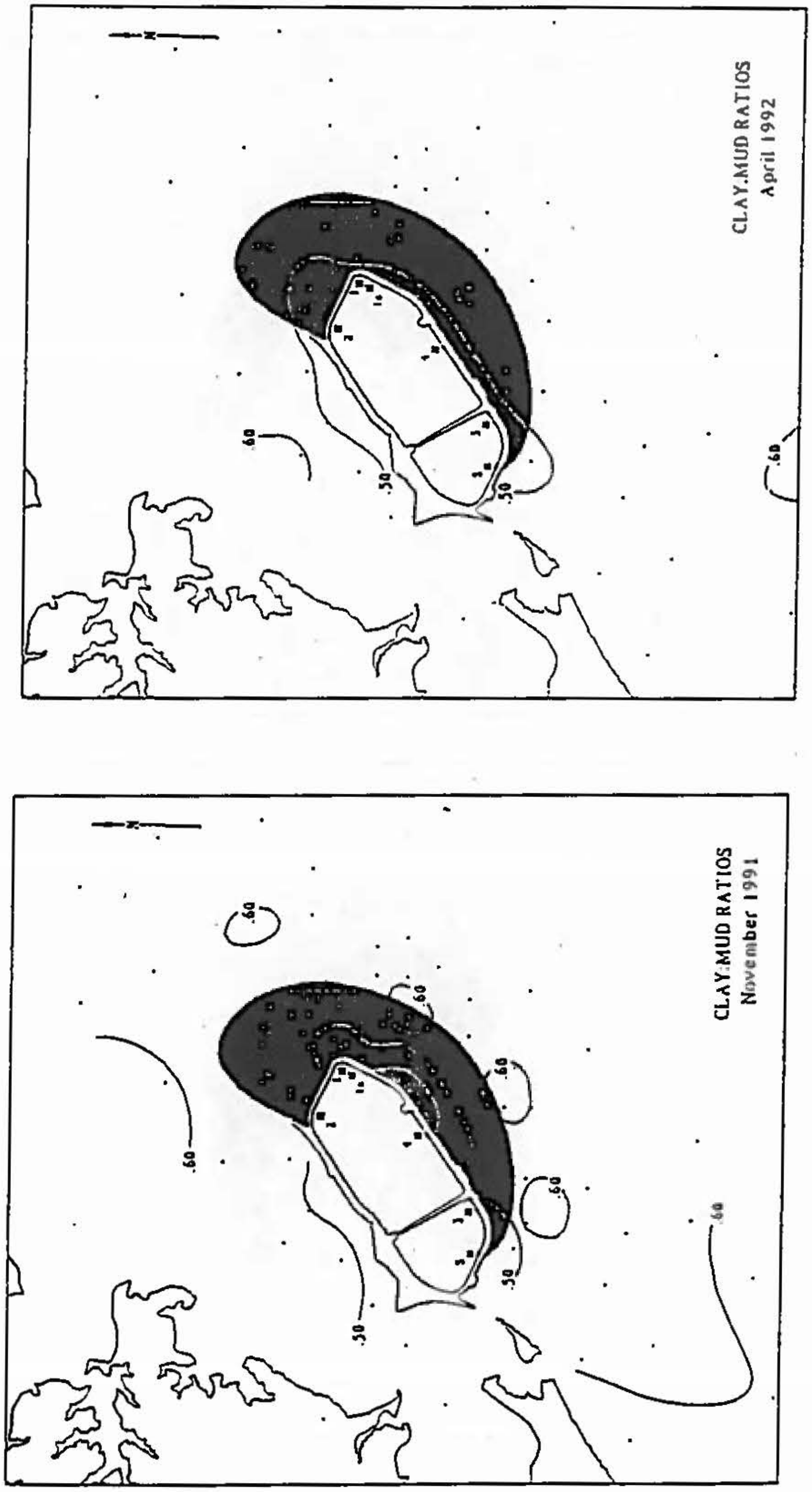


Figure 1-8: Distribution of clay:mud ratios - eleventh year monitoring: (a) November 1991 and (b) April 1992.

sand) sediment extend north-northeast of the dike and east of Black Marsh and become systematically finer (less sandy) offshore.

The clay:mud ratio maps (Figs. 1-7 and 1-8) include, in addition to the contours, an ear-shaped boundary outlining an area around the dike that has been most densely sampled over time. Within this boundary, the zones lying between contours have been shaded - the more clay-rich the fine fraction, the darker the shading. For all four sampling periods shown, the coarsest (siltiest) sediments flank the perimeter of the dike. In a general way, the proportion of clay in the fine fraction increases with distance from the dike.

As described in the *Ninth Year Interpretive Report* (Hennessee and Hill, 1992), a seasonal pattern developed in the distribution of the fine fraction following the opening of spillway #1: the clay:mud ratio varied over a smaller range in the fall than in the spring. The reverse was true during the eleventh year, with minimum ratios between 0.30-0.40 in November 1991 and between 0.40-0.50 in April 1992. (Maximum clay:mud ratios were between 0.60-0.70 for both cruises.) However, the same pattern noted above for the 24 continuously monitored stations - fining of the muddy fraction over the winter and coarsening over the summer - is evident in these maps. A somewhat larger portion of the ear-shaped area is blanketed by clay-rich (clay:mud>0.50) fine sediments in April 1992 than in November 1991. These seasonal differences may be related to the interplay between flow from the dike and Susquehanna River discharge.

TRACE METALS

Six trace metals were analyzed as part of the ongoing effort to assess the effects of operation of the containment facility on the surrounding sedimentary environment. The method used to interpret changes in the observed metal concentrations takes into account grain size induced variability and references the data to a regional norm. The method involves correlating trace metal levels with grain size composition on a data set that can be used as a reference for comparison. For the HMI study area, data collected between 1983 and 1988 are used as the reference. Samples collected during this time showed no aberrant behavior in trace metal levels. Normalization of grain size induced variability of trace element concentrations was accomplished by fitting the data to the following equation:

$$X = a(\text{Sand}) + b(\text{Silt}) + c(\text{Clay}) \qquad (2)$$

where X = the element of interest
a, b, and c = the determined coefficients

Sand, Silt, and Clay = the grain size fractions of the sample

A least squares fit of the data was obtained by using a Marquardt (1963) type algorithm. The results of this analysis are presented in Table 1-3. The correlations are excellent for Cr, Fe, Ni, and Zn, indicating that the concentrations of these metals are directly related to the grain size of the sediment. The correlations for Mn and Cu are weaker, though still strong. In addition to being part of the lattice and adsorbed structure of the mineral grains, Mn occurs as oxy-hydroxide chemical precipitate coatings. These coatings cover exposed surfaces, that is, they cover individual particles as well as particle aggregates. Consequently, the correlation between Mn and the disaggregated sediment size fraction is weaker than for elements, like Fe, that occur primarily as components of the mineral structure. The behavior of Cu is more strongly influenced by sorption into the oxy-hydroxide than are the other elements.

Table 1-3: Coefficients and R^2 for a best fit of trace metal data as a linear function of sediment grain size around HMI. The data are based on analyses of samples collected during eight cruises, from May 1985 to April 1988.

$$X = [a*Sand + b*Silt + c*Clay]/100$$

	Cr	Mn	Fe	Ni	Cu	Zn
a	25.27	668	0.553	15.3	12.3	44.4
b	71.92	218	1.17	0	18.7	0
c	160.8	4158	7.57	136	70.8	472
R^2	0.733	0.36	0.91	0.82	0.61	0.77

The strong correlation between the metals and the physical size fractions makes it possible to predict metal levels at a given site if the grain size composition is known. This can be done by substituting the least squares coefficients from Table 1-3 for the determined coefficients in equation 2. These predicted values can then be used to determine variations from the regional norm due to deposition; to exposure of older, more metal-depleted sediments; or to loadings from anthropogenic or other enriched sources.

The following equation was used to examine the variation from the norm around the containment facility:

$$\% \text{ excess Zn} = \frac{(\text{measured Zn} - \text{predicted Zn})}{\text{predicted Zn}} * 100 \qquad (3)$$

Here, the differences between the measured and predicted Zn levels (positive values => enrichment; negative values => depletion) are normalized to predicted Zn levels.

Zn is used in the following discussion as an indicator of change in sediment chemistry. As elaborated in previous reports (Kerhin *et al.*, 1982a; Wells *et al.*, 1984), there are several reasons for focusing on Zn:

1. Of the chemical species measured, Zn has been the least influenced by variation in analytical technique. Since 1976, at least four different laboratories have been involved in monitoring the region around HMI. The most consistent results have been obtained for Zn.

2. Zn is one of the few metals in the Bay that has been shown to be affected by anthropogenic input.

3. There is a significant down-Bay gradient in Zn enrichment that can be used to detect the source of imported material.

4. Zn concentrations are highly correlated with other metals of environmental interest.

Since the eighth monitoring year, increased levels of Zn have been noted in bottom sediments east and south of spillway #1. These enriched levels of metals were correlated with low discharge rates from the spillway. Initially, it was thought that high metal levels had not been detected prior to that, because higher discharge rates propelled the metal-laden sediments further out into the Bay, beyond the monitored area. The distribution of Zn during the ninth and tenth monitoring years was consistent throughout the four sampling periods. However, during the tenth year, the size of the area most enriched in Zn diminished, and the maximum level of Zn decreased (maximum concentrations: April 1990 - 133%; November 1990 - 114%; April 1991 - 87%). The apparent diminution of Zn levels between April 1990 and November 1990 was attributed to high rates of discharge from spillway #1, coupled with periods of no flow. Further decreases in Zn levels between November 1990 and April 1991 were attributed to the inactivity of spillway #1 and the utilization of spillway #2 during the period.

Trends observed previously persisted during the eleventh year (November 1991 and April 1992). This can be seen by comparing Figures 1-9 j&k, with Figures 1-9 a-i. However, there was an increase in Zn enrichment east and south of HMI between April 1991 and November 1991. The increase in metals loadings to these areas was modest, from 2σ to 3σ. In April 1992, Zn enrichment decreased east of HMI, dropping back to 2σ, which is considered background level. South of the facility, a high enrichment value, greater than 6σ, was measured at one station. This is only one data point, which may be in error. It is, nonetheless, included in the contouring, because it is consistent with previous years' trends. Nothing noted in the sample handling or in the sample's characteristics indicates that the sample should be excluded from the data set.

In previous interpretive reports, Zn enrichment in the exterior sediments around HMI has been linked to discharge from the facility. In lieu of the more rigorous 3-D hydrodynamic model of the upper Bay, a model based on trajectories was used to explain the increase in metal loadings to the sediment as discharge from the facility decreased. However, the 3-D model has been completed, including scenario runs for different discharge rates from the facility and different flow rates from the Susquehanna River. The details of this modelling effort were presented in an addendum to the *Tenth Year Interpretive Report* (Wang, 1993). The results pertinent to a discussion of contaminant distribution around HMI follow:

1. A circulation gyre exists east of HMI. The gyre circulates water in a clockwise pattern, compressing the discharge from the facility against the eastern and southeastern perimeter of the dike.

2. Releases from spillways #1 and #4 travel in a narrow, highly concentrated band up and down the eastern side of the dike. This explains the location of the areas of periodic high metal enrichment to the east and southeast of the facility.

   Releases from spillway #2 are spread more evenly to the north, east and west. However, dispersion is not as great as from spillways #1 and #4 because of the lower shearing and straining motions.

3. The circulation gyre is modulated by fresh water flow from the Susquehanna River. The higher the flow from the Susquehanna, the stronger the circulation pattern and the greater the compression against the dike. Conversely, the lower the flow, the less the compression and the greater the dispersion away from the dike.

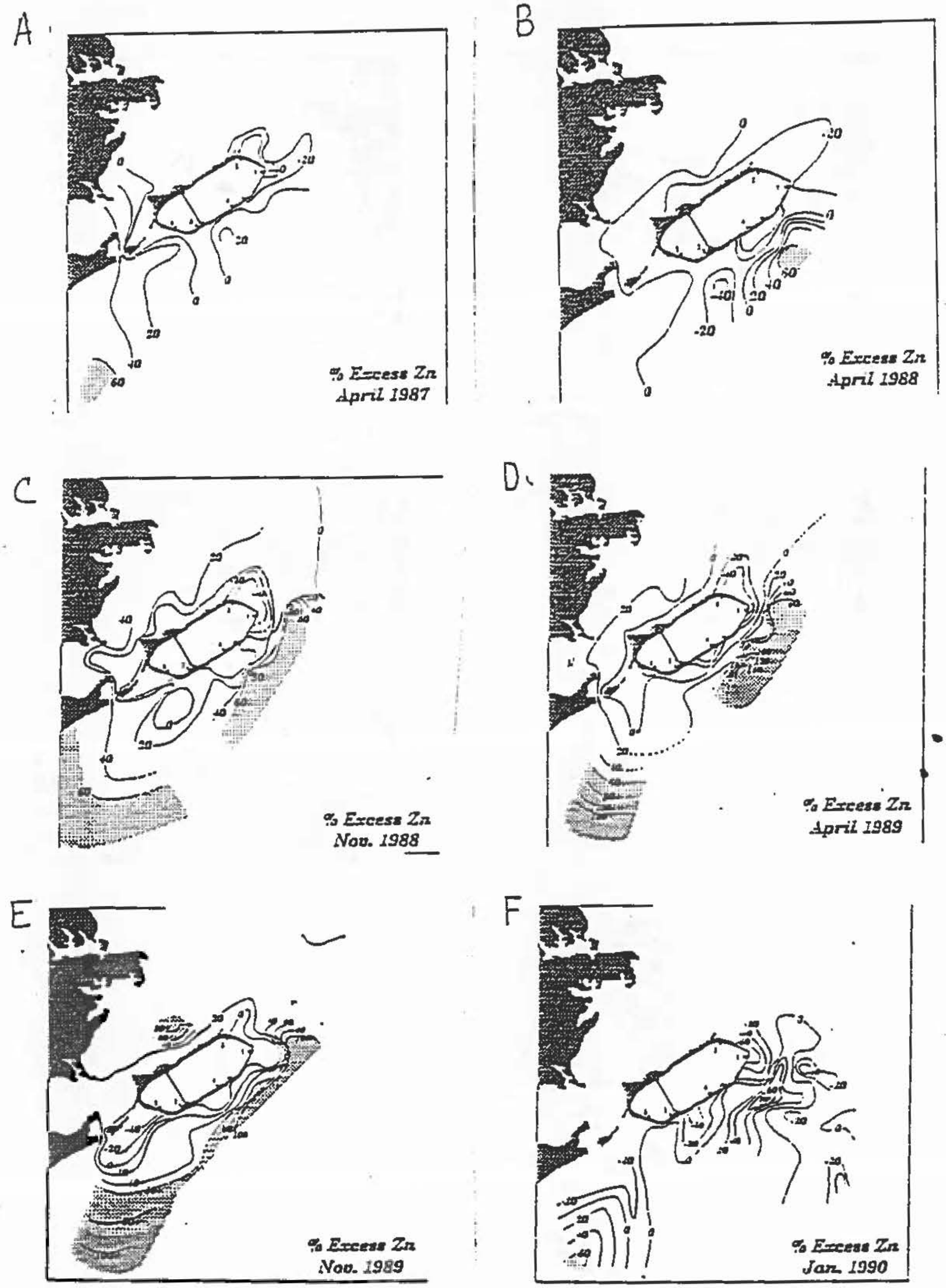


Figure 1-9: % Excess Zn contours in the area around HMI.

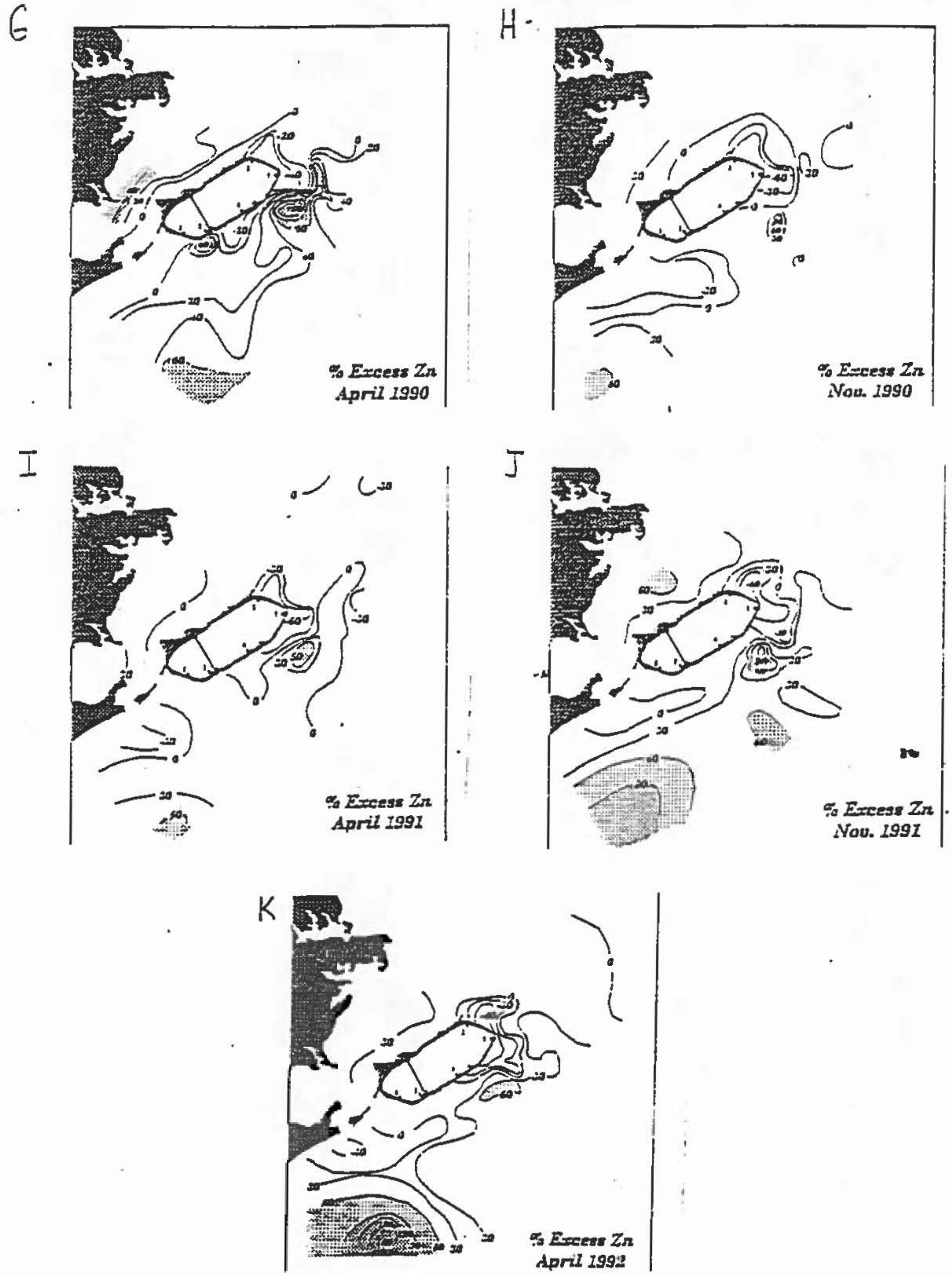


Figure 1-9: % Excess Zn contours in the area around HMI.

4. Discharge from the dike has no influence on the circulation gyre. This was determined by simulating point discharges of 0-70 MGD from three different spillways. Changes in discharge rate only modulated the concentration of a hypothetical conservative species released from the dike; the higher the discharge, the higher the concentration in the plume outside the dike.

The 3-D hydrodynamic model explains the structure of the plume of material found in the exterior sediments, but it does not explain why the level of Zn in the sediments increases at lower discharges. To account for this behavior, the chemistry of the effluent discharged from the dike must be examined. Discharge data for Zn and Fe have been collected more frequently since 1990, in response to the detection of Zn enrichment. Prior to January 1990, Zn and Fe in the discharged waters were analyzed quarterly; since then, they have been analyzed weekly during periods of discharge.

Figure 1-10 shows a plot of the log of the Zn/Fe ratio as a function of the total discharge from HMI. The two lines on the plot show (1) a regression fit for the data, with discharge rates less than 60 MGD, and (2) the background ratio of Zn/Fe in the area around the facility. Releases with a ratio similar to the background value do not contribute to enriched metal loading to the exterior sediments. The regression line shows a marked increase of metal enrichment with diminished flow. From this information, a model can be constructed to predict the Zn loading to the exterior sediments. The model has two components: (1) loading due to material similar to the sediment in place and (2) loading of enriched material as predicted from the regression line in Figure 1-10.

The graphical results of the model can be seen in Figure 1-11. The units on the Zn loading axis of the plot are intentionally omitted because of uncertainties inherent in the model. Assigning absolute loading quantities based on the numbers with high levels of uncertainty would be misleading and would direct attention away from the more important features of the model. The general behavior predicted by the model is the most important feature at this time. The different contributions of materials supplied to the exterior sediments are shown by the different lines. Input of material resembling the exterior sediments is shown as the solid line, which gently increases with increasing discharge. The dashed line is the contribution of excess metal loading due to leaching of the sediments within HMI. The shaded area shows the difference in loading between background levels and excess loadings. The maximum loading due to leaching is between 0.3-10 MGD. These discharge rates (0.3 and 10 MGD) bracket the maximum Zn loading and have loadings one half the maximum loading. The leaching component diminishes rapidly with discharge rates higher than 10 MGD, due to flushing with high volumes of water.

The source of the excess metal loading is attributed to leaching of the metals from the sediment in the dike. These sediments contain metal sulfides similar to the sulfides responsible for acid mine drainage. When sulfide minerals are exposed to aerobic conditions, they oxidize. Oxidation releases the metals bound in the sulfides, and the sulfide sulfur oxidizes to form sulfuric acid. The metals that are released are free to enter an aqueous phase, form other non-labile species, or act as a catalyst in propagating the oxidation of the sulfide minerals. The sulfuric acid reduces the pH of the fluids in contact with the sediment, which in turn leaches sorbed species (metals and acid-soluble organics) from the sediments.

Processes that aid in dewatering the sediments also promote acid mine-type drainage. To dewater the sediments, the sediments are mounded and channelized. This allows for gravity flow of water out of the sediments and removal of the water through the channels. Unfortunately, this increases the surface area of the sediment exposed to atmospheric oxygen and promotes the flow of aerated fresh water, from rain, through the sediment. At lower discharge rates, the low flow of water allows for accumulation of leachate and a longer period of time for the more acidic, aerated water to react with the sediment. Both of these factors contribute to higher loadings.

The applicability of the leachate model to the observed metal loadings around HMI can be seen by comparing Figure 1-12 with Figure 1-9. Figure 1-12 qualitatively represents the periods of time when flow from HMI might affect the sediments exterior to the dike. This was determined by assigning a value of 1 to total discharges between 0.3 to 10 MGD and a value of 0 (zero) to all other total discharge rates. The sediments do not respond instantaneously but, rather, reflect longer term trends. Consequently, a two-week moving average was calculated for spillway #1 to show periods when discharge from the dike might be expected to contribute excess metal loadings to the sediment. Discharge from spillway #1 was the only discharge point of consequence to the exterior sediments, based on the hydrodynamic model and the discharge rates from the other spillways. The periods prior to each of the sampling cruises, shown as alternating lighter and darker bands, are also indicated in Figure 1-12. From Figure 1-12, the periods during which metal loading would be most significant are times where there is an extended period of elevated "Effect" values. These times would be detected if they corresponded to the sampling periods. Comparing the predicted "Effect" with the distribution of Zn in

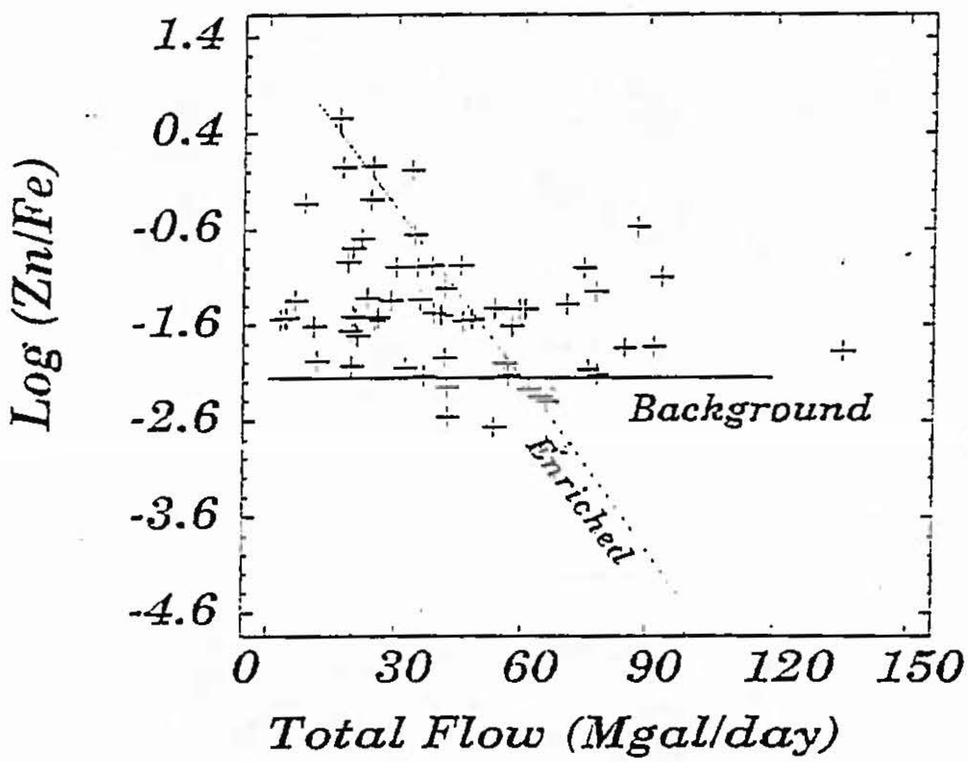


Figure 1-10: Logarithm of the ratio of Zn:Fe as a function of discharge from HMI. The horizontal line is the regional background level of the exterior sediments, and the sloping line is a regression fit used in the discharge model.

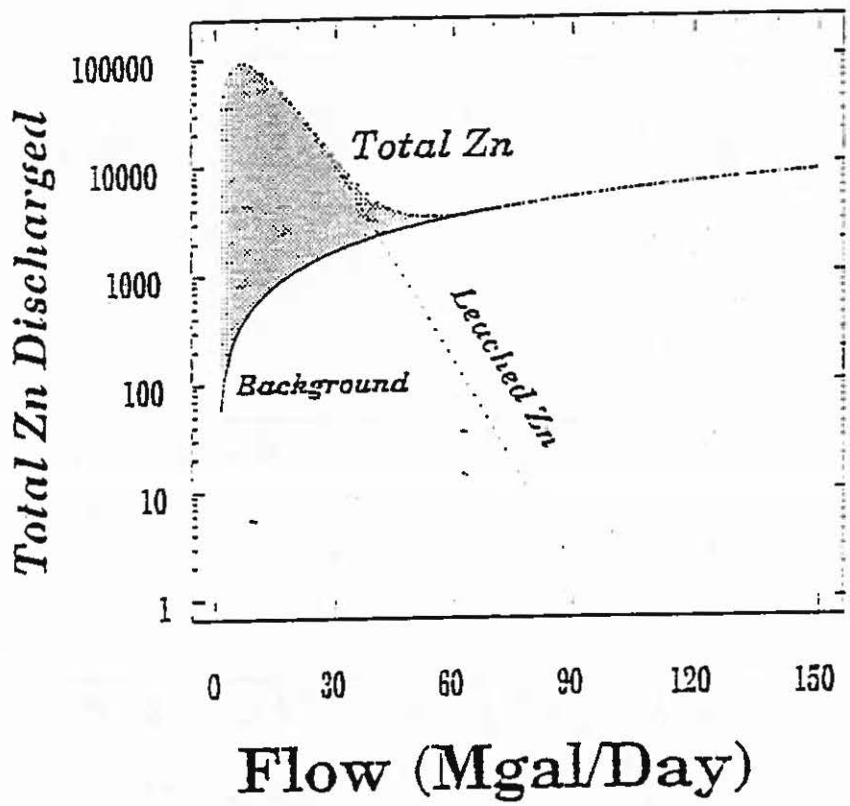


Figure 1-11: Graphical result of a two-component model: loading due to background plus enriched material from leaching. The shaded area highlights the amount of excess loading over background.

the exterior sediments shows a direct correspondence between the times when the sediment was enriched or at background levels and the predicted times of enrichment and baseline behavior. Remember that the "Effects" measure is a qualitative tool, indicating times of expected enrichment - not the extent or the levels found in the sediment. A quantitative model would require more detailed information on the biogeochemistry of the waters inside the dike and more frequent sampling of the discharge.

CONCLUSIONS

The grain size distribution of exterior bottom sediments, mapped during the eleventh monitoring year, was similar to tenth year findings and consistent with earlier post-discharge periods. The distribution of sand around the facility has remained largely unchanged since November 1988. The typical seasonal pattern in the distribution of the fine (mud) fraction - coarsening over the summer and fining over the winter - was also evident again this year. This indicates that, hydrodynamically, the depositional environment around the facility was somewhat quieter between the November 1991 and April 1992 cruises than it had been prior to the November 1991 cruise.

Since the initial detection of Zn enrichment, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, higher than expected Zn levels persisted through the eleventh monitoring year in the vicinity of the dike. In previous reports, elevated Zn levels were associated with low flow releases of effluent from the facility. Results obtained from a 3-D hydrodynamic model of the upper Chesapeake Bay explain the structure of the plume of material found in exterior sediments, but not why Zn levels increase after periods of low flow discharge from the dike. However, the chemistry of the effluent released from the dike does seem to account for this association. Metal levels in ponded water increase due to leaching of metals from the sediment in the dike, through a process analogous to acid mine drainage. The maximum Zn loading due to leaching occurs at releases between 0.3-10 MGD. At higher discharge rates, flushing with large volumes of water effectively dilutes Zn loadings in the effluent and, consequently, precludes Zn enrichment in the surrounding bottom sediments.

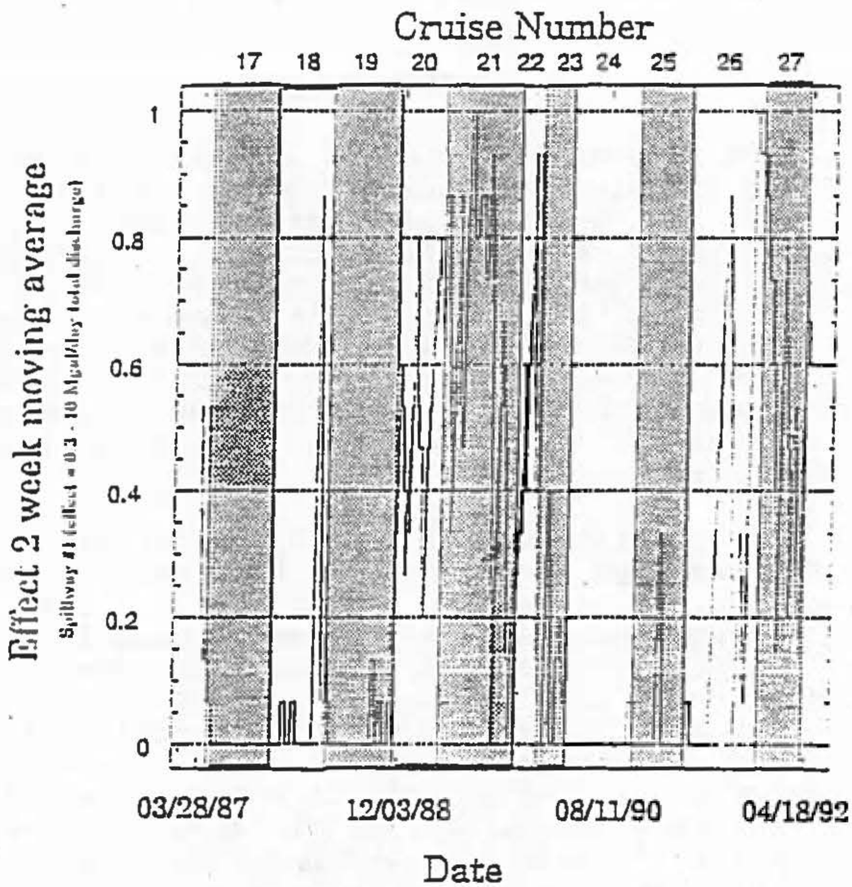


Figure 1-12: Times when the discharge from HMI would be expected to affect the exterior sediments, based on the model in Figure 1-11.

RECOMMENDATIONS

Persistent high metal levels in sediments around HMI indicate a need for continued monitoring. Even though the dike has nearly reached its capacity and the volume of effluent is expected to decline, dewatering of the contained material may lead to higher metal levels in the effluent. Exposure of dredged material to the air is likely to result in the mobilization of metals associated with those sediments, an effect analogous to acid mine drainage. Metals released in the effluent, particularly at low discharge rates, will probably be deposited on the surrounding Bay floor. Continued monitoring is needed to detect such effects. Monitoring will also be valuable in assessing the effectiveness of any amelioration protocol implemented by MES to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MES will be important in this endeavor.

ACKNOWLEDGMENTS

We would like to thank our colleagues at MGS for their willing assistance during all phases of the project: Captain Jerry Cox and first mate Rick Younger of the R/V Discovery, for their expert seamanship and spirit of cooperation; Dean Freeman, Rebecca Gast, Jennifer Isoldi, Jim Lowry, and Rich Ortt, for braving the elements during sample collection; Bill Panageotou, for helping to x-ray the cores; June Park, for coaxing the lab equipment to produce results; Jason Shadid, for his careful analysis of sediment samples; and Randy Kerhin, for his open door and his guidance in political matters. In addition to MGS staff members, we extend our thanks to Cece Donovan at MES, who provided us with much of the information related to site operation.

PART 2: BEACH EROSION STUDY

INTRODUCTION

The recreational beach created between Hart and Miller Islands for use by the general public has been studied and monitored by the Maryland Geological Survey (MGS) since May 1984 (Fig. 2-1). The geologic processes operating on the beach have been identified and discussed in previous reports (Wells *et al.*, 1985, 1986, 1987; Hennessee *et al.*, 1989, 1990a, 1990b; Cuthbertson, 1992, 1993).

Designation of the erosional/depositional areas along the beach, present during the monitoring period (May 1991 - May 1992), is essential for planning proper maintenance. The beach has sustained extensive erosion north and minor deposition south of dike station 24+00. The presence of a wave-cut escarpment emphasized the extent of erosion. Deposition was almost non-existent, and, therefore, the shoreline remained in about the same position.

For several years, MGS had recommended that the shoreline be nourished with sand from an outside source. In April 1991 that recommendation was implemented, and sand was deposited in the foreshore north of 24+00 to the terminus of the beach. The addition of sand reduced the slope of the beach, restored a wide foreshore, and provided an adequate recreational area for the general public.

PREVIOUS WORK

MGS has monitored the recreational beach since May 1984. Previous reports described the changes that the beach experienced through the years as a result of the forces of nature and man. The reports also designated the three geomorphic areas of the beach (Fig. 2-2): (1) the outer dike face, extending from the chain link fence at the edge of the dike roadway to the high water mark, usually a wave-cut escarpment; (2) the foreshore, between the high water mark and mean low water (0 ft MLW); and (3) the nearshore, bayward of MLW.

The outer dike face was regraded to form two drainage ditches and two berms. The construction of these features, along with the subsequent planting of grass effectively stopped runoff erosion.

In the past, the foreshore was modified by wind generated waves assaulting the beach in conjunction with higher than normal tides. The result of the waves attacking the shoreline was a wave-cut escarpment of varying height extending most of the length of the beach. Bulldozing the foreshore in late spring

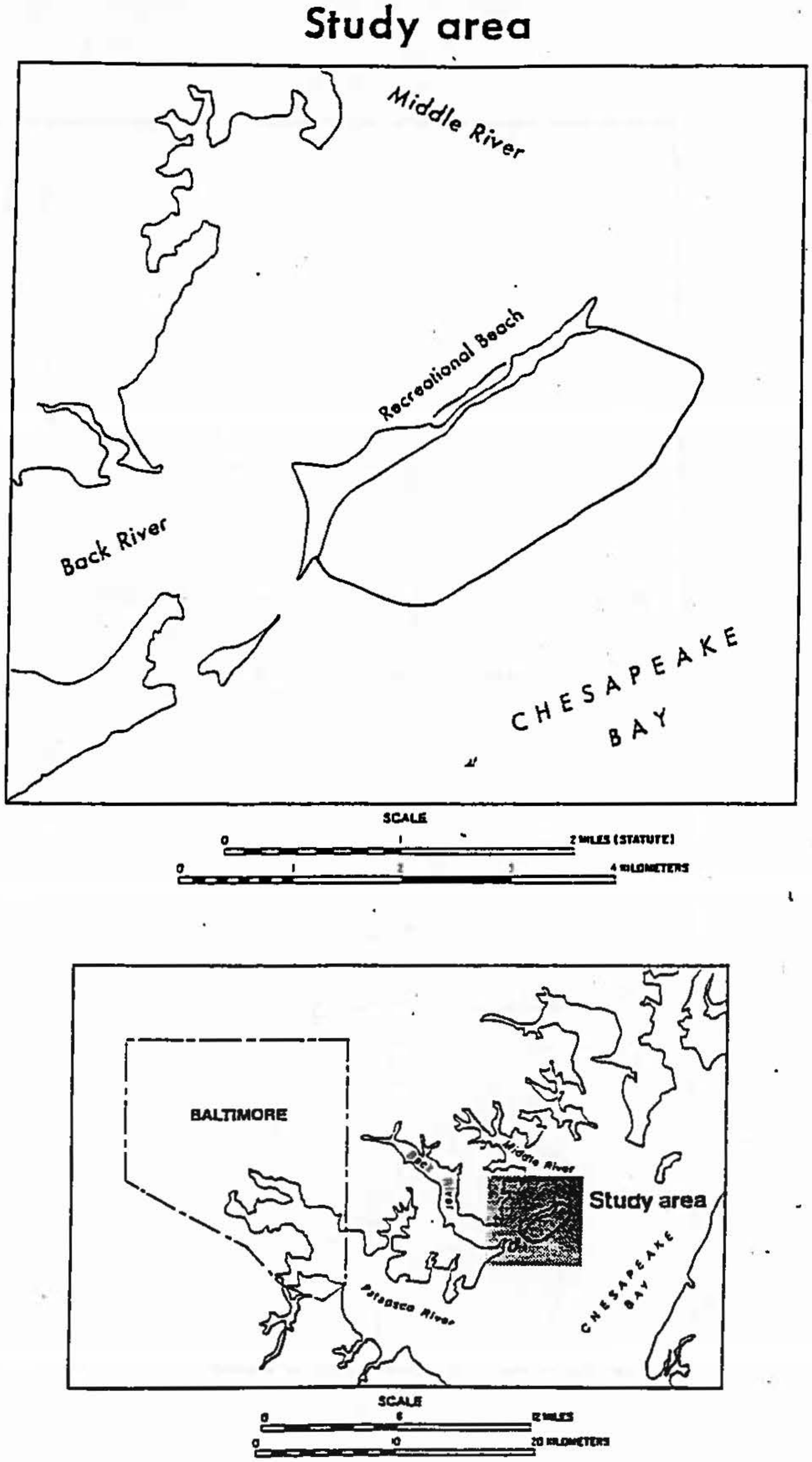


Figure 2-1: Location of the study area.

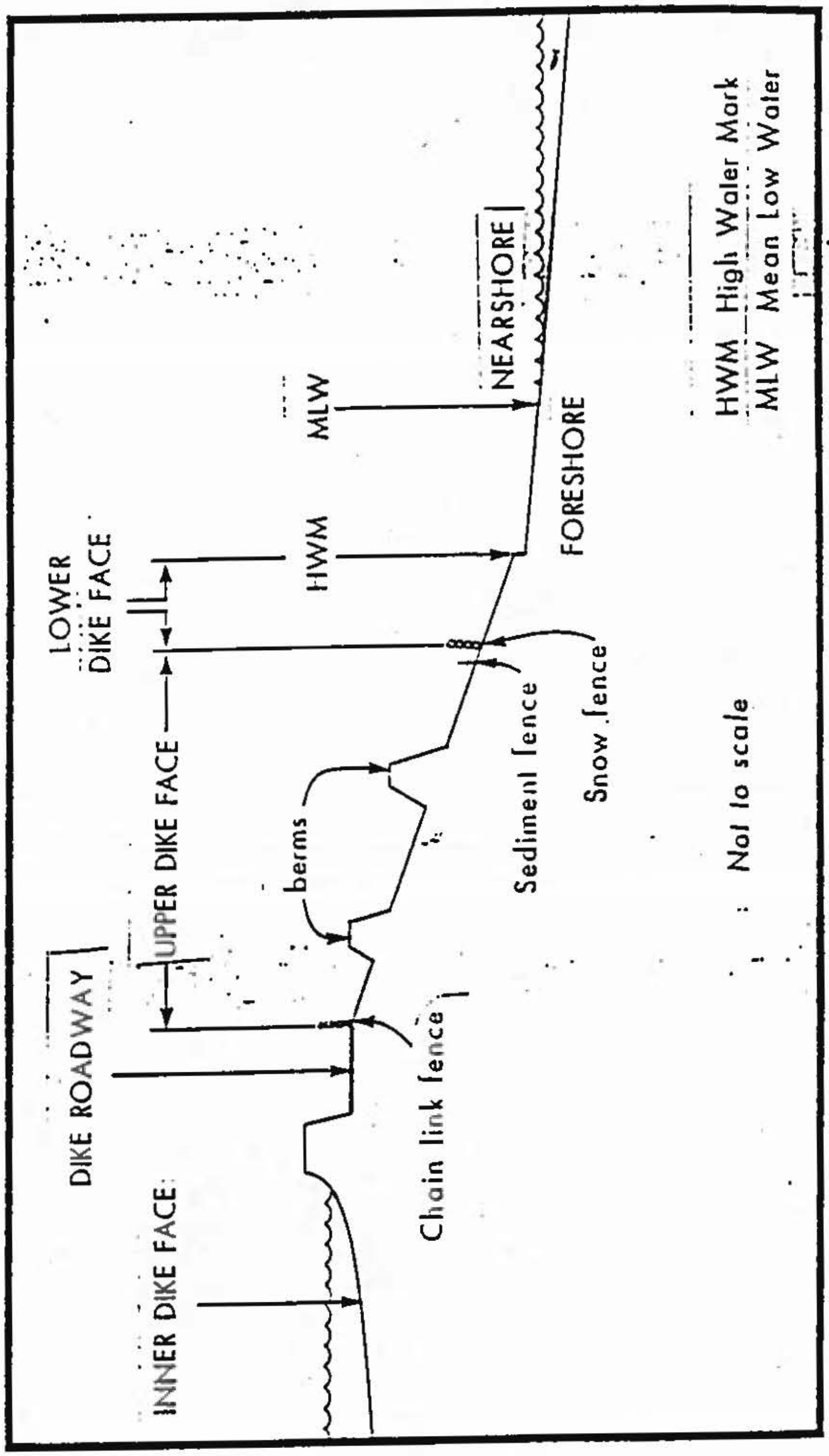


Figure 2-2: Post-reconstruction (August 1988), schematic cross-section of the dike, illustrating geomorphic regions of the beach.

erased the escarpment, but it returned, usually with the next storm event.

The nearshore was modified by wind-produced waves inducing a longshore current and, thereby, moving littoral drift from north to south. The segment of beach south of dike station 24+00 benefitted and widened considerably over the years.

Net sediment loss along the recreational beach is summarized in Table 2-1 for the period June 1984 to May 1992. The approximations do not include gully and nearshore erosion.

Table 2-1: The net volume change of sediment from the recreational beach (above 0 ft MLW) for each monitoring period, June 1984 to May 1992.

Time Period	Sediment Volume Gain/Lost* (yd^3)	(m^3)
June 1984 - March 1985	-1190	-910
June 1985 - April 1986	-2083	-1593
June 1986 - March 1987	-3472	-2656
June 1987 - May 1988	-3129	-2394
September 1988 - May 1989	-594	- 454
May 1989 - May 1990	-3081	-2356
May 1990 - February 1991	-2100	-1606
February 1991- May 1991	+14000	+11000
May 1991 - May 1992	+500	+384

* based on ISRP (Birkemeier, 1986)

OBJECTIVES

This report was written specifically to summarize the results of monitoring the beach. The objectives were to:

1. identify the areas of erosion/deposition,

2. calculate the amount of sediment eroded/deposited along the beach, and

3. highlight the addition of sand to the foreshore of the shoreline through the use of cross-sectional profiles.

METHODOLOGY

FIELD METHODS

MGS monitored ten profile lines along the beach (Fig. 2-3). Two surveys were conducted along the ten profiles during the monitoring period, May 1991 - May 1992 (Table 2-2).

Table 2-2: Beach profile survey dates.

Profile	Survey 1	Survey 2	Survey 3
21+75	2-6-91	5-2-91	5-20-92
24+00	2-6-91	5-2-91	6-10-92
28+00	2-6-91	5-2-91	5-20-92
30+00	2-21-91	5-8-91	5-20-92
32+00	2-6-91	5-8-91	5-20-92
36+00	2-6-91	5-8-91	5-20-92
40+00	2-7-91	5-8-91	5-21-92
44+00	2-7-91	5-8-91	5-21-92
48+00	2-7-91	5-8-91	5-21-92
49+00	2-7-91	5-8-91	5-21-92

Distance and elevation data collected during the three surveys are listed in the *Eleventh Year Data Report*. Standard techniques of leveling were followed in surveying the ten profiles using a Sokkisha engineers precision automatic level (Model B1).

Elevation points along each profile were transferred directly from the Maryland Port Administration bench mark number 281614 (elevation 14.57 ft MLW), located approximately 22 ft east of the centerline of the dike roadway at station 30+00, and bench marks established by the Great Lakes Dredging Company along the dike roadway, shown in Figure 2-3 and listed in Table 2-3.

To locate the centerline of the dike roadway, from which point the survey profiles originated, 13 ft were measured from the chain link fence using a fiberglass survey rod. The correct azimuth of each profile was maintained by using a hand held compass. The chain link fence was also marked with orange paint to indicate the azimuth of the profile as viewed through the level from the centerline of the dike roadway. Elevations were transferred from the centerline of the dike roadway to wooden stakes placed in the sand close to the snow fence. Each profile

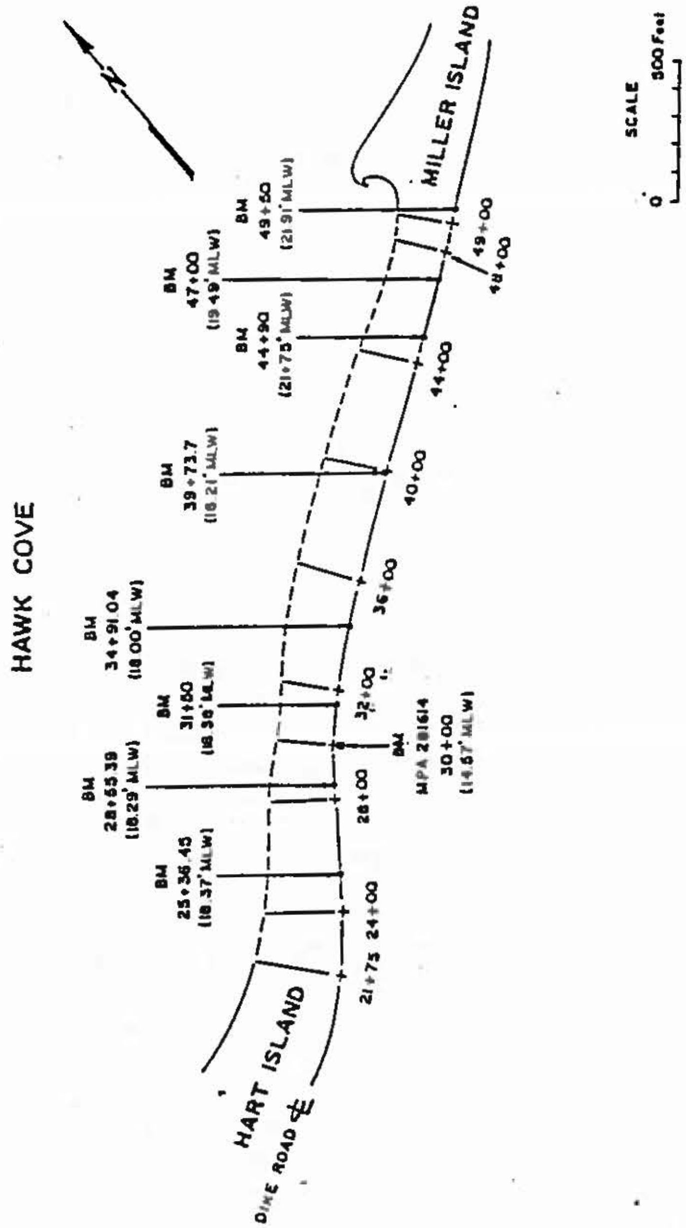


Figure 2-3: Dike location of the surveyed profile lines and bench marks.

Table 2-3: Bench mark location, elevation and type of structure.

Station	Elevation (ft)	Type of Structure
28+55.39	18.29	cemented pipe
30+00	14.57	nipple inside pipe
31+50	18.38	stake
34+91.04	18.00	cemented pipe
39+73.7	18.21	stake
44+00.91	21.75	fence crosspipe
49+50	21.91	fence crosspipe

was then surveyed below the snow fence. The level was set up either uphill or downhill of the start of each profile depending upon the elevational changes and the amount of wind (potential for bending the survey rod).

DATA REDUCTION

Sediment gains and losses above and below datum (0 ft MLW) were calculated for each profile using a computer program - Interactive Survey Reduction Program (ISRP)(Birkemeier, 1986). The net sediment gains/losses for two adjacent profiles were averaged, then multiplied by the distance between them. The products of the multiplications for all the profiles were summed to provide a net volume change along the monitored beach.

RESULTS AND DISCUSSION

In April 1991, the beach was nourished with sand dredged from the channels approaching Baltimore Harbor. Construction crews at HMI transported sand from an on-island stockpile in dump trucks. A bulldozer smoothed the sand dumped by the trucks. The sand consisted mainly of clean, medium-grained (1.0f-2.0f) sand with some fine (3.0f-4.0f) sand. The sand was distributed from 28+00 north to the end of the beach. Approximately 14,700 yd^3 (11,240 m^3) of sand were deposited in front of the existing wave-cut escarpment. The shoreline was extended bayward approximately 30-40 ft (Table 2-4). By May 1991, the beach had been subjected to several strong weather events, and some erosion of the newly restored beach had occurred. Approximately 2,000 yd^3 (1529 m^3) of sand were eroded from the foreshore of the beach. Of the total

total amount of sand eroded from the beach, more was lost north of 44+00 with the development of wave cut escarpments. Even with

Table 2-4: Distance (ft) from the centerline of the dike roadway to the 0 ft contour, by survey date.

Dike station	2/91	5/91	5/92
21+75	341	328	330
24+00	283	279	289
28+00	219	237	236
30+00	192	229	220
32+00	182	237	212
36+00	216	255	234
40+00	220	260	249
44+00	185	222	210
48+00	174	208	190
49+00	192	219	191

the erosion of beach between 44+00 and 49+00, the overall profile still extended bayward.

Through beach monitoring, the location and extent of areas of erosion and deposition have been identified. Both the shoreline position and the foreshore were modified between February 1991-May 1992. To assess the changing slope of the beach, ten cross-sectional profiles were constructed using ISRP (Appendix D).

The beach from Profile 21+75 to 28+00 changed very little over the profile period, between May 1991 to May 1992. At Profile 28+00, a small erosional escarpment developed on the upper beach face, with deposition of sand on the lower beach face. At profiles 21+75 and 24+00, the shoreline advanced bayward approximately 5-10 ft, with deposition occurring along the lower beach face. Volume changes for profiles 28+00 and 24+00 were calculated at +10.0 yd^3/ft of beach and +1.5 yd^3/ft, respectively.

Profiles 30+00, 32+00, 36+00, 40+00 and 44+00 experienced overall erosion, with volume changes ranging from -10.2 yd^3/ft to -1.0 yd^3/ft. Erosion occurred primarily on the upper beach face and in the nearshore, below datum, with deposition on the lower beach face (See Appendix D). The shoreline retreated 9 ft at 30+00 to 24 ft at 36+00.

Profiles 48+00 and 49+00 exhibited overall erosion along the entire beach profile, from the upper beach to the nearshore below datum. Volume changes were 3.5 yd^3/ft for Profile 49+00 to -2.0 yd^3/ft for Profile 48+00, with shoreline retreat of 18-26 ft. The lower beach face along 49+00 eroded back to the pre-nourishment profile of February 1991.

Wind driven waves from the west to northwest attacking the shoreline between 44+00 and 49+00 approach at an angle most conducive to erosion. The most damage is done to the shoreline when shore-parallel waves hit the beach in this area. The unconsolidated sand is not protected by vegetation or the consistency of the sand - no clay particles hold it together. Longshore currents are produced when wind driven waves approach the shoreline at an angle. In this area the waves would have to approach from the north-northwest to north in order to produce a longshore current that would transport sand to the south. To a minor extent, waves approaching from the southwest in summer create longshore currents carrying sand to the north around Miller Point.

CONCLUSIONS

The recreational beach between Hart and Miller Islands displayed three different beach forms during this profiling period. The three southern profiles, 21+75 to 28+00, are the most stable, with minor erosion on the upper beach face. The lower beach face accretes as sediments derived from the north move southward along the shore. The middle profiles, 30+00 to 44+00, are transitional beach forms. Erosional characteristics along the upper beach face and nearshore, below datum, dominate the profile. Along the lower beach face, sediments eroded from the upper beach face accrete along this section of the profile. The northern profiles, 48+00 to 49+00, are erosional along the entire length of the beach. Shoreline retreat is most evident at 49+00, where the profile eroded to its pre-nourishment state.

The largest amount of erosion occurred between 44+00 and 49+00. Deposition was recorded south of 24+00. The amount of sand deposited was significantly less than that of previous years because of the beach nourishment. The sediment eroded north of 44+00 was transported south via longshore transport established when wind driven waves from the northwest to north attacked the shoreline. Deposition will continue as long as there is sand to be eroded and wind driven waves approach from the proper angle.

The amounts of erosion and deposition will be determined by the frequency of storm events; the direction, intensity, and duration of the wind driven waves; and the slope of the foreshore.

RECOMMENDATIONS

Monitoring of the recreational beach should continue, to assess any future erosional damage. If erosional damage becomes severe enough to endanger the public or the integrity of the dike, the shoreline should be replenished with sand. Periodic renourishment of the beach with a coarser sand will slow erosion. The shoreline developed during the April 1991 beach nourishment project is the benchmark against which future beach conditions will be referenced. If the shoreline retreats or the profile form erodes to pre-nourishment conditions, then immediate action should be taken to restore the beach.

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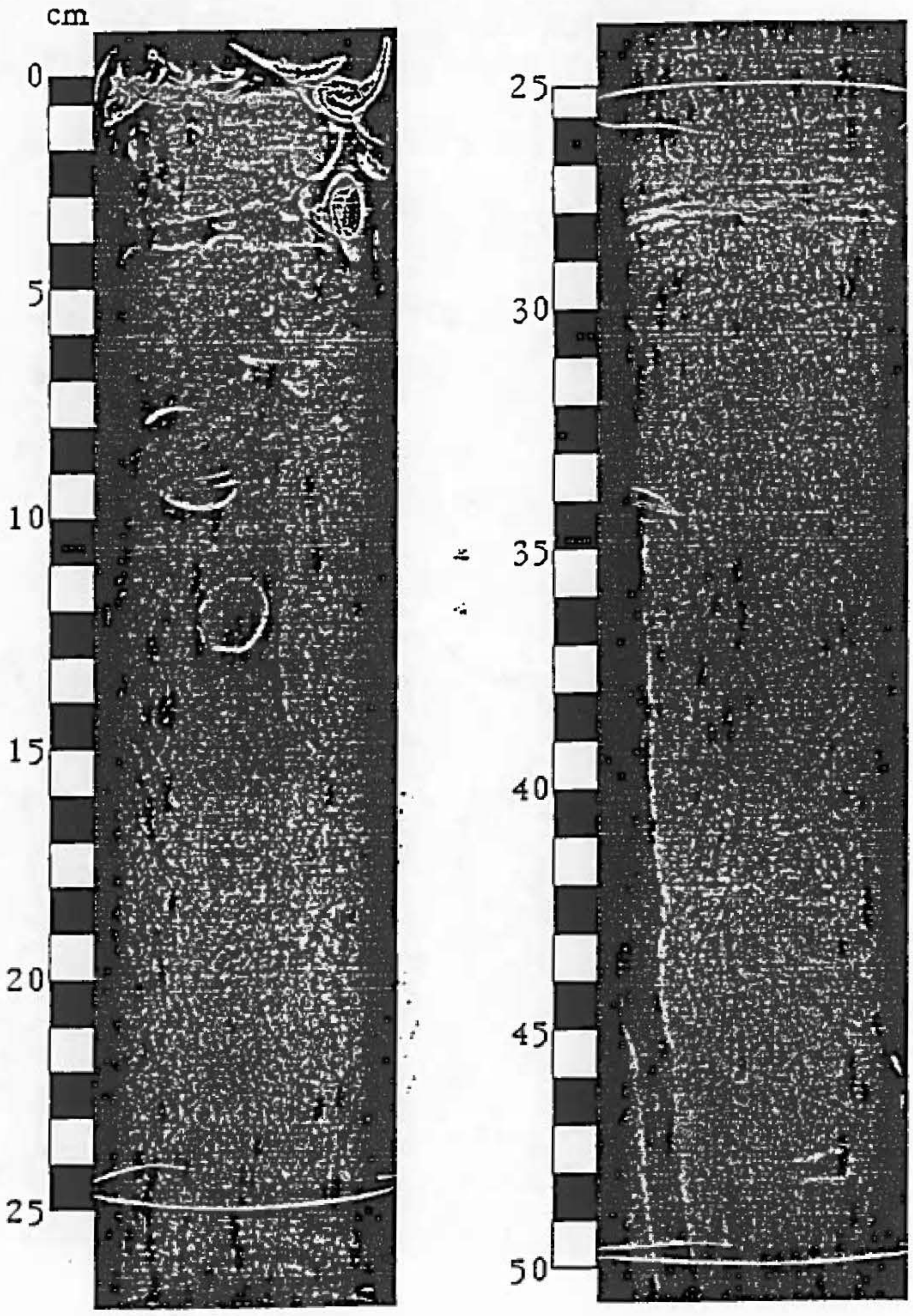
APPENDICES

Appendix A

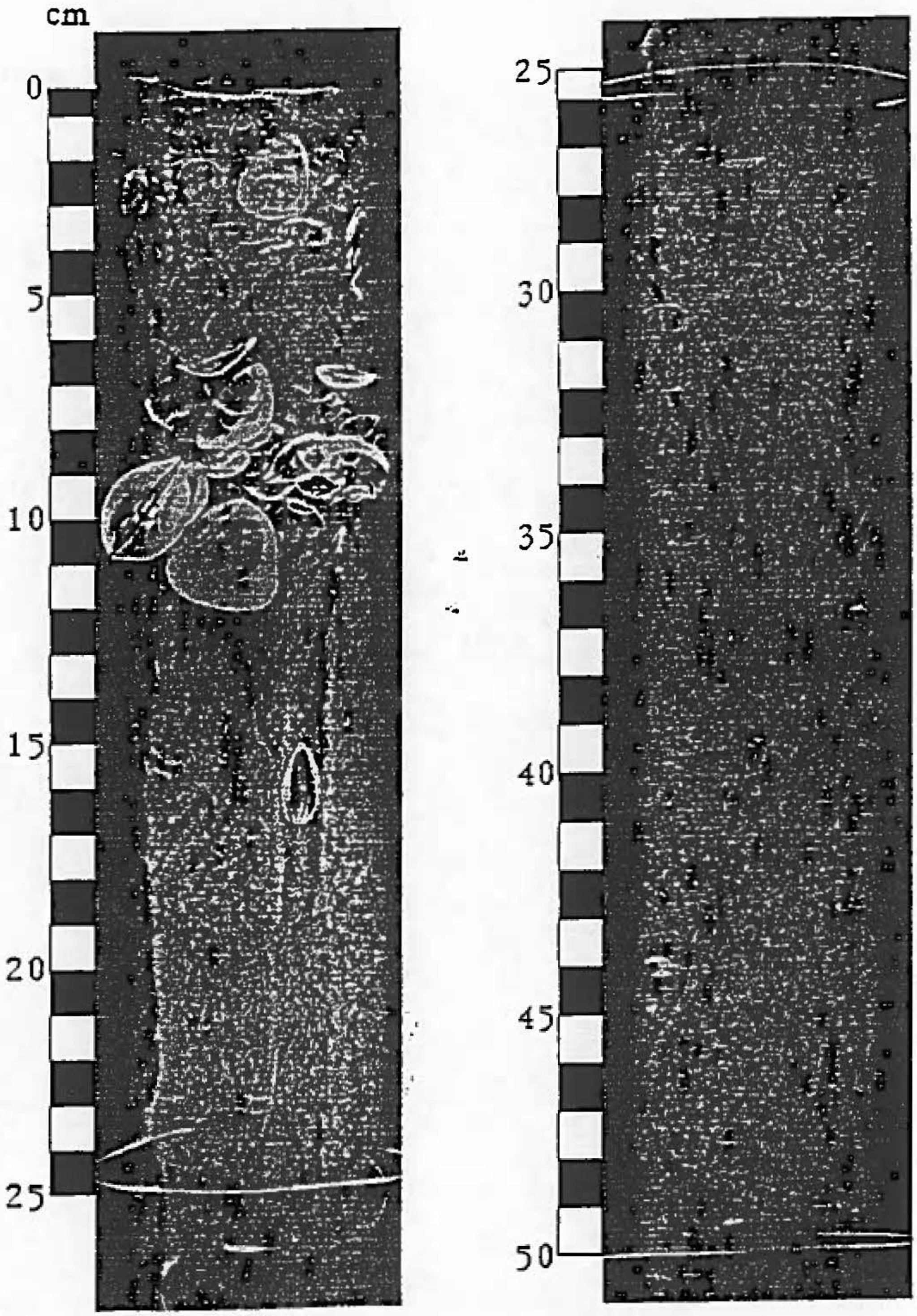
Xeroradiographs of the gravity cores.

HART-MILLER ISLAND - 11th Year
Core 12 April 9, 1992

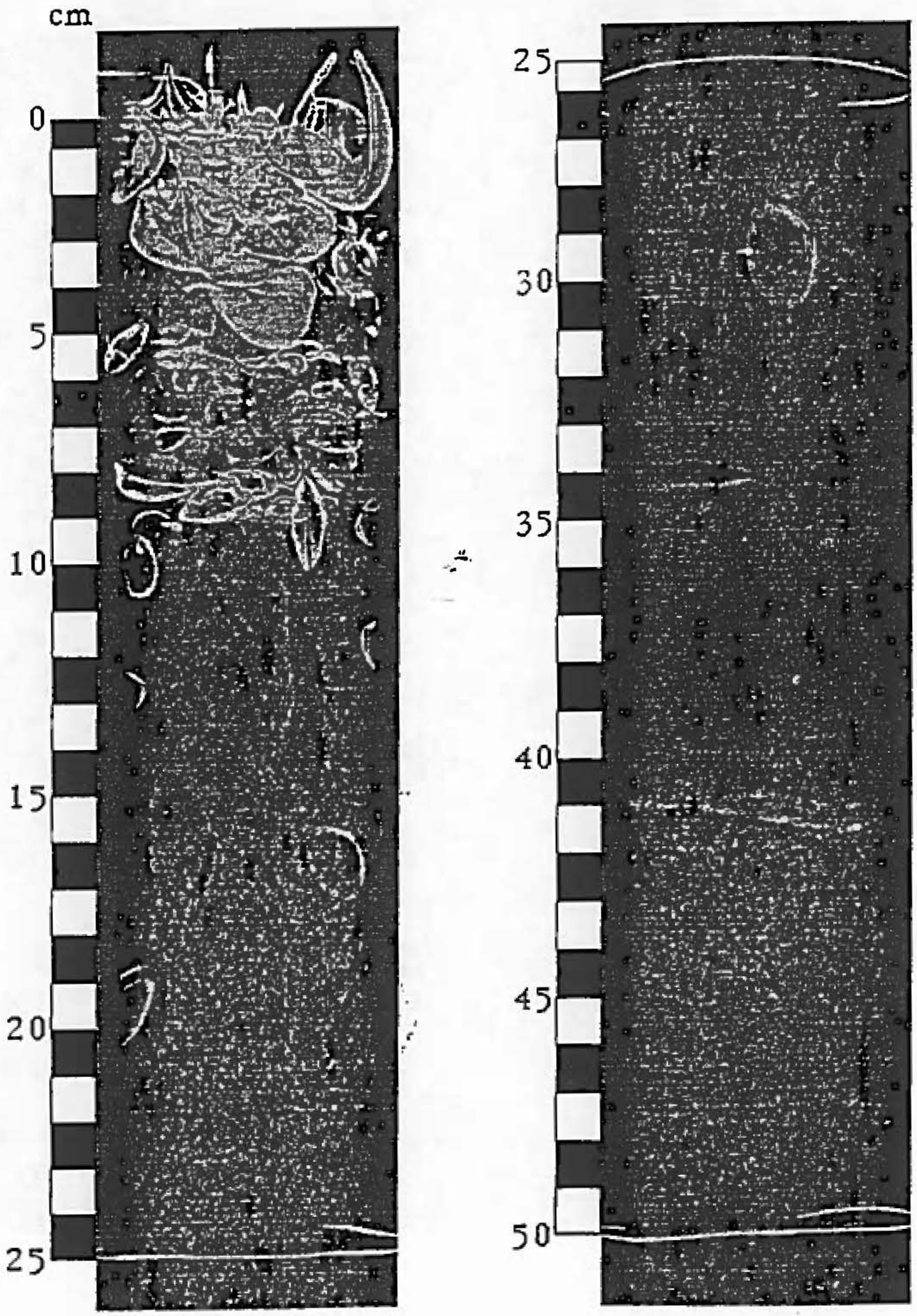
HART-MILLER ISLAND - 11th Year
Core 25 April 9, 1992



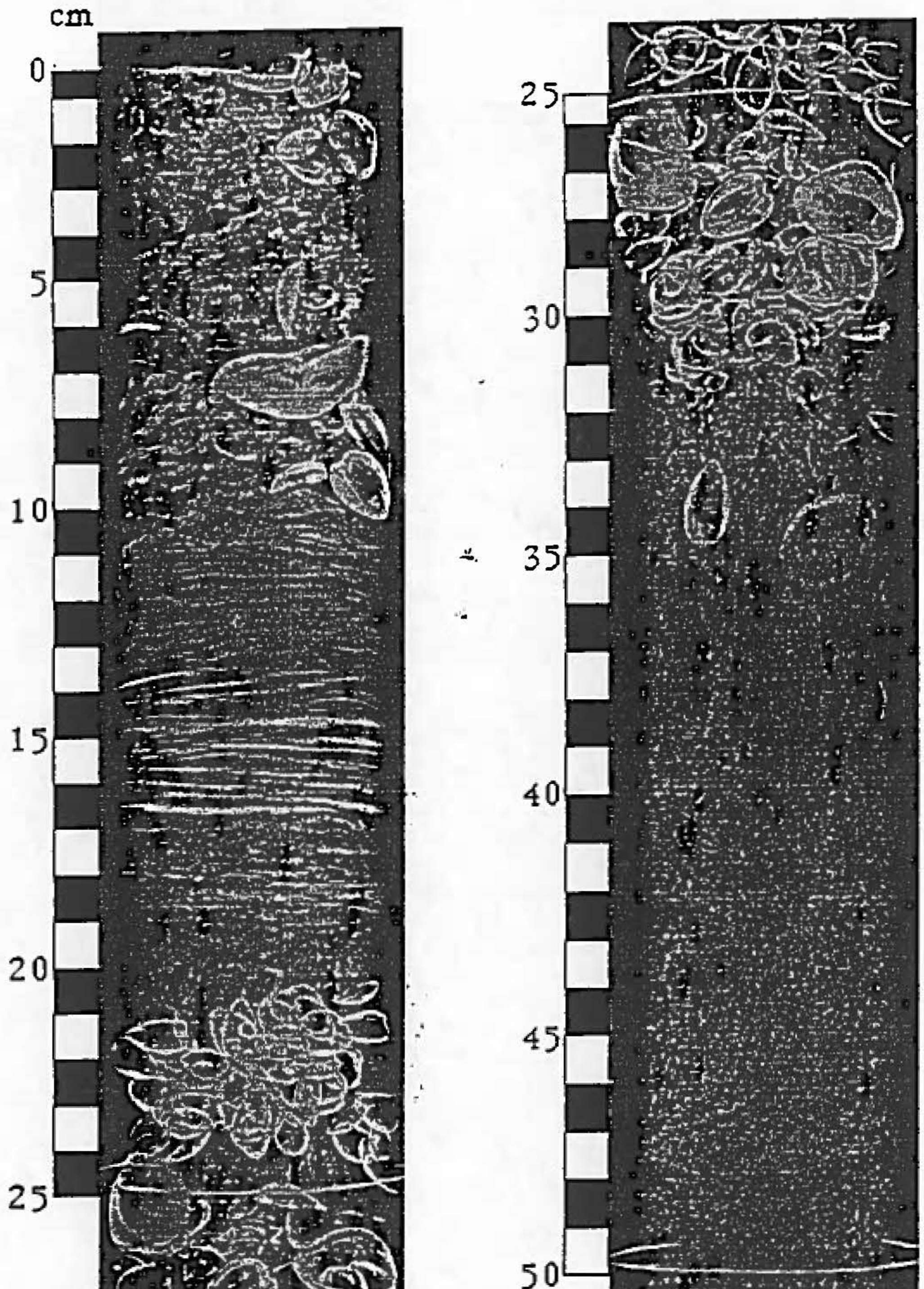
HART-MILLER ISLAND - 11th Year
Core BC-1 April 9, 1992



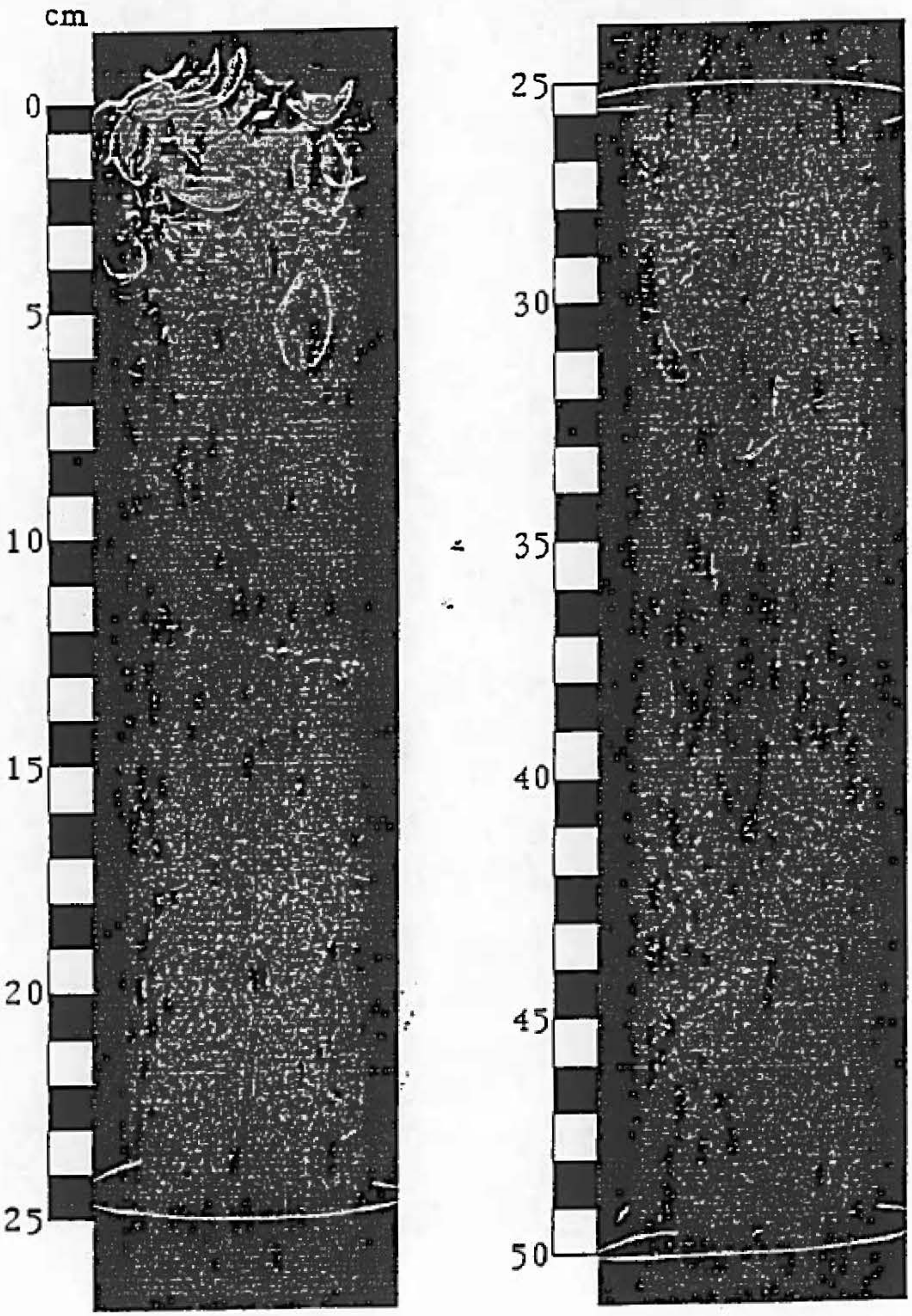
HART-MILLER ISLAND - 11th Year
Core BC-2 April 9, 1992



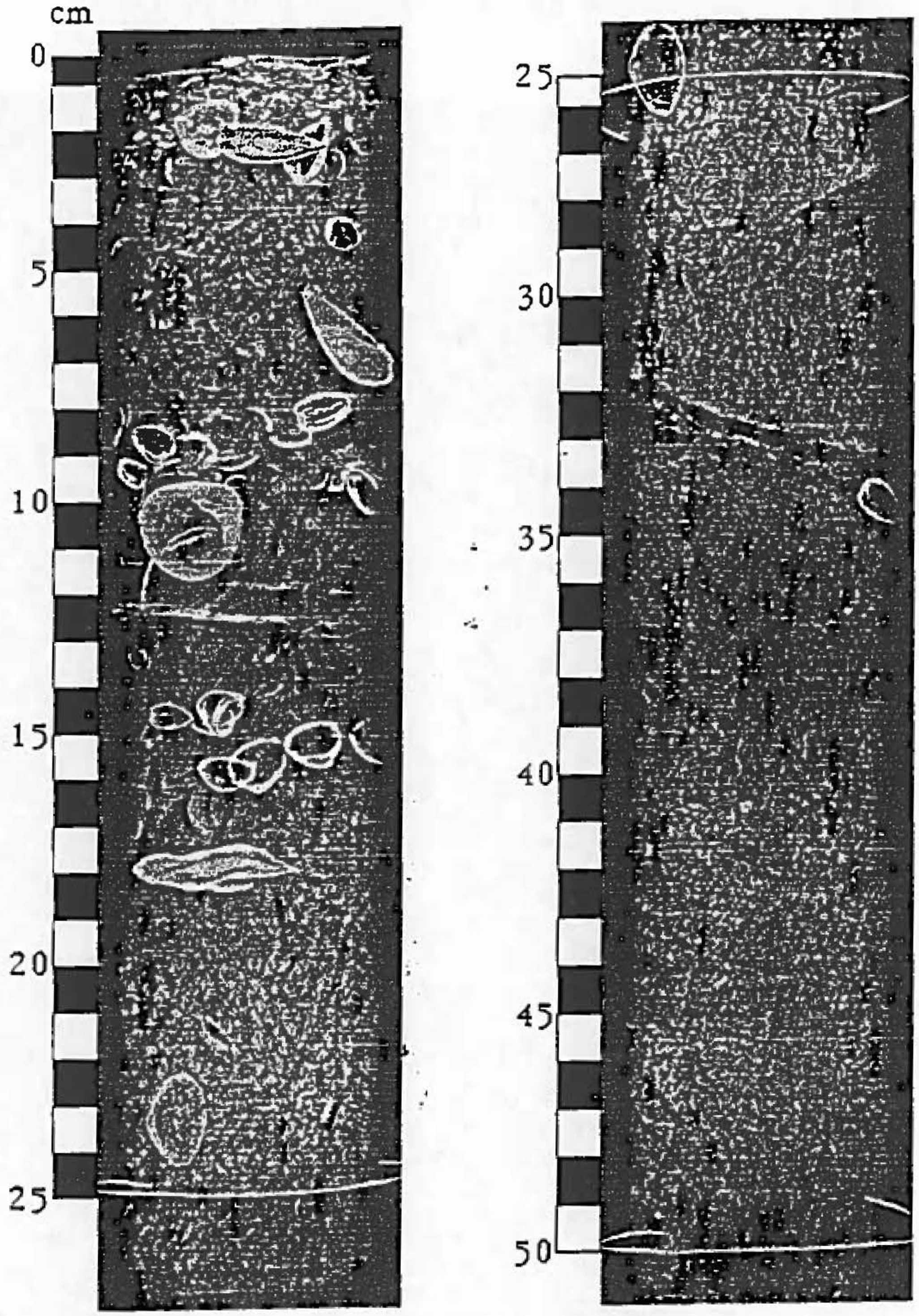
HART-MILLER ISLAND - 11th Year
Core BC-3 April 9, 1992



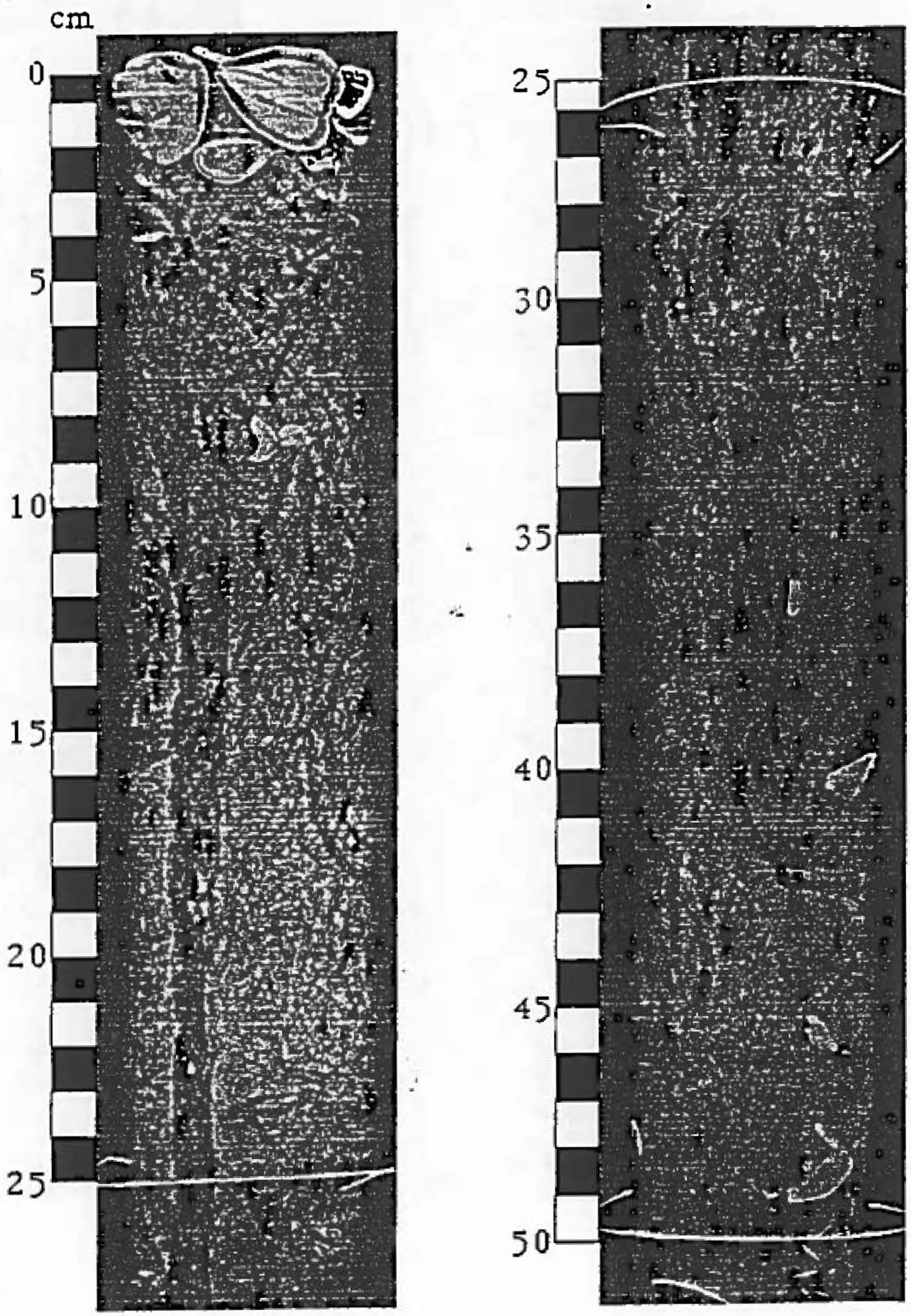
HART-MILLER ISLAND - 11th Year
Core BC-4 April 9, 1992



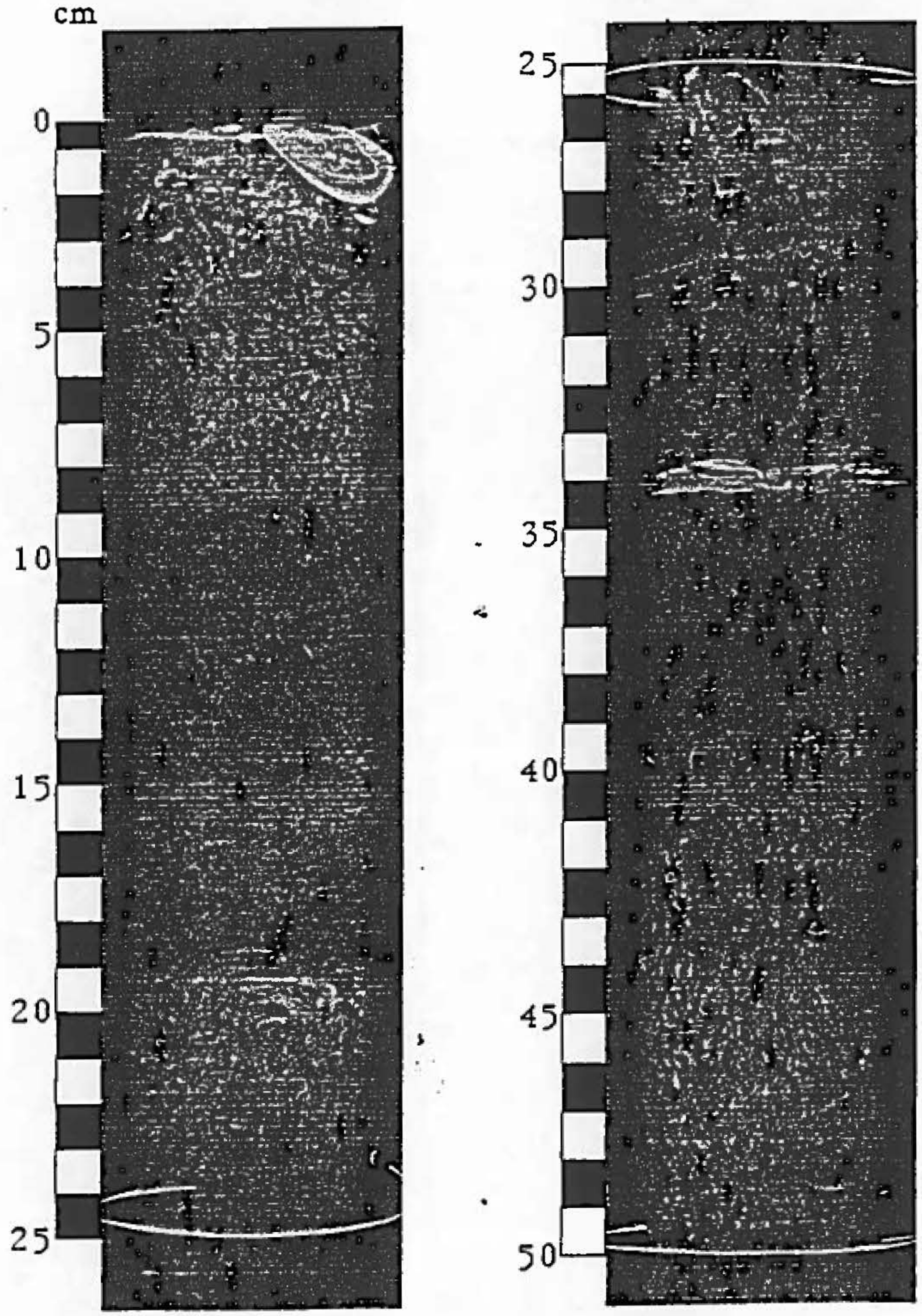
HART-MILLER ISLAND - 11th Year
Core BC-5 April 9, 1992



HART-MILLER ISLAND - 11th Year
Core BC-6 April 9, 1992

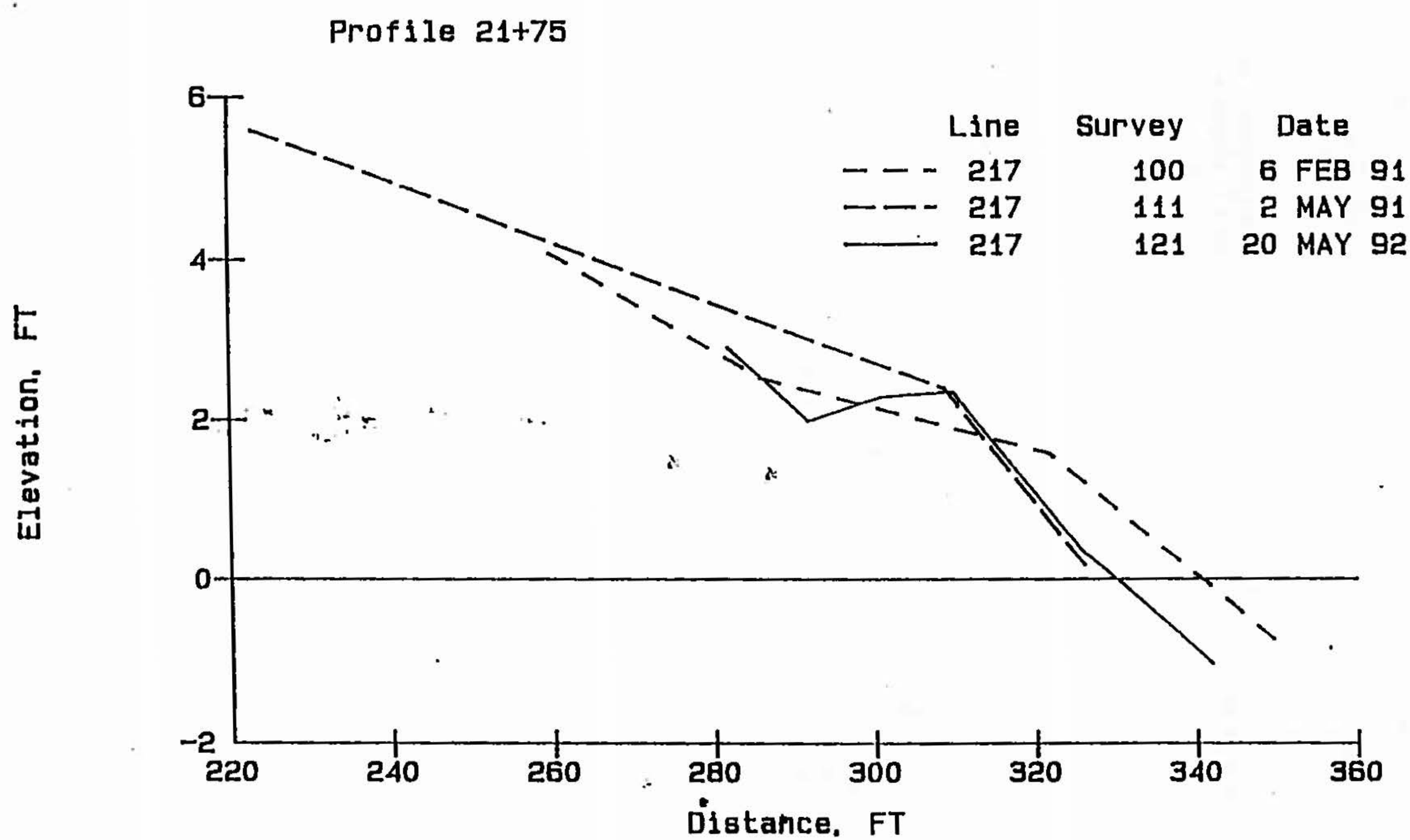


HART-MILLER ISLAND - 11th Year
Core BC-7 April 9, 1992

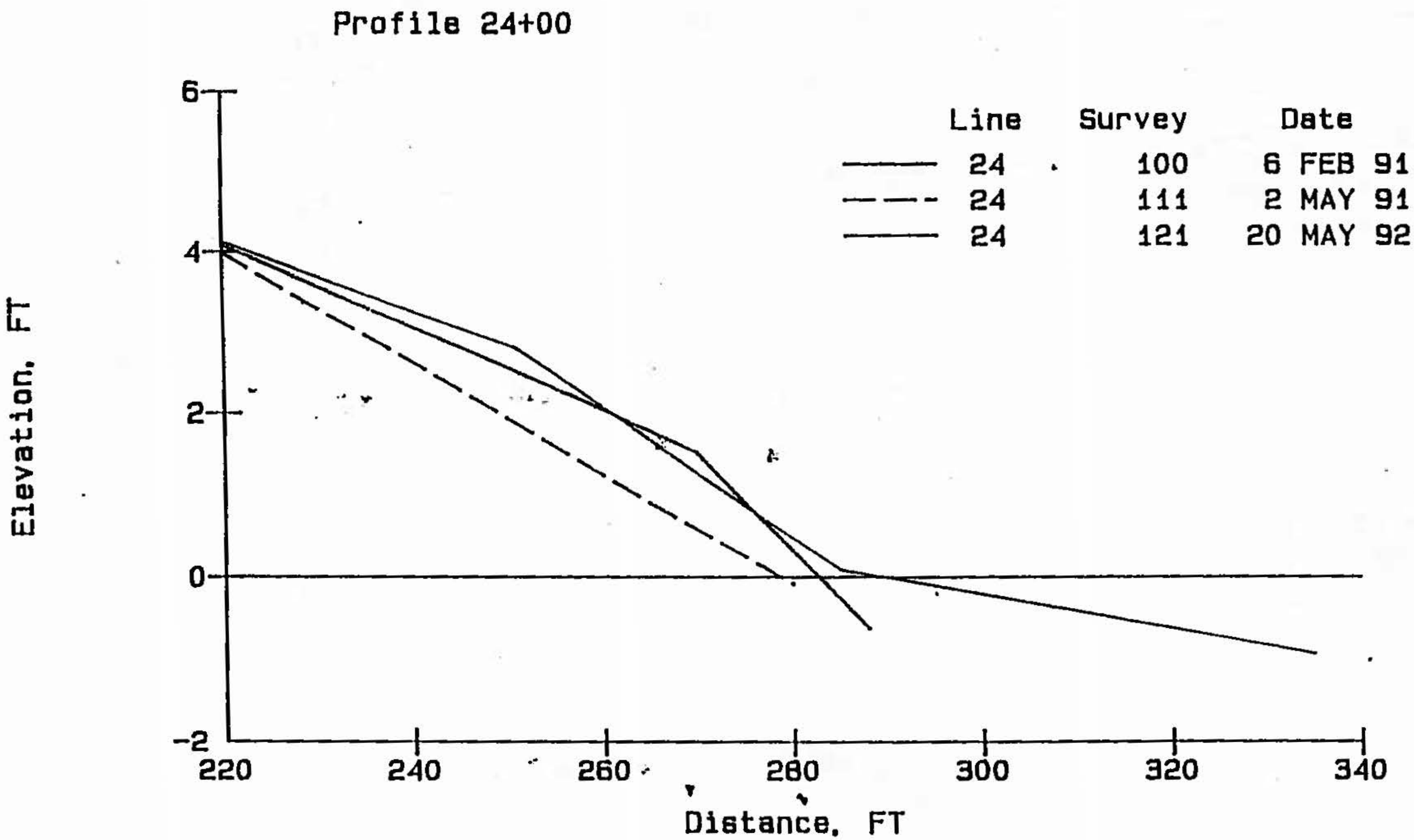


Appendix B

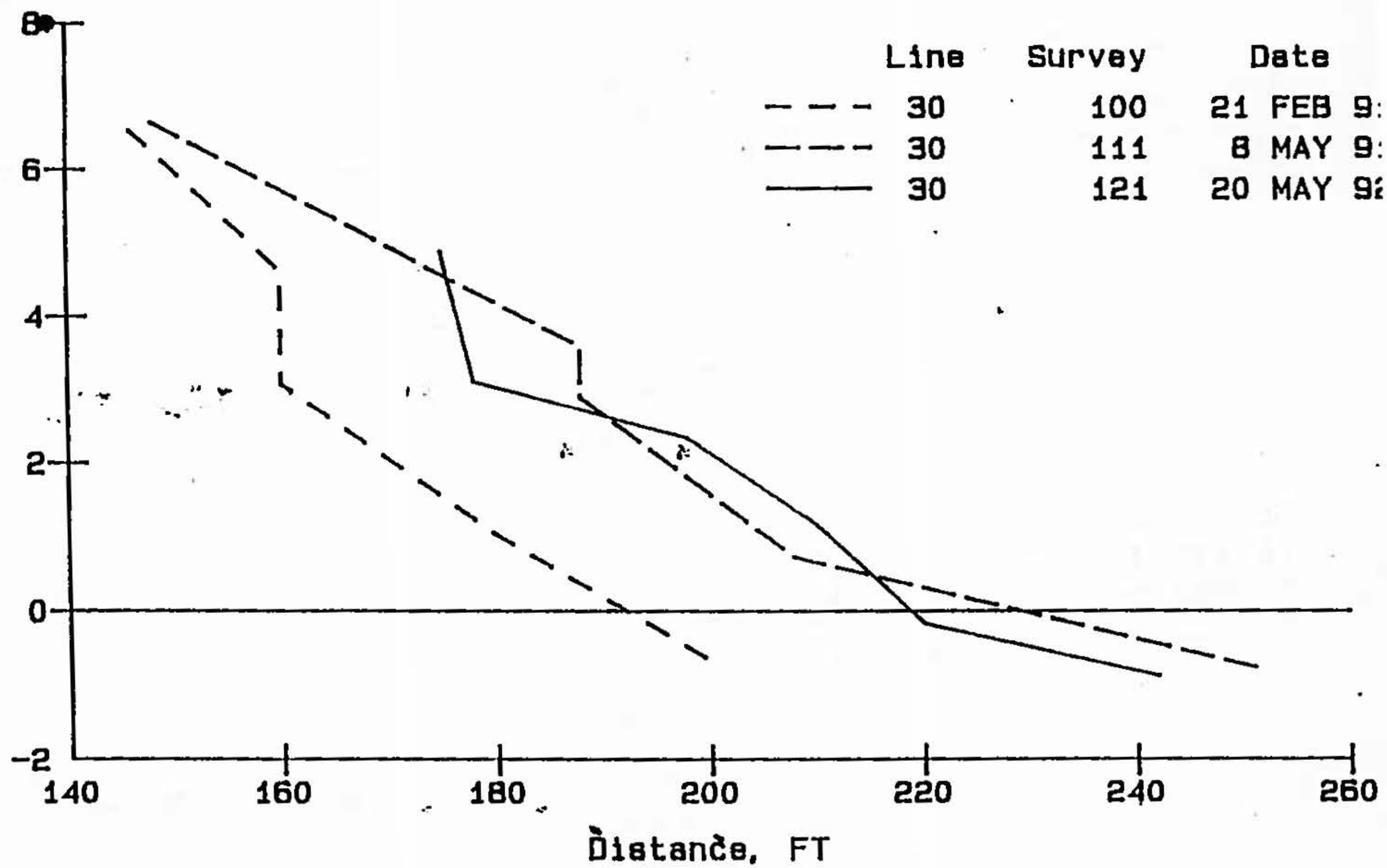
Cross-sectional profiles of the recreational beach, from measurements made during three surveys: February 1991, May 1991, and May 1992.

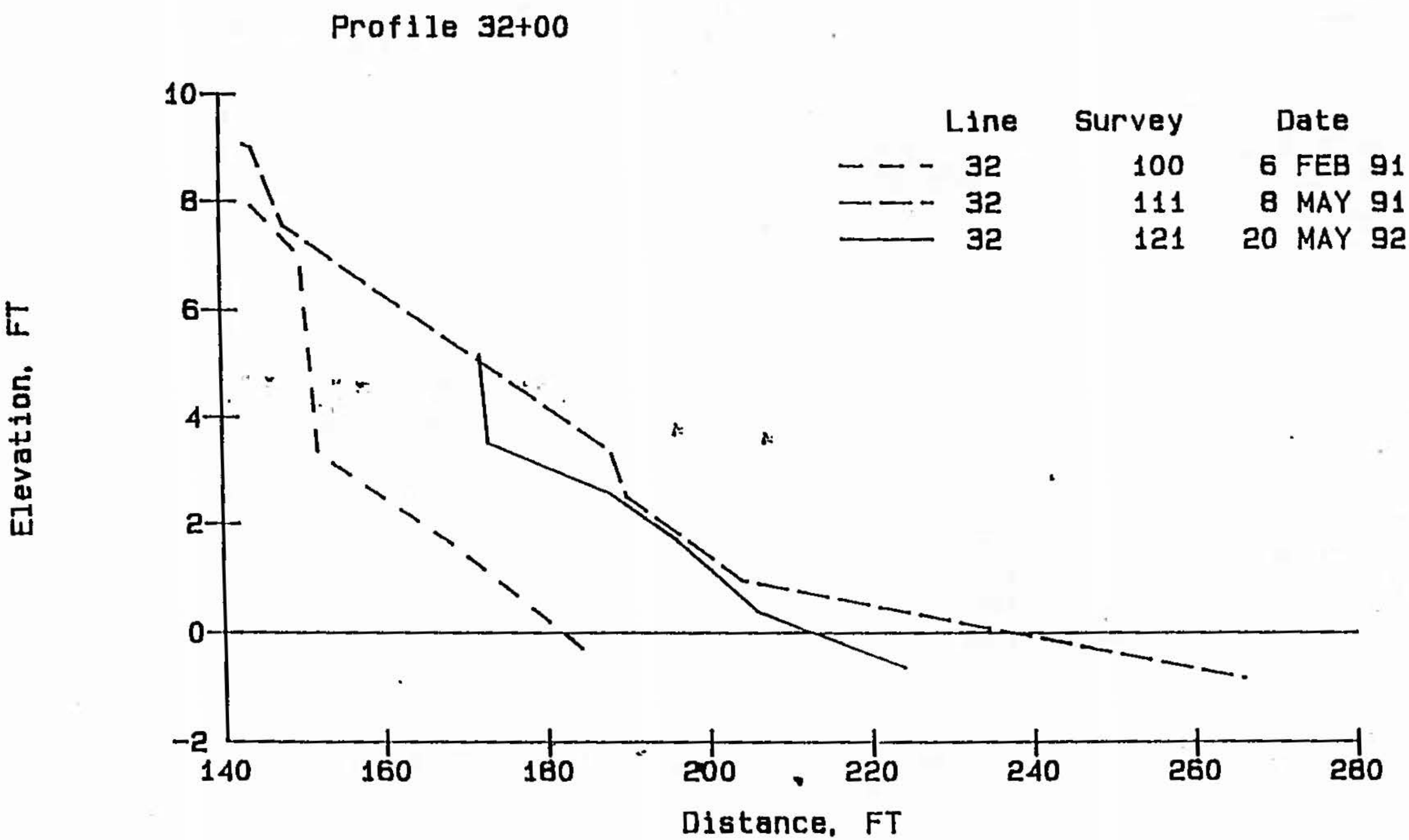


Profile 21+75
Line Survey Date
217 100 6 FEB 91
217 111 2 MAY 91
217 121 20 MAY 92
Elevation, FT
6
4
2
0
-2
220
240
260
280
300
320
340
360
Distance, FT

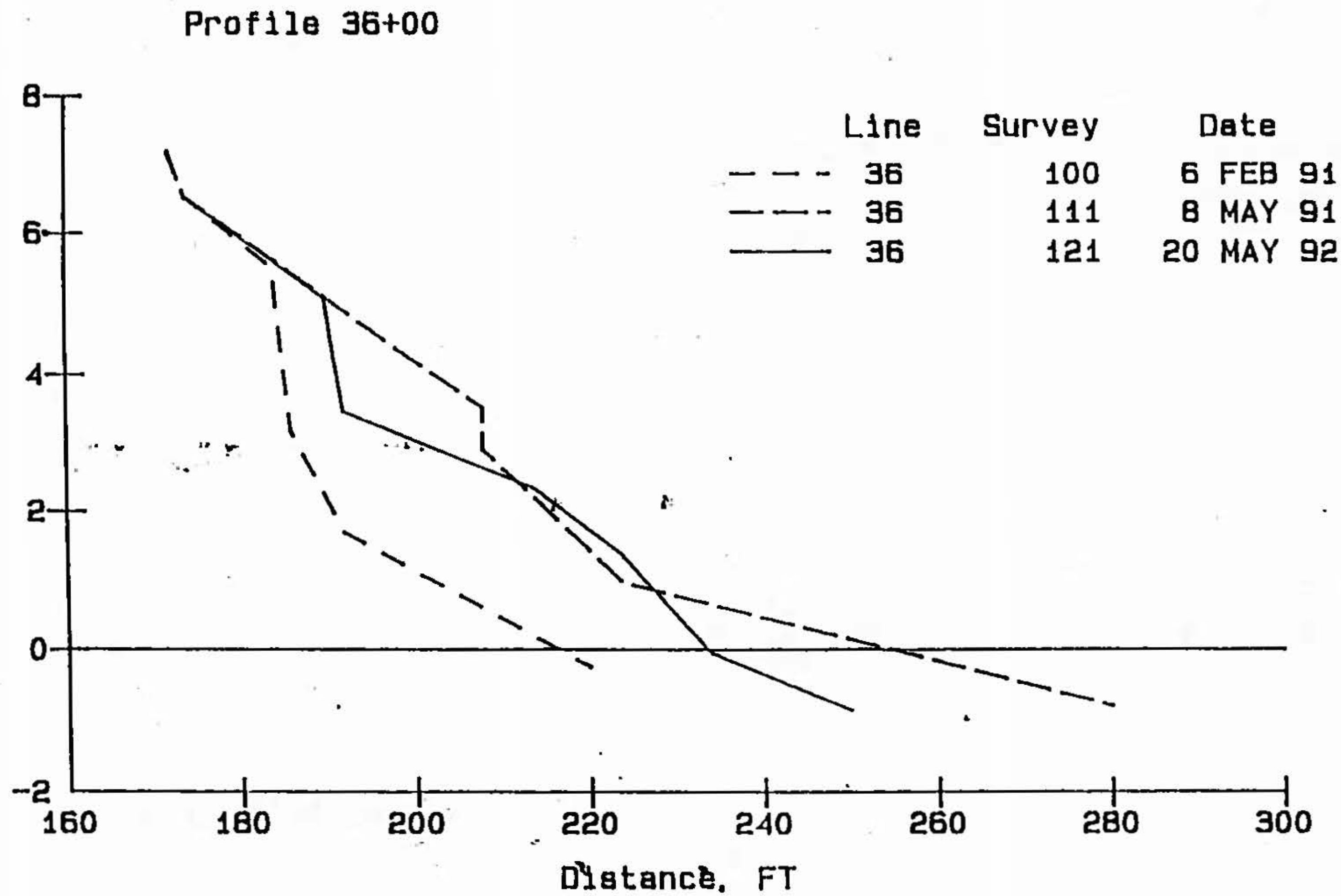

Profile 24+00
Line Survey Date
24 100 6 FEB 91
24 111 2 MAY 91
24 121 20 MAY 92
Elevation, FT
Distance, FT
6
4
2
0
-2
220
240
260
280
300
320
340

Profile 30+00




Profile 32+00
Line Survey Date
32 100 6 FEB 91
32 111 8 MAY 91
32 121 20 MAY 92
Elevation, FT
10
8
6
4
2
0
-2
140
160
180
200
220
240
260
280
Distance, FT

74



Profile 36+00
Line Survey Date
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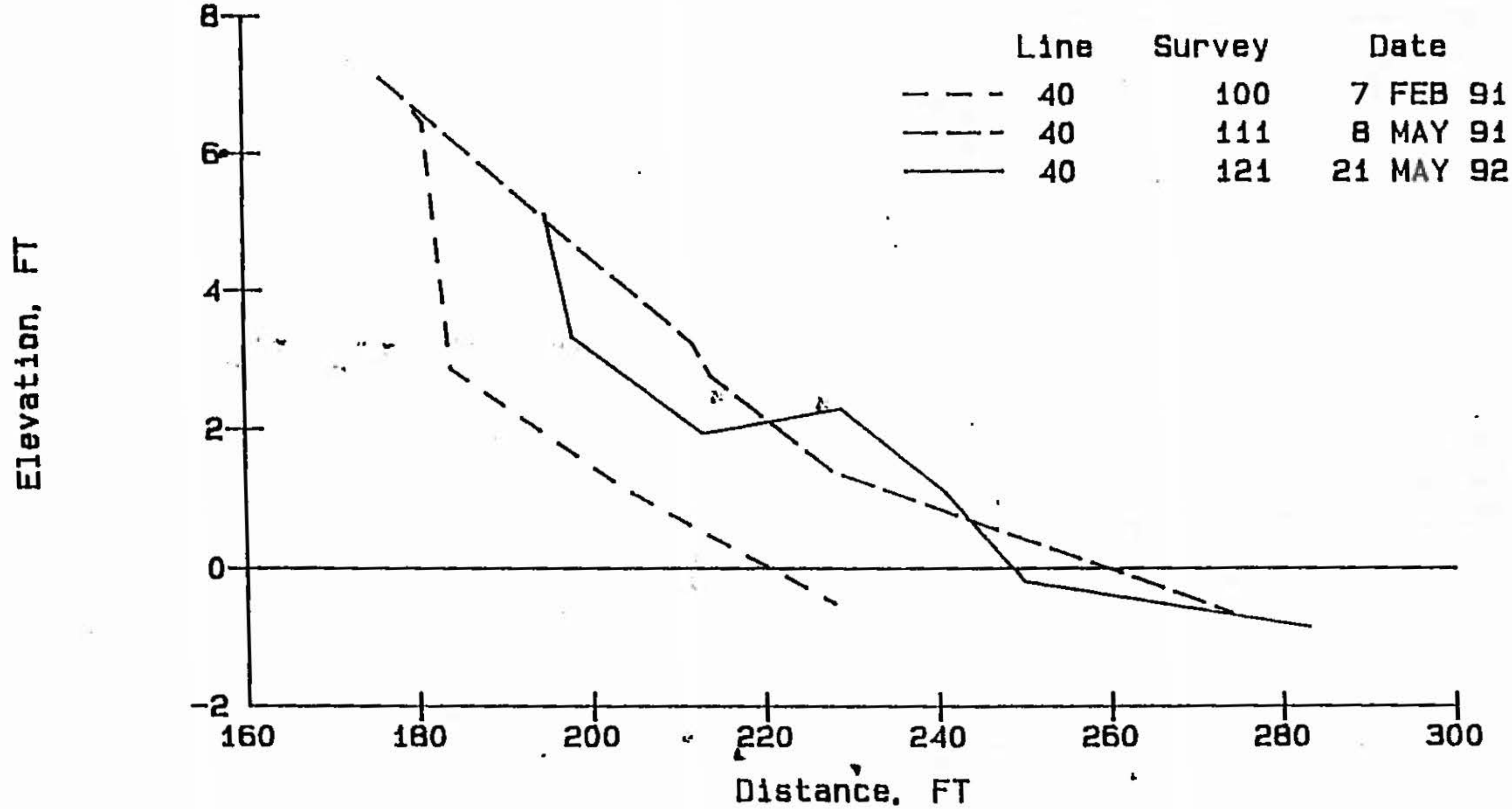
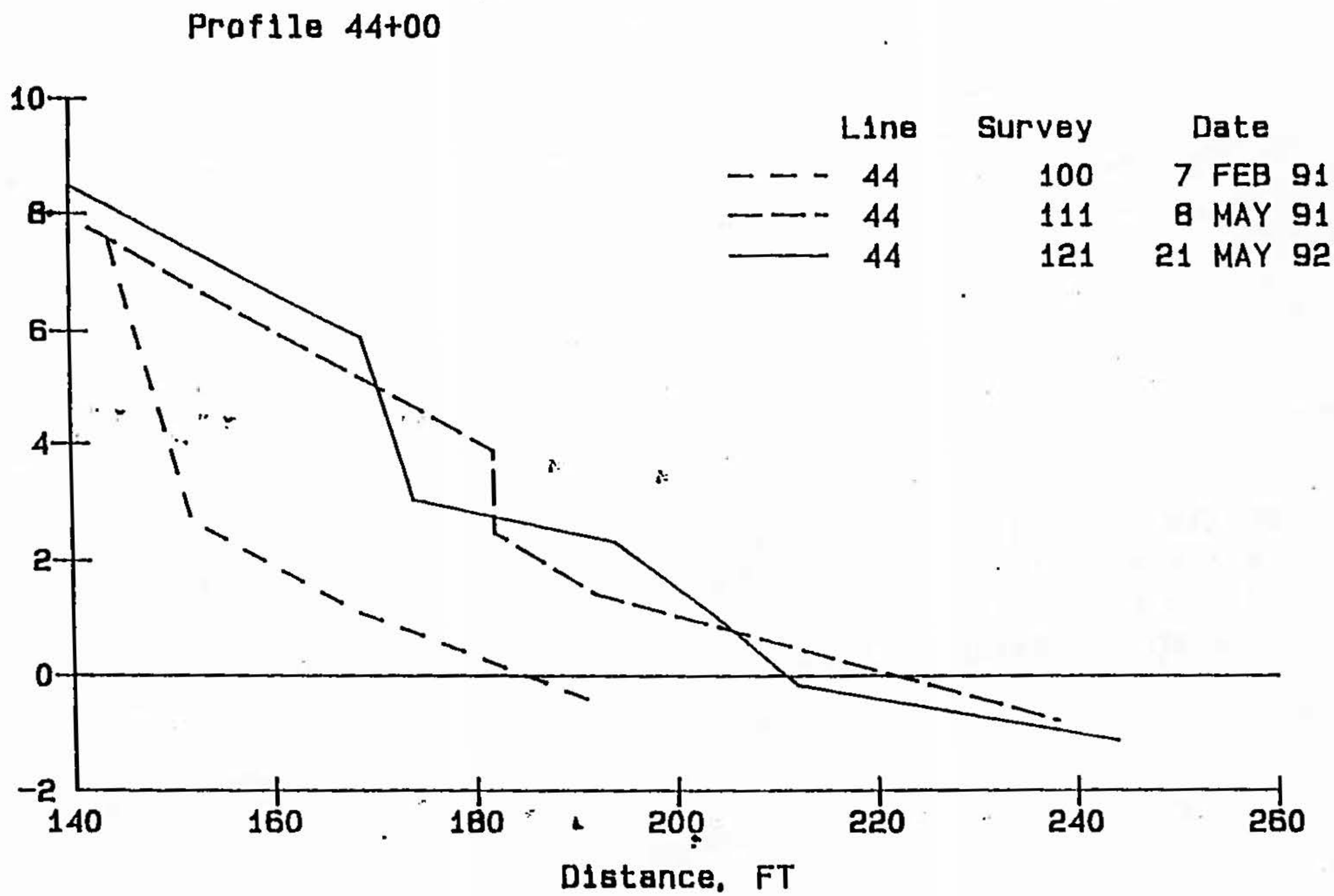
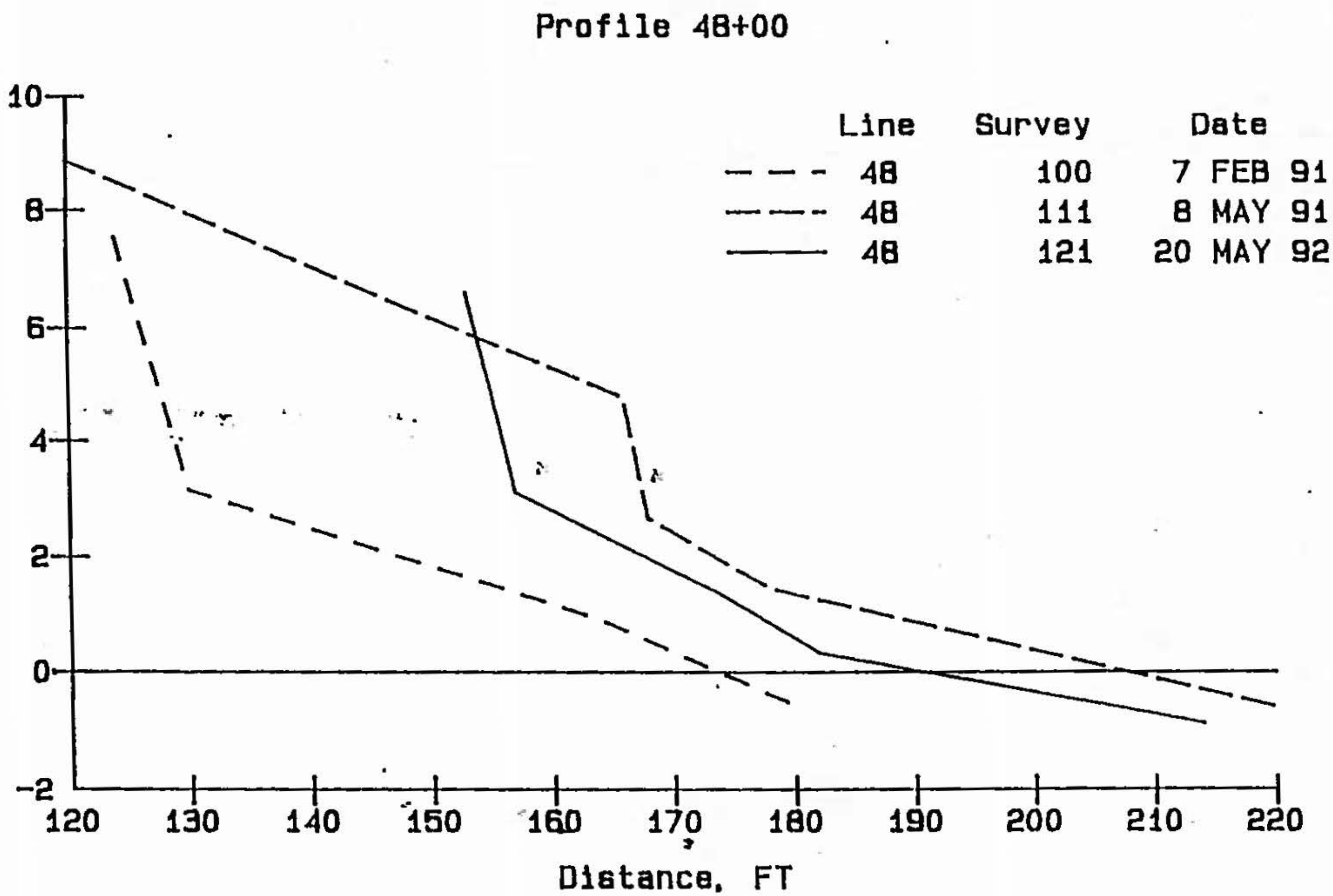
36 111 8 MAY 91
36 121 20 MAY 92
Elevation, FT
Distance, FT
8
6
4
2
0
-2
160
180
200
220
240
260
280
300

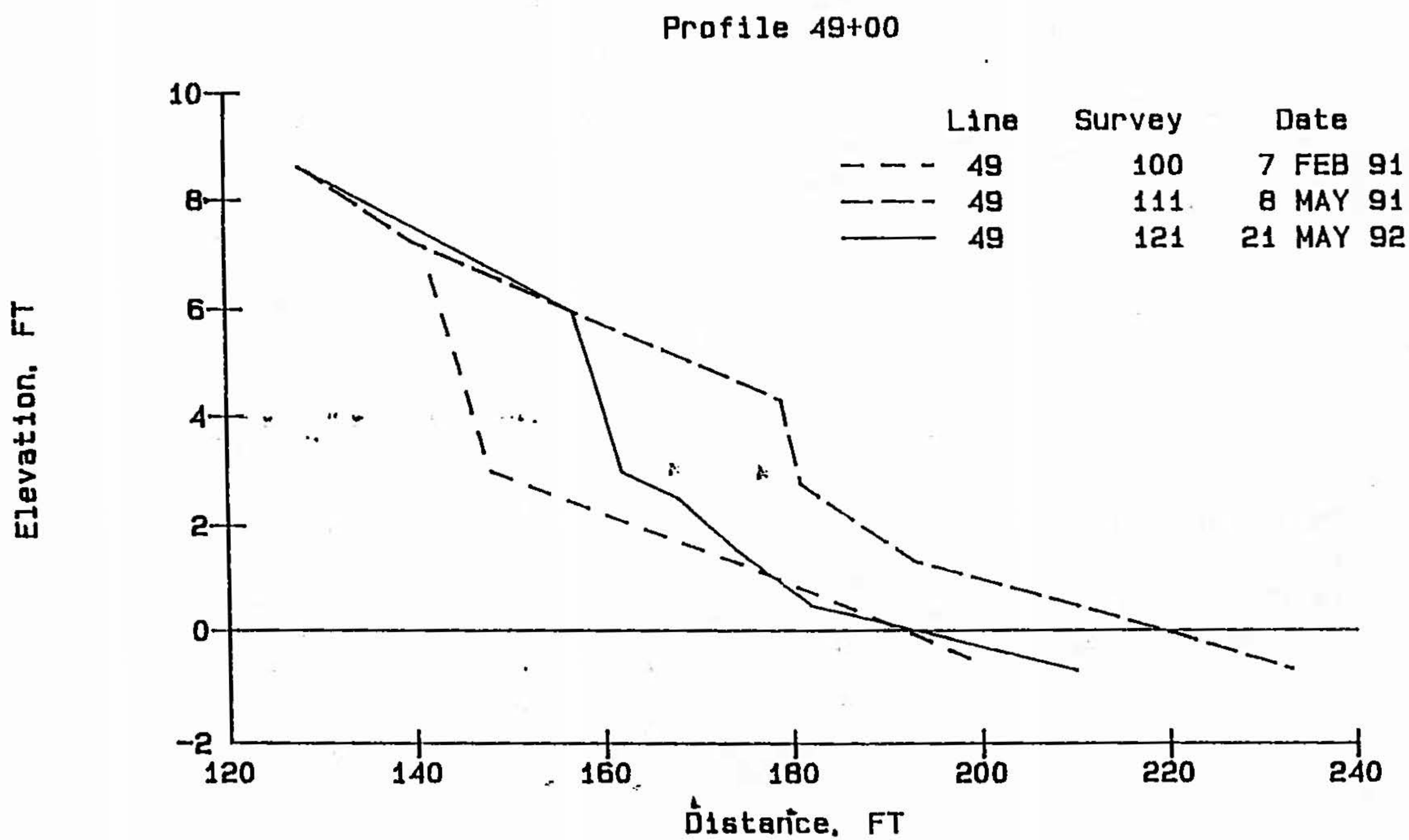
Profile 40+00




Profile 44+00
Line
Survey
Date
44 100 7 FEB 91
44 111 8 MAY 91
44 121 21 MAY 92
Elevation, FT
10
8
6
4
2
0
-2
140
160
180
200
220
240
260
Distance, FT



Profile 48+00
Line
Survey
Date
48
100
7 FEB 91
48
111
8 MAY 91
48
121
20 MAY 92
10
8
6
4
2
0
-2
Elevation, FT
120
130
140
150
160
170
180
190
200
210
220
Distance, FT


Profile 49+00
Line
Survey
Date
49
100
7 FEB 91
49
111
8 MAY 91
49
121
21 MAY 92
Elevation, FT
Distance, FT
10
8
6
4
2
0
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120
140
160
180
200
220
240

Ref. No. [UMCEES]CBL 93-034

Eleventh Annual Interpretive Report for Project III: Benthic Studies

Exterior Monitoring at the Hart-Miller Island Dredged Material Containment Facility (HMI)

For:

Maryland Department of Natural Resources
Tidewater Administration

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INTRODUCTION

The results of the benthic population studies conducted during the eleventh consecutive year of the exterior monitoring program in and around the vicinity of the Hart-Miller Island Dredged Material Containment Facility are presented in this report. The HMI site, lies within the estuarine portion of the Chesapeake Bay and experiences seasonal salinity and temperature fluctuations. This region of the Chesapeake Bay encompasses vast soft-bottom shoals, which are important to protect as they serve as important breeding and nursery grounds for many commercial as well as non-commercial species of invertebrates and migratory fish. Since it is an area that is environmentally unpredictable from year to year, it is important to maintain as complete a record as possible on all facets of the ecosystem. Holland (1985) and Holland *et al.* (1987) completed long-term studies of more stable mesohaline (mid range of salinity) areas which are further down-Bay and found that most macrobenthic species showed significant year-to-year fluctuations in abundance, primarily as a result of slight salinity changes and that the spring season was a critical period for the establishment of both regional and long-term distribution patterns. One would expect even greater fluctuations in the benthic organisms inhabiting the region of HMI which is located in the highly variable oligohaline (low salinity) portion of Chesapeake Bay. Indeed past studies (Pfitzenmeyer and Tenore, 1987; Duguay, Tenore, and Pfitzenmeyer, 1989; Duguay, 1989, 1990, 1992, 1993) indicate that the benthic invertebrate populations in this region are predominantly opportunistic or r-selected species with short life spans, small body size and often high numerical densities. These opportunistic species are characteristic of disturbed and environmentally variable regions (Beukema, 1988).

The major objectives of the eleventh year benthic monitoring studies were:

1. To monitor the nearfield benthic populations for possible effects of discharged effluent and possible seepage of dredge materials from the containment facility by following changes in population size and species composition over the seasonal cycle.

2. To collect samples of the epibenthic fauna on the pilings along the perimeter of the containment facility to check for any immediate sign of detrimental effects to these organisms as a result of discharge or seepage from the facility.

3. Continued monitoring of benthic and epibenthic populations at established reference stations for comparisons with the nearfield stations surrounding the containment facility.

4. Continued monitoring of benthic populations at four stations at which the Maryland Geological Survey sedimentary group found elevated levels of zinc (zinc enriched).

5. To provide selected species of benthic invertebrates for chemical analysis of organic and metal concentrations by an outside laboratory (Martel, Inc.), in order to ascertain various contaminant levels of organisms and to follow if there is any possible bioaccumulation occurring.

6. To cooperate with scientists from Maryland Department of the Environment in collecting sediments and analyzing results of sediment toxicity tests.

METHODS AND MATERIALS

Three cruises were conducted during the eleventh monitoring year on December 5, 1991, April 6, 1992 and August 17, 1992. The location of all the sampling stations (infaunal - reference, nearfield, and zinc-enriched; epifaunal - reference and nearfield) are shown in Figure 1 with their CBL designations. The stations were located in the field by means of the LORAN-C navigational system of the ship. Latitude and longitude of each station and the state identification numbers can be found in the eleventh year data report and the state designation numbers are also listed in Table 6 of this report. Three replicate grabs were taken with a 0.05 m^2 Ponar grab at the established benthic infaunal stations (S1-S8, HM7, HM9, HM16, HM22, HM26, HM12, G5, G25, G84) at each sampling period. All the individual samples were washed on a 0.5 mm screen and fixed in 10% formalin/seawater on board the ship. Back in the laboratory the samples were again washed on a 0.5 mm sieve and then transferred to 70% ethyl alcohol. The samples were then sorted and each organism was removed, identified, and enumerated. Measurements of length-frequency were made on the three most abundant clams. A qualitative sample was scraped from the pilings at the epifaunal stations (R2-R5, see Figure 1) by a specially designed piling scraping device constructed of aluminum. The scrape samples were treated in a similar manner to the infaunal benthic samples with regard to preservation and general handling. However, only a qualitative or relative estimate of abundance was made for each species through a set of numerical ratings, which ranged from 1 - very abundant, 2 - abundant or common, to 3 - present. Station depths were recorded from the ship's fathometer. Temperature and salinity of the water were measured from surface water samples collected through the vessels seawater intake hoses. Temperature was determined with a hand-held mercury thermometer (range of -20 to 110°C) to the nearest 0.5°C. Salinity was determined with an AO Goldberg hand-held salinometer to the nearest part per thousand (ppt - ‰).

Quantitative infaunal sample data were analyzed by a series of statistical tests carried out with the SAS statistical software package (SAS Institute, Cary, N.C.). Simpson's (1949) method of rank analysis was used to determine the dominance factor. The Shannon-Wiener (H') diversity index was calculated for each station after data conversion to base $_2$ logarithms (Pielou, 1966). After constructing a distance matrix comprised of pairwise station abundance chi-square values, stations were grouped according to numerical similarity of the fauna by single-linkage cluster analysis performed using the SASTAXAN computer program developed and provided by Dr. Dan Jacobs (Maryland Sea Grant, College Park, MD). Analysis of variance and the Ryan-Einot-Gabriel-Welsch multiple comparison procedure (Ryan, 1960; Einot and Gabriel, 1975; Welsch, 1977) were used to determine differences in faunal abundance between stations. Friedman's nonparametric rank analysis test (Elliott, 1977) was used to compare mean numbers of the 11 most abundant species, between the slit/clay - nearfield, reference, and zinc-enriched stations singly and then the reference and nearfield or zinc-enriched stations were added together and retested.

RESULTS AND DISCUSSION

Since the beginning of the benthic survey studies in 1981, a small number of species have been the dominant members of the benthic invertebrate populations collected at the various nearfield and reference sites in the vicinity of the HMI. The most abundant species this year were the annelid worms, *Scolecolepides viridis* and *Heteromastus filiformis*; the crustaceans, *Leptocheirus plumulosus* and *Cyathura polita* and the clams, *Rangia cuneata* and *Macoma balthica* and the barnacle, *Balanus improvisus* (see Tables 3, 4, and 5). Variations in the range and average number of *S. viridis*, *L. plumulosus*, and *R. cuneata* at the reference stations since the initial sampling in August 1981 are presented in Table 1. The populations, of these three species, have remained relatively stable over the monitoring period. This particular monitoring year *Leptocheirus* was within the same general range and average numbers as reported for the 10th year report. Both *Scolecolepides* and *Rangia* had a decline in the overall range of numbers of worms and clams compared with the 9th and 10th year data but were still at levels comparable to earlier years. The average number of *Scolecolepides* was exactly the same as the tenth year data. The average number of *Rangia* declined from the high values observed for the past two years (9th and 10th) but were similar to values for the 8th and 9th year.

The major variations observed in dominant or most abundant species for a station occur primarily as a result, of the different bottom types (Table 2). Soft bottoms are preferred by the annelid worms, *S. viridis*, *Tubificoides* sp., and *S.*

benedicti, as well as the crustaceans, *L. plumulosus* and *C. polita*. The most common inhabitants of the predominately old oyster shell substrates are more variable often with the barnacle, *Balanus improvisus*, the worm, *Nereis succinea*, or the encrusting bryozoan, *Membranipora tenuis* amongst the dominant organisms. The crustacean, *L. plumulosus* was the most numerous organism at soft bottom stations and the most numerous organism on shell bottom stations was the worm, *S. viridis*.

Station HM26, at the mouth of the Back River has in past years usually had the most diverse annelid worm fauna. This year, HM26 tied with S2 and S6 for the highest overall annelid diversity; HM26 had 6 species in December and April, with a high of 7 species of worms in August, S6 had 7 species in December and April, and 5 in December, while S2 had 7 species in December, 6 species in April and 5 in August. The most diverse annelid fauna this year was found in December at stations S6 and S2, and in August at station HM26 and in April at station S6, all of which had 7 species of worms in these particular months (see Tables 3 and 4). The annelid worms populations were fairly evenly distributed throughout all three sampling periods. The most abundant worm at each of the above stations was different; *Heteromastus filiformis* was the most abundant worm at station S6, *Scolecolepides viridis* at station S2, and *Strebospio benedicti* at station HM26. *Scolecolepides viridis* was the most abundant worm species at both the nearfield and zinc-enriched stations whereas *Heteromastus filiformis* was the most abundant worm at the reference stations, with *Tubificoides* sp. and *Scolecolepides viridis* following as a close second and third, respectively.

The worm, *S. viridis*, and the crustacean, *L. plumulosus* occurred most frequently at all three sets of stations, the nearfield, reference, and zinc enriched, with *S. virdis* being absent only in December at station S7. *L. plumulosus* was present at all stations, except at station HM9 in August. These two species were not only the most frequently found but were also among the numerically most abundant organisms at the various stations, including, on occasion, the hard bottom stations where shells are interspersed with silt/clay (see Tables 3, 4, and 5). Over the course of the benthic monitoring studies, the worm, *S. viridis* has frequently alternated with the crustaceans, *C. polita* and *L. plumulosus*, as the foremost dominant species. It appears that slight modifications in the salinity patterns during the important seasonal recruitment period in late spring play an important role in determining the dominance of these species. The crustaceans, *C. polita* and *L. plumulosus*, become more abundant during low salinity years while the worm, *S. viridis* prefers slightly higher salinities. This year *L. plumulosus* was the most abundant species closely followed by *S. viridis*.

Once again *L. plumulosus* was ahead of *C. polita* in terms of overall abundance at all three sets of stations (see Tables 3, 4,

5) and was present at nearly all stations on all dates sampled. The isopod crustacean, *Cyathura*, was also present at nearly all stations on all sampling dates and appears to be very tolerant of physical and chemical disturbances and repopulates areas such as dredged material disposal piles more quickly than other crustacean species (Pfitzenmeyer, 1985).

All of the dominant species, with the exception of *R. cuneata*, brood their young. This is an advantage in an area of unstable and variable environmental conditions such as the low salinity regions of the upper Chesapeake Bay. Organisms released from their parents as juveniles are known to have high survival rates and often reach high densities of individuals (Wells, 1961). The total number of individual organisms collected at the various reference, nearfield, and zinc-enriched stations are comparable and ranged for the most part between 1000 and 5000 individuals/m^2. The highest recorded value occurred at station HM26 in August (7260 individuals/m^2) as a result of high concentrations of the worm, *Tubificoides* sp. (2147 individuals/m^2) and the crustacean, *L. plumulosus* (1733 individuals/m2). The lowest recorded values occurred at station S8 in December (406 individuals/m^2) followed by station S1 (541 individuals/m^2) in December. There did not appear to be any consistent pattern in terms of the highs and lows at the reference or nearfield stations, however April and August values were nearly always above December, most likely reflecting maximum recruitment at this time. The predominant benthic populations at the three sets of stations, nearfield, reference, and zinc-enriched areas are similar and consist of detrital feeders which have an ample supply of fine substrates in this region of the Chesapeake Bay and particularly around the Hart-Miller Island Dredged Material Containment Facility itself (Wells *et al.*, 1984).

Surface salinity and temperature were recorded at various infaunal stations on all sampling dates (Table 6). In December salinity ranged from 1.0 - 8.0 ‰ whereas in April the salinity varied between 0.5 and 6.0 ‰. In August salinity ranged from 2.0 -4.5 ‰. The salinity ranges were somewhat higher than over the previous years values in December and April, when the values were 0-2 ‰, 0-4 ‰, respectively, but lower than last years values of 9-10 ‰ for August. Temperature was lower on each of this years sampling dates than it had been during the previous year. This year the average temperatures were: 5.7°C in December, 8.9°C in April, and 23.3°C in August, compared with the previous year of 7.2, 13.3 and 27.6°C, respectively.

Species diversity values must be interpreted carefully in analyzing benthic data from the upper Chesapeake Bay. Generally, high diversity values reflect a healthy, stable fauna with the numbers of all species in the population somewhat equally distributed, and no obvious dominance by one or two species.

However, in this area of the Chesapeake, we have observed this year, as in the past monitoring studies, that the normal condition is for one, two or three species to assume numerical dominance. This dominance is variable from year to year depending on environmental factors, in particular the amount of freshwater entering the Bay from the Susquehanna River. Because of the overwhelming numerical dominance of a few species, diversity values are fairly low in this productive area of the Bay when compared to values obtained elsewhere. Diversity values for each of the quantitative benthic samples for the three different sampling dates are presented in Tables 7, 8, 9. This year the highest diversity values for the various stations were concentrated in August with a total of 12 stations having their highest values at that time. Of the remaining five stations, three (S6, G25, and G84) had their highest values in December and two (HM9, HM26) had their highest values in April. Highest diversity values occurring in the summer had been postulated in the First Interpretive Report (Pfitzenmeyer *et al.*, 1982) and was frequently the case in the earlier reports and it seems to be the case again this year. The lowest and highest diversity values actually both occurred in April; the lowest value (0.725) was obtained for station, S1 and the highest value (4.482) was at station, HM26.

The largest number of species recorded for any station was 21 at station HM26 in August, followed by 20 at HM9 in April and at S1 in August. The lowest number of species, 11, was recorded in December at nearfield station S8.

Three species of clams, *Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*, were measured to the nearest mm in shell length to determine if any size/growth differences were noticeable between the reference and nearfield stations and to begin to compare the clams collected in the zinc-enriched areas with the other two areas (see Figures 2, 3, 4). The most abundant clam again this year was *R. cuneata*. In contrast to the last two years of data, this year there was not a large set of *Rangia* clams in August. The numbers of *R. cuneata* were more uniformly spread out in December, April, and August and the numbers were considerably lower, than observed in August of the previous year. Last August the number of small *Rangia* were in the thousands, whereas this year they were only in the hundreds. In December and April, the largest number of clams was found in the 15 - 20 mm size range, while in August the highest numbers were found in the 40+ mm size class (249 individuals). The nearfield stations had somewhat higher numbers of *R. cuneata* than either the reference or zinc-enriched stations (see Figure 2).

The next most abundant clam during the eleventh year of studies, as was the case for the five previous years (sixth, seventh, eighth, ninth and tenth year) was *M. balthica* (see Figure 3). Once again, in December, there were very few *M.*

balthica at the nearfield stations (a total of 2). The reference and zinc-enriched stations had 17 and 135 individuals each. The number of *M. balthica* during this December time period at the various stations are in keeping with the population levels reported last August 1991. In April there appeared to be a significant settlement of small individuals in the range of 2-6 mm at the nearfield, reference, and zinc-enriched stations. The nearfield stations had the highest number of these smaller individuals, 499 compared with 170 for the reference and 169 for the zinc-enriched stations. In August the nearfield stations still had the highest numbers of *M. balthica* and there appeared to have been growth in this region as evidenced by a large cohort of organisms in the 6-15 mm size range.

The length frequency distribution and abundance pattern of the third clam, *M. mitchelli* was somewhat similar to that observed in the previous three years (the 8th, 9th and 10th). *M. mitchelli* has a much lower abundance than either of the other two species (see Figure 4). There was again sustained increase in the overall numbers of *M. mitchelli* found in this region of the Bay indicating more favorable conditions for this particular species. The total number of *M. mitchelli*, for all three sampling dates, nearly doubled the number found last year (10th year total, 144 and the 11th year total, 229). During all three sampling dates, the *M. mitchelli* clams remained in the same size classes (2-15 mm), except for one 20 mm individual in April. There were some variations in the numbers in the various size classes between the nearfield, reference, and zinc-enriched stations; the numbers of *M. mitchelli* clams were nearly always higher at the nearfield stations. As has been reported for the previous 5 years, (Duguay *et al.*, 1989; Duguay 1989, 1990, 1992, 1993) there had been a slight shift in relative dominance to greater numbers of *M. balthica* than *M. mitchelli* over the past few years.

We again employed cluster analysis in this years study in order to examine relationships among the different groups of stations based upon the numerical distribution of the numbers of species and individuals of a species. In Figures 5, 6, and 7 the stations with faunal similarity (based on chi-square statistics derived from the differences between the values of the variables for the stations), are linked by vertical connections in the three dendrograms. Essentially each station was considered to be a cluster of its own and at each step (amalgamated distances) the clusters with the shortest distance between them were combined (amalgamated) and treated as one cluster. Cluster analysis in past studies at HMI has clearly indicated a faunal response to bottom type (Pfitzenmeyer, 1985). Thus, any unusual grouping of stations tends to suggest changes are occurring due to factors other than bottom type and further examinations of these stations may be warranted. Most of the time experience and familiarity with the area under study can help to explain the differences.

However, when they cannot be explained other potential outside factors must be considered.

The basic grouping of the stations for the December 1991 sampling period is presented in Figure 5. There is an initial joining of a nearfield and zinc-enriched station (S5 and G5, both silt/clay stations). The next four stations to join the initial pair of stations were also silt/clay stations (HM7, a reference station and S3, S8, and S6, three nearfield stations). The last stations to join the dendrogram were S7 (nearfield station), HM26 (reference station) and G84 (zinc-enriched station); as usual, station HM26 was one of the last stations to join the dendrogram in December. The clustering of stations observed for December is similar to that observed in previous reports (Duguay *et al.*, 1989; Duguay, 1989, 1990, 1992) and the zinc-enriched stations appear in clusters with both the reference and nearfield stations. All indications are that no anomalous changes are occurring at either the nearfield or zinc-enriched stations.

In April 1992 (Figure 6), the first three stations to join the dendrogram were HM12, a zinc-enriched station, HM7, a reference station, and S3, a nearfield station; this is a good mixture of the three groups of stations. The first eleven stations to join the dendrogram were all silt/clay stations; this same trend occurred last year, in April. The last two stations to join the other groupings of stations were S1, a sand station and S7, a shell station.

The August summer sampling period represents a season of continued recruitment for the majority of benthic species, as well as a period of heavy stress from predatory activities, higher salinity, and higher water temperature. These stresses exert a moderating effect on the benthic community holding the various populations in check. There was again this year a main cluster composed of a mixture of nearfield, reference, and zinc-enriched stations. The first nine stations to join the dendrogram in August were all silt/clay stations; this seemed to be a common trend in all three sampling months this year. The outermost members of the cluster consisted of S5 along with G25 and HM9, another mixture of nearfield, reference, and zinc-enriched stations. The clusters formed over these three sampling dates, during the 1991-92 sampling period, represented previously observed normal groupings for the reference and nearfield stations with no unusually isolated stations. These clusters were consistent with earlier studies and often grouped stations according to bottom type and general location within the study area. The zinc-enriched stations clustered along with the nearfield and reference stations and indicated no unusually isolated stations in this recently sampled group of stations. If the benthic invertebrates in this region were being affected by some adverse or outside force it would appear in the groupings, and no such indications were found during the three sampling periods reported in this study.

The Ryan-Einot-Gabriel-Welsch Multiple Comparison test was used to determine if a significant difference could be detected when population means of benthic invertebrates were compared at the various sampling stations. The total number of individuals of each species was transformed (log) before the analysis was performed. Subsets of groups, the highest and lowest means of which do not differ by more than the shortest significant range for a subset of that size, are listed as homogeneous subsets. The results of these tests for the three different sampling dates are presented in Tables 10, 11 and 12.

In December 1991, the stations sorted themselves out into five subsets (Table 10). Three nearfield stations, S2, S4, and S7, two reference stations, HM26 and HM16 and one zinc-enriched station, G84 formed the first subset and the second subset was made up by adding two stations, G5, (zinc enriched) and HM9 (reference) and dropping one station (HM26). The third subset dropped station HM26 and added stations S5, HM12, G25, S3, HM7. The fourth subset consisted of six nearfield stations, all of the reference stations and two zinc-enriched stations. The fifth and final subset dropped one nearfield station (S2) and then added one (S8). The December subsets each have a mixture of nearfield, reference, and zinc-enriched stations indicative of no major differences in the population means of these three types of stations.

In April, only two subsets were evident (Table 11). The first subset was comprised of nearfield stations S2, S5, S1 close in to the facility. The second subset consisted of all the stations except S2, which dropped out.

The analysis of the August 1992 data resulted in the occurrence of six subsets somewhat similar to those observed in the December sampling period, because the subsets, for the most part, again had a mixture of nearfield, reference, and zinc-enriched stations. Subset one consisted of two reference stations (HM26, HM9) and five nearfield stations (S2, S3, S6, S5, and S7). The other five subsets, as mentioned previously, all contained a mixture of nearfield, reference, and zinc-enriched stations.

The results of running Friedman's non-parametric test for differences in the means of samples (for ranked abundances of 11 selected species) taken only at the silt/clay stations for the nearfield, reference, and zinc-enriched stations are presented in Table 13. Significant differences ($p<0.05$) were found in December and April, at the nearfield stations and the combined nearfield and reference stations. In August, significant differences were found only at the combined nearfield and reference stations.

Table 14 provides the data for the epifaunal samples from a series of pilings surrounding the facility (nearfield) and one located in the Pleasure Island boat channel (reference). Samples this year were again limited to depths of about 3 feet (1.0 to 1.3 m) below the surface and at 6-8 feet (2-3 m) below the surface to avoid the region of ice scour in the upper levels of the pilings, where the fauna becomes depauperate in winter. Thus, a reasonably well developed fauna occurred on all three sampling dates and there were no obvious major differences between the upper and lower samples. The densities and distribution of the various epifaunal species on both the nearfield pilings (R2-R4) and the reference piling (R5) are quite similar and sometimes nearly identical. Essentially the same 10 species observed this year were the predominant species over the past six study years (Pfitzenmeyer and Tenore, 1987; Duguay *et al.*, 1988; Duguay, 1989, 1990, 1992, 1993). The amphipod, *Corophium lacustre*, again was one of the most abundant and widespread species (Pfitzenmeyer and Tenore, 1987; Duguay *et al.*, 1988; Duguay, 1989, 1990, 1992, 1993). It was the most abundant organism at all stations on all sampling dates with two exceptions when it was replaced by the bryozoan, *Victorella pavida* at the upper depths of the reference station in December and at the lower depths at the reference station in August. The worm, *Polydora* was, in general, the second most abundant species in December and April. In August, the second most abundant species was the bryozoan, *Victorella*. Other abundant but at times more variable organisms consisted of the worm, *Nereis*, the barnacles, *Balanus subalbidus* or *B. improvisus* and the bryozoan, *Membranipora*. *Corophium* is a small amphipod crustacean which is extremely opportunistic and constructs tubules out of detritus in which it lives a protected existence on the piling. The tubules are quite tough and other colonial forms attach themselves to the tubule network. *Corophium* is not limited to the pilings but also occurs on shell and/or other hard surfaces on the bottom. No particular zonation of species was observed on the pilings. The same species which were found at the first meter were also collected at 2-3 m. The area is relatively shallow and no specific depth restrictions would be expected for the common species. The two colonial forms, the bryozoan, *Victorella*, and the hydroid, *Cordylophora*, once again reached their greatest abundance in August which most likely reflects their maximal reproductive and growth season.

CONCLUSIONS AND RECOMMENDATIONS

For this the eleventh year of sampling and monitoring the benthic populations of organisms in and around the Hart-Miller Island Dredged Material Containment Facility, the sampling locations, sampling techniques and analysis of the data were again maintained as close as possible to that for the previous years in order to eliminate as much variation as possible. Maintenance of sampling locations, techniques and analysis should render differences due to effects of the containment facility more readily apparent. We have continued to use the special piling scraping device developed in the seventh-year program for our qualitative epifaunal samples. We have continued to monitor the four infaunal sampling stations which were established over the course of the 9th year in response to the findings of the sedimentary group, from Maryland Geological Survey (MGS), of an observable enrichment of zinc in the sediments of these stations beginning in the eighth monitoring year.

The results presented in this report are similar to those presented in the reports of the last six years (5th through 10th year of monitoring). A total of 35 species (compared with 32, 34, 31, 35, 30 and 26 for the 10th, 9th, 8th, 7th, 6th and 5th years, respectively) were collected in the quantitative infaunal grab samples. Again six species were numerically dominant on soft bottoms. These six dominants are the worms, *S. viridis* and *H. filiformis*, the crustaceans, *L. plumulosus* and *C. polita*, and the clams, *R. cuneata* and *M. balthica*. The oyster shell substrate stations, had two numerically dominant species (*R. cuneata* and *H. filiformis*) in common with the soft bottom regions as well as three other numerically dominant species characteristic of oyster substrate stations, the worms, *S. benedicti* and *Tubificoides* sp., and the barnacle, *B. improvisus*. Salinity fluctuations on yearly and seasonal time scales appear to be important in regulating the position of dominance of the major species in this low and variable salinity region of the Bay.

The average number of individuals per square meter (m^2) per station was highest for the nearfield (11,057) stations with slightly decreasing values observed for the reference stations (9,282) and zinc-enriched stations (7,741) over the three sampling periods. Pfitzenmeyer and Tenore (1987) had reported a greater number of individuals at the nearfield versus the reference stations for the fifth monitoring year, which they attributed to an abundance of finer sediments close to the containment facility dike. This seems to be the trend observed this year.

The highest average species diversity values this year were found in August which had been the rule for several previous monitoring years. The lowest diversity values were in April this year. Length frequencies and cohort sizes of the clam *R. cuneata* were highest at the nearfield stations, as was the case for the other two common bivalves, *M. balthica* and *M. mitchelli*. The largest recruitment of young clams was observed in April for *Macoma balthica*. All three clams were present at all of the zinc-enriched stations and the populations appeared comparable to those observed at the reference and nearfield stations.

The cluster analysis grouped stations of similar faunal composition in response to sediment type and general location within the HMI study area, as has been the case in previous years. There were no incidences of individual stations being isolated from common groupings during the three sampling periods. The nearfield oyster shell substrate stations, S2 and S7, were frequently two of the last stations to join the cluster. The Ryan-Einot-Gabriel-Welsch multiple range test resulted in subsets of stations which contained a mix of nearfield, reference, and zinc-enriched stations. Friedman's non-parametric test indicated some differences in the nearfield stations in December and April and in the combined nearfield and reference stations, in December, April and August. However, no differences were observed in the reference or zinc-enriched stations on their own or when the zinc-enriched stations were combined with the reference stations.

The epifaunal species were quite similar in terms of distribution at the nearfield and reference stations at all three sampling periods. Since sampling this year was again confined to the region below winter ice scour and low tide desiccation levels, no absence of species from the pilings was recorded. The amphipod, *Corophium*, was again one of the most abundant organisms as were the hydroid, *Cordylophora*, the bryozoan, *Victorella* and the worm, *Polydora*. At present, there does not appear to be any discernible differences in the nearfield, reference and zinc-enriched populations of benthic organisms resulting directly from the Hart-Miller Island Dredged Material Containment Facility itself. The barge activity does appear to churn up and scour the area but the opportunistic species inhabiting this low and variable salinity region of the Bay appear to be readily capable of repopulating these disturbed areas.

The Hart-Miller Island Dredged Material Containment Facility will continue to operate at least until the year 2000. It is strongly recommended that the infaunal and epifaunal populations continue to be sampled at the established locations along with the more recently added zinc-enriched areas during this continued period of active operation of the containment facility to ascertain any possible effects. Station locations and sampling techniques should be maintained as close as possible to the last few years to eliminate sampling variations and permit rapid recognition of effects resulting from the operation and existence of the HMI facility.

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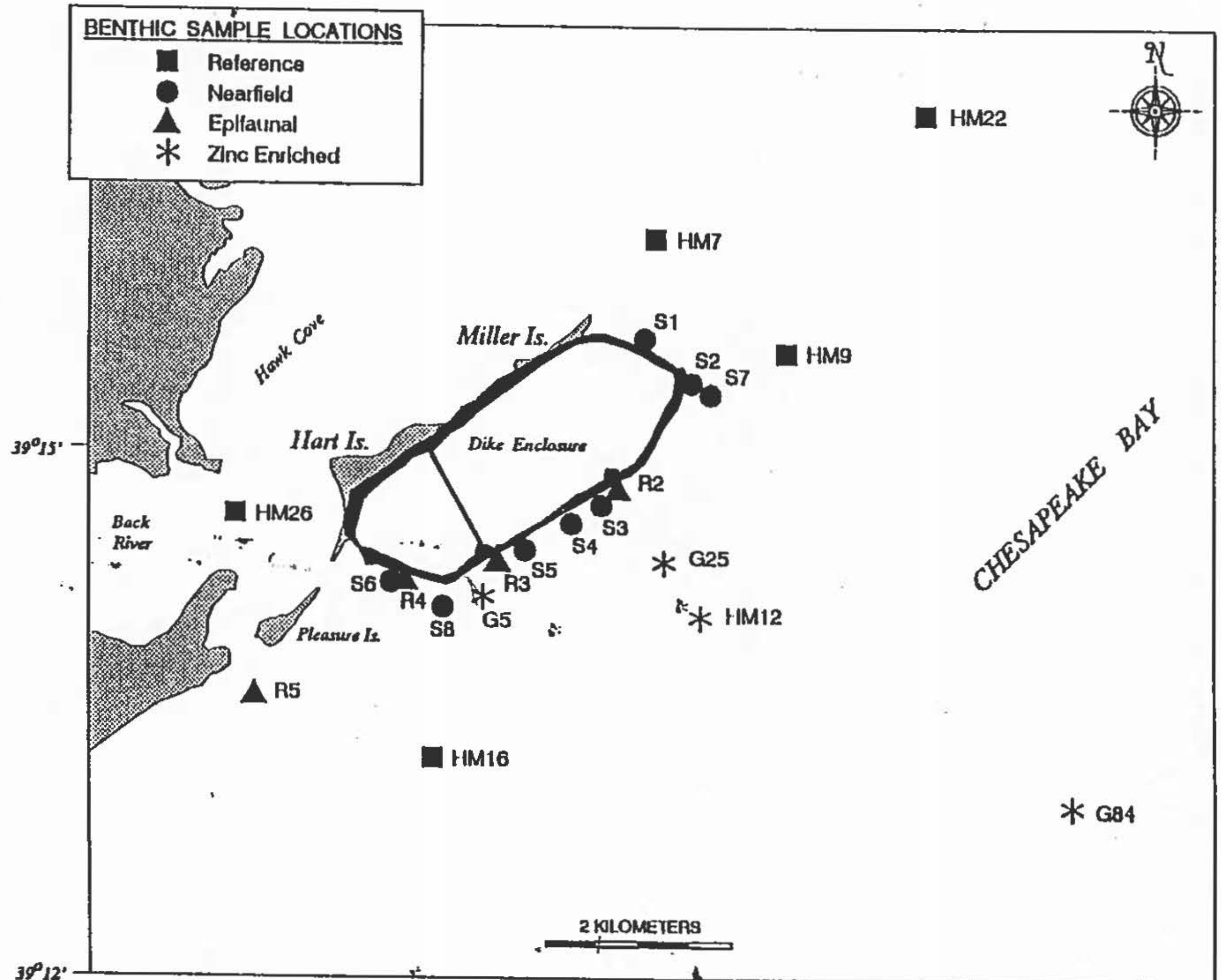

Figure 1. Benthic infaunal and epifaunal sampling station locations at HMI. University of Maryland, Chesapeake Biological Laboratory designations.

Length Frequency Distribution
Macoma mitchelli

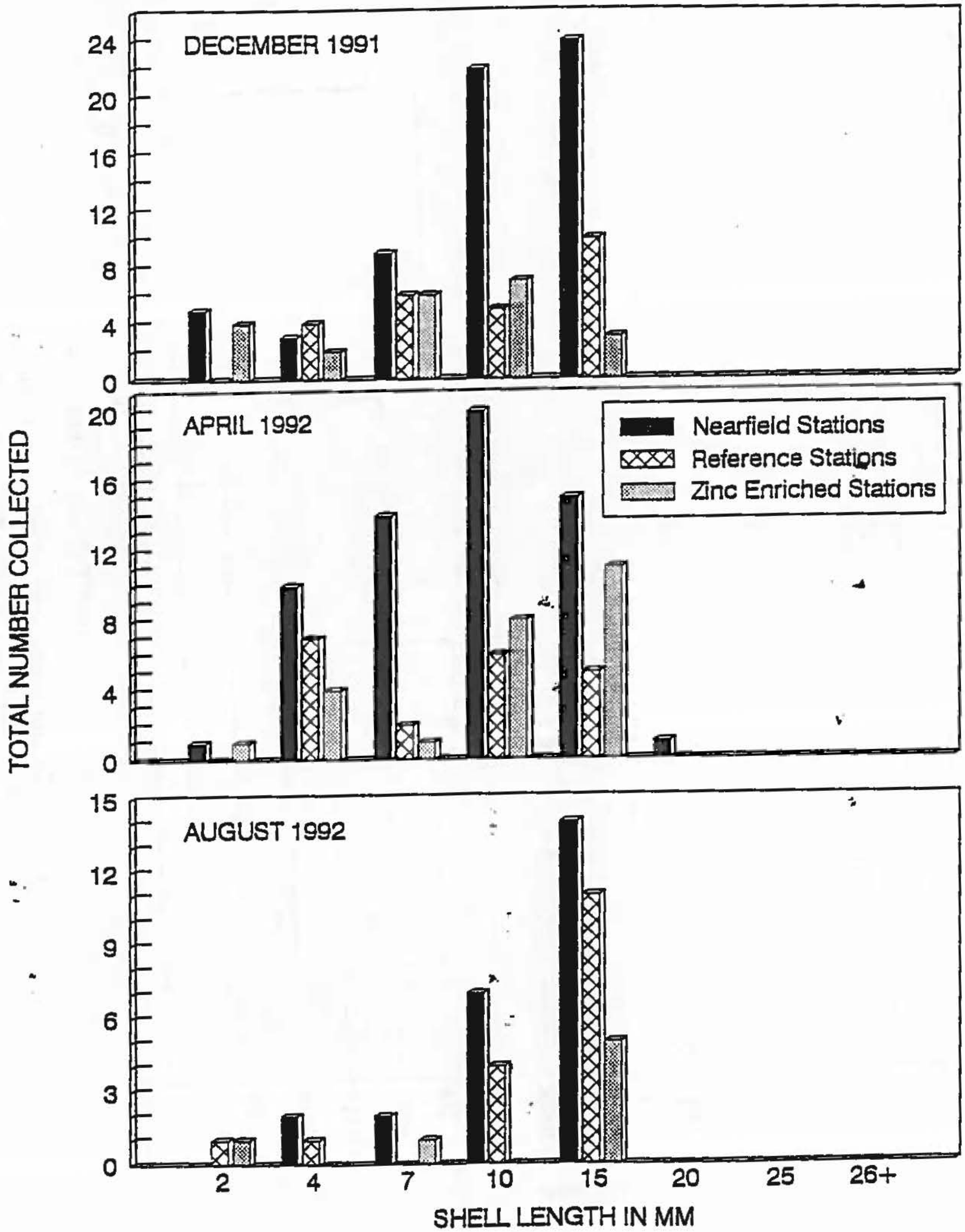

Figure 4. Length frequency distribution of the clam, *Macoma mitchelli*, during the eleventh year of benthic monitoring studies at HMI.

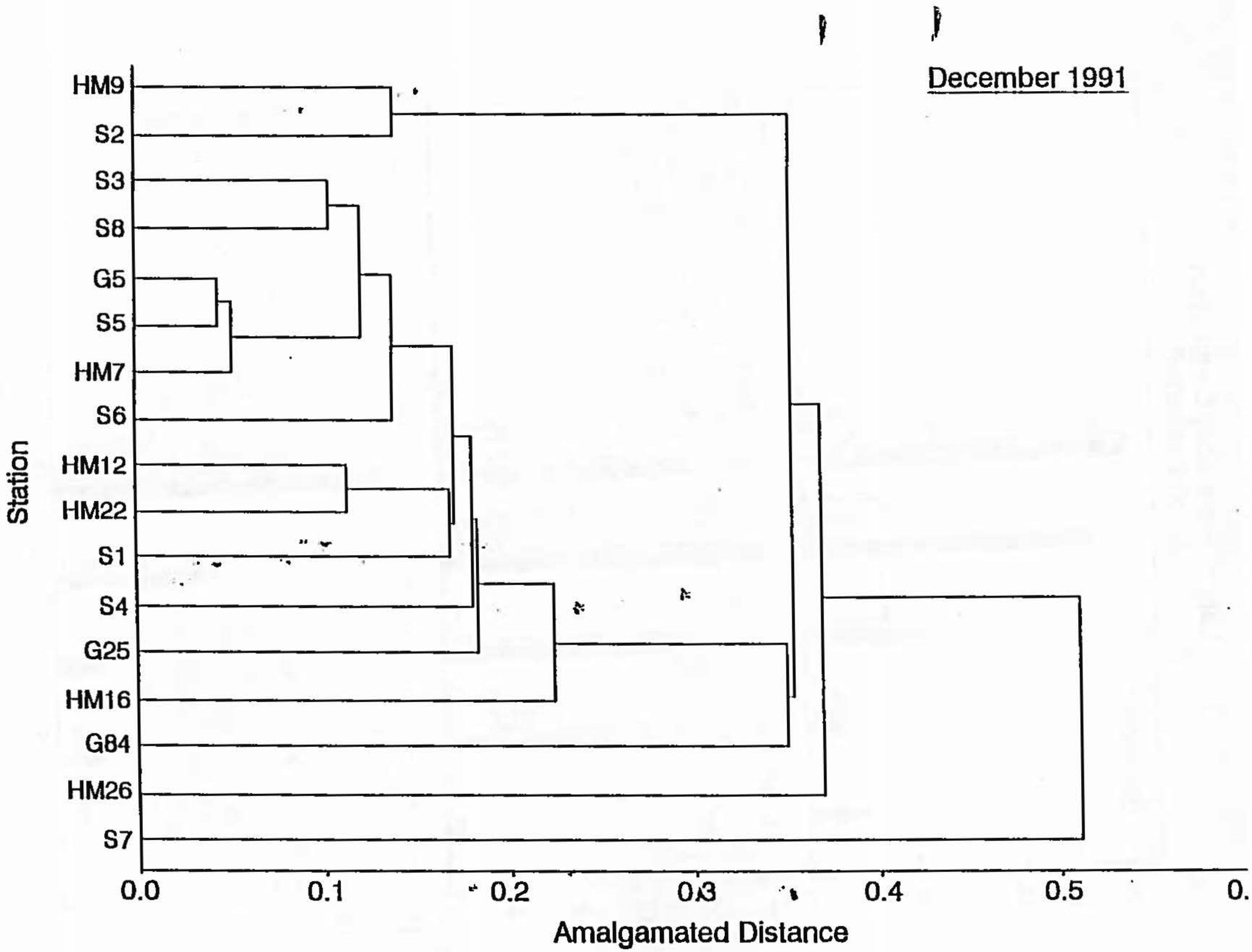

Figure 5: Cluster Analysis for all of the HMI Sampling Stations in December 1991 during the Eleventh Year of Benthic Studies.

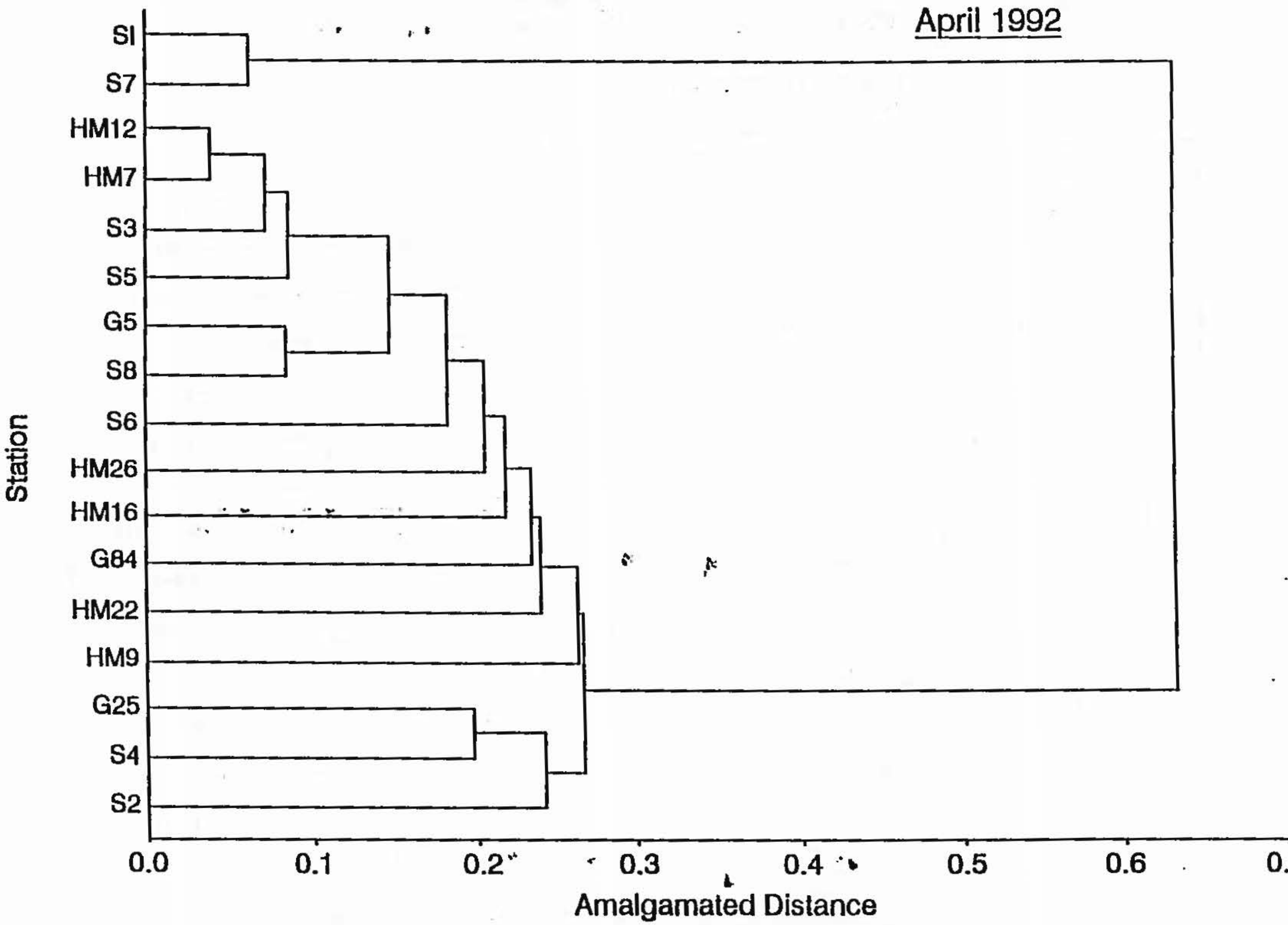

Figure 6: Cluster Analysis for all of the HMI Sampling Stations in April 1992 during the Eleventh Year of Benthic Studies.

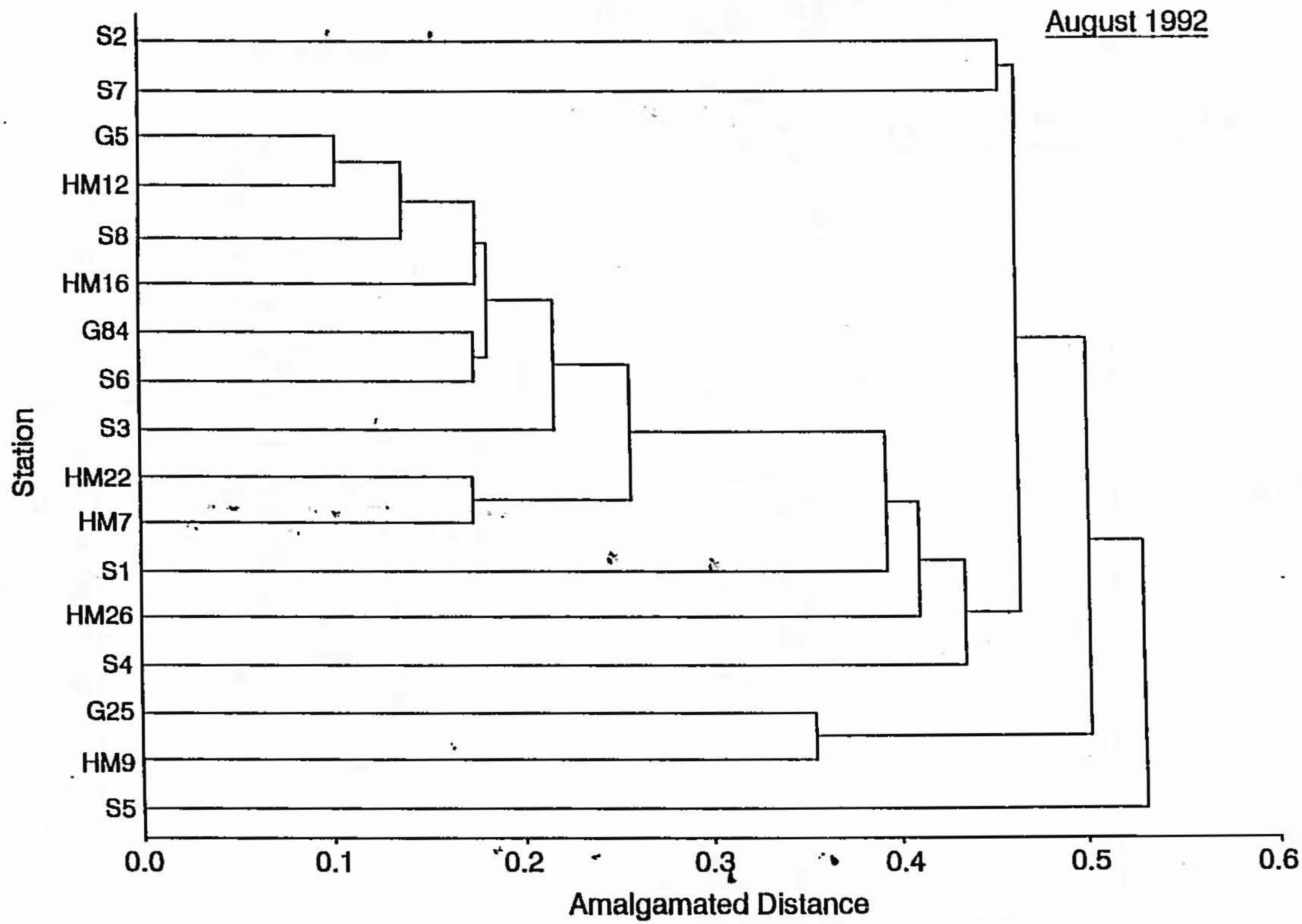

Figure 7: Cluster Analysis for all of the HMI Sampling Stations in August 1992 during the Eleventh Year of Benthic Studies.

TABLE 1. Relative abundances (#/m2) of three of the most abundant species of benthic organisms which occur at the HMI Reference Stations over the eleven year study period from August 1981 to August 1992.

	Aug.,Nov. 1981	Feb.,May, Aug.,Nov. 1982	Feb.,May 1983	Sep.1983 Mar.1984	Oct.1984 Apr.1985	Dec. 1985 Apr., Aug. 1986	Dec.1986 Apr.,Aug. 1987	Dec.1987 Apr.,Aug. 1988	Dec.1988 Apr.,Aug. 1989	Dec.1989 Apr.,Aug. 1990	Dec.1990 Apr.,Aug. 1991	Dec.1991 Apr.,Aug. 1992
Scolecolepides viridis												
Range/m2	0-1825	0-286	0-264		11-153	7-1287	13-447	0-657	20-3420	27-9393	7-2313	20-880
Avg./m2	229	121	69	546	92	398	179	176	998	2012	231	231
Leptocheirus plumulosus												
Range/m2	0-2960	0-5749	7-6626		20-441	7-1293	7-3312	0-3693	0-2474	67-2820	0-3607	13-2740
Avg./m2	832	1459	2259	614	272	308	1111	398	327	829	806	1064
Rangia cuneata												
Range/m2	0-46	0-99	0-135		0-75	0-273	13-3007	0-2267	0-560	13-12420	0-9000	7-853
Avg./m2	9	9	22	455	27	102	687	359	123	1587	1647	269

TABLE 2: A list of the 3 numerically dominant benthic organisms collected from each bottom type on each sampling date during the eleventh year of Benthic Studies at HMI.

STATION	December 1991	April 1992	August 1992
NEARFIELD SOFT BOTTOM (S3,4,5,6,8)			
	Leptocheirus plumulosus	Leptocheirus plumulosus	Leptocheirus plumulosus
	Rangia cuneata	Scolecolepides viridis	Macoma balthica
	Heteromastus filiformis	Macoma balthica	Cyathura polita
NEARFIELD SHELL BOTTOM (S2,7)			
	Membranipora tenuis	Scolecolepides viridis	Balanus improvisus
	Nereis succinea	Rangia cuneata	Membranipora tenuis
	Rangia cuneata	Leptocheirus plumulosus	Scolecolepides viridis
REFERENCE SOFT BOTTOM (HM7,16,22)			
	Leptocheirus plumulosus	Leptocheirus plumulosus	Leptocheirus plumulosus
	Rangia cuneata	Scolecolepides viridis	Cyathura polita
	Cyathura polita	Macoma balthica	Heteromastus filiformis
REFERENCE SHELL BOTTOM (HM9)			
	Membranipora tenuis	Scolecolepides viridis	Heteromastus filiformis
	Rangia cuneata	Rangia cuneata	Balanus improvisus
	Hydrobia sp.	Leptocheirus plumulosus	Tubificoides sp.
BACK RIVER REFERENCE SOFT BOTTOM (HM26)			
	Leptocheirus plumulosus	Leptocheirus plumulosus	Tubificoides sp.
	Heteromastus filiformis	Scolecolepides viridis	Leptocheirus plumulosus
	Corphium lacustre	Macoma balthica	Streblospio benedicti
ZINC ENRICHED SOFT BOTTOM (G5,25,84,HM12)			
	Leptocheirus plumulosus	Leptocheirus plumulosus	Heteromastus filiformis
	Rangia cuneata	Scolecolepides viridis	Leptocheirus plumulosus
	Macoma balthica	Macoma balthica	Cyathura polita

TABLE 3: Number of benthic organisms per m squared (m2) found at the Reference Stations during the Eleventh Year (December 1991 - August 1992) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	HM7 Dec	HM7 Apr	HM7 Aug	HM9 Dec	HM9 Apr	HM9 Aug	HM16 Dec	HM16 Apr	HM16 Aug	HM22 Dec	HM22 Apr	HM22 Aug	HM26 Dec	HM26 Apr	HM26 Aug	TOTALS
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2	13	13	7		7	33	13	13	60	20	7		13	13	40	252
ANNELIDA (worms)	Heteromastus filiformis	3	33	40	300	40	133	1393	140	167	573	20	47	113	540	40	173	3752
	Nereis succinea	5			7	153	313	547	13	7		13	40	20	33	60	67	1273
	Eteone heteropoda	8	13	47		7	27			53			27		33	53	7	267
	Polydora ligni	9						7				13					20	40
	Scolecolepides viridis	10	40	647	87	47	880	100	20	93	40	20	753	233	73	213	213	3459
	Streblospio benedicti	11	47	7	60	20	167	60	27	100	33	33	40	47	53	47	773	1514
	Limnodrilus hoffmeisteri	13																0
	Tubificoides sp.	14	20	7	33	13	113	767	20	7	47		20	133	173	33	2147	3533
	Capitella capitata	15			7													7
MOLLUSCA (mollusks)	Ischadium recurvus	16																0
	Congeria leucophaeta	17																0
	Macoma balthica	19		260	153		87	47	107	547	493		147	173	7	127	393	2541
	Macoma mitchelli	20	27	47	20		7		100	60	13	7	7	20	33	13	60	414
	Rangia cuneata	21	240	93	133	420	540	493	47	13	13	660	473	347	7		853	4332
	Mya arenaria	22					7		7				13					27
	Hydrobia sp.	23			487									493			167	1147
	Doridella obscura	25				13												13
ARTHROPODA (crustaceans)	Balanus improvisus	27				27	27	1280										1334
	Balanus subalbidus	28																0
	Leucon americanus	29																0
	Cyathura polita	30	87	87	533	80	133	180	167	120	533	40	47	387	87	27	320	2788
	Cassidinidea lunifrons	31				7												7
	Edotea triloba	33			7	13	7	7					7		20	7	67	135
	Gammarus palustris	35																0
	Leptocheirus plumulosus	36	587	933	613	13	467		1920	2400	1600	73	520	260	2740	2100	1733	15959
	Corophium lacustre	37	20	7		20	13			7		13	20		180	13	80	373
	Gammarus daiberi	38																0
	Gammarus tigrinus	39															13	13
	Melita nitida	40			47	13	73	80	13		107			7			33	353
	Chiridotea almyra	41			7												7	14
	Monoculodes edwardsi	42		20	33	20	20				53	13	20	27	7		47	260
	Chironomid sp.	43																0
	Rhithropanopeus harrisi	44			60	27	13	153			13			27			47	340
COELENTERA (hydroids)	Garveia franciscana	47									7							7
PLATYHELMIA (flatworms)	Stylochus ellipticus	48						7										7
BRYOZOA (bryozoans)	Membranipora tenuis	49	7			1020	307	727		153		7	20	7				2248
	Victorella pavida	50																0
	TOTAL NUMBERS		1214	2206	2474	1953	3341	5861	2594	3740	3585	932	2208	2294	3999	2748	7260	46409

TABLE 4: Number of benthic organisms per m squared (m2) found at the Nearfield Stations during the Eleventh Year (December 1991-August 1992) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	S1 XIF5710 Dec	S1 Apr	S1 Aug	S2 XIF5406 Dec	S2 Apr	S2 Aug	S3 XIF4811 Dec	S3 Apr	S3 Aug	S4 XIF4715 Dec	S4 Apr	S4 Aug
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2				7	47	13	27	33	80	40		60
ANNELIDA (worms)	Heteromastus filiformis	3	20	27	160	27	240	207	167	107	940	87	7	453
	Nereis succinea	5	27		80	247	313	133	7	7		153	167	120
	Eteone heteropoda	8		27		20	60		7	133			33	
	Polydora ligni	9	20			67						7		
	Scolecolepides viridis	10	53	4353	660	53	5153	13	27	1067	953	80	2640	220
	Streblospio benedicti	11	7	7	20	73	93	267	53	13	60	80	47	47
	Limnodrilus hoffmeisteri	13												
	Tubificoides sp.	14			87	27	140	113	40	13	167	20	7	80
	Capitella capitata	15												
MOLLUSCA (mollusks)	Ischadium recurvus	16												
	Congeria leucophaeta	17												
	Macoma balthica	19		27	20		93	13	13	613	720		120	400
	Macoma mitchelli	20	20	20	7				133	113	67	47	13	40
	Rangia cuneata	21	193	100	400	433	1100	53	140	267	393	993	787	320
	Mya arenaria	22					7						7	
	Hydrobia sp.	23			27									
	Doridella obscura	25				20						20		
ARTHROPODA (crustaceans)	Balanus improvisus	27			353	40		2920				13		893
	Balanus subalbidus	28				7	7							
	Leucon americanus	29												
	Cyathura polita	30	47	7	307	60	80	120	73	60	1033	80	73	300
	Cassidinidea lunifrons	31				53	13	7		13				
	Edotea triloba	33			20		7			27	33		7	
	Gammarus palustris	35												
	Leptocheirus plumulosus	36	27	213	547	13	340	20	593	1627	780	87	473	167
	Corophium lacustre	37	93	27	80	60	27	27	27	27		7	87	
	Gammarus daiberi	38												
	Gammarus tigrinus	39												
	Melita nitida	40			67	47	53	213		7	27	33	20	20
	Chirodotea almyra	41		7	7									
	Monoculodes edwardsi	42	27	13	47		7		7	13	27		7	13
	Chironomid sp.	43												
	Rithropanopeus harrisi	44			213	40	20	253		7		7	7	67
	Gammarus mucronatus	45												
COELENTERA (hydroids)	Garveia franciscana	47												
PLATYHELMIA (flatworms)	Stylochus ellipticus	48												
BRYOZOA (bryozoans)	Membranipora tenuis	49	7	7	427	2033	380	1280	7	7		307	213	73
	Victorella pavida	50			7			7						
	TOTAL NUMBERS		541	4835	3536	3347	8180	5659	1321	4354	5300	2041	4735	3273

TABLE 4: Number of benthic organisms per m squared (m2) found at the Nearfield Stations during
CONT. the Eleventh Year (December 1991-August 1992) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	S5 X1F4420 Dec	S5 Apr	S5 Aug	S6 X1F4327 Dec	S6 Apr	S6 Aug	S7 X1G5405 Dec	S7 Apr	S7 Aug	S8 X1F4124 Dec	S8 Apr	S8 Aug	TOTALS ALL STATIONS ALL DATES
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2	33	27	47	27	13	93	7			20	13	87	654
ANNELIDA (worms)	Heteromastus filiformis	3	60	53	567	100	267	667	73	47	233	13	13	200	4715
	Nereis succinea	5	7		33	20	7	20	467		133	20	100	20	2101
	Eteone heteropoda	8	7	247		53	140		53	13			27		820
	Polydora ligni	9				13	7		40			7			161
	Scolecolepides viridis	10	13	1660	33	20	340	60		3807	433	13	193	273	22117
	Streblospio benedicti	11	80	73	113	47	20	167	160	20	60			140	1667
	Limnodrilus hoffmeisteri	13													0
	Tubificoides sp.	14	7	20	413	20	27	427	167		147			260	2202
	Capitella capitata	15													0
MOLLUSCA (mollusks)	Ischadium recurvus	16													0
	Congeria leucophaeta	17													0
	Macoma balthica	19	20	1087	727		893	973		27		13	360	407	6726
	Macoma mitchelli	20	87	107	13	107	87	33		13		47	53	7	994
	Rangia cuneata	21	240	93	40	27	27	47	27	33	293	73	47	40	6166
	Mya arenaria	22													14
	Hydrobia sp.	23						7			7			7	46
	Doridella obscura	25							13						53
ARTHROPODA (crustaceans)	Balanus improvisus	27							247		1673				6139
	Balanus subalbidus	28							67						81
	Leucon americanus	29													0
	Cyathura polita	30	127	113	527	73	87	413	7		160	40	27	667	4501
	Cassidinidea lunifrons	31							93		33				212
	Edotea triloba	33	13	20	7	47		7	13		7		7	7	222
	Gammarus palustris	35													0
	Leptocheirus plumulosus	36	1133	1927	553	460	2467	2040		387	33	147	1267	667	15988
	Corophium lacustre	37	40	27		73	73	27	27	7	7			7	770
	Gammarus daiberi	38													0
	Gammarus tigrinus	39													0
	Melita nitida	40			27	7		20	87		67			27	722
	Chirodotea almyra	41								13					27
	Monoculodes edwardsi	42		60	20	13	27	27		33	13		40	47	441
	Chironomid sp.	43													0
	Rithropanopeus harrisi	44	7		47			33	60		120			33	914
	Gammarus mucronatus	45									47				47
COELENTERA (hydroids)	Garveia franciscana	47													0
PLATYHELMIA (flatworms)	Stylochus ellipticus	48													0
BRYOZOA (bryozoans)	Membranipora tenuis	49	7	7	1793		7		2640	7	507	13	7	7	9936
	Victorella pavida	50				7									21
	TOTAL NUMBERS		1861	5521	4960	1114	4509	5061	4468	4407	3993	406	2154	2883	88459

TABLE 5: Number of benthic organisms per m squared (m2) found at the Zinc Enriched Stations during the Eleventh Year (December 1991 - August 1992) of Benthic Studies at HMI.

X162560

PHYLUM	SPECIES NAME	#	G5 Dec	G5 Apr	G5 Aug	G25 Dec	G25 Apr	G25 Aug	G84 Dec	G84 Apr	G84 Aug	HM12 Dec	HM12 Apr	HM12 Aug	TOTALS
			XIF 4774			XIF4712/4405			X163570			XIF5805			
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2	27	13	20	33	20	93	87	60	7	40	33	67	440
ANNELIDA (worms)	Heteromastus filiformis	3	67	7	380	60	67	607	420	453	127	93	100	473	2400
	Nereis succinea	5	7	33		247	227	273	20	20	40	160		13	1000
	Eteone heteropoda	8	7	13		13	13		7				67		120
	Polydora ligni	9													0
	Scolecolepides viridis	10	33	400	100	13	1733	20	67	73	33	20	787	53	3332
	Streblospio benedicti	11	53	20	53	93	20	33	13	13	27	60	13	27	425
	Limnodrilus hoffmeisteri	13			13										13
	Tubificoides sp.	14	33		60	73		60	53	47	7	20	13		386
	Capitella capitata	15													0
MOLLUSCA (mollusks)	Ischadium recurvus	16													0
	Congeria leucophaeta	17													0
	Littoridinops sp.	18			7										7
	Macoma balthica	19	27	527	573	13	120	107	787	460		73	187	487	3361
	Macoma mitchelli	20	60	93	20	13	13		40	27	13	33	33	13	358
	Rangia cuneata	21	260	20	33	553	380	127	93	33	27	1140	60	140	2866
	Mya arenaria	22	7	7			7						7		28
	Hydrobia sp.	23			20			7						20	47
	Doridella obscura	25				7									7
ARTHROPODA (crustaceans)	Balanus improvisus	27				33	7	853				7		7	907
	Balanus subalbidus	28													0
	Leucon americanus	29													0
	Cyathura polita	30	107	60	633	140	147	127	240	153	73	73	113	426	2292
	Cassidinidea lunifrons	31				7									7
	Edotea triloba	33	13		20	7								7	47
	Gammarus palustris	35													0
	Leptocheirus plumulosus	36	1213	1260	633	20	460	7	1800	2100	520	73	1300	427	9853
	Corophium lacustre	37	33			7	13			13	7		7		80
	Gammarus daiberi	38													0
	Gammarus tigrinus	39													0
	Melita nitida	40	20		13		27	33	7	20				7	127
	Chirodotea almyra	41													0
	Monoculodes edwardsi	42		20	40		7	7		20		13	20	20	147
	Chironomid sp.	43												7	7
	Rithropanopeus harrisi	44			27	7	7	120						13	174
COELENTERA (hydroids)	Garveia franciscana	47													0
PLATYHELMIA (flatworms)	Stylochus ellipticus	48													0
BRYOZOA (bryozoans)	Membranipora tenuis	49	13			260	427	1160			7	47		13	1967
	Victorella pavida	50	13												13
	TOTAL NUMBERS		1993	2493	2845	1619	3715	3674	3634	3492	888	1852	2740	2220	30985

TABLE 6: Salinity (in parts/thousand-0/00), temperature (in degrees centigrade-oC), and depth (in feet-ft.) data for the benthic sampling stations on the 3 collection dates during the Eleventh Year of Benthic Studies at at HMI.

CBL STA. ID	STATE STA. #	DECEMBER 91			APRIL 92			AUGUST 92		
		SAL.	TEMP.	DEPTH	SAL.	TEMP.	DEPTH	SAL.	TEMP.	DEPTH
R1	XIF4811	**NS	NS	NS	NS	NS	NS	NS	NS	NS
R2	X1F4813	*NR	NR	NR	4.5	9	NR	NR	NR	NR
R3	X1F4514	NR	NR	NR	NR	NR	NR	NR	NR	NR
R4	XIF4518	NR	NR	NR	NR	NR	NR	NR	NR	NR
R5	XIF3636	NR	NR	NR	NR	NR	NR	NR	NR	NR
S1	XIF5710	4	5.5	5	NR	NR	6	2	23	7
S2	XIF5406	4	6	9	NR	NR	12	2	23	13
S3	XIF4811	4	5.5	15	5	9	15	3	23	16
S4	XIF4715	4	6	14	NR	NR	12	3	23	14
S5	XIF4420	2	5.5	17	NR	NR	17	3.5	23	18
S6	XIF4327	4	6	8	3	10	9	3.5	23	10
S7	XIG5405	4	5.5	10	NR	NR	11	2	23	10
S8	XIF4124	5	5.5	12	4	9	14	4	23	13
HM7	XIF6388	4	5.5	9	NR	NR	9	2	24	10
HM9	XIF3297	4	6	13	4	9	15	2	25.5	16
HM12	XIF5805	4	6.5	14	NR	NR	15	4	23.5	16
HM16	XIF3325	8	6	14	6	8.5	17	4	23	18
HM22	XIG7689	4	6	9	0.5	9	10	2	23	13
HM26	XIF5145	1	5	15	NR	NR	NR	3.5	23	14
G5	XIF4221	4	5	12	5.8	7.6	15	3.5	23	16
G25	XIF4405	3	5	14	4	9	15	2.5	23	16
G84	XIG3570	4	6	15	3	9	16	4.5	24	11

*NR= NOT RECORDED **NS= NOT SAMPLED

TABLE 7. Number of species and the total number of individuals collected in three grab samples (0.05m2 each) at the infaunal stations for DECEMBER 1991. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for the Eleventh Year of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINANCE FACTOR S.I.
NEARFIELD					
S1	Sand (?)	12	81	2.931	0.187
S2	Shell	19	502	2.258	0.394
S3	Silt/Clay	15	198	2.707	0.247
S4	Silt/Clay	17	306	2.694	0.274
S5	Silt/Clay	16	279	2.149	0.398
S6	Silt/Clay	17	167	3.086	0.205
S7	Shell	18	670	2.152	0.423
S8	Silt/Clay	11	61	2.835	0.195
REFERENCE					
HM 7	Silt/Clay	12	182	2.143	0.367
HM 9	Shell	18	293	2.361	0.329
HM16	Silt/Clay	13	389	1.593	0.559
HM22	Silt/Clay	13	140	1.817	0.512
BACK RIVER REFERENCE					
HM26	Silt/Clay	15	600	1.755	0.493
ZINC ENRICHED					
G5	Silt/Clay	18	299	2.258	0.395
G25	Silt/Clay	19	243	3.001	0.185
G84	Silt/Clay	13	545	2.234	0.312
HM12	Silt/Clay	14	278	2.246	0.396

TABLE 8. Number of species and the total number of individuals collected in three grab samples (0.05m2 each) at the infaunal stations for APRIL 1992. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for the Eleventh Year of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINANCE FACTOR S.I.
NEARFIELD					
S1	Sand (?)	13	725	0.725	0.814
S2	Shell	20	1227	2.087	0.422
S3	Silt/Clay	19	653	2.538	0.241
S4	Silt/Clay	18	710	2.204	0.354
S5	Silt/Clay	15	828	2.401	0.255
S6	Silt/Clay	16	676	2.163	0.355
S7	Shell	12	661	0.851	0.754
S8	Silt/Clay	13	323	2.058	0.386
REFERENCE					
HM 7	Silt/Clay	13	331	2.306	0.283
HM 9	Shell	20	501	3.266	0.141
HM16	Silt/Clay	14	561	1.927	0.440
HM22	Silt/Clay	17	331	2.646	0.225
BACK RIVER REFERENCE					
HM26	Silt/Clay	13	412	4.482	0.594
ZINC ENRICHED					
G5	Silt/Clay	13	374	2.075	0.336
G25	Silt/Clay	18	557	2.570	0.265
G84	Silt/Clay	14	524	2.015	0.399
HM12	Silt/Clay	14	411	2.230	0.317

TABLE 9. Number of species and the total number of individuals collected in three grab samples (0.05m2 each) at the infaunal stations for AUGUST 1992. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for the Eleventh Year of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINANCE FACTOR S.I.
NEARFIELD					
S1	Sand (?)	20	530	3.478	0.112
S2	Shell	17	849	2.310	0.326
S3	Silt/Clay	13	795	2.961	0.149
S4	Silt/Clay	16	491	3.292	0.137
S5	Silt/Clay	16	744	2.802	0.197
S6	Silt/Clay	17	759	2.637	0.233
S7	Shell	18	599	2.913	0.218
S8	Silt/Clay	18	432	3.087	0.153
REFERENCE					
HM 7	Silt/Clay	18	371	3.102	0.152
HM 9	Shell	16	879	3.008	0.155
HM16	Silt/Clay	14	538	2.408	0.267
HM22	Silt/Clay	15	344	3.186	0.132
BACK RIVER REFERENCE					
HM26	Silt/Clay	21	1089	3.032	0.177
ZINC ENRICHED					
G5	Silt/Clay	17	397	2.833	0.185
G25	Silt/Clay	16	551	2.837	0.196
G84	Silt/Clay	12	133	2.137	0.377
HM12	Silt/Clay	18	333	2.880	0.173

TABLE 10. The Ryan-Einot-Gabriel-Welsch Multiple F test of significance among mean number of individuals per station for stations sampled in December 1991. Subsets show groupings of stations different at (P<0.05). Stations in a separate vertical row and column are significantly different from others. Eleventh Year of Benthic Studies at HMI.

DECEMBER 1991

SUBSET	STATION NUMBERS																
1	S7	HM26	G84	S2	HM16	S4											
2		HM26	G84	S2	HM16	S4	G5	HM9									
3			G84	S2	HM16	S4	G5	HM9	S5	HM12	G25	S3	HM7				
4				S2	HM16	S4	G5	HM9	S5	HM12	G25	S3	HM7	S6	HM22	S1	
5					HM16	S4	G5	HM9	S5	HM12	G25	S3	HM7	S6	HM22	S1	S8

ANALYSIS OF VARIANCE

SOURCE	D.F	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB.
BETWEEN GROUPS	16	170523	10658	5.5	0.0001
WITHIN GROUPS	34	65861	1937		
TOTAL	50	236384			

TABLE 11. The Ryan-Einot-Gabriel-Welsch Multiple F test of significance among mean number of individuals per station for stations sampled in April 1992. Subsets show groupings of different stations ($P<0.05$). Stations in a separate vertical row and column are significantly different from others. Eleventh Year of Benthic Studies at HMI.

APRIL 1992

SUBSET	STATION NUMBERS																
1	S2	S5	S1														
2		S5	S1	S4	S6	S7	S3	HM16	G25	G84	HM9	HM26	HM12	G5	HM22	HM7	S8

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB.
BETWEEN GROUP	16	279502	17469	3.93	0.0004
WITHIN GROUPS	34	151258	4449		
TOTAL	50	430760			

TABLE 12. The Ryan-Einot-Gabriel-Welsch Multiple F test of significance among mean number of individuals per station for stations sampled in August 1992. Subsets show groupings of stations different at ($P<0.05$). Stations in a separate vertical row and column are significantly different from others. Eleventh Year of Benthic Studies at HMI.

AUGUST 1992

SUBSET	STATION NUMBERS															
1	HM26	HM9	S2	S3	S6	S5	S7									
2		HM9	S2	S3	S6	S5	S7	G25	HM16	S1	S4					
3			S2	S3	S6	S5	S7	G25	HM16	S1	S4	S8				
4				S3	S6	S5	S7	G25	HM16	S1	S4	S8	HM7			
5					S6	S5	S7	G25	HM16	S1	S4	S8	HM7	HM22	HM12	
6							S7	G25	HM16	S1	S4	S8	HM7	HM22	HM12	G84

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	16	318313	19895	6.24	0.0001
WITHIN GROUPS	34	108398	3188		
TOTAL	50	426711			

TABLE 13. Results of Friedman's non-parametric test for differences in the abundances of (11) selected species between stations with silt/clay substrates for the Eleventh Year of Benthic Studies at HMI. (Silt/clay stations are: NEARFIELD STAS.- S3,S4,S5,S6,S8; REFERENCE STAS.- HM7, HM16, HM22; ZINC ENRICHED STAS.-G5,G25,G34,HM12.)

	SOURCE	D.F.	CHI-SQUARED	CHI-SQUARED (0.05)
DEC 1991				
	NEARFIELD	4	9.91*	9.49
	REFERENCE	2	1.68	5.99
	ZINC ENRICHED	3	2.86	7.81
	NEARFIELD & REFERENCE	7	15.57*	14.07
	ZINC ENRICHED & REFERENCE	6	11.36	12.59
APR 1992				
	NEARFIELD	4	11.27*	9.49
	REFERENCE	2	1.77	5.99
	ZINC ENRICHED	3	4.77	7.81
	NEARFIELD & REFERENCE	7	19.01*	14.07
	ZINC ENRICHED & REFERENCE	6	6.22	12.59
AUG 1992				
	NEARFIELD	4	8.18	9.49
	REFERENCE	2	0.32	5.99
	ZINC ENRICHED	3	4.01	7.81
	NEARFIELD & REFERENCE	7	16.79*	14.07
	ZINC ENRICHED & REFERENCE	6	5.01	12.59

*SIGNIFICANT DIFFERENCE AT THE 0.05 LEVEL

TABLE 14. Benthic species listed in descending order of density found on the piers and pilings surrounding HMI and at a reference piling at 1m and 2-3m depth for the three sampling periods for the Eleventh Year of Benthic Studies at HMI.

	STATIONS R2-R4 DEPTH (M)		REFERENCE STATION R5 DEPTH (M)	
DEC 1991	1.0 m	2-3 m	1.0 m	2-3 m
	Corophium	Corophium	Victorella	Corophium
	Polydora	Polydora	Corophium	Polydora
	Nereis	Membranipora	Polydora	Victorella
	Victorella	B. improvisus	Membranipora	Nereis
	B. subalbidus	Nereis	Nereis	Membranipora
	B. improvisus	B. subalbidus	B. subalbidus	B. subalbidus
APR 1992	1.0 m	2-3 m	1.0 m	2-3 m
	Corophium	Corophium	Corophium	Corophium
	Polydora	Polydora	Polydora	Membranipora
	B. subalbidus	B. improvisus	Membranipora	Garveia
	G. tigrinus	Nereis	Victorella	Nereis
	Nereis	Membranipora	Nereis	Polydora
	B. improvisus	Victorella	Cordylophora	B. improvisus
AUG 1992	1.0 m	2-3 m	1.0 m	2-3 m
	Corophium	Corophium	Corophium	Victorella
	Victorella	Victorella	Victorella	Corophium
	Cordylophora	Garveia	Cordylophora	Cordylophora
	Rithropanopeus	B. improvisus	Nereis	Garveia
	B. improvisus	Rithropanopeus	B. improvisus	Nereis
	Nereis	Nereis	Rithropanopeus	B. improvisus

ADDENDUM

In conjunction with the eleventh-year Benthic and Sedimentary Monitoring Programs, scientists from Maryland Department of the Environment (MDE) conducted laboratory toxicity studies. The studies were conducted with freshly collected sediments from the spring cruises for the Benthic Program on 6 April 1992 of the University of Maryland System's Chesapeake Biological Laboratory (CBL), and the Maryland Geological Survey (MGS) cruises on 19 April 1992. The appended report provided by MDE presents the findings of these laboratory studies.

TOXICITY ASSESSMENT OF SEDIMENTS SURROUNDING THE HART-MILLER ISLAND DREDGED MATERIAL CONTAINMENT FACILITY

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INTRODUCTION

For approximately ten years, the environmental impact of the construction and operation of the Hart-Miller Island Dredged Material Containment Facility has been assessed by monitoring benthic macroinvertebrate community structure and select physical and geochemical properties of sediments in the surrounding area. In 1989 during the eighth year of monitoring, enriched levels of zinc were reported in surficial sediments surrounding the Facility. The biological impact of this zinc enrichment, and possibly that of other contaminants that may be present (*e.g.*, limited organic chemical data exists for this area), is difficult to evaluate from chemical and benthic community analyses alone. Chemical analyses measure the concentration of sediment contaminants, but the complexity of sediment-contaminant interactions makes it difficult to predict bioavailability and toxicity of the identified contaminants (Hale and Huggett, 1988; Jenne and Zachara, 1987). Ecological surveys of benthic community structure may fail to discriminate among community changes due to pollution (*e.g.*, toxic chemicals); water quality fluctuations (*e.g.*, dissolved oxygen, temperature, pH, salinity); differences in physical parameters (*e.g.*, sediment characteristics, water depth); and biotic factors (*e.g.*, competition, predation and recruitment).

Sediment toxicity tests were undertaken during the eleventh year of the Hart-Miller Island Dredged Material Containment Facility studies to provide direct, quantifiable information on the biological effects of sediment-associated contaminants (Chapman and Long, 1983). This report describes results of these tests, including statistical analyses and interpretation.

MATERIALS AND METHODS

Test sediments were collected on 6 and 10 April 1992, coinciding with the spring field sampling efforts of the Chesapeake Biological Laboratory and Maryland Geological Survey, respectively. Test stations were chosen in the area of observed zinc enrichment or in proximity to spillways (Figure 1). Reference sediment was collected at station HM22, a station located outside the area of enrichment (Figure 1). The reference sediment is used to assess localized sediment conditions exclusive of the chemical(s) of concern, thereby providing a site-specific basis for comparison. Surficial sediment, the approximate top 2 cm of two or three benthic grabs (Petersen or Ponar dredge), was collected with a stainless steel spoon. The collected sediment was mixed manually in a stainless steel bowl until homogenous in texture and color. Aliquots for use in the crustacean, amphipod sediment toxicity test were placed in glass containers covered with teflon-lined lids. Sediments for porewater toxicity tests to bacteria using the Microtox® Analyzer system were placed in centrifuge tubes. The collected sediments were kept on ice or refrigerated (4°C) until subsequent analyses. All glassware used for sediment samples was cleaned by rinsing sequentially in 5% HCl, distilled water, acetone and distilled water to remove residual chemicals (EAD, 1990). In addition, the stainless steel bowl and spoon were rinsed in ambient water prior to collection at each station. Bottom water quality parameters (dissolved oxygen, temperature, pH, and salinity) and depth were measured with a Hydrolab Surveyor II.

Amphipod Sediment Toxicity Test

A 28-day partial life cycle test with the crustacean amphipod, *Hyalella azteca*, was conducted according to protocols developed under the guidance of the American Society for Testing and Materials (1991; EAD, 1990). Amphipod toxicity tests were initiated within 4 days of sediment collection. Tests with samples collected on 6 April (S1, G5, G25, HM12, and HM22) and 10 April (BC4 and G9) were initiated on 8 April and 14 April, respectively. Experimental endpoints were survival and growth, as measured by amphipod length. Experimental chambers consisted of 1-L glass jars containing water and sediment in a ratio of 4:1 (v/v). Aeration at a rate of approximately two bubbles per second was provided by a 1-ml glass pipette. Test water was Instant Ocean® prepared and diluted to a salinity of 7 ppt with a 4:1 (v/v) mixture of glass-distilled and spring water. Control sediment, defined as sediment known to be non-toxic to, and within the geochemical requirements of, the test organism (ASTM, 1991) was collected from the Corsica River on Maryland's eastern shore. This sediment was wet-pressed through a 500-μm sieve to remove indigenous organisms and debris. Control sediment was included in both tests (referred to as CON1 and CON2 for tests initiated on 8 and 14 April, respectively). Sediments and water were allowed to equilibrate for 24 hr before the random addition of 20 laboratory-cultured juvenile *H. azteca* amphipods per replicate jar. Amphipods were obtained by selecting those retained on a 250-μm sieve after passing through a 500-μm sieve. There were 4 replicates per treatment. Water temperature was maintained at 20°C (± 2°C) and the photoperiod was 16:8 light:dark. Amphipods were fed a 1:1 (w/w) mixture of TetraMin® and Tetra® Conditioning Food three times per week. Each replicate received 6 mg per feeding period for the first 10 days and 12 mg per feeding thereafter. One-third of the overlying water was replaced twice weekly. Water quality parameters (dissolved oxygen concentration, pH, temperature, and salinity) were measured daily in one replicate per treatment on a rotating basis so that measurements were taken on each replicate at least six times over the course of the exposure period. On the first and last day of the experiment, water quality parameters were measured in all experimental chambers, except pH, which was measured in one replicate per treatment.

At the end of the 28-day exposure period, amphipods were retrieved by sieving the contents of each test chamber through a 500-μm sieve. The contents remaining on the sieve were rinsed into sorting pans where adults were recorded as alive or dead. Missing individuals or those exhibiting no movement of limbs or antennae after gentle prodding with a blunt probe were considered dead. Surviving animals were preserved in 95% denatured ethanol for subsequent length measurements. An ocular micrometer in the eyepiece of the microscope was used to measure adult body length from the base of the first antenna to the base of the third pleon segment along the dorsal surface.

Prior to statistical comparisons, survival and length data were checked for conformation to the parametric statistical assumptions of normality and homogeneity of variance using Shapiro-Wilks and Bartlett's tests, respectively. Length data were found to be heteroscedastic and were transformed using the natural log transformation. Means were compared via analysis of variance (ANOVA) followed by pairwise contrasts between experimental treatments and the reference treatment (station HM22). In order to maintain a comparison-wise alpha = 0.05, significance of individual contrasts was determined by the sequential Bonferroni technique as described by Rice (1989). These analyses were performed using the TOXSTAT and SYSTAT statistical software packages (Gulley *et al.*, 1989; Wilkinson, 1988).

Microtox Porewater Test

Sediment porewater was obtained by centrifuging samples in 50-ml containers for 10 min at 2000 rpm. Samples were held no longer than 10 d prior to centrifugation. The supernatant was tested using the Microtox® 100% Test protocol (Microbics Corporation, 1992, Carlsbad, CA) within one hr of centrifuging. In this test, luminescent bacteria, *Photobacterium phosphoreum*, were exposed to the following dilutions of sediment porewater: 90%, 45%, 22% and 11%. The Microtox®500 Analyzer measured the light emission of the bacteria after 5 and 15-min exposures to the porewater dilutions. The reduction in luminescence is proportional to the toxicity of the sample (Microbics Corporation, 1992). Results were evaluated by the determination of an EC50, the concentration of porewater at which there was a 50% reduction in light output, for both 5 and 15-min exposures.

RESULTS AND DISCUSSION

Bottom water quality parameters and qualitative sediment descriptions for each station are shown in Table 1. Indigenous benthic organisms were observed in the sediments from almost all stations.

Amphipod Sediment Toxicity Test

Water quality conditions in every replicate of all treatments were acceptable during the exposure period (Table 2). Mean survival of *H. azteca* exposed to control sediment (from the Corsica River) was 94.4% (e.d. = 6.2; Figure 2). This value is above the recommended minimum acceptable limit of 80% (ASTM, 1991; EAD, 1990) and indicates no problems associated with test organism health or test conditions. Mean survival of *H. azteca* exposed to reference sediment (HM22) was low (28.8%) and highly variable (s.d. = 17.0; Figure 2). Most likely, poor survival in reference sediment was due to interactions (predation, competition) between experimental and indigenous organisms. Clams (*e.g.*, *Rangia cuneata*, *Macoma balthica*), polychaete worms (*e.g.*, *Nereis* spp., *Scolecolepides viridis*, *Streblospio benedicti*), and other crustaceans (*e.g.*, *Leptocheirus plumulosus*, mud crab) were observed in the reference and test sediments. Similarly, survival in most test sediments was low and highly variable, with the exception of station S1 (Figure 2). Mean survival in S1 sediment (83.7%, s.d. = 4.8) was significantly higher than in reference sediment (HM22). Interestingly, this sandy sediment, collected just north of the spillway on the north side of the island approximately 100 yd offshore (Figure 1), was almost devoid of indigenous organisms. Only a few small polychaetes (*S. benedicti*, *Eteone* sp.) were found in each replicate. That survival in S1 sediment was high and quite similar to survival in control sediment (also devoid of indigenous organisms) is consistent with the hypothesis that mortality observed in the remaining test and reference sediments is primarily due to interference from indigenous species. Mortality due to chemical toxicity would most likely have been manifested as higher mortality in test than reference sediment; however, this difference was not observed.

Comparison of mean amphipod length in reference sediment to test sediments indicated amphipods were significantly smaller in S1 and G5 sediments (Figure 3). However, since reference survival was poor, these results were interpreted with caution. Consequently, mean amphipod lengths in test and reference sediments were also compared to that in the appropriate control sediment. Results indicated that mean amphipod length in reference (HM22), S1, G5 and G25 sediments was significantly less than in control sediment. It is unclear at this time whether these growth differences reflect sublethal effects of toxicity or detrimental interactions with indigenous organisms.

Microtox Porewater Test

Results of the Microtox® bacterial luminescence assay of sediment porewater indicated no toxicity associated with porewater from the sediment samples. No reduction of light emission was observed in any porewater concentration from any of the stations.

At present, based upon the results of these laboratory studies, there is no readily apparent toxicity associated with sediments surrounding the Hart-Miller Island Dredged Material Containment Facility. Low survival of *H. azteca* in reference and all but one test sediment is most likely attributable to interspecific interactions (*i.e.*, predation, competition) with indigenous organisms, rather than chemical concentration. Current sediment toxicity test protocols recommend minimizing sediment manipulation procedures (*e.g.*, sieving), if the purpose of the test is to assess *in situ* sediment toxicity. Sieving can alter the physical and chemical properties of the sediment, resulting in unpredictable effects on contaminant bioavailability and hence, toxicity (Ingersoll and Nelson, 1990; DeWitt *et al.*, 1988). Other methods, including the application of heat, antibiotics, and gamma radiation have been used to destroy biological organisms in sediment (Ingersoll and Nelson, 1990); but, the caveat mentioned above still applies. Nonetheless, in light of the difficulty encountered in the interpretation of results of this study, we recommend sieving sediments containing numerous indigenous organism in future toxicity assessments. In our estimation, the benefit of eliminating the confounding effects of these organisms outweighs the potential alteration of sediment toxicity.

The results of the Microtox® test indicated no sediment porewater-associated toxicity. This result supports the interpretation that effects on survival observed in the amphipod test were due to interspecific interactions and not a result of chemical toxicity. Apparent effects on amphipod growth were more difficult to interpret. Comparison of mean amphipod length in reference sediment (HM22) to that in test sediments indicated amphipods in S1 and G5 were significantly smaller. However, these results were cautiously interpreted because of low reference survival. Subsequent comparison of mean amphipod length in control sediment to both reference and test sediments indicted amphipods were significantly smaller in the reference (HM22), S1, G5 and G25 sediments than in control sediment. The relative contribution of interspecific interactions versus chemical contamination to the apparent growth effects is difficult to distinguish. If we assume that HM22 was an appropriate reference (*i.e.*, a sediment reflective of background conditions in the area but not contaminated by the chemical(s) of concern), then we can hypothesize that at least some apparent growth effects were due to interspecific interactions. However, the degree to which these interactions affected amphipod growth and survival can only be ascertained by integrating these toxicity test data with results of the other two study components -sediment chemistry and benthic community structure.

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Table 1. Ambient bottom water quality measurements and qualitative sediment descriptions for the Hart-Miller Island stations. Station identification numbers refer to Maryland Geological Survey or Chesapeake Biological Laboratory designations. Stations G5, G25, HM12 and S1 were sampled on 6 April 1992; G9 and BC4 were sampled on 10 April 1992.

Station	Depth (m)	Temp (°C)	D.O. (ppm)	Salinity (ppt)	pH	Sediment Description
G5	9.5	7.58	10.76	9.5	7.23	Muddy clay; thin, brown oxidized layer over dark grey/black; fluid top layer.
G25	4.9	7.44	9.65	8.8	7.68	Muddy clay; brown oxidized layer over dark grey/black; fluid top layer; much shell debris (*Rangia*, *Macoma*); live amphipod (*Leptocheirus*).
HM12	4.4	7.03	9.82	8.7	7.62	Muddy clay/silt; brown oxidized layer over dark grey; semi-fluid top layer, compact underneath; some shell, live *Leptocheirus*.
HM22	3.5	7.56	10.25	3.8	7.74	Muddy clay; brown oxidized layer over dark grey; fairly compact; live *Leptocheirus*.
S1	No Hydrolab measurements taken at this station.					Sandy; no obvious oxidized layer; live Leptocheirus.
BC4	No Hydrolab measurements taken at this station.					Muddy clay; thin, brown oxidized layer over dark grey; high density of shell material; live *Leptocheirus* and *Gammarus*.
G9	No Hydrolab measurements taken at this station.					Muddy clay; light brown oxidized layer over dark grey with black streaks; much shell debris.

Table 2. Mean (standard deviation in parentheses) measured overlying water quality for each treatment of the 28-d amphipod sediment toxicity test. Each parameter was measured daily in one replicate per treatment. CON1 and CON2 refer to the control sediment included in tests of sediments collected on 6 and 10 April 1992, respectively.

Treatment	Temp. (°C)	D.O. (ppm)	Salinity (ppt)	pH
CON1	20.3 (.42)	7.3 (.72)	7.0 (.11)	7.79 (.16)
CON2	20.2 (.58)	7.3 (.84)	7.1 (.20)	7.81 (.16)
S1	20.4 (.50)	7.4 (.71)	6.8 (.15)	7.66 (.13)
G5	20.4 (.43)	7.2 (.65)	6.9 (.16)	7.68 (.14)
G25	20.4 (.43)	7.2 (.60)	6.9 (.13)	7.69 (.10)
HM12	20.4 (.41)	7.3 (.68)	6.9 (.10)	7.63 (.08)
HM22 (REF)	20.4 (.44)	7.3 (.70)	6.7 (.19)	7.62 (.07)
BC4	20.3 (.61)	6.7 (.69)	6.9 (.17)	7.76 (.14)
G9	20.3 (.55)	7.2 (.59)	6.9 (.09)	7.76 (.13)

FIGURES

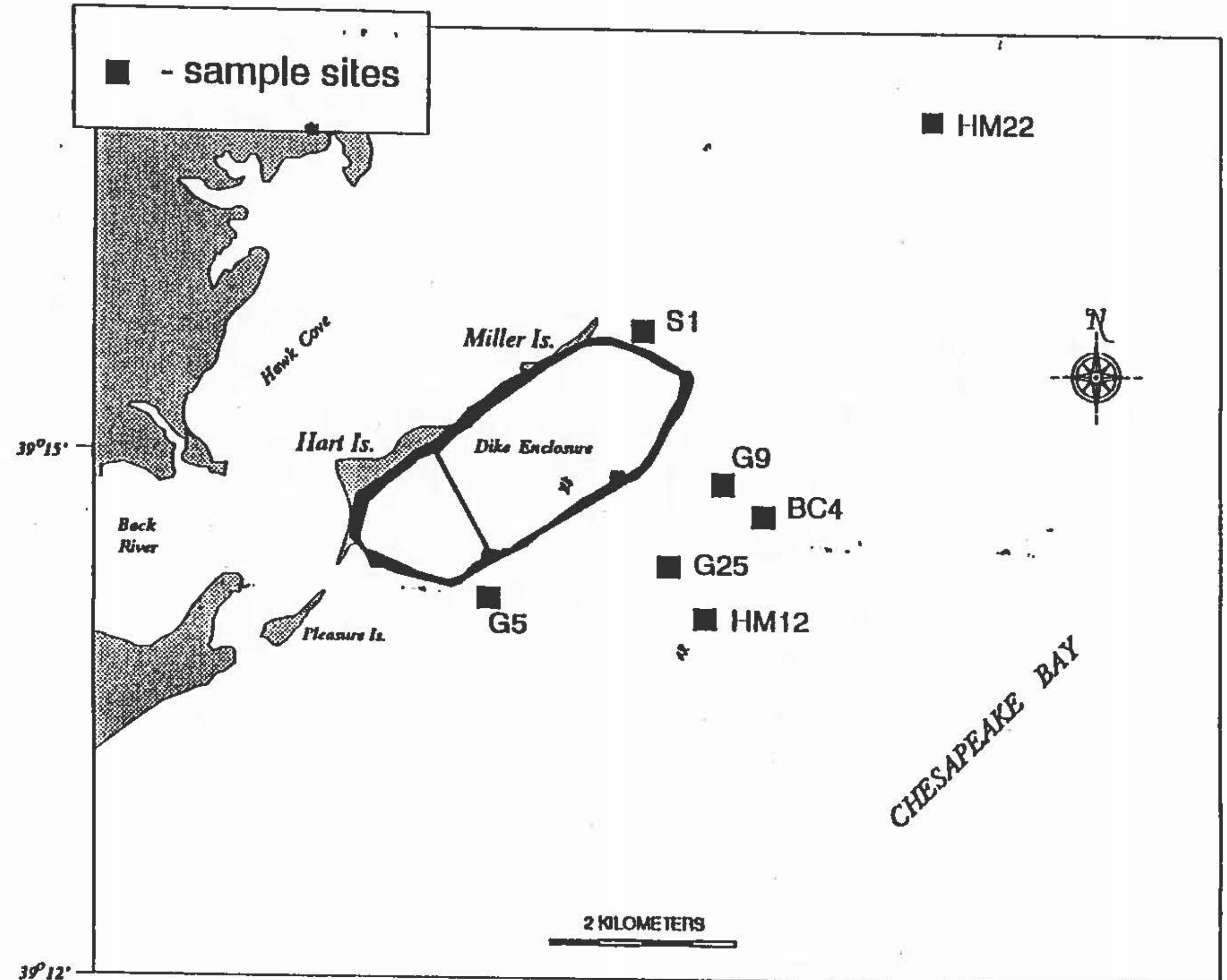

Figure 1. Maryland Geological Survey map of HMI modified to show approximate locations of sediment toxicity test samples collected 6 and 10 April 1992.

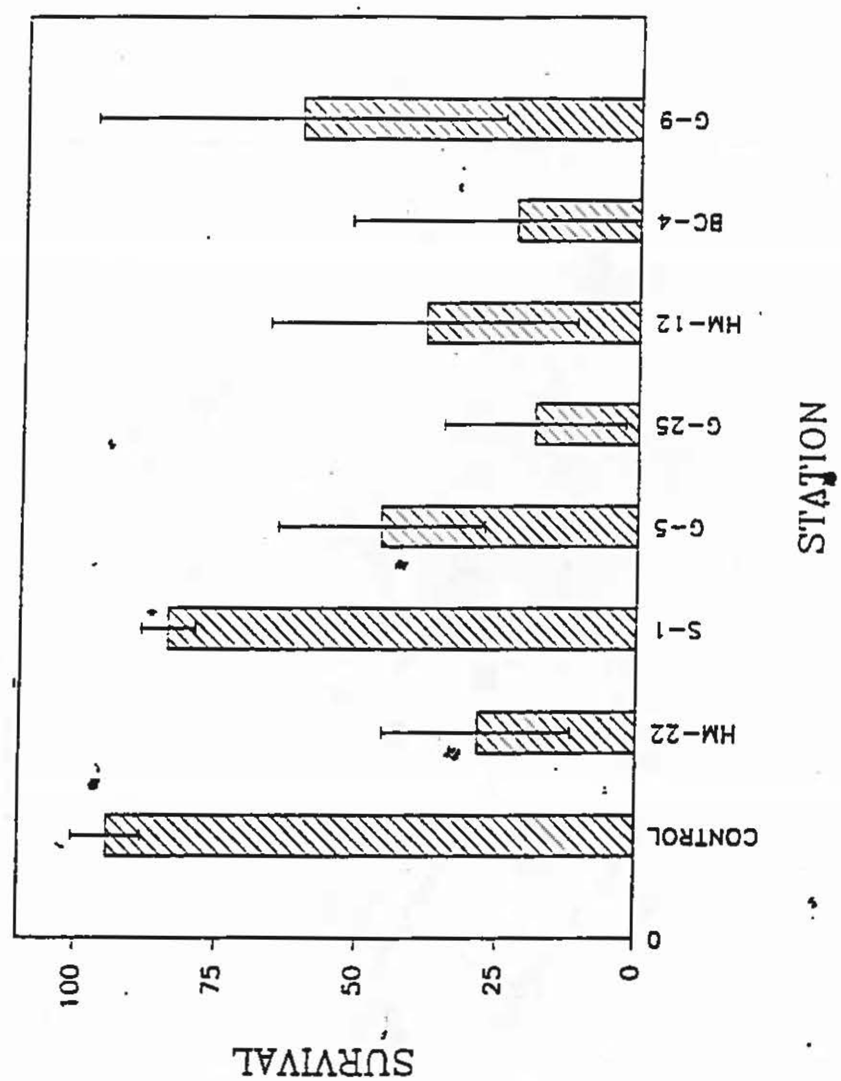

Figure 2. Mean survival (± standard deviation as indicated by error bars) of *Hyalella azteca* exposed for 28 d to sediments collected around the Hart-Miller Island Dredged Material Containment Facility. Asterisk indicates significant difference in mortality of test sediment when compared to reference sediment (HM22).

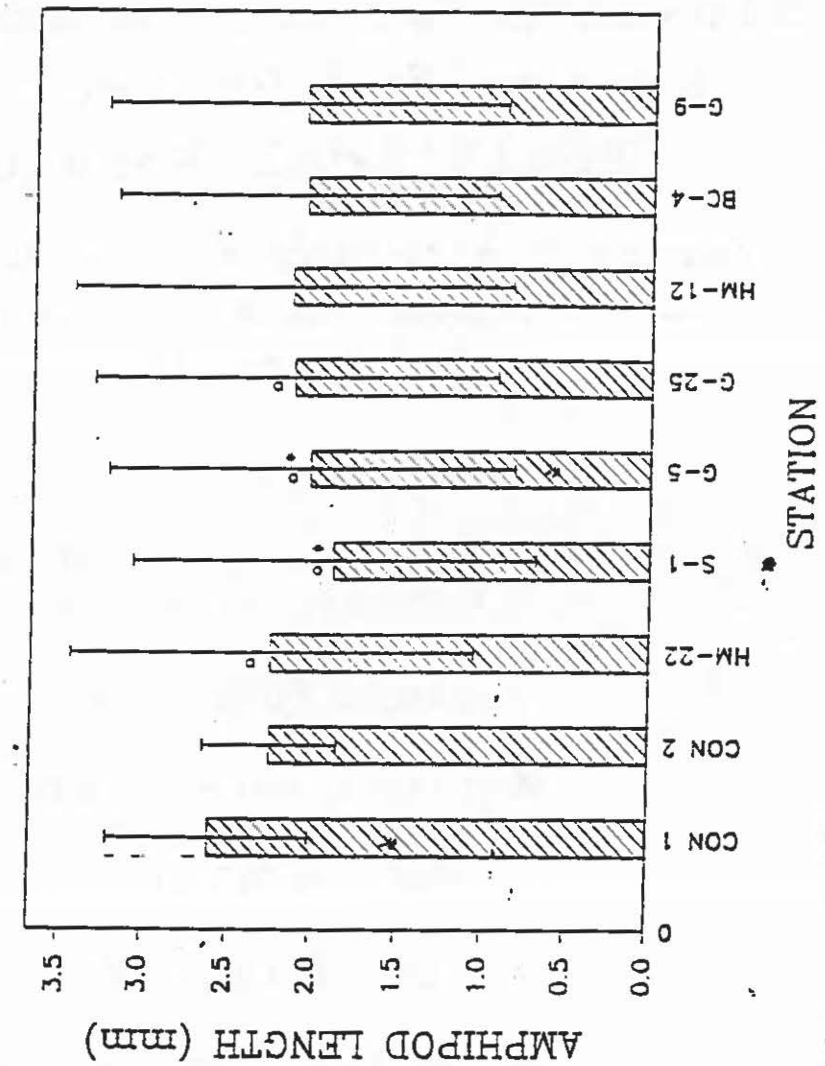

Figure 3. Mean length (± standard deviation as indicated by error bars) of *Hyalella azteca* exposed for 28 d to sediments collected around the Hart-Miller Island Dredged Material Containment Facility. CON1 and CON2 refer to length data for control sediment amphipods from tests of sediments that were collected on 6 and 10 April, respectively. HM22 serves as the reference site. Asterisks indicate significant differences between test sediments and the references sediment, while circles indicate significant length differences between test sediment and the appropriate control sediment (*i.e.*, CON1 for S1, G5, G25, HM12 and HM22; and CON2 for BC4 and G9).

Eleventh Annual Interpretive Report for Project IV: Analytical Services

Exterior Monitoring at the Hart-Miller Island Dredged Material Containment Facility (HMI)

For:

Maryland Department of Natural Resources
Tidewater Administration

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INTRODUCTION

A long-term monitoring program has been conducted since 1981 in order to examine the possible impacts of the construction and operation of the Hart-Miller Island Dredged Material Containment Facility (HMI). Biological studies have monitored the abundance and diversity of the benthos populations while geological studies have characterized the nature of the currents and sediments. Chemical studies have measured levels of selected trace metal and organic contaminants in sediments and biota. The Coastal and Estuarine Geology Program of the Maryland Geological Survey is responsible for the collection and characterization of sediment samples, while the Benthic Project is directed by the Chesapeake Biological Laboratory and is responsible for the collection and characterization of the benthic biota samples. This interpretive report deals solely with contaminant levels in biological samples. Data on contaminant levels in sediments can be found under the Project II report on the sedimentary environment.

Analyses have been performed since the inception of the program, with the first three years (pre-operation 1981-1983) used as a baseline with which to compare subsequent operational years (though no chemical analyses were performed from August 1983 - August 1984). The sampling program since 1984 has evolved from modest in 1984-1987 to more intensive sampling in years 1987 and 1988 and back to less intensive sampling in the most recent surveys. In previous reports, the data set was comprised of three sampling times; Winter (December), Spring (April), and Fall (August). In year 11, the data set is comprised of only one sampling date (April 1992).

METHODS

Sampling and Chemical Analyses

Thirteen benthic stations were sampled for chemical analysis of biota (Figure 1). These represent a subset of the overall sampling stations for the benthos project. Benthos stations fall into three categories. Stations G5, G25, G84, and HM12 are stations which have been added in order to examine the zinc enrichment issue described under the sedimentary environment report (*i.e.* zinc is enriched in the sediments at these stations relative to the baseline years). Stations HM16 and HM22 are designated as reference stations that are not immediately adjacent to the facility. Stations S1, S2, S4, and S6 are designated as nearfield stations and are immediately adjacent to the facility. It should be noted, however, that the flow descriptions described under the sedimentary project suggest that these designations may not *a priori* indicate where contaminant burdens should be differentiable based on operation of the facility.

Benthic biota samples were collected by the Chesapeake Biological Laboratory using a 0.05 m^2 Ponar grab in April 1992. Benthos were identified to genus or species prior to submission for metal and organic analyses. In year 11, two benthic bivalves, *Macoma sp.* and *Rangia cuneata* and the benthic isopod, *Cyathura polita* were collected.

Biota samples were collected and frozen in pre-cleaned glass containers until extraction and analyses were performed by Martel Laboratories, Inc. Biota were analyzed for chromium, copper, iron, manganese, nickel, zinc, selected chlorinated pesticides, PCBs, and selected polycyclic aromatic hydrocarbons (PAHs). The analytical methods used are listed in Table 1. Individual organic analytes are also listed in the summary Tables.

Data Analysis

Data were entered into Quattro Pro 1.0 for Windows for presentation and for summary purposes. An exhaustive statistical analysis of this data was not performed for several reasons. In general, appropriate statistical tests are not available for this type of data. The data set is characterized by very small sample sizes (frequently only one sample at a station for all three sampling dates) and a substantial number of non-detects with varying detection limits.

With small data sets and censored data (non-detects), it is impossible to estimate and partition variance so that appropriate among-station contrasts can be performed. In essence, there is insufficient data to estimate both among-sample and within-sample variability. The among-sample variance is the true variability in contaminant burdens at a station while the within-sample variance can be viewed as the "analytical error" variance. Most sampling programs designed to determine contaminant differences among stations and or sampling years, incorporate a standardization protocol (*e.g.* size, age, lipid content) in order to reduce unwanted variance (Popham and D'Auria, 1983). Since many contaminant burdens are correlated with these variables, standardization can often reduce variance and allow true station differences to be resolved. Alternatively, multivariate techniques can be used if sufficient additional biological variables related to contaminant burdens are collected and used in the analysis (*e.g.* age, length, weight, lipid concentration, etc.; see for example Misra and Uthe, 1987). These kinds of issues can not be addressed using the current sampling protocol.

Finally, the interpretive report supplied for the sedimentary environment project suggests that contaminant distributions resulting from effluent flow (particularly spillway #1) may vary substantially depending on the flow in any given year. This suggests that the contaminant burdens seen in sediments and biota may not, and probably should not, be a simple function of distance from the facility. Clearly, a major controlling mechanism for the dispersion of pollutants exiting from the facility will be factors associated with the distribution of water and particles around the facility. It is clear that this is not a simple process in space or time. Therefore, the data presentation used here is to simply summarize the analytical results in tabular format and to highlight unusual or atypical results where noted. The data summaries are grouped into the station types discussed above (nearfield, reference and zinc-enriched sediments) using bold lines to separate the groups. Tabulated summaries as well as individual sample data have been included.

In this report, all chemical concentrations are reported as wet weight values. Trace metal concentrations are listed as μg/g (ppm) while organic contaminants are listed as ng/g (ppb). Since many bivalve sampling programs report dry weight values (*e.g.* NOAA's Mussel Watch), approximate comparisons can be made by increasing wet weight values by 8-fold (*i.e.* biological tissues are typically 80-90% water).

RESULTS AND DISCUSSION

Trace Metals

Summary statistics for individual trace metal concentrations in benthic biota, including the frequency of detection, detection limits for non-detects, maximum and individual values by station, and species summaries (min, max, and range) are provided in Tables 2A-F. Individual sample summaries are provided in Appendix A.

Two tables have been provided as reference information from which to compare selected trace metal concentrations in HMI benthos samples. Table 3 is a compilation of information from the NOAA benthic surveillance program, a nationwide survey of contaminants in the blue mussel, *Mytilus edulis* (NOAA, 1987). Table 3 contains information from the highest and lowest stations encountered nationwide. The data were converted from the original dry weight data by using a conversion factor of 8 (*i.e.* dry weight data were decreased by 8-fold to account for an approximate 80% water content of biological tissue). Table 4 is a summary of selected trace metal concentrations found in a survey of Chesapeake Bay soft shell clams, *Mya arenaria* (Murphy, 1990). These data are the original reported wet weight data. The data compilation are for selected trace metals since neither of the surveys analyzed the same complement of trace metals as that of HMI. In addition, in each section, contaminant concentrations have been compared to previous results.

Rangia cuneata

Twelve Rangia samples were collected in the Eleventh Year, one sample from the reference areas, 6 from nearfield and 5 from zinc-enriched stations.

Chromium was detected in none of the samples in the Eleventh Year with detection limits of between 1 and 2 μg/g (Table 2A). This compares to detection of Cr in 33% of the samples from the Tenth Year with one of two samples from the reference station (HM22) yielding the highest concentration of 66 μg/g.

Copper was detected in all *Rangia* samples (Table 2B). Concentrations of copper were within a narrow range near 1.4-2.7 μg/g. Among-station differences were not notable. These values are similar to HMI Seventh, Ninth, and Tenth Year data and are in contrast to the wide range of concentrations found in the Eighth Year. Copper concentrations were in the same range as soft shell clams from the Chesapeake, and were generally in the highest sample range of the nationwide NOAA survey of the blue mussel.

Nickel was detected in all of the *Rangia* samples with a high value of 12 μg/g in one sample at Reference HM22 (Table 2C). Values were variable among station types, with no major differences notable. In general, nickel concentrations at most stations were similar to the Eighth, Ninth, and Tenth year data. Detected nickel concentrations were generally 2-10 times higher than the highest sample concentrations in blue mussels nationwide.

Zinc was detected in all samples with the highest value (38 μg/g) in one at station G25 (Table 2D). In general, the range of concentrations of zinc were similar to previous years, though the extreme high values in previous years were not found. There were no apparent differences among station types. Zinc concentrations were similar to concentrations found by Murphy (1990) in Chesapeake Bay soft shell clams and similar to the high sample range found in blue mussels.

Iron and Manganese were detected in all samples of *Rangia* (Table 2E & F). As is typical, the values are characterized by high variability within and among station types, though the variability and the range of values were substantially lower than previous years. Both of these elements are required for normal physiological processes, though very few values are available for comparison with these data. Roesijadi and Crecelius (1984) measured the elemental composition of a representative near-shore sample of the blue mussel (*Mytilus edulis*) and found concentrations of 30 μg/g iron and 1 μg/g manganese (estimated from dry weight data). Assuming similar needs for these elements among bivalves, these data serve as a useful comparison. Most of the values encountered in HMI *Rangia* samples are well above these values.

As mentioned previously, the high variability in these data could be due to varying amounts of iron and manganese enriched sediments present in the guts of the animals at the time of sampling. Wright *et al.* (1986) discussed this concern in their sampling of *Macoma* from a variety of bay stations. In *Macoma* samples collected from Chalk Point and Clay Island, these investigators noted a substantial reduction in iron and manganese concentrations in *Macoma* allowed to purge gut contents before analyses were conducted. It is important to note that the bivalves are not purged of gut contents at the time of sampling and thus all analytical results are presumed to reflect the combination of true tissue burdens as well as contamination from particles in the gut (Wright *et al.*, 1986).

Macoma **sp.**

Only one sample of *Macoma* was sampled in the Eleventh Year from a zinc-enriched station. Chromium was not detected in this sample (Table 2A). In contrast, in the Tenth Year chromium was found in 33% (two values) of all samples with a high of 8.2 μg/g at station G84.

Copper, nickel, zinc, iron, and manganese were all detected in the sample (Tables 2B-F). Compared to *Rangia*, relatively high copper was detected in the sample. Copper concentrations were over ten-fold higher than the high range samples of blue mussels in the NOAA survey, and about twice the high concentrations found in Chesapeake Bay soft shell clams. Zinc concentrations in *Macoma* were more than an order of magnitude higher than the high sample range found for blue mussels nationwide.

Cyathura polita

Three samples of *Cyathura* were collected for the Eleventh Year: one from a zinc-enriched station, one from a reference station, and one from a nearfield station.

Chromium was not detected in any *Cyathura* samples from the Eleventh Year samples (Table 2A). Detection limits were 2 μg/g, similar to previous years. In previous reports, chromium appeared most frequently in *Cyathura* samples from the nearfield stations.

Copper was detected in all samples of *Cyathura* and concentrations were typically higher than those found for *Rangia* by about 4 to 14 fold (Table 2B). Values were higher than the blue mussel reference values listed in Table 3 and on the high side of values from Chesapeake Bay softshell clam tissue (Table 4).

Iron, and manganese were found in all samples and were generally at levels higher than *Rangia*. The maximum and range of values were high relative to the proposed background concentrations of 30 μg/g and 1 μg/g. Nickel was also found in all *Cyathura* samples (Table 2C) at levels below those in *Rangia*.

Zinc was found in all of the *Cyathura* samples with a maximum value of 50 μg/g found at the zinc-enriched nearfield station G84. Concentrations of zinc in Eleventh Year samples are ten-fold less than reported in the Ninth Year and are similar to values found in the Eighth Year. Zinc concentrations in *Cyathura* were generally slightly higher than in the bivalves. This is in contrast to the Ninth Year, where *Cyathura* zinc concentrations were 5-10-fold higher than in *Rangia* or *Macoma*. The reasons for year-to-year fluctuations in zinc concentrations in *Cyathura* are unknown.

Organic Contaminants

Because of sample size constraints, only 8 samples of *Rangia* and the one sample of *Macoma* were analyzed for organic contaminants. All *Rangia* were analyzed for both pesticides/PCBs and PAHs while *Macoma* was only analyzed for the latter. In none of these 9 samples were any organic contaminants found above the limits of detection (Table 5). Caution should be used in the interpretation of these data since, while improved over previous years, the detection limits for these samples range over an order of magnitude (ignoring Methoxychlor).

Quality Assurance (QA)/ Quality Control (QC)

Tables 6, 7 and 8 contain a summary of the QA/QC performance data for the organic contaminant analyses. This is the first year QA/QC have been done. Recoveries of the surrogate spikes for the Base neutral/acid extractable compounds (*i.e.* PAHs) were generally good and often quantitative (Table 6). The exception was 2,4,6-tribromophenol. Spike recoveries for surrogate organochlorine compounds were also generally quite high and acceptable (Table 7), giving confidence that recoveries for contaminants with similar characteristics would also be good. Similarly, several matrix spike experiments found high recoveries, including a sample of *Rangia* tissue amended with a suite of target contaminants.

CONCLUSIONS AND RECOMMENDATIONS

Concentrations of trace metals in the benthic biota samples were highly variable and did not show any distinct differences based on station type (nearfield, reference, and zinc enriched).

In general, these data are similar to values found in previous years. However, some of the differences among benthic populations noted in the Ninth Year were not apparent in the Tenth or Eleventh Year. The Tenth and Eleventh Year samplings represented decreases in numbers and frequency as compared to previous years.

In contrast to previous years, chromium was not detected in biota from any site. Nickel concentrations in benthos near HMI are higher than found in other coastal U.S. waters. Copper and zinc concentrations are not atypical of other areas of the Chesapeake Bay, though they are high compared to NOAA Mussel Watch data.

In past years, the frequency of detection of organic contaminants was quite low. In the Eleventh Year, there were no detectable organic contaminants in any sample of benthos. In general, there were no obvious trends in differences in contaminant concentrations among stations or from the Eighth Year to the Eleventh Year. The small sample sizes, however, do not facilitate rigorous statistical analyses and interpretation of these data.

The following recommendations are suggested as possible ways to improve the program.

Standardize sampling protocols so that there is better concordance between the sediment sampling effort and the benthos monitoring effort. Stations for sediment contaminant analyses should be the same as those for benthos sediment analyses.

Re-evaluate the sampling locations. This suggestion is related to the first. The data provided under the sedimentary environment report clearly suggest that the distribution of materials from the spillways and hence into the area surrounding HMI is not a simple function of proximity to the containment facility. The incorporation of a transect sampling strategy, extending away from the facility in several directions, may provide a more insightful estimation of any contamination stemming from HMI.

Drop the analysis of iron and manganese in tissues. These data are not currently providing any insight into the impacts of HMI. Alternatively, this project should either add additional trace metals of toxicologic concern (*e.g.* cadmium) or direct the costs associated with analysis of these metals to additional numerical or spatial coverage.

Decrease the number of target organic analytes. Several of the analytes chosen are not likely to be associated with these sediments, as nine years of monitoring have now corroborated. If the goals of the HMI project are to assess the impacts of HMI operations, then the focus should be contaminants which are known to be associated with dredge materials. Organic contaminants which could be dropped are aldrin and endrin. Additional numerical and spatial coverage would be preferable.

Standardize sampling of biota with respect to size and/or age of the organisms in order to attempt to reduce variability and facilitate the detection of interstation differences in contaminant burdens. Sampling protocols should incorporate the recording of the size information and be included with the submission of the samples to the contractor. Normalization of organic contaminant burdens to lipid weight would also be desirable.

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Table 1. Analytical methods used to determine concentrations of metals and organic contaminants in biota.

Parameter	Media	EPA Method Number/Reference
Chromium (Cr)	Tissues	(EPA 200.7) (EPA 1983)
Manganese (Mn)	Tissues	(EPA 200.7) (EPA 1983)
Iron (Fe)	Tissues	(EPA 200.7) (EPA 1983)
Copper (Cu)	Tissues	(EPA 200.7) (EPA 1983)
Zinc (Zn)	Tissues	(EPA 200.7) (EPA 1983)
Nickel (Ni)	Tissues	(EPA 200.7) (EPA 1983)
Pesticides/PCBs	Tissues	(EPA 8080) (EPA 1986)
Phthalate Esters and Polycyclic Aromatic Hydrocarbons	Tissues	(EPA 8270) (EPA 1986)

Trace Metals ICP

Table 2A, Chromium							
Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/ Max/ Range
Cyathura	G 84	1	0	2	ND	ND	
Cyathura	HM 16	1	0	2	ND	ND	
Cyathura	S 6	1	0	2	ND	ND	
Cyathura	All Stations	3	0	2	ND	ND	
Macoma	G 84	1	0	1	ND	ND	
Rangia	G 5	1	0	1	ND	ND	
Rangia	G 25	2	0	1,2	ND	ND	
Rangia	G 84	1	0	1	ND	ND	
Rangia	HM 12	1	0	1	ND	ND	
Rangia	HM 22	1	0	1	ND	ND	
Rangia	S 1	2	0	1	ND	ND	
Rangia	S 2	2	0	1	ND	ND	
Rangia	S 4	1	0	1	ND	ND	
Rangia	S 6	1	0	1	ND	ND	
Rangia	All Stations	11	0	1, 2			

Table 2B, Copper

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/ Max/ Rang
Cyathura	G 84	1	100		7.7	7.7	
Cyathura	HM 16	1	100		18	18	
Cyathura	S 6	1	100		28	28	
Cyathura	All Stations	3	100		28		7.7/ 28/ 20
Macoma	G 84	1	100		31	31	
Rangia	G 5	1	100		1.6	1.6	
Rangia	G 25	2	100		2.7	1.5, 2.7	
Rangia	G 84	1	100		1.9	1.9	
Rangia	HM 12	1	100		2.3	2.3	
Rangia	HM 22	1	100		2.1	2.1	
Rangia	S 1	2	100		1.6	1,5, 1.6	
Rangia	S 2	2	100		1.9	1.9, 1.9	
Rangia	S 4	1	100		1.5	1.5	
Rangia	S 6	1	100		1.4	1.4	
Rangia	All Stations	11	100		2.7		1.6/ 2.7/ 1.1

Table 2C, Nickel

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/ Max/ Range
Cyathura	G 84	1	100		1.8	1.8	
Cyathura	HM 16	1	100		1.1	1.1	
Cyathura	S 6	1	100		1.1	1.1	
Cyathura	All Stations	3	100		1.8		1.1/ 1.8/ 0.7
Macoma	G 84	1	100		0.9	0.9	
Rangia	G 5	1	100		3.4	3.4	
Rangia	G 25	2	100		5.3	3.5, 5.3	
Rangia	G 84	1	100		5.3	5.3	
Rangia	HM 12	1	100		4.7	4.7	
Rangia	HM 22	1	100		12	12	
Rangia	S 1	2	100		5.4	3, 5.4	
Rangia	S 2	2	100		4.2	4.2, 4.2	
Rangia	S 4	1	100		3.3	3.3	
Rangia	S 6	1	100		8.8	8.8	
Rangia	All Stations	11	100		12		3/ 12/ 9

Table 2D, Zinc							
Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/ Max/ Range
Cyathura	G 84	1	100		50	50	
Cyathura	HM 16	1	100		41	41	
Cyathura	S 6	1	100		39	39	
Cyathura	All Stations	3	100		50		39/ 50/ 11
Macoma	G 84	1	100		54	54	
Rangia	G 5	1	100		28	28	
Rangia	G 25	2	100		38	21, 38	
Rangia	G 84	1	100		17	17	
Rangia	HM 12	1	100		21	21	
Rangia	HM 22	1	100		29	29	
Rangia	S 1	2	100		23	19, 23	
Rangia	S 2	2	100		29	19,.29	
Rangia	S 4	1	100		25	25	
Rangia	S 6	1	100		18	18	
Rangia	All Stations	11	100		38		17, 38, 21

Table 2E, Iron							
Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/ Max/ Range
Cyathura	G 84	1	100		1300	1300	
Cyathura	HM 16	1	100		220	220	
Cyathura	S 6	1	100		280	280	
Cyathura	All Stations	3	100		1300		220/ 1300/ 1080
Macoma	G 84	1	100		310	310	
Rangia	G 5	1	100		310	310	
Rangia	G 25	2	100		250	31, 250	
Rangia	G 84	1	100		68	68	
Rangia	HM 12	1	100		57	57	
Rangia	HM 22	1	100		43	43	
Rangia	S 1	2	100		35	35, 210	
Rangia	S 2	2	100		170	170, 250	
Rangia	S 4	1	100		260	260	
Rangia	S 6	1	100		130	130	
Rangia	All Stations	11	100		310		31/ 310/ 279

Table 2F, Manganese							
Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/ Max/ Range
Cyathura	G 84	1	100		140	140	
Cyathura	HM 16	1	100		85	85	
Cyathura	S 6	1	100		120	120	
Cyathura	All Stations	3	100		140		85/ 140/ 55
Macoma	G 84	1	100		140	140	
Rangia	G 5	1	100		41	41	
Rangia	G 25	2	100		2.9	2.9, 27	
Rangia	G 84	1	100		6.9	6.9	
Rangia	HM 12	1	100		7.5	7.5	
Rangia	HM 22	1	100		13	13	
Rangia	S 1	2	100		22	4.1, 22	
Rangia	S 2	2	100		26	26, 26	
Rangia	S 4	1	100		24	24	
Rangia	S 6	1	100		26	26	
Rangia	All Stations	11	100		41		2.9/ 41/ 28

Table 3. Trace metal concentrations in bivalve mussels from the National Status and Trends Program 1984, 1985, and 1986 (NOAA 1987). Estimated μg/g wet weight concentrations from original dry weight data (8X conversion).

Metal	Highest Samples (Range)	Lowest Samples (Range)
Copper	1.3 - 2.5	0.7 - 0.9
Nickel	0.4 - 1.6	0.07 - 0.1
Zinc	19 - 39	7 - 12

Table 4. Levels of chromium copper and zinc in soft shell clams from the Chesapeake Bay and its tributaries: 1981-1985. From Murphy 1990. Data as $\mu g/g$ wet weight.

Metal	Range	Mean	Median
Chromium	<0.1 - 1.4	0.3	<0.5
Copper	0.63 - 15.8	6.55	6.26
Zinc	8.04 - 451	29.1	19.8

Table 5a. LIMITS OF DETECTION				
Compound	XMON-QC	XMON-QC	All Samples	
	ug/kg			
Naphthalene	200	100	100	
2-Chloronaphthalene	200	100	100	
Acenaphthylene	200	100	100	
Acenaphthene	200	100	100	
Fluorene	200	100	100	
Phenanthrene	200	100	100	
Anthracene	200	100	100	
Fluoranthene	200	100	100	
Pyrene	200	100	100	
Benzo(a)anthracene	200	100	100	
Benzo(b+k)fluoranthene	200	100	100	
Benzo(a)pyrene	200	100	100	
Indeno(123cd)pyrene	200	100	200	
Dibenz(ah)anthracene	200	100	200	
Benzo(ghi)perylene	200	100	200	

4 ug/kg
1000, 100, 1000, ppb
50

Table 5b. LIMITS OF DETECTION				
Compound	XMON-QC	XMON-QC	Samples 9204-48,50, 53-56,58	Sample 920449
	ug/kg			
a-BHC	5	5	100	200
g-BHC	5	5	100	200
b-BHC	5	5	100	200
Heptachlor	5	5	100	200
d-BHC	5	5	100	200
Aldrin	5	5	100	200
Heptachlor Epoxide	5	5	100	200
Endosulfan	5	5	100	200
Dieldrin	5	5	100	200
4,4'-DDE	5	5	100	200
Endrin	5	5	100	200
4,4'-DDD	5	5	100	200
Endosulfan II	5	5	100	200
4,4'-DDT	5	5	100	200
Endrin Aldehyde	5	5	100	200
Endosulfan Sulfate	5	5	100	200
Chlordane	50	50	1000	2000
Toxaphene	50	50	1000	2000
Methoxychlor	2500	2500	50000	100000
PCB-1016			1000	2000
PCB-1221			1000	2000
PCB-1232			1000	2000
PCB-1242			1000	2000
PCB-1248			1000	2000
PCB-1254			1000	2000
PCB-1260			1000	2000

XMON QC2 = marine sediment standard
XMON QC3 = mussel tissue standard

Table 6. QA/QC Base Neutral / Acid Extractable Compounds (EPA 8270), HMI Samples, April 1992

Species	Site	Sample #	2-Fluro-phenol	Phenol-d6	2,4,6-Tribrom phenol	2-Fluro-biphenyl	Nitro-benzene-	Terphenyl d14
			% Recovery					
Macoma	G 84-2	920460	66	63	2	103	121	110
Rangia	G 25-1	920448	56	54	3	102	123	114
Rangia	G 25-2	920449	58	55	6	99	114	111
Rangia	HM 12-1	920450	47	48	8	92	109	82
Rangia	HM 22-1	920458	66	63	2	103	121	110
Rangia	S 1-1	920456	60	60	2	101	121	99
Rangia	S 2-1	920454	58	57	1	106	122	113
Rangia	S 2-2	920455	55	54	48	99	112	124
Rangia	S 4-1	920453	56	55	15	93	111	109
	Blank							
	MS	920458						
	XMON-QC2		18	48	10	120	64	86
	XMON-QC3		75	60	20	123	73	79
	7 + MS		119	104	6	176	219	184
	High		119	104	48	176	219	184
	Low		18	48	1	92	64	79
	Average		61	60	10	110	118	110

MS = matrix spike
XMON QC2 = marine sediment standard
XMON QC3 = mussel tissue standard

Table 7. QA/QC Pesticides/ PCBs (EPA 8080), HMI Samples, April 1992: Surrogate Spikes

Species	Site	Sample #	Dibutyl-cholorendate	2,4,5,6- tetra-chloro-m-xylene
			% Recovery	
Rangia	G 25-1	920448	98	101
Rangia	G 25-2	920449	22	34
Rangia	HM 12-1	920450	109	96
Rangia	HM 22-1	920458	122	123
Rangia	S 1-1	920456	138	108
Rangia	S 2-1	920454	130	119
Rangia	S 2-2	920455	111	128
Rangia	S 4-1	920453	53	93
	Blank		102	92
	MS	920458	122	102
	XMON-QC		(lost)	67
	XMON-QC		(lost)	53
	Blank + MS		115	107
	15 + MS		122	102
	High		138	128
	Low		0	34
	Average		89	95

MS = matrix spike
XMON QC2 = marine sediment standard
XMON QC3 = mussel tissue standard

Table 8. QA/QC Pesticides/ PCBs (EPA 8080), HMI Samples April 1992: Matrix Spikes

Compound		920458	Blank + MS	15 + MS
		% Recovery		
g-BHC		100	107	104
Aldrin		100	101	78
Heptachlor		100	114	114
Dieldrin		75	91	85
Endrin		75	93	83
4,4'-DDT		100	103	92

Table 9. Detects in standards

Compound	XMON-QC2	XMON-QC3
	ug/kg	
Naphthalene	1200	
Phenantrene	500	
Antracene	300	
Fluoranthene	1000	
Pyrene	900	
Chrysene	400	
Benzo(b+k)fluoranth	2800	
Benzo(a)pyrene	1700	
Heptachlor epoxide	17	
Dieldrin	11	72
4,4'-DDE	7	32
4,4'-DDD	26	110
4,4'-DDT	10	16

Table 10. Summary of HMI Metal Analyses, April 1992 Samples

Species	Station	Sample #	Cr	Cu	Ni	Zn	Fe	Mn	Organics
			mg/ kg						
Cyathura	G 84-3	920452	< 2	7.7	1.8	50	1300	140	
Cyathura	HM 16-1	920444	< 2	18	1.1	41	220	85	
Cyathura	S 6-2	920446	< 2	28	1	39	280	120	
Cyathura	All Stations		< 2	7.7- 28	1- 1.8	39- 50	220- 1300	85- 140	
Macoma	G 84-2	920460	< 1	31	0.9	54	310	140	
Rangia	G 5-1	920447	< 1	1.6	3.4	28	310	41	
Rangia	G 25-1	920448	< 1	1.5	5.3	21	31	2.9	ND
Rangia	G 25-2	920449	< 2	2.7	3.5	38	250	27	ND
Rangia	G 84-1	920451	< 1	1.9	5.3	17	68	6.9	
Rangia	HM 12-1	920450	< 1	2.3	4.7	21	57	7.5	ND
Rangia	HM 22-1	920458	< 1	2.1	12	29	43	13	ND
Rangia	S 1-1	920456	< 1	1.6	5.4	19	35	4.1	ND
Rangia	S 1-2	920457	< 1	1.5	3	23	210	22	
Rangia	S 2-1	920454	< 2	1.9	4.2	19	250	26	ND
Rangia	S 2-2	920455	< 2	1.9	4.2	29	170	26	ND
Rangia	S 4-1	920453	< 1	1.5	3.3	25	260	24	ND
Rangia	S 6-1	920445	< 1	1.4	8.8	18	130	26	
Rangia	All Stations		< 2	1.4- 2.3	3- 12	17- 38	31- 310	2.9- 41	
XMON-QC1			< 1.0	64	1.9	890	470	12	

XMON-QC1 = oyster tissue standard