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 twelfth 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). The 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 twelfth 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 Zn 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 Zn concentrations persisted in the vicinity of the dike through the twelfth monitoring year. The 3-D hydrodynamic modelling effort previously reported in the tenth monitoring year was utilized to explain the structure of metal loadings to the sediments surrounding HMI as observed during the twelfth monitoring year. The chemistry of the contained sediments and effluent released from the dike also influences the distribution of the Zn 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 stations. The investigations at the monitoring stations added in response to the zinc enrichment continued through the twelfth 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 twelfth monitoring year. Data produced by sampling efforts during the twelfth 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 twelfth 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 twelfth year.

Surficial bottom sediments sampled during two cruises, in November 1992 and April 1993, were analyzed for grain size composition and trace metal content. The grain size distribution of exterior bottom sediments - presented as percent sand and clay:mud ratios - was similar to the last two 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 seasonal pattern in the distribution of the fine (mud) fraction - coarsening over the summer and fining over the winter - typical of previous monitoring years was not evident this year. During the twelfth year, the distribution of the fine fraction changed very little from fall to spring, remaining almost identical to the April 1992 distribution of clay:mud. The similarities among the three most recent sampling periods is related to the consistently low and intermittent release of effluent from the dike's spillways during the monitoring year.

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 twelfth monitoring year in the vicinity of the dike. In fact, some of the highest levels observed to date were recorded during this monitoring period.

The elevated Zn levels are associated with low flow releases of effluent from the facility. Results obtained from a 3-D hydrodynamic model of the upper Chesapeake Bay predict the structure of the plume of material found in exterior sediments. The metal loadings to the sediment are the result of the chemical environment within the dike and discharge from the dike. Metal levels in ponded water within the dike may increase due to leaching from the sediment, through a process analogous to acid mine drainage. Dewatering practices, such as trenching, increase the probability of sulfide oxidation and metal leaching. 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 resulting in the mobilization of metals associated with those sediments. Higher metal levels in the effluent will 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 February 1991, immediately prior to the eleventh year study (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 were 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.

Generally, the HMI beach has displayed erosional characteristics during the profiling period covered in this report. Profiles 21+75 to 24+00, southern profiles, are the most stable. Deposition dominated the entire upper beach face at Profile 24+00 as north-derived sediments move along the shore towards the south. The middle profiles from 28+00 to 40+00(as compared to previous years of 30+00 to 44+00) experienced erosion along the upper beach face and nearshore, below datum. Profile 28+00 approached the benchmark profile of February 1991, while Profiles 30+00, 32+00, 36+00, and 40+00 were still above the February 1991 level. The greatest erosional volumes were recorded between 44+00 and 49+00. The profiles levels are lower than the benchmark level.

Many of the beach profiles are critically approaching the February 1991 level with some of the profiles actually lower than pre-nourishment conditions. It is strongly recommended that a new plan for beach nourishment be devised and implemented. Volumes of 10,000 to 14,000 yd^3 should be sufficient to sustain the recreational beach for the next several years.

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 twelfth 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 1992 and April and August 1993.

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 30 species were collected from these seventeen infaunal stations. The most abundant species were the worms, *Scolecolepides viridis*, *Streblospio benedicti*, *Tubificoides sp.* and *Heteromastus filiformis*; the crustaceans, *Leptocheirus plumulosus* and *Cyathura polita*; and the clam, *Rangia cuneata*.

Species diversity (H') values were evaluated at each of the infaunal stations at the three sampling periods. The highest diversity value (3.478) was obtained for the reference station HM9, in April 1993. The lowest diversity value (1.685) occurred in December 1992 at the Back River station, HM26. For the three sampling dates, the overall highest diversity values (with only two stations under 2.5 and ten greater than 3.0) occurred in August 1993 and the lowest overall diversity occurred in December 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 reference stations, the combined nearfield and reference stations and the combined zinc enriched stations in December only. No significant differences were found in April or August.

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. We were unable to reach reference station R5 in April due to rough sea conditions. The epifaunal populations at both the nearfield and reference stations were very similar over all three sampling periods and as previously reported the amphipod, *Corophium lacustre*, was one of the most abundant organisms present at all nearfield and reference stations sampled during the Twelfth Year. The encrusting bryozoans, *Victorella pavida* and *Membranipora tenuis* were the next most frequently observed species on the pilings.

The results of the 12th monitoring year studies again reveal that no adverse effects on the benthic populations have been observed which could be attributed to the maintainance and operation of the Hart-Miller Island Dredged Material Containment Facility. We have continued to monitor the 4 zinc enrichment stations (G5,G25, HM12, G84) established in the 9th year of sampling as a result of Maryland Geological Survey's findings of zinc enriched sediments in the vincinity of HMI. During this the fourth 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.

PROJECT III: ANALYTICAL SERVICES

Concentrations of trace metals in the benthic biota samples were characterized by high variability within station type (where replication permitted evaluation) as in previous years. Some of the variability within stations could be explained by the size class differences between replicates and the relative amount of sediment associated with the tissue samples. These factors were particularly relevant for the *Macoma* data and interfered with their interpretation. While it is assumed that sediment has always been present in tissue samples from previous years, this is the first year the contract lab specified which samples carried the greatest burdens and their associated analytical problems. This was also the first year in which cadmium was analyzed and it was detected in 73% of all samples at levels close to the detection limit. Chromium was detected more frequently, but in narrower concentration ranges, in the present year than in the Tenth Year, compared to no detects in the Eleventh Year. Though *Macoma* carried the highest burdens, within species, there were no strong trends in chromium levels among station type. As in the previous three monitoring years, copper concentrations were highest in *Cyathura*, and similar in range for all species as in the previous two years. Nickel concentrations were greatest in the *Rangia* samples and similar in range to the previous two years. Zinc concentrations were elevated in *Rangia* samples over the previous two years. In general, zinc distributions at the zinc enriched stations were similar in magnitude to the reference stations.

Despite (unsuccessful) efforts to improve detection limits, the frequency and number of organic analyte detection were quite low in the present monitoring year as in previous years. The high detection limits and complete loss of some analytes were due, in part, to minimal sample mass and application of recommended methods which were inappropriate for some classes of target organics. The only analyte detected, apart from a small pesticide burden in one sample, was the plasticizing agent, bis (2-ethylhexyl) phthalate. No conclusions can be drawn nor general trends observed from the organic data set in the present sampling year due to continuing problems with high and variable detection limits.

Another problem highlighted in the present monitoring year concerns the locations selected for reference stations in the HMI benthic monitoring program. One cannot necessarily exclude HMI facility operation as a contributing agent for the contaminant levels observed in samples from the reference stations, based on recently available data and results from hydrodynamic modeling studies. Should data sets with improved detection limits and appropriate replication become available in the future, it would still be difficult to statistically assess the impacts of the facility if many of the designated reference sites are potentially under the influence of HMI operation. It is strongly suggested that the monitoring program address the concerns raised over sampling locations in this, as well as in previous, interpretive reports.

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 the long term data base should also be continued.

Specific recommendations resulting from the exterior monitoring activities during the twelfth 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 atmoshere, thereby potentially reducing pH and mobilizing metals. Close cooperation with Maryland Environmental Services will be important in this endeavor.

2) The shorelines developed during the February 1991 beach nourishment project is the benchmark to which future beach conditions will be referenced. As shown by the profile comparisons, many of the profiles are critically approaching that February 1991 level with some of the profiles actually lower than pre-nourishment levels. It is strongly recommended that a new plan for beach nourishment be devised and implemented. Volumes of 10,000 to 14,000 yd^3 should be sufficient to sustain the recreational beach for the next several years.

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) Evaluate the sampling locations, particularly those for reference stations. Coordinate data from the sedimentary project, results from the hydrodynamic pollutant modeling study in the Tenth Year and knowledge of projected spillway operation to design a sampling scheme able to detect contaminant gradients around the facility and to find reference sites well-removed from the influences of HMI.

6) Adopt more sensitive analytical techniques for target organic analytes so that true contaminant differences can detected. With present methodology, only gross contamination, which often exceeds FDA action limits, is sporadically detected and no trends can be assessed. Since the associated costs of improved detection limits will be higher, monitoring studies could be performed less frequently. It is questionable whether anything is to be gained from using less sensitive analytical techniques in intervening years.

7) Consult the contractor prior to sampling for proper collection methods and adequate tissue needs. True trace level determinations require extra sampling precautions to protect against contamination. Consider dropping *Cyathura* for organic analyses. There is rarely sufficient tissue mass to justify the cost and resulting high detection limits for these data.

8) Try to determine the minimum number of individuals needed to provide an adequate composite tissue sample for analyses after consultation with the contractor. Alternatively, a minimum of 5 grams wet weight per sample is suggested. Subdivide large samples of similar size class into enough replicates to provide for statistical comparisons. It would not be prudent to invest in more sensitive testing if there is still insufficient sample or replication to draw conclusions.

9) Consider using only *Rangia* as a monitoring species to eliminate problems with comparing contaminant levels from different species among stations. Allow flexibility in the selection of sampling locations so that only those sites with enough individuals to provide adequate tissue and replication are used.

10) Consider purging the samples of sediment prior to submission for analyses. The presence of sediment in the present year as in years past has confounded the interpretation of metal burdens in the benthic samples. Alternatively, adopt an experimental scheme recommended in the Ninth Year to evaluate the influence of sediment on the apparent concentration of contaminants in tissues by dividing a sample and analyzing purged and unpurged sets.

11) Reevaluate whether iron and manganese are really providing any information pertinent to the benthic monitoring program. While iron data are sometimes used to calculate enrichment in sediments, the data do not seem to be serving any purpose in the benthic biota data set. Alternatively, add arsenic to the analyte list or direct the costs associated with analysis of these metals to additional numerical or spatial coverage.

12) Decrease the number of target organic analytes. Consider dropping aldrin, endrin, ethyl and methyl parathion, linuran, malathion, trifluralin, atrazine, diazinon, beta BHC, naphthalene and alkylated naphthalenes as these compounds do not readily accumulate in sediments or biota or are not stable in estuarine environments. It is also questionable whether toxaphene should be kept as an analyte using the current analytical methodology.

13) With improved detection limits and new reference sites selected in the future, consider repeating the sediment toxicity tests performed in the Eleventh Year. These tests were inconclusive due to predation and/or mortality in the reference sediment. To complete the sediment quality triad concept (Chapman et al. 1987) it is important to have the same stations for sediment

and tissue contaminant burdens, as for toxicity tests and benthic community assessments.

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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 Twelfth *Annual Interpretive Report* presents the results of the environmental monitoring of the Hart-Miller Island Containment Facility from August 1992 through August 1993.

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 Table 1 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 No. 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 yd^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 yd^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. Signficant quantities were also produced from the 42' foot channel maintenance, East Alco, and Bulk Stevedores.

During 1992 the dredging opertations 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.

In 1993 a total of 500,000 cubic yards of dredged material was placed in the facility. Almost all of this material came from maintenance dredging activity for the 50 foot channel.

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
1988	Brandon Shore/Wagner pt.	18,464
1988	Canton Waterfront	2,500

Table 1 (Cont.)

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
1993	Baltimore Yacht Club	4,000
1993	Fifty-foot Federal Maintenance	496,000
	TOTAL 1993	500,000
	Grand Total* (cubic yards)	59,656,200

* Through December 1993

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 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 TWELFTH YEAR INTERPRETIVE REPORT

(November 1992 - October 1993)

BY
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January 1995

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 twelve 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.

Data collected by the Department of Natural Resources and research institutions during the twelve years of the environmental assessment program, are stored on the Department of Natural Resources, Annapolis Data Center's mainframe computer 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 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 1992-1993 monitoring year are included in the **Twelfth 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 and maintained 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
TWELFTH YEAR INTERPRETIVE REPORT
(November 1992 - October 1994)

Part 1: **Sedimentary Environment**
James M. Hill, Lamere Hennessee, and June Park

Part 2: **Beach Erosion Study**
Randall T. Kerhin

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File Report 94-11

submitted to

Tidewater Administration
Maryland Department of Natural Resources
Tawes State Office Building
Annapolis, MD 21041

October 1994

ABSTRACT

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 twelfth 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 twelfth year.

Surficial bottom sediments sampled during two cruises, in November 1992 and April 1993, were analyzed for grain size composition and trace metal content. The grain size distribution of exterior bottom sediments - presented as percent sand and clay:mud ratios - was similar to the last two 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 seasonal pattern in the distribution of the fine (mud) fraction - coarsening over the summer and fining over the winter - typical of previous monitoring years was not evident this year. During the twelfth year, the distribution of the fine fraction changed very little from fall to spring, remaining almost identical to the April 1992 distribution of clay:mud. The similarities among the three most recent sampling periods is related to the consistently low and intermittent release of effluent from the dike's spillways during the monitoring year.

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 twelfth monitoring year in the vicinity of the dike. In fact, some of the highest levels observed to date were recorded during this monitoring period.

The elevated Zn levels are associated with low flow releases of effluent from the facility. Results obtained from a 3-D hydrodynamic model of the upper Chesapeake Bay predict the structure of the plume of material found in exterior sediments.

The metal loadings to the sediment are the result of the chemical environment within the dike and discharge from the dike. Metal levels in ponded water within the dike increase due to leaching from the sediment, through a process analogous to acid mine drainage. Dewatering practices, such as trenching, increase the probability of sulfide oxidation and metal leaching. 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 resulting in the mobilization of metals associated with those sediments. Higher metal levels in the effluent will 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 February 1991, immediately prior to the eleventh year study (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 were 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.

Generally, the HMI beach has displayed erosional characteristics during the profiling period covered in this report. Profiles 21+75 to 24+00, southern profiles, are the most stable. Deposition dominated the entire upper beach face at Profile 24+00 as north-derived sediments move along the shore towards the south. The middle profiles from 28+00 to 40+00(as compared to previous years of 30+00 to 44+00) experienced erosion along the upper beach face and nearshore, below datum. Profile 28+00 approached the benchmark profile of February 1991, while Profiles 30+00, 32+00, 36+00, and 40+00 were still above the February 1991 level. The greatest erosional volumes were recorded between 44+00 and 49+00. The profiles levels are lower than the benchmark level.

Many of the beach profiles are critically approaching the February 1991 level with some of the profiles actually lower than pre-nourishment conditions. It is strongly recommended that a new plan for beach nourishment be devised and implemented. Volumes of 10,000 to 14,000 yd^3 should be sufficient to sustain the recreational beach for the next several years.

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 (Figure 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

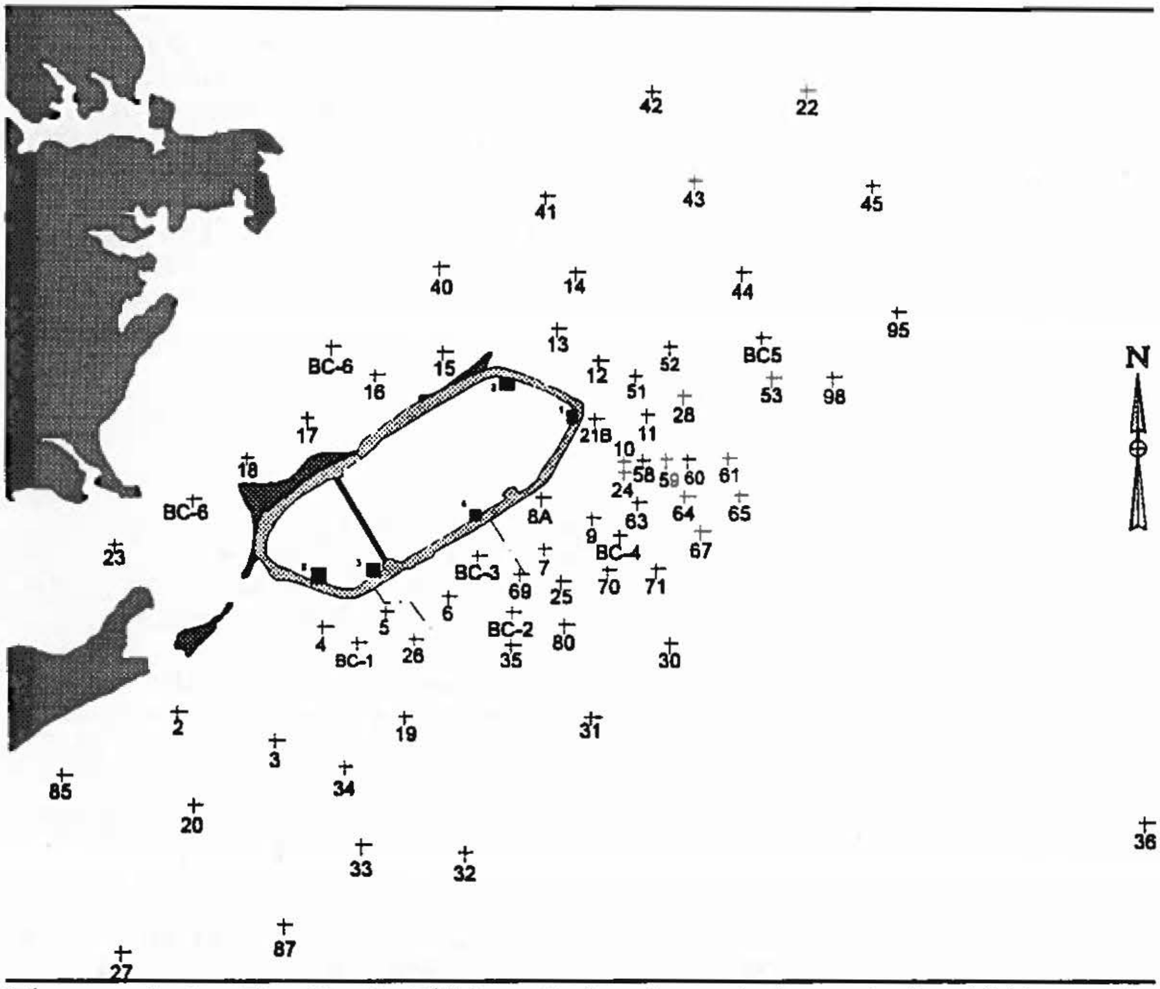


Figure 1-1: The Hart-Miller Island containment facility and vicinity, with locations of the surficial sediment and core stations sampled during the twelfth year of exterior monitoring.

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 twelfth 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 twelfth year cruises are summarized below. Information was extracted from two *Operations Reports* prepared by MES, covering the periods April 1, 1992 - September 30, 1992, and October 1, 1992 - March 31, 1993.

During the twelfth monitoring year, dredged sediments were not emplaced into the HMI containment facility. On April 9, 1992, an eighteen month hiatus in disposal began, during this time dike operations focused on increasing the capacity by 8.4 MCY. The increased capacity was to be gained by dewatering of the sediments within the facility through crust management and the reactivation of Spillway #1.

The plan for crust management involved constructing a system of internal and perimeter trenches. Trenching increases surface area and elevation of the sediment above the standing water level, which increases dewatering rates. Additionally, the trenches are channels which direct the water to the spillways. The plan called for trenches to be constructed every 200' over the entire area of the Northern cell, and every 100' within the Southern cell. By March 1993, over 90% of the trenching operation was complete in the Northern cell and the work in the Southern cell was well underway. This entailed over 322,000 linear ft of internal trenches, with an additional 162,000 linear ft of perimeter trenches.

Although trenching facilitates dewatering, lowering the standing water level is also required to remove the water from the dike. This requires that the access to spillways into the Bay be as close to mean high water (MHW) as possible. Reactivating Spillway #1 decreased the elevation from 16 ft above mean high water (MHW), for Spillway #1a, down to 4 ft above MHW. Spillway #1 was reopened on January 19, 1993.

During this period there were no permit violations and no incidents of toxicity. However, a trend of increasing acidity was noted through time well within operating limits of the dike. Discharge from the dike was low and on an intermittent basis primarily from Spillways #1a and #2.

OBJECTIVES

As in the past, the main objectives of the twelfth 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.

METHODOLOGY

FIELD METHODS

The information presented in this report is based on observations and analyses of samples collected on two cruises aboard the R/V Discovery during the twelfth year of monitoring. Sampling sites (Figure 1-1) were located in the field by means of the LORAN-C navigational system. For the past ten 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 given in the *Twelfth Year Data Report*, along with the corresponding Resource Monitoring Database (RESMON) identifier.

Surficial sediment samples were collected in November 1992 (Cruise 28) and May 1993 (Cruise 29). During the ninth year of monitoring, the number of sampling stations was increased in response to the detection of abnormally high Zn levels in sediments near Spillway #1 (Hennessee and Hill, 1992). Sampling sites were added to determine the extent of the area of Zn enrichment and to coincide with benthic sampling stations. The expanded sampling scheme (60-66 locations/cruise) was retained throughout the eleventh monitoring year.

During the twelfth year, the number of stations occupied during each cruise was reduced to 47, based, in part, on output from the 3-D hydrodynamic model of the upper Chesapeake Bay. The 24 stations that had been monitored continuously since dike completion were retained, as were the stations that corresponded to benthic sampling sites. Selection of the remaining stations was based on discharge activity during the months preceding each cruise, coupled with the results of the 3-D model. All of the sites chosen on the basis of the 3-D model had been occupied previously. The same locations sampled in November 1992 were revisited in May 1993.

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 seven stations (11, 16, 24, 25, 28, BC3, and BC6). During the May 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 (see appendix to *Twelfth Year Data Report*) and subsampled.

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 the Maryland Environmental Service (MES) office at the containment facility, then transferred to a private laboratory for analysis.

In May 1993, gravity cores were collected at the seven box core (BC) stations and at Stations 12 and 25 (Figure 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 an appendix to the *Twelfth Year Data Report*.

Each core was then extruded, split with an osmotic knife, photographed, and described. Visual and radiographic observations of the cores are also presented in the *Twelfth 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

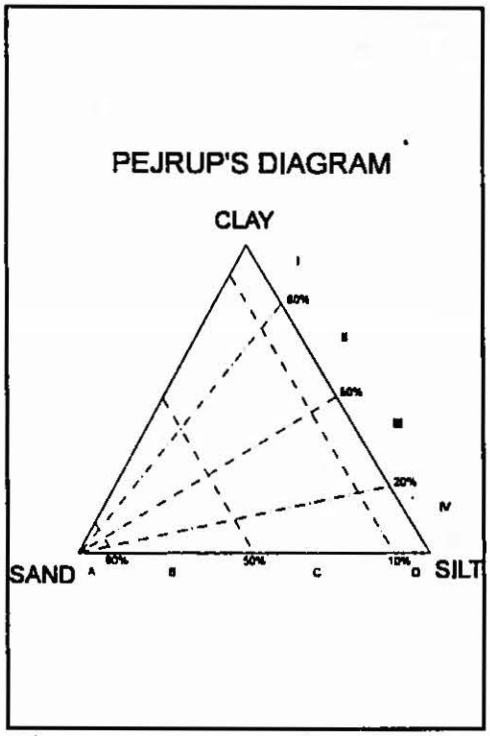


Figure 1-2: Pejrup's (1988) classification of sediment type.

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 (Figure 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.

Trace Metal Analysis

Sediment solids were analyzed for six trace metals - iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), and nickel (Ni). Prior to the eleventh monitoring year, 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, beginning with the eleventh year, a different analytical protocol was implemented. The current procedure uses a microwave digestion technique followed by analysis on an Inductively Coupled Argon Plasma Spectrometer (ICAP). This protocol, modified from EPA Method #3051 (Soil Sample Digestion Procedure for Floyd Digestion Vessels), has many advantages over the fusion followed by AA analytical procedure:

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.

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.)

RESULTS AND DISCUSSION

SEDIMENT DISTRIBUTION

Since November 1983, sand-silt-clay percentages have been determined twice a year for 23 of the stations around HMI. The grain size composition of these sediments is depicted in ternary diagrams for five different sampling periods (Figure 1-3). The first diagram (Figure 1-3a) is typical of the post-construction, **pre-discharge** sediment distribution around the facility. The next four diagrams - all **post-discharge** - summarize eleventh year (Figure 1-3 b&c) and twelfth year (Figure 1-3 d&e) findings. Related statistics are presented in Table 1-2.

Table 1-2: Summary statistics for five cruises, based on 23 continuously monitored stations around HMI.

Cruise	Date	Clay:mud ratio		% Sand	
		Range	Average	Range	Average
9	11/83	0.39-0.63	0.54	0.33-97.34	24.30
26	11/91	0.34-0.61	0.53	0.95-98.05	32.30
27	4/92	0.42-0.61	0.54	1.27-97.75	32.06
28	11/92	0.40-0.63	0.55	0.59-97.79	33.48
29	5/93	0.38-0.68	0.54	0.71-98.29	27.98

For the 23 continuously monitored sampling locations, Figure 1-4 depicts percent sand and clay:mud ratios, averaged over all 23 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. Since then, average sand content has fluctuated erratically between 28% and 34%, dropping below the maximum pre-discharge level of 28.6% only twice, most recently during the second cruise of the twelfth monitoring year.

The overall decrease in average sand content in May 1993 primarily reflects major changes at five stations (3, 10, 12, 22, and 23) around the facility. Comparing the November 1992 and May 1993 cruises, the difference in percent sand at each of these five sites ranged from 10 to nearly 60 percentage points.

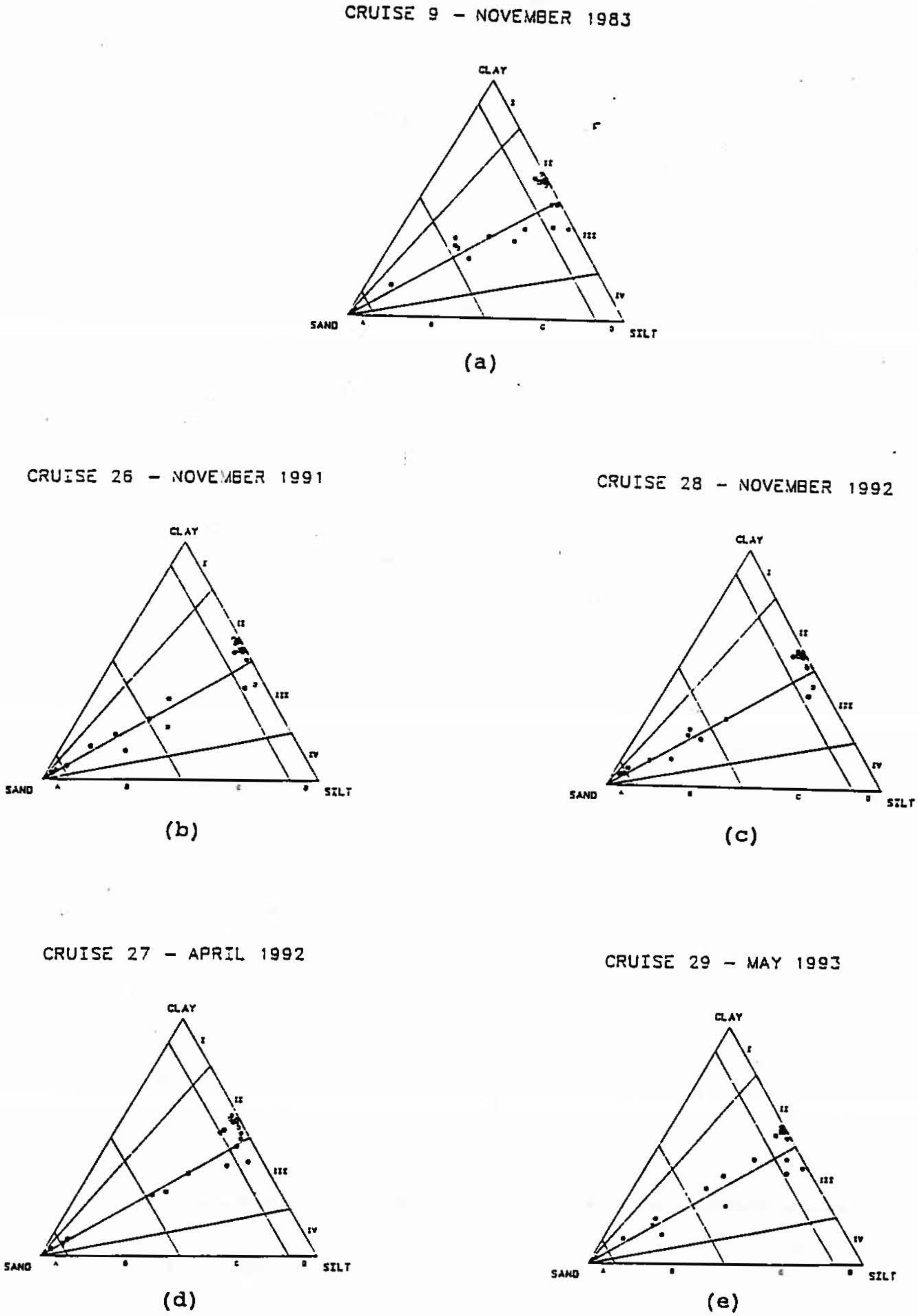


Figure 1-3:Sediment type of samples collected in (a) November 1983 (post-construction, pre-discharge), (b) November 1991, (c) April 1992, (d) November 1992, and (e) May 1993.

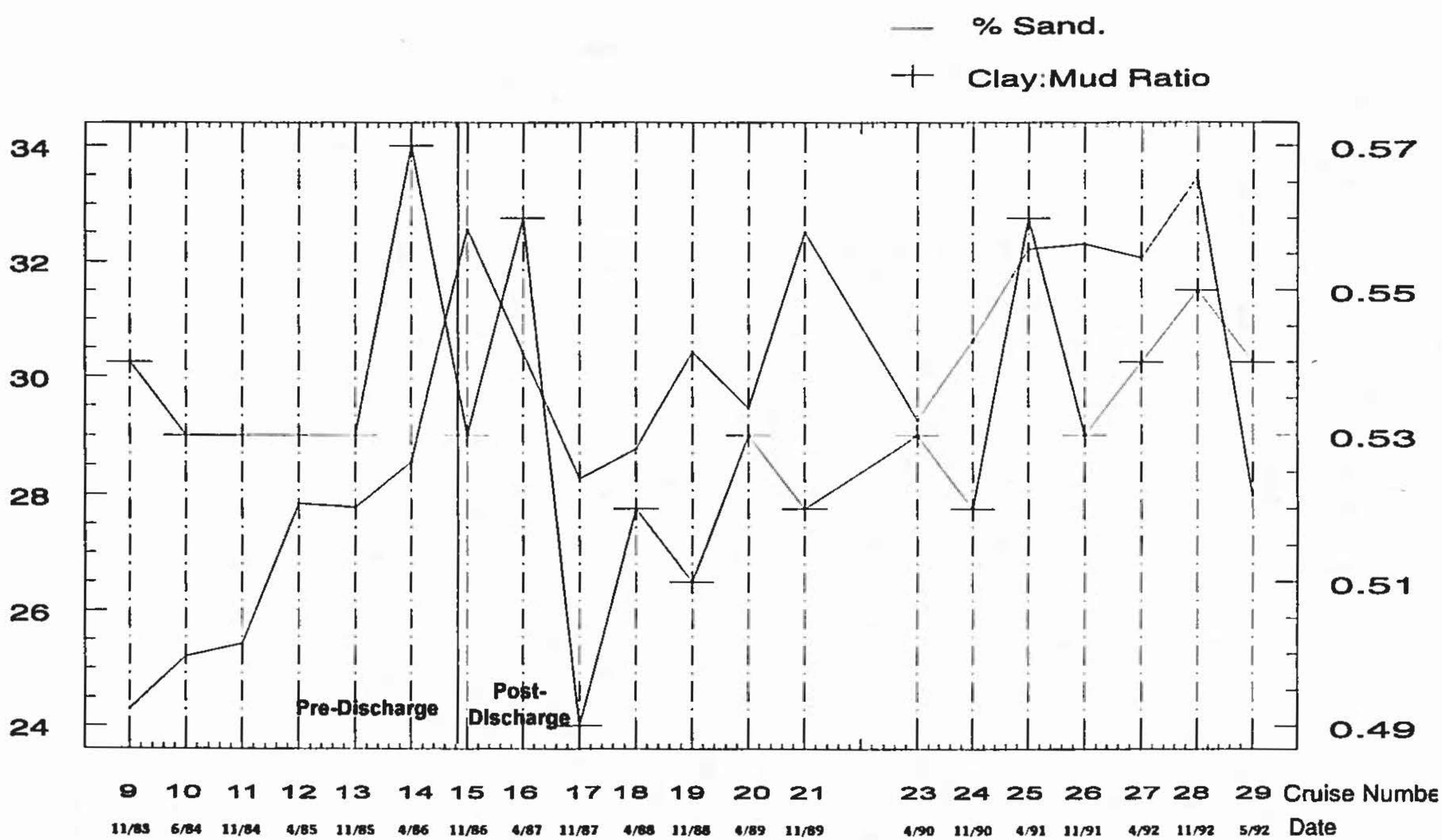


Figure 1-4: Average percent sand and clay:mud ratios, based on 23 continuously monitored stations, for all post-construction cruises.

The biggest change occurred at Station 12: sand content was 91% in November 1992 and 32% in May 1993. Because these stations are scattered around the facility, some at fairly great distances from the dike, the reason for the decrease in sand content is unclear. It is noteworthy, however, that grain size composition at each of these sites is highly variable. For each site, the May 1993 grain size composition has been observed previously.

Average clay:mud ratios for the 23 stations also show distinctly different pre- and post-discharge patterns. Overall pre-discharge ratios varied over a relatively small range (0.53-0.57); no seasonal trend is evident. During the post-discharge period, ratios have varied over a somewhat wider range (0.49-0.56). A consistent seasonal pattern developed and persisted through the eleventh monitoring year. The muddy fraction of the sediment became finer (more clay-rich) during the winter (between fall and spring cruises) and coarser during the summer. That pattern was interrupted during the twelfth year, with sediments becoming finer during the summer and slightly coarser during the winter.

Since November 1987, the trend has been one of overall fining of the silt plus clay fraction of the sediment. Such fining is thought to be associated with a general decrease in the turbulence of the depositional environment. Turbulence, in turn, is mainly a function of the interplay between the flow of the Susquehanna River and the release of effluent from the facility.

Two sets of contour maps, based on the entire suite of samples, show the spatial distribution of sediment type during the eleventh and twelfth 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% sand) sediment extend north-northeast of the dike and east of Black Marsh and become systematically finer (less sandy) offshore. The overall decrease in percent sand for the 23 continuously monitored stations, described above, is reflected in minor shifts in the placement of contours between twelfth year sampling periods, but the general distribution of sand remains unchanged.

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.

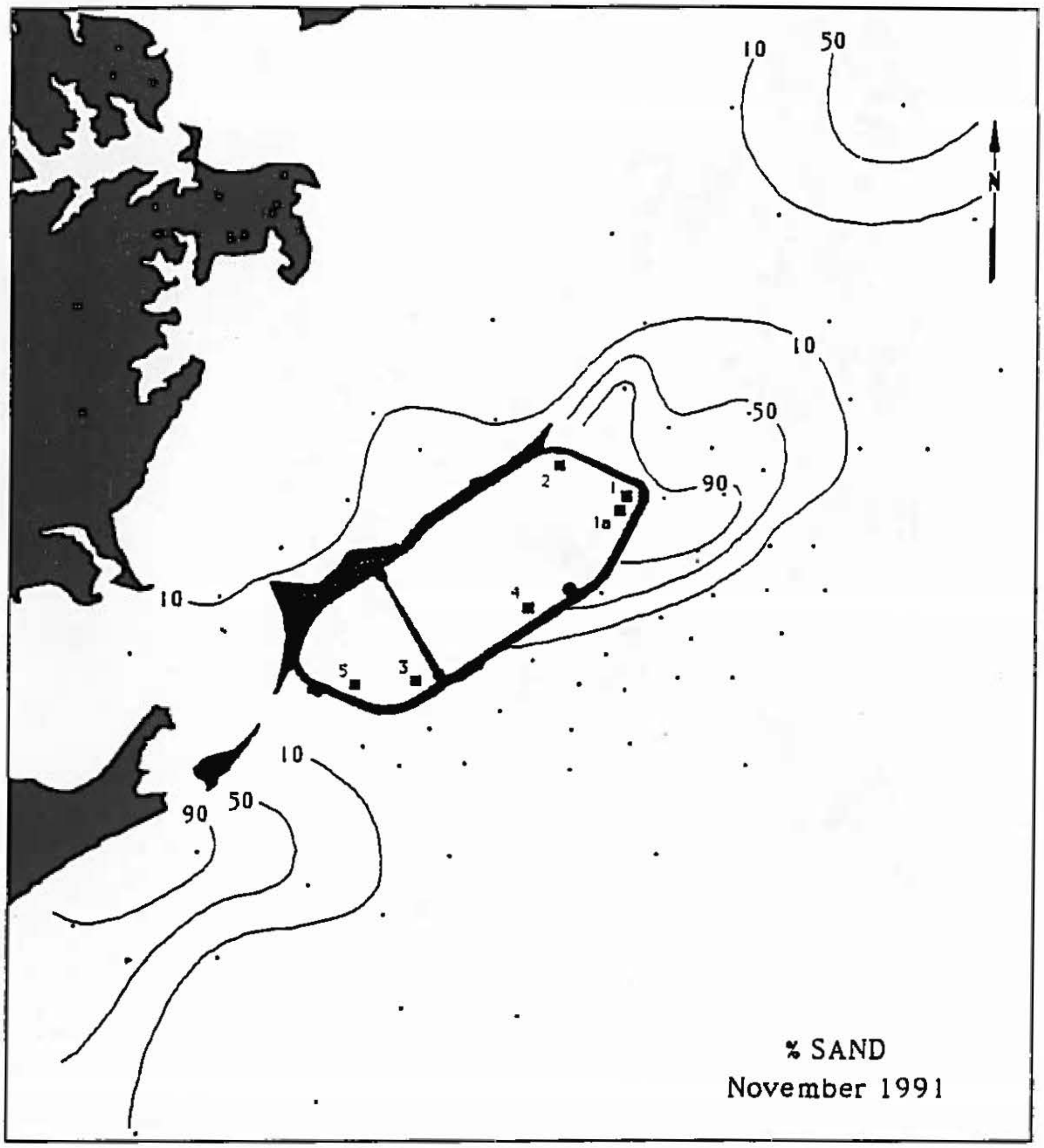


Figure 1-5(a):Distribution of percent sand - eleventh year monitoring: November 1991.

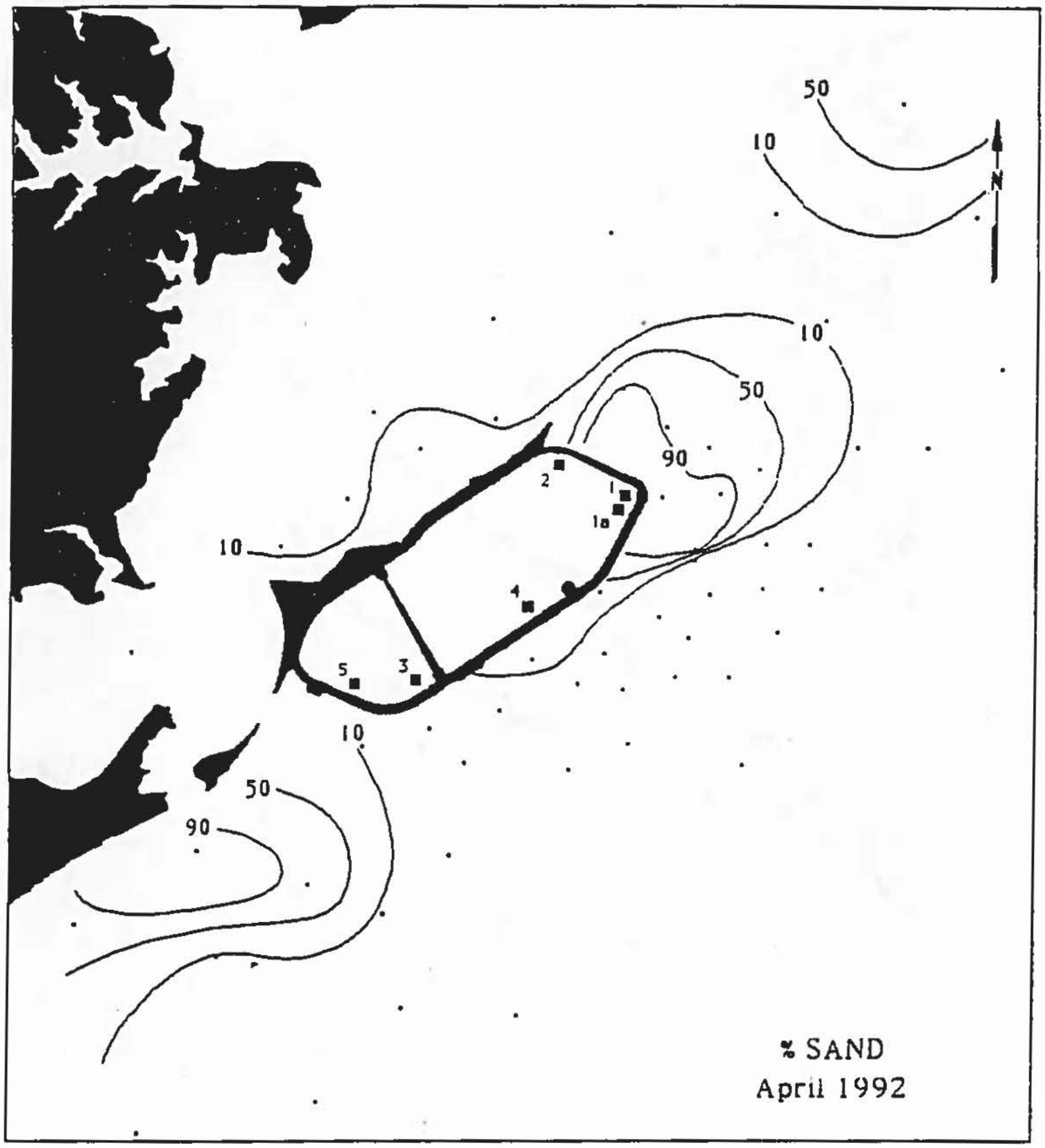


Figure 1-5(b):Distribution of percent sand - eleventh year monitoring: April 1992.

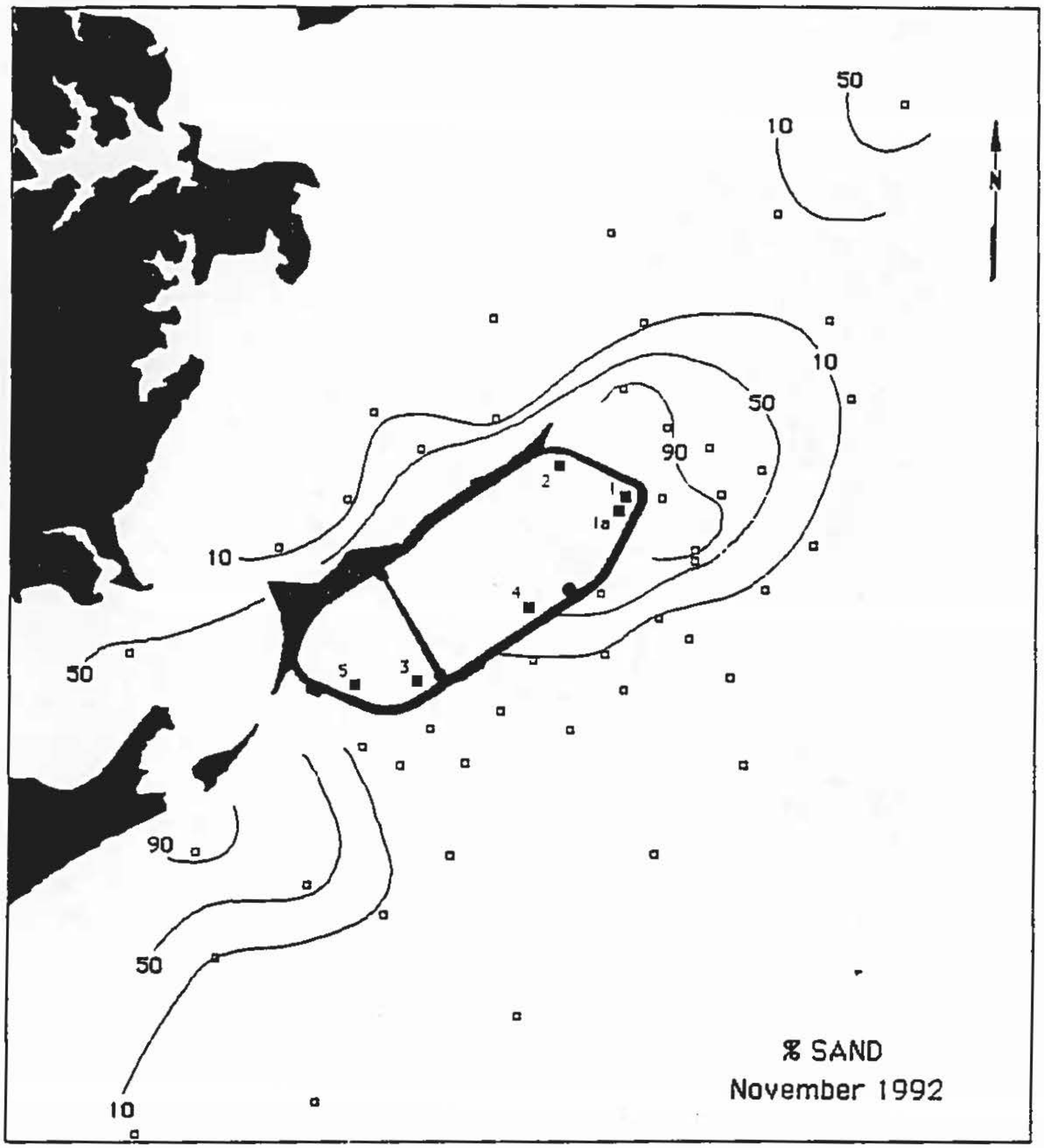


Figure 1-6(a):Distribution of percent sand - twelfth year monitoring: November 1992.

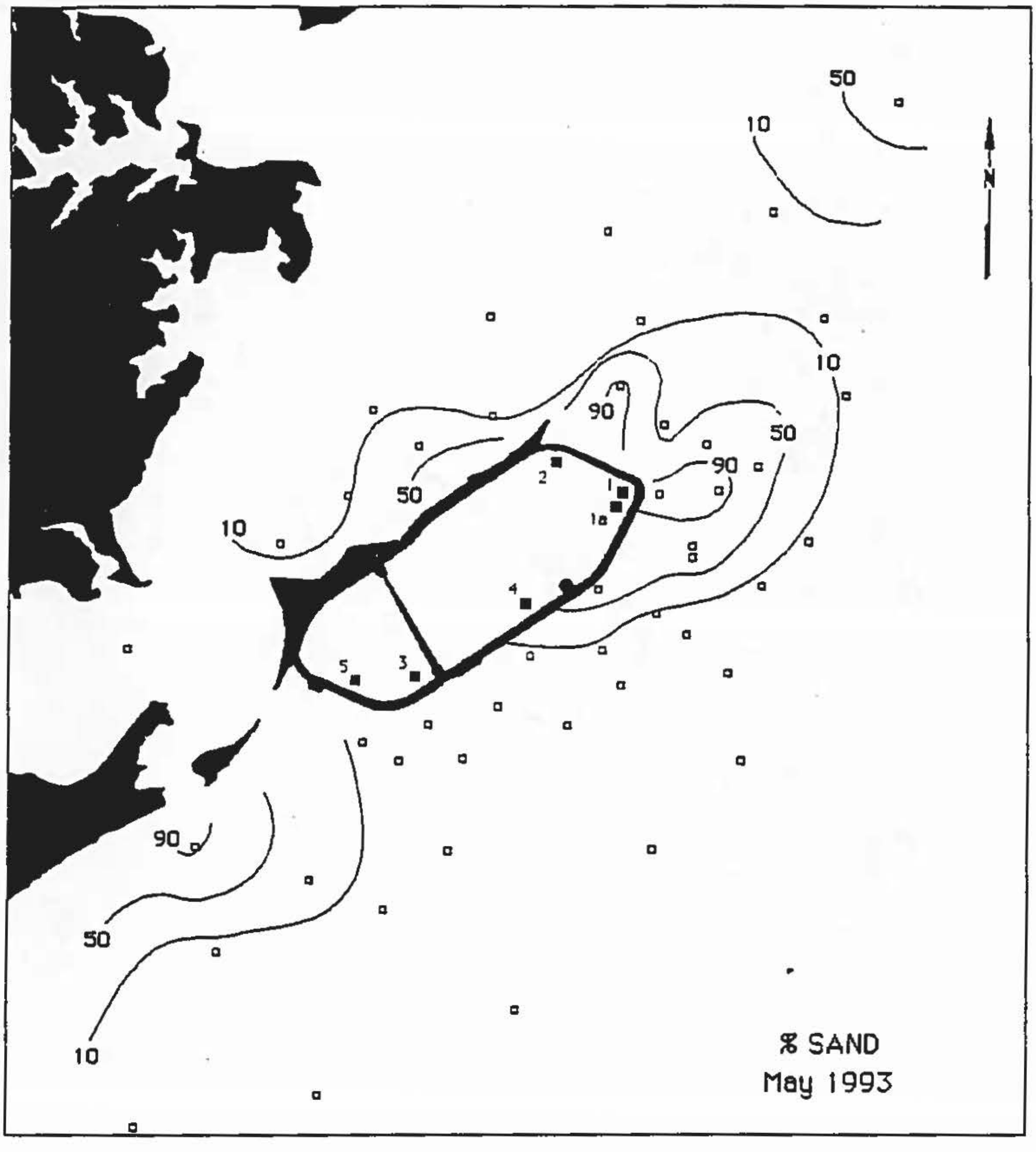


Figure 1-6(b):Distribution of percent sand - twelfth year monitoring: May 1993.

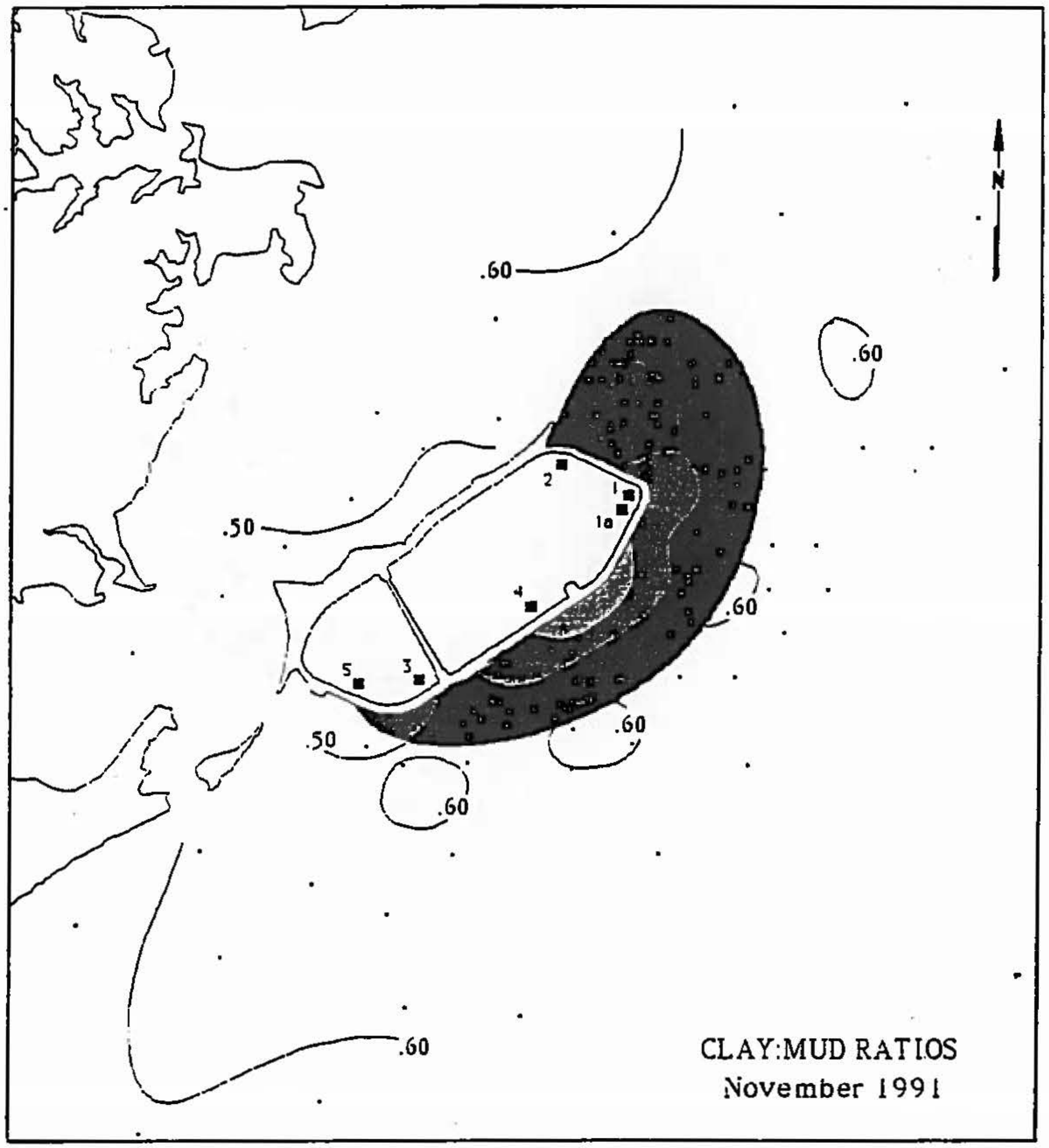


Figure 1-7(a):Distribution of clay:mud ratios - eleventh year monitoring: November 1991.

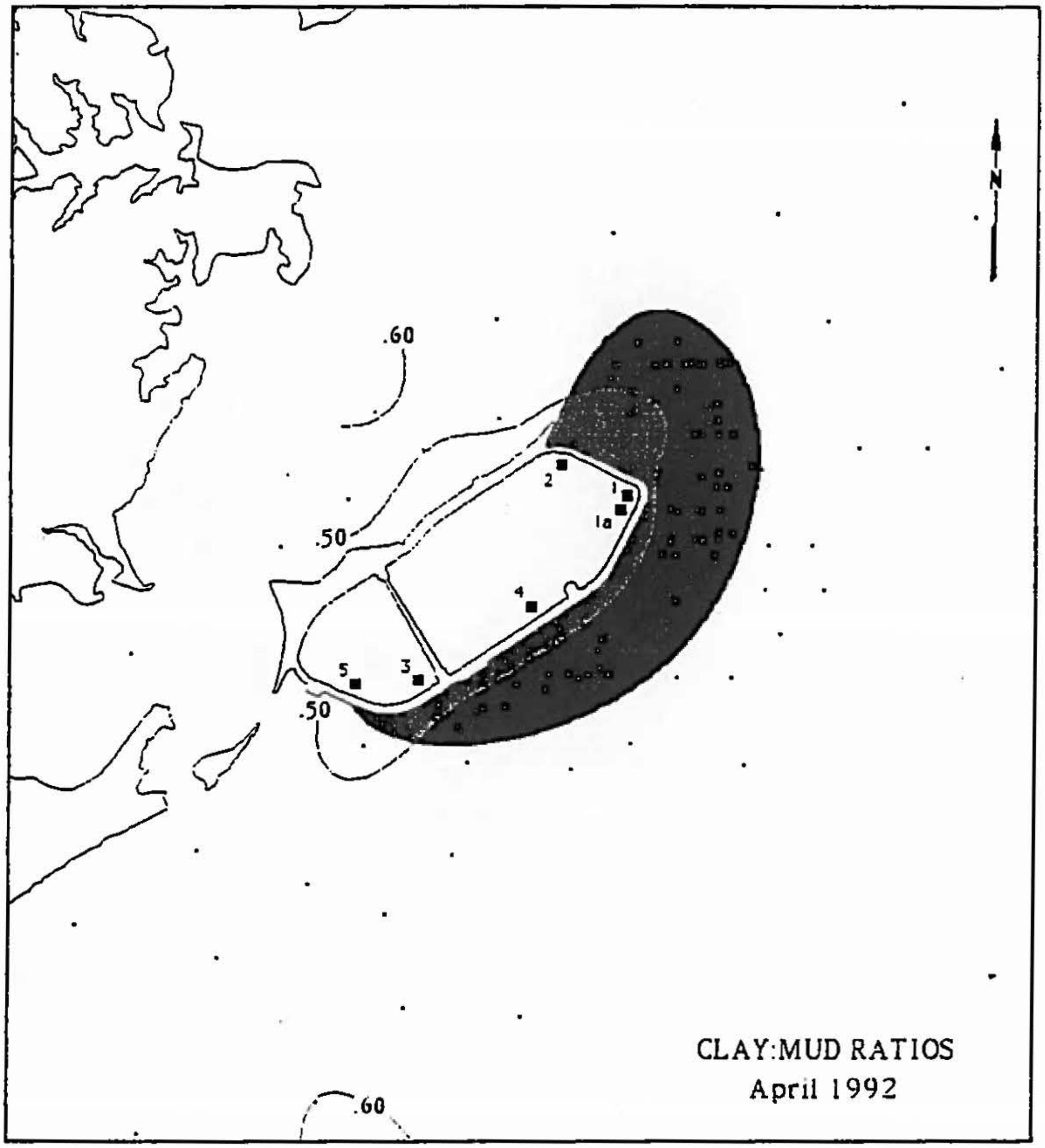


Figure 1-7(b):Distribution of clay:mud ratios - eleventh year monitoring: April 1992.

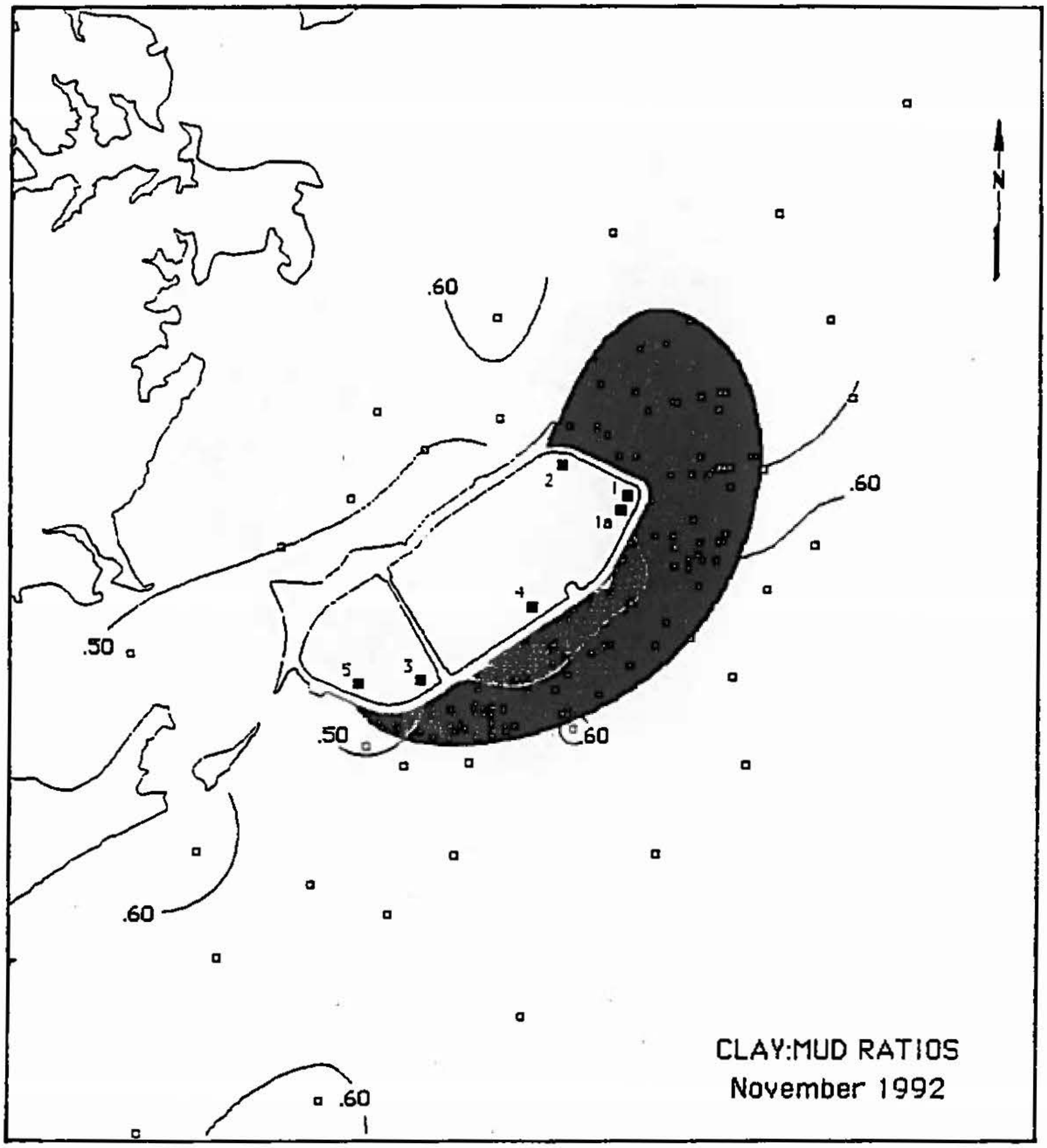


Figure 1-8(a):Distribution of clay:mud ratios - twelfth year monitoring: November 1992.

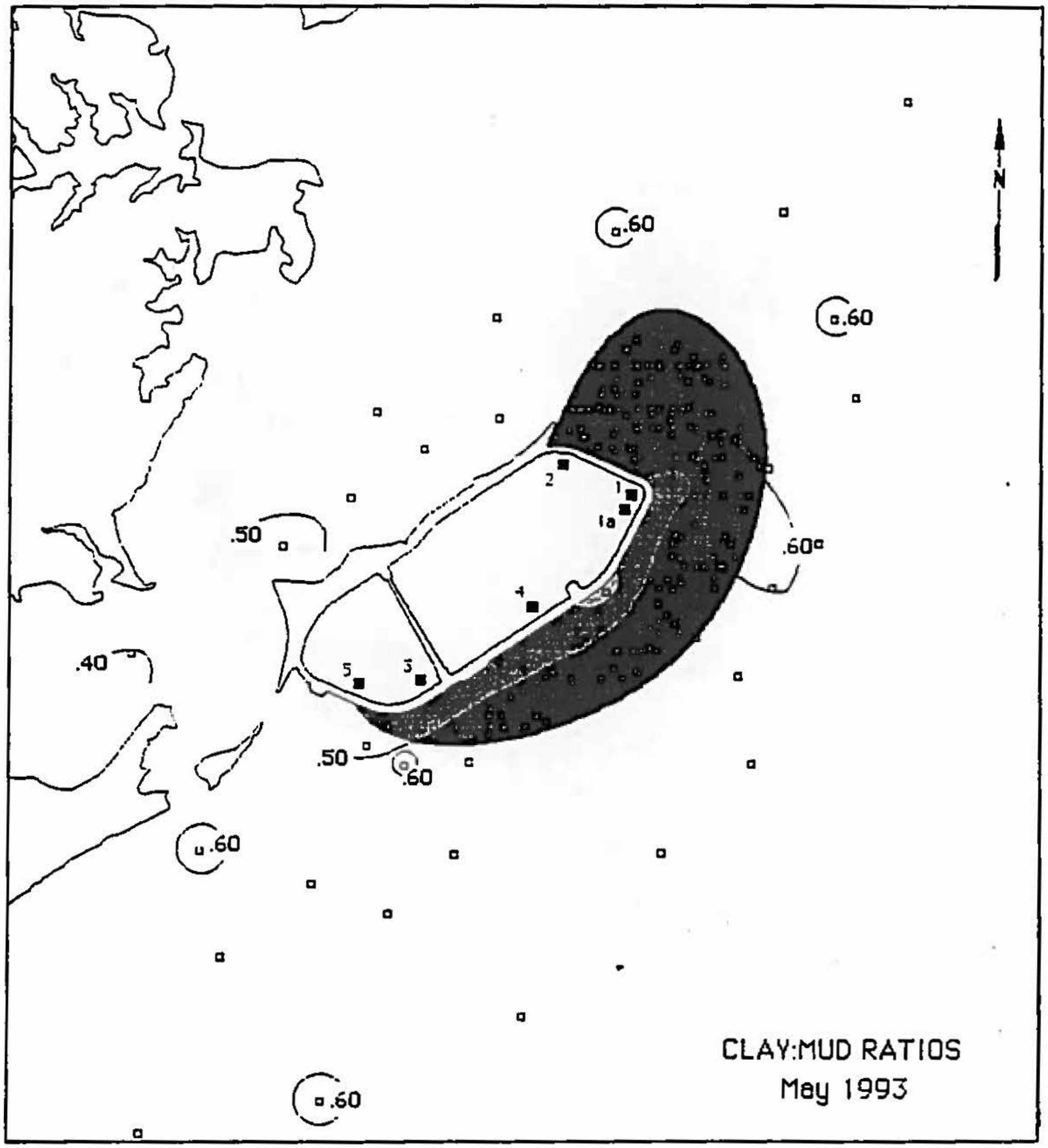


Figure 1-8(b):Distribution of clay:mud ratios - twelfth year monitoring: May 1993.

As described in previous reports, a seasonal pattern developed in the distribution of the fine fraction following the opening of Spillway #1: until the eleventh year, 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 clay:mud 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 eleventh year cruises.) During the twelfth year, the distribution of the fine fraction changed very little from fall to spring, remaining almost identical, in fact, to the April 1992 distribution of clay:mud. The similarities among the three most recent sampling periods is undoubtedly related to the consistently low and intermittent release of effluent from the dike's spillways during the monitoring year.

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, or baseline, around the containment facility:

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

Note: The differences between the measured and predicted Zn levels are normalized to predicted Zn levels.
positive values => enrichment
negative values => depletion

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 (November 1988 and April 1989), increased levels of Zn have been noted in bottom sediments east and south of Spillway #1 (see Figure 1-9 for previous years Zn enrichment levels). These enriched levels of metals are correlated with low discharge rates from the spillway. The distribution of Zn during the ninth (November 1989 & April 1990) and tenth (November 1990 & April 1991) 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.

The trends persisted during the eleventh year (November 1991 and April 1992). 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 was only one data point, which may be in error. It was, nonetheless, included in the contouring, because it was consistent with previous years' trends. Nothing noted in the sample handling or in the sample's characteristics indicated that the sample should be excluded from the data set.

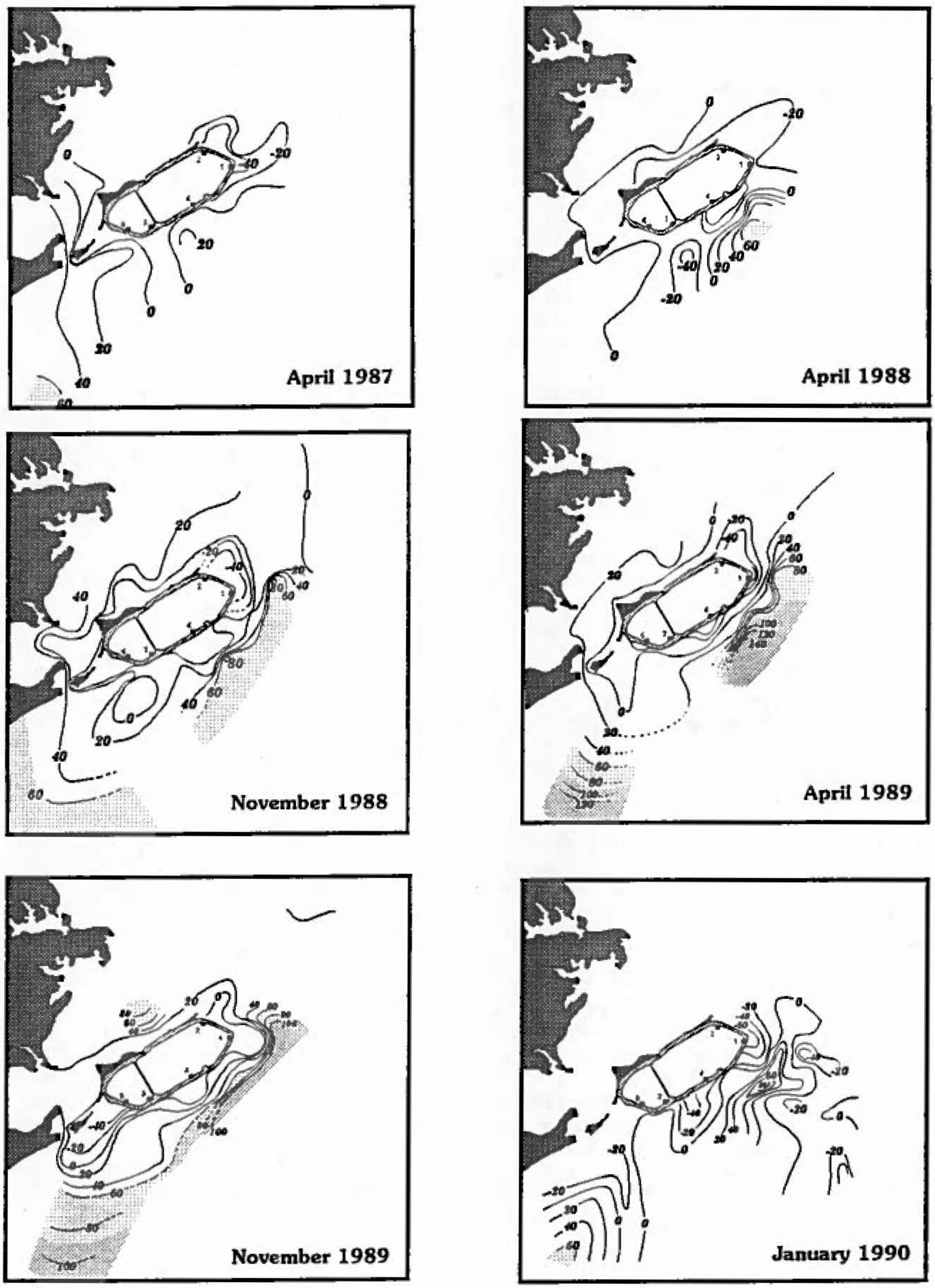


Figure 1-9: Distribution of % Excess Zn for cruises prior to the twelfth monitoring year. Shaded areas indicate levels >2σ above background levels.

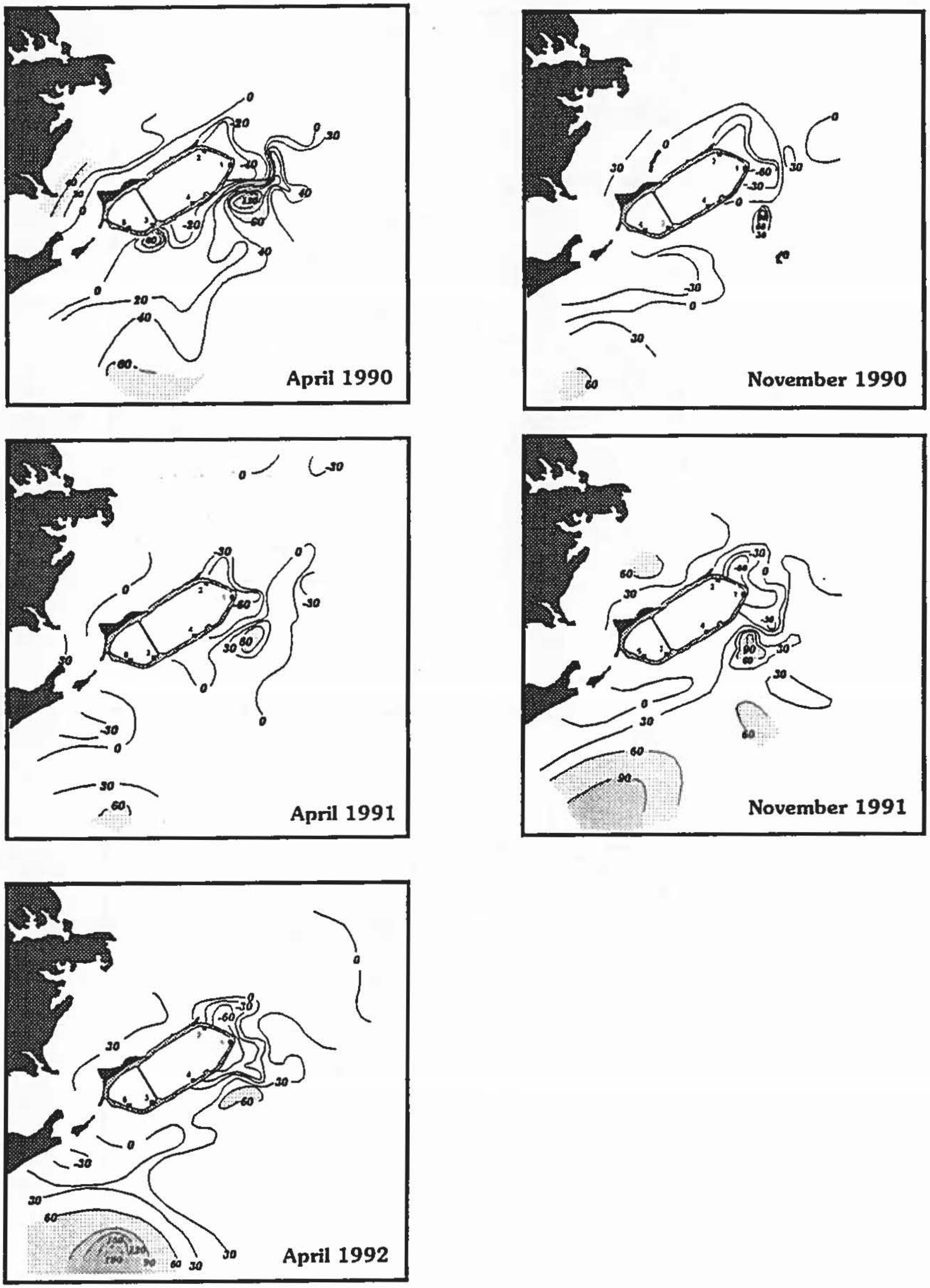
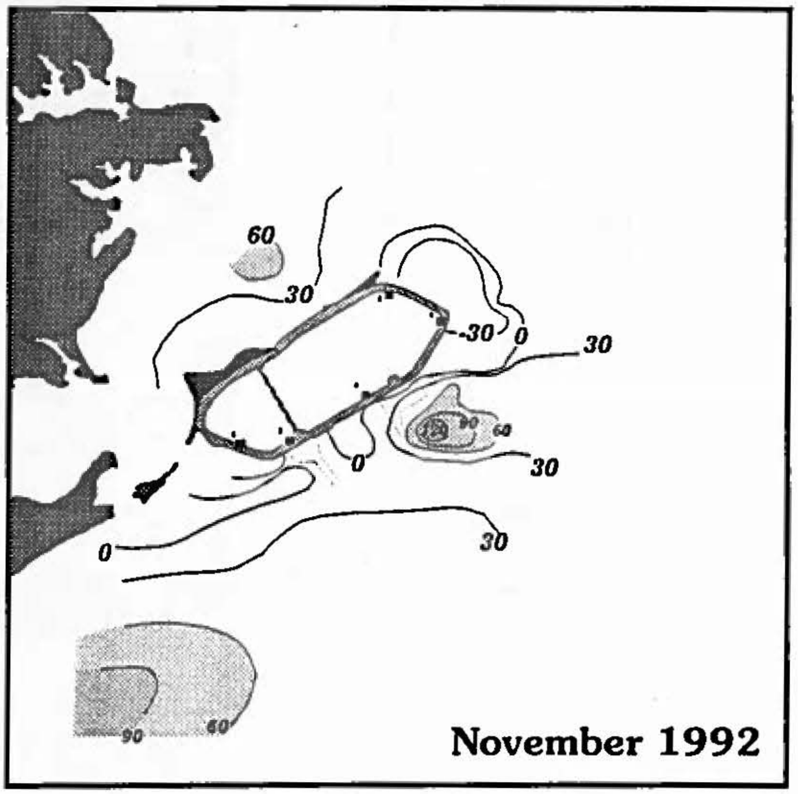


Figure 1-9 (con't): Distribution of % Excess Zn for cruises prior to the twelfth monitoring year. Shaded areas indicate levels >2σ above background levels.



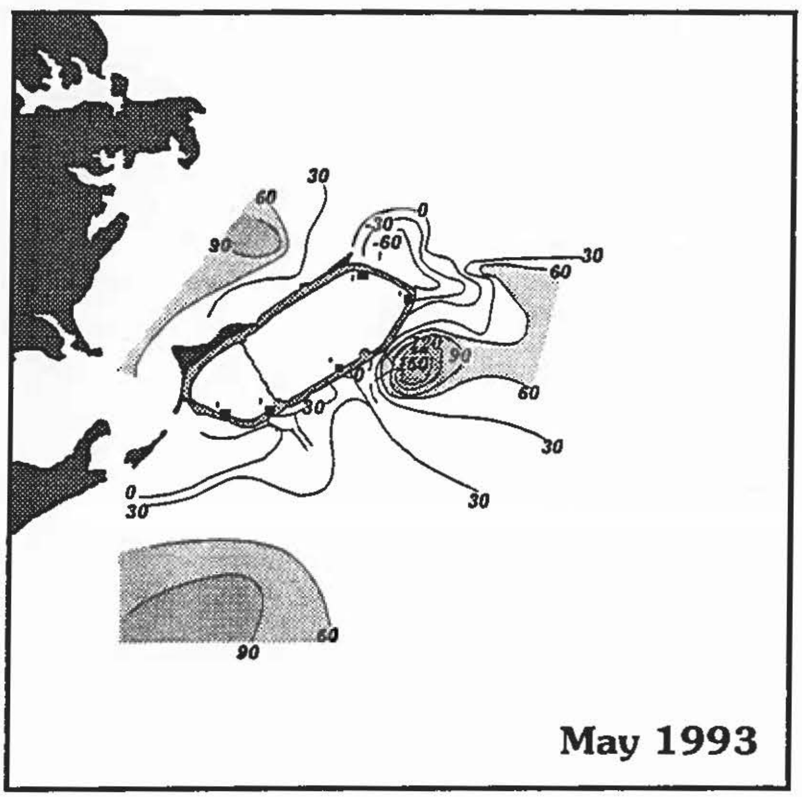


Figure 1-10:Distribution of % Excess Zn for cruises the twelfth monitoring year

During the twelfth year (November 1992 and May 1993; see Figure 1-10), the metals levels increased to 4σ and 5σ,respectively, in the area south and east of Spillway #1. These levels are some of the highest measured to date, and indicate significant elevation above background levels. Additionally, in May 1993 the metal levels on the Hawk Cove side, the western side of HMI, were elevated up to 3σ. This level is the highest value measured for this area; however, the 3σ level is marginally within background levels.

The factors which influence the metals loadings to the exterior sediments from the dike are the circulation patterns in the northern Bay, and the rate and nature of discharge from the dike. The circulation of the northern Bay in the area around HMI has been modelled by Wang (1993) and presented as an addendum in the *Tenth Year Interpretive Report*. 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.

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 was examined in the *Eleventh Year Interpretive Report*. As a result of this examination, a model was constructed that predicts the general trend in the behavior of Zn as a function of discharge rate from the dike. 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 a regression line based on discharge data supplied by MES.

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 applicability of the leachate model to predict the observed metal loadings behavior around HMI was shown in the *Eleventh Year Interpretive Report*.

The source of the excess metal loading is attributed to leaching of 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, nutrients, and acid-soluble organics) from the sediments.

Processes that aid in dewatering the sediments also promote acid mine-type drainage, also called "desulfurization". To dewater the sediments, trenches are formed by mounding and channelizing the sediment. 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 observed behavior of the excess Zn levels during the twelfth monitoring year follows the predicted behavior based on the operations of the dike, coupled with the upper Bay hydrodynamics. Dike operations focused on dewatering by managing the crust through trenching, without the addition of any further dredged material. As a result, discharge rates were low and intermittent, which subsequently led to the release of higher levels of excess metals. The release of higher metal levels, even with low discharge rates, would be expected to produce higher levels of excess Zn in the exterior sediments, as found during the twelfth monitoring year.

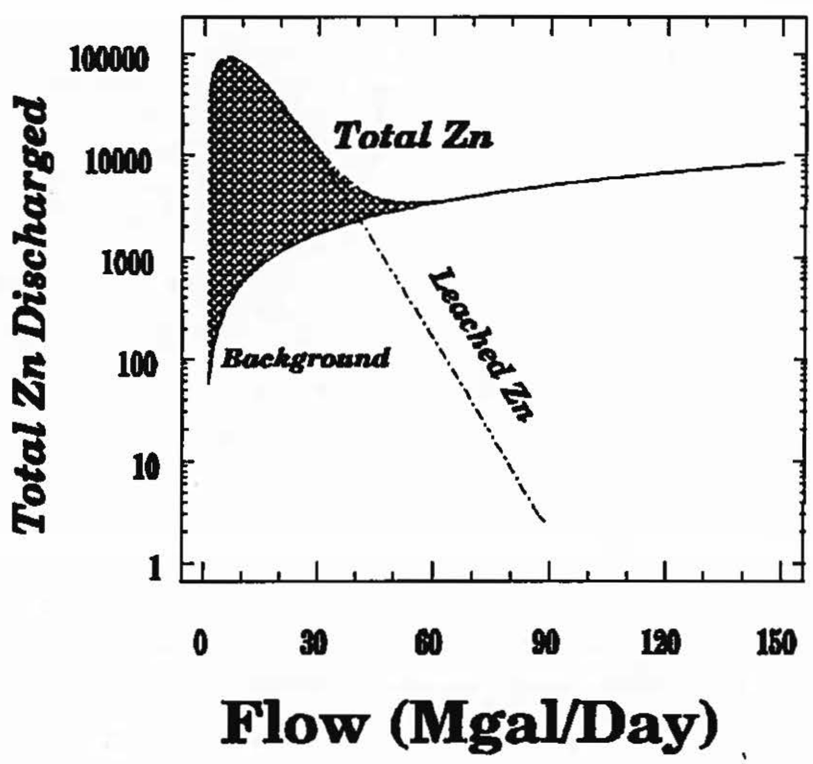


Figure 1-11:Graphical result of a two-component model: loading due to background plus enriched material from leaching. The shaded area highlights the amount of excess loading over background.

CONCLUSIONS

The grain size distribution of exterior bottom sediments, mapped during the twelfth monitoring year, was similar to eleventh 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 not evident this year. During the twelfth year, the distribution of the fine fraction changed very little from fall to spring, remaining almost identical to the April 1992 distribution of clay:mud. The similarities among the three most recent sampling periods is related to the consistently low and intermittent release of effluent from the dike's spillways during the monitoring year.

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 twelfth monitoring year in the vicinity of the dike; with excess metal levels reaching their highest values to date. In previous reports, elevated Zn levels were associated with low flow releases of effluent from the facility; this holds true for the twelfth monitoring year. Two factors control metal loadings to the exterior sediments; regional hydrodynamics of the upper Chesapeake Bay (Wang, 1993) and the chemistry of the effluent from the dike. The chemistry of the effluent from the dike is affected by leaching of the sediment. Leaching of sediments in the dike increases the dissolved metal load 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.

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 resulting 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; Rebecca Gast, Jennifer Isoldi, and Rich Ortt, for braving the elements during sample collection; Bill Panageotou, for helping to x-ray the cores; 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 (Figure 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).

Designation of the erosional/depositional areas along the beach, present during the monitoring period (May 1992 - May 1993), is essential for the planning of proper maintenance. The beach has sustained extensive erosion north and significant deposition at Station 24+00 during the past reporting period. Erosion at each station has lowered the beach profile close to February 1991 levels, immediately prior to beach renourishment. Within the next year, erosion may reach the February 1991 levels whereby renourishment must be a serious consideration.

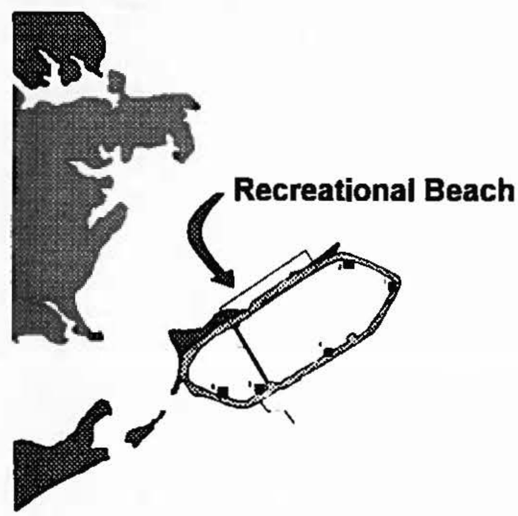


Figure 2-1: Location of the study area.

MGS had recommended that the shoreline be nourished with sand from an outside source for several years. 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. The beach levels at this reporting period show removal of a significant volume of previously renourished sand. It is our recommendation that renourishment be given serious consideration for the upcoming year.

PREVIOUS WORK

MGS has monitored the recreational beach since May 1984. The interpretation of the results of the monitoring surveys has been stated in many prior reports. Those reports stated 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:
(1) <u>the outer dike face</u>, extending from the chain link fence at the edge of the dike roadway to the high water mark, usually a wave-cut escarpment;
(2) <u>the foreshore</u>, between the high water mark and mean low water 0 ft MLW, and;
(3) <u>the nearshore</u>, 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 adequately stopped runoff erosion.

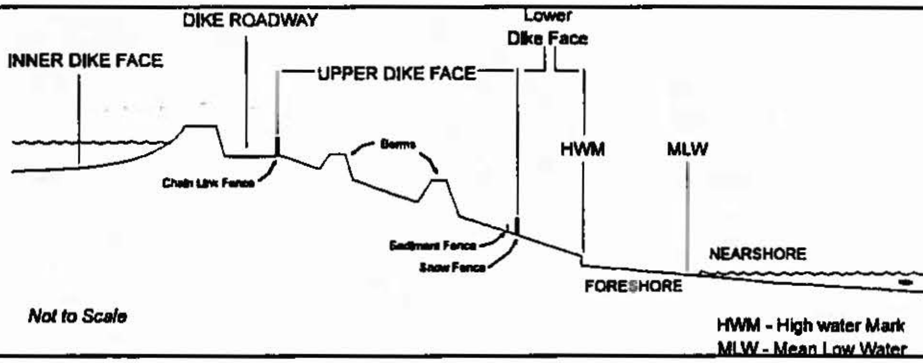


Figure 2-2: Post-reconstruction (August 1988) schematic cross-section of the dike illustrating geomorphic regions of the beach.

The foreshore, in the past, 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 over much of the length of the beach. Bulldozing of the foreshore removed the escarpment during the gradation of the beach in the late spring, but it returned, usually with the next storm event.

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

The net sediment loss along the recreational beach is summed 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	+9428	+7252
May 1991 - May 1992	+1863	+1433
May 1992 - June 1993	-5828	-4479

* based on ISRP (Birkemeier, 1986)

OBJECTIVES

This report was written specifically to be a summary of the monitoring results of the beach. The objectives of this report 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 (Figure 2-3). There were two surveys conducted along the ten profiles during the monitoring period, May 1992 - June 1993 (Table 2-2).

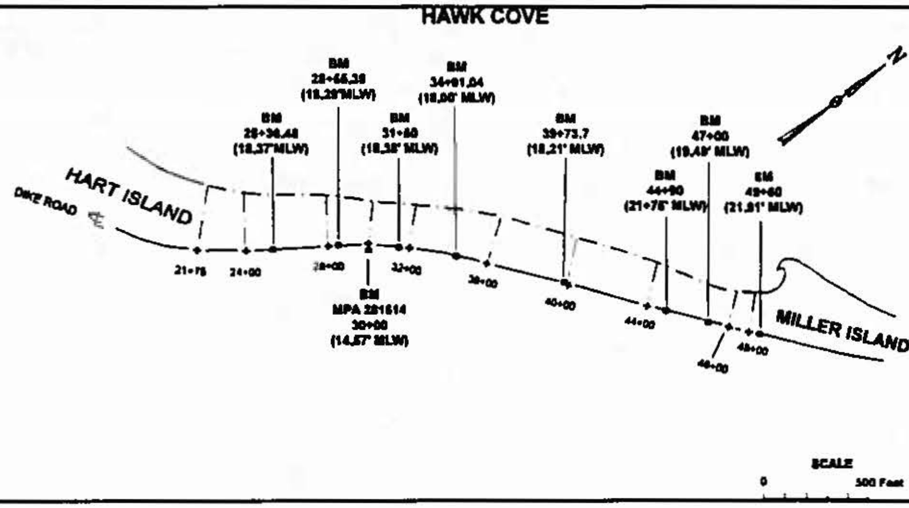


Figure 2-3: Dike location of the surveyed profile lines and bench marks.

Table 2-2: Beach profile survey dates.

Profile	Survey 1	Survey 2	Survey 3
21+75	5-2-91	5-20-92	6-3-93
4+00	5-2-91	5-20-92	6-3-93
28+00	5-2-91	5-20-92	6-3-93
30+00	5-8-91	5-20-92	6-3-93
32+00	5-8-91	5-20-92	6-3-93
36+00	2-8-91	5-20-92	6-3-93
40+00	5-8-91	5-20-92	6-3-93
44+00	5-8-91	5-20-92	6-3-93
48+00	5-8-91	5-20-92	6-3-93
49+00	5-8-91	5-20-92	6-3-93

Distance and elevation data collected during the two surveys are listed in the *Twelfth 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 benchmarks 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

Table 2-3: Benchmark 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

transferred from the centerline of the dike roadway to wooden stakes emplaced into the sand close to the snow fence. Each profile 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 elevation changes and the amount of wind (potential for bending the survey rod).

DATA REDUCTION

To calculate the sediment gains and losses above and below datum (0 ft MLW) for each profile, a computer program, *Interactive Survey Reduction Program* (ISRP), was employed (Birkemeier, 1986).

Net beach sediment volumes were determined by the formula:

$$V_c = D/2(A_1+A_2) \qquad \text{(eq 1)}$$

where: V_c = volume change in cu yds

D = distance (ft) between profile stations
$A_{1,2}$= volume loss(cu yds/ft of beach)for each profile

RESULTS AND DISCUSSION

In April 1991, the beach was nourished with sand dredged from the approach channel to Baltimore Harbor. Construction crews at Hart-Miller Island transported sand from an on-island stockpile via dump trucks. A bulldozer smoothed the sand dumped by the trucks. The sand consisted mainly of clean medium-grained (1.0ϕ-2.0ϕ) sand with some fine (3.0ϕ-4.0ϕ) 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 to 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.

The result of monitoring the beach at Hart-Miller Island has been the identification and extent of erosion/deposition. Both the shoreline position and the foreshore have been modified during the period May 1992-June 1993. To assess the changing slope of the beach, ten cross-sectional profiles were constructed using ISRP (Appendix A).

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

Dike Station	5/91	5/92	6/93
21+75	328	330	330
24+00	279	289	304
28+00	237	236	216
30+00	229	220	208
32+00	237	212	208
36+00	255	234	220
40+00	260	249	238
44+00	222	210	198
48+00	208	190	174
49+00	219	191	172

The beach profile at Profile 24+00 exhibited significant deposition along the entire profile above datum. Volume increases measured +3.0 yd^3 per linear ft of beach from May 1992 and from February 1991, +3.36 yd3 per linear ft of beach. The mean low water shoreline moved seaward by 15 ft from 1992 to 1993.

The deposition at Profile 24+00 is offset with erosion along Profiles 28+00 to 36+00. The beach at Profile 28+00 eroded below the February 1991 or pre-nourishment level. The volume loss measured -4.06 yd^3/ft of beach from May 1992 to June,1993 with a shoreline retreat of -21.0 ft. Profiles 30+00,32+00, and 36+00 experienced erosion from May 1992 but beach levels were still above the February 1991 levels. Erosion volumes ranged from -1.5 yd^3/ft to -3.25 yd^3/ft of beach. Shoreline retreated along the entire section from -21.0 ft at Profile 28+00 to -4.0 ft at Profile 36+00. The configuration of each profile shows a concave plan form indicative of extensive erosion above the MLW datum.

At Profile 40+00, very little change was measured during the profile period. The volume change was less the 1 yd^3 but shoreline retreat measured -10.0 ft. More of the change in the profile appear to occur below datum, in the nearshore area. The very gentle slope of the nearshore area when eroded can translate into a shoreline retreat of the distance measured at Profile 40+00 with very little volume loss.

Erosional conditions were observed from Profile 44+00 to Profile 49+00, at the southern tip of Miller Island. At Profile 44+00, erosion lowered the beach by -3.7 yd^3/ft with shoreline retreat of -10.0 ft. The profile at 44+00, although lower than May 1992, is still above the February 1991 level. This is not the case for Profiles 48+00 and 49+00. Both profiles are at or near February 1991 levels. Erosional losses measured for Profile 48+00 and Profile 49+00, -4.7 yd^3/ft and -6.4 yd^3/ft, respectively.

CONCLUSIONS

The Hart and Miller Island beach displayed general erosional characteristics during this profiling period. Profiles 21+75 to 24+00, southern profiles, are the most stable. Deposition dominated the entire upper beach face at Profile 24+00, as north-derived sediments moved along the shore towards the south. The middle profiles, from 28+00 to 40+00(as compared to previous years of 30+00 to 44+00), experienced erosion along the upper beach face and nearshore, below datum. Profile 28+00 approached the benchmark profile of February 1991 while Profiles 30+00, 32+00, 36+00, and 40+00 were still above the February 1991 level.

The greatest erosional volumes were recorded between 44+00 and 49+00. The profile levels are lowered than the benchmark level. The sediments eroded north of 44+00 were transported south via longshore transport.

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

The shorelines developed during the February 1991 beach nourishment project is the benchmark to which future beach conditions will be referenced. As shown by the profile comparisons, many of the profiles are critically approaching that February 1991 level with some of the profiles actually lower than pre-nourishment levels. It is strongly recommended that a new plan for beach nourishment be devised and implemented. Volumes of 10,000 to 14,000 yd^3 should be sufficient to sustain the recreational beach for the next several years.

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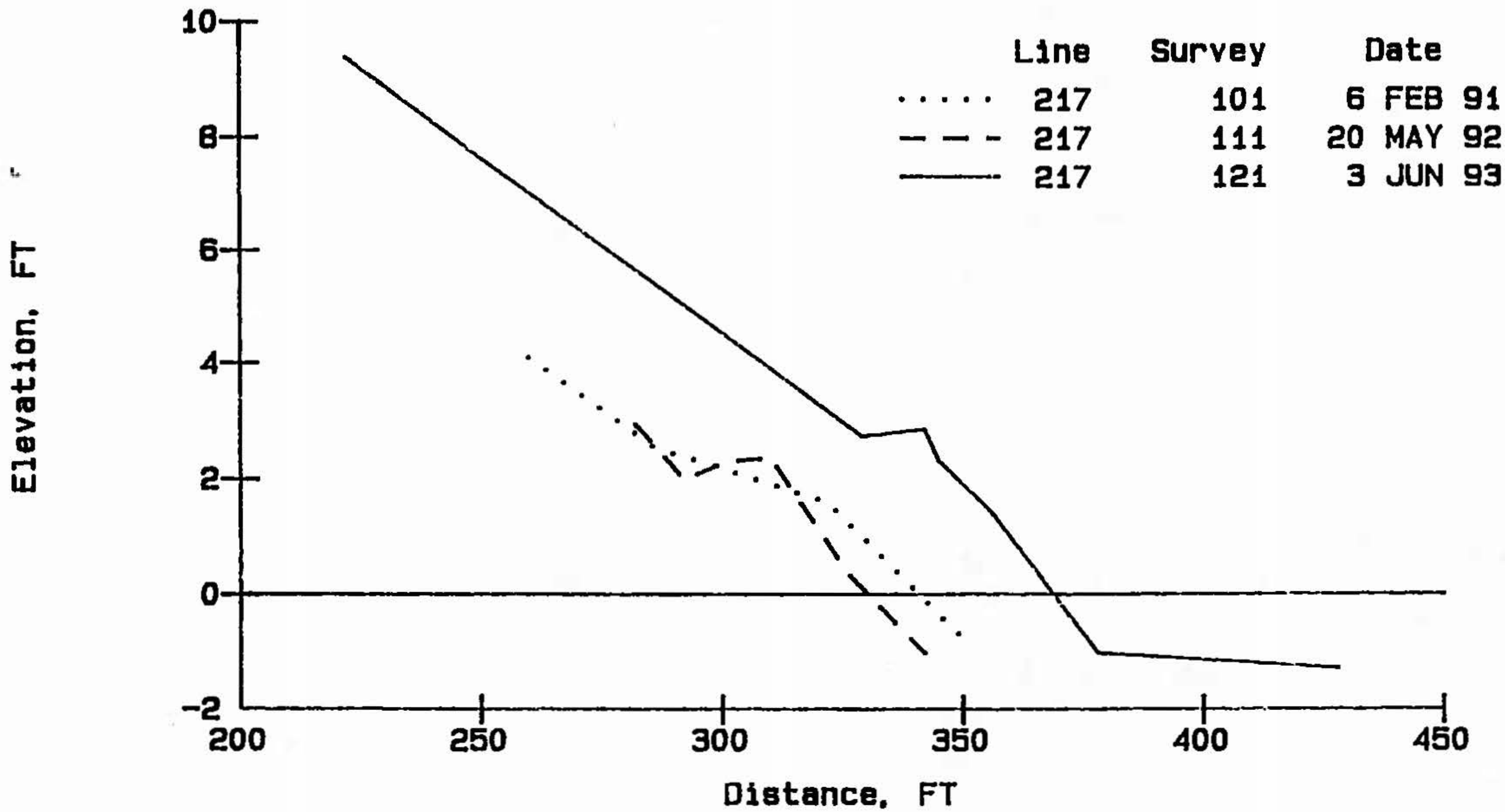
Appendix A:

i. Cross-sectional profiles;

ii. Profile volume changes of the recreational beach, from measurements made during three surveys: May 1992 and May 1993.

Appendix A(i):

Cross-sectional beach profiles.



Line
Survey
Date
217
101
6 FEB 91
217
111
20 MAY 92
217
121
3 JUN 93
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Distance, FT
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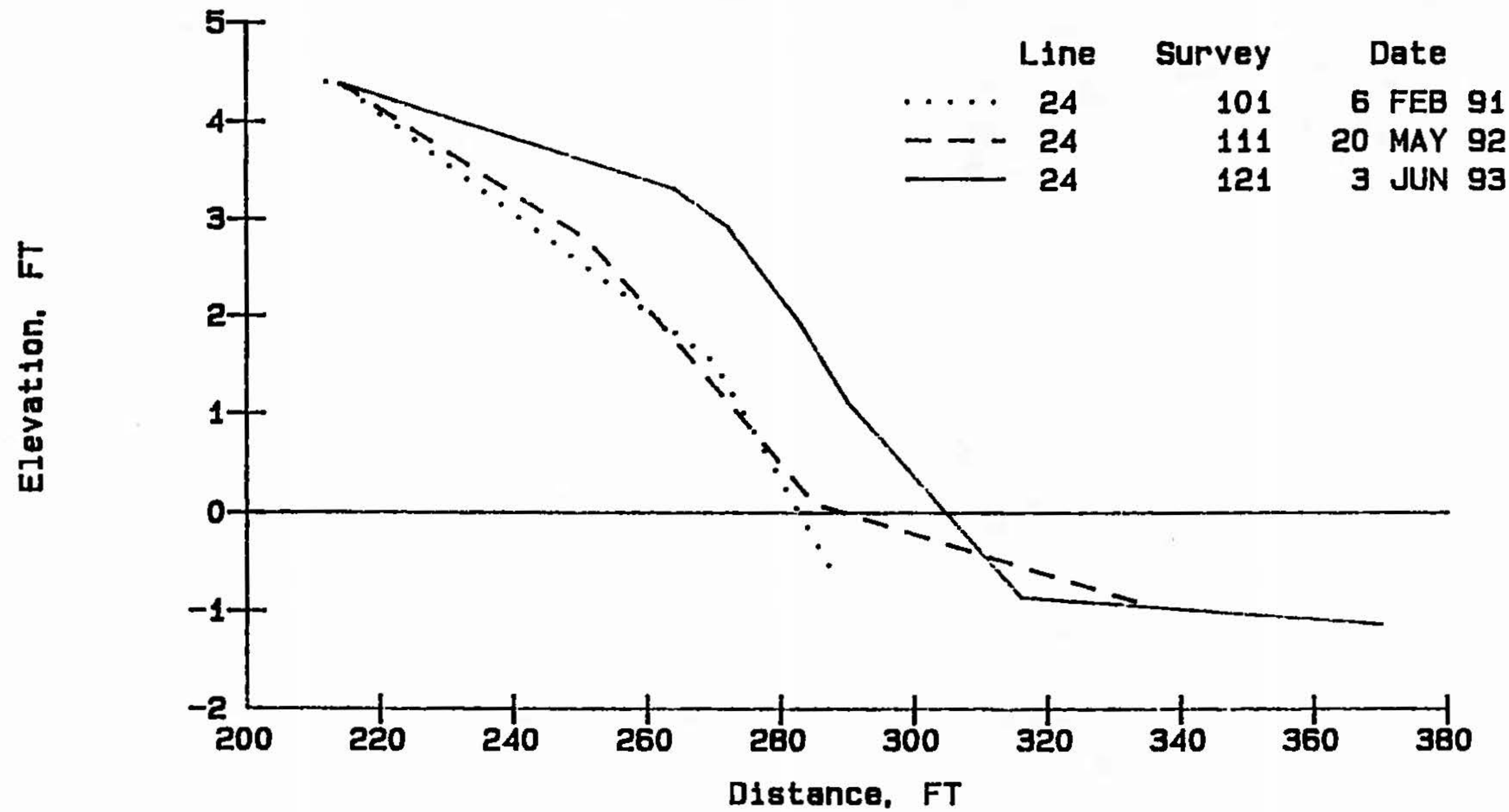
8
6
4
2
0
-2
200
250
300
350
400
450



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Distance, FT
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4
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0
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-2
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260
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300
320
340
360
380
Line Survey Date
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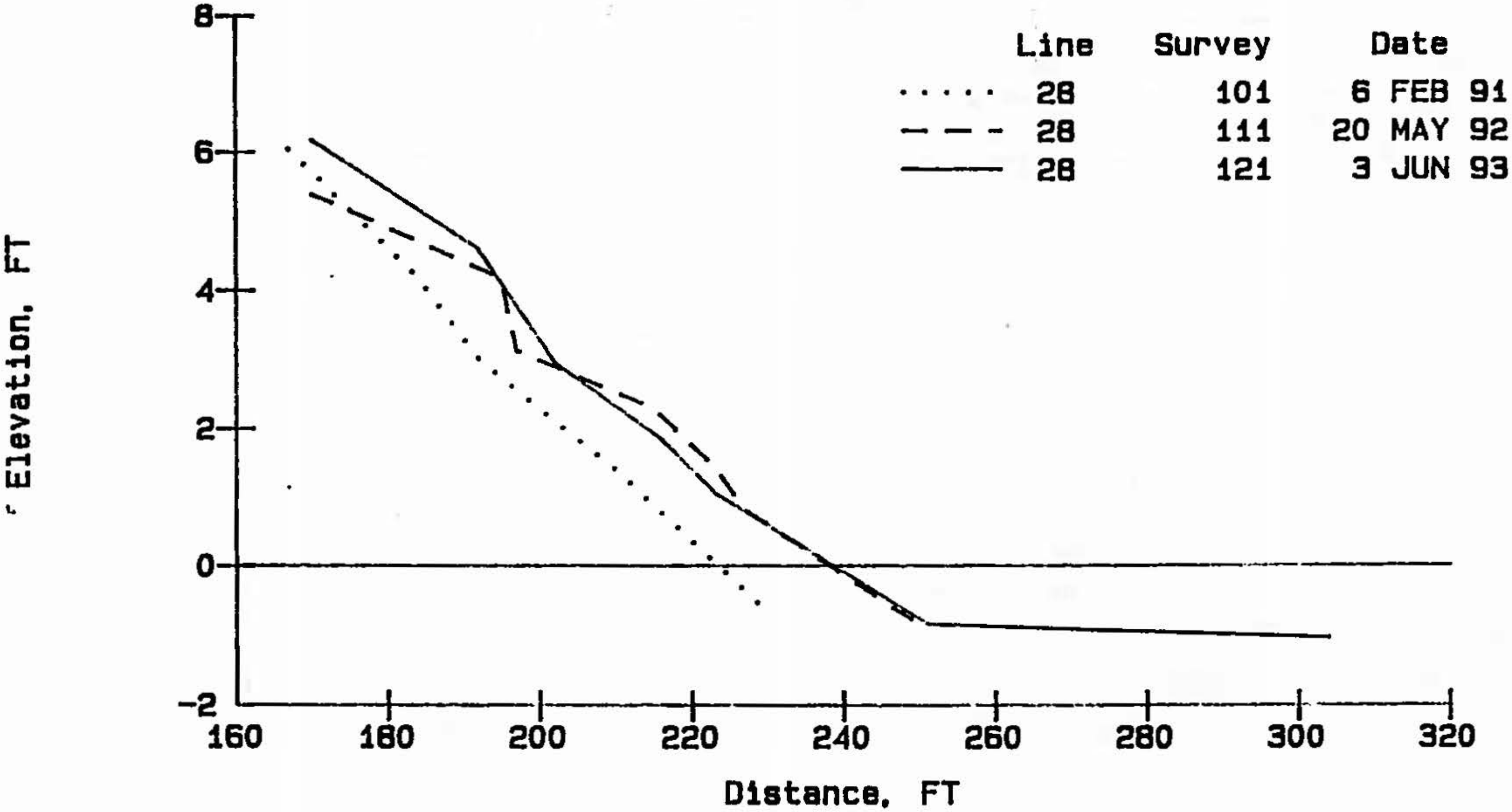
24 111 20 MAY 92
24 121 3 JUN 93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28 121 3 JUN 93
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Distance, FT
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6
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2
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-2
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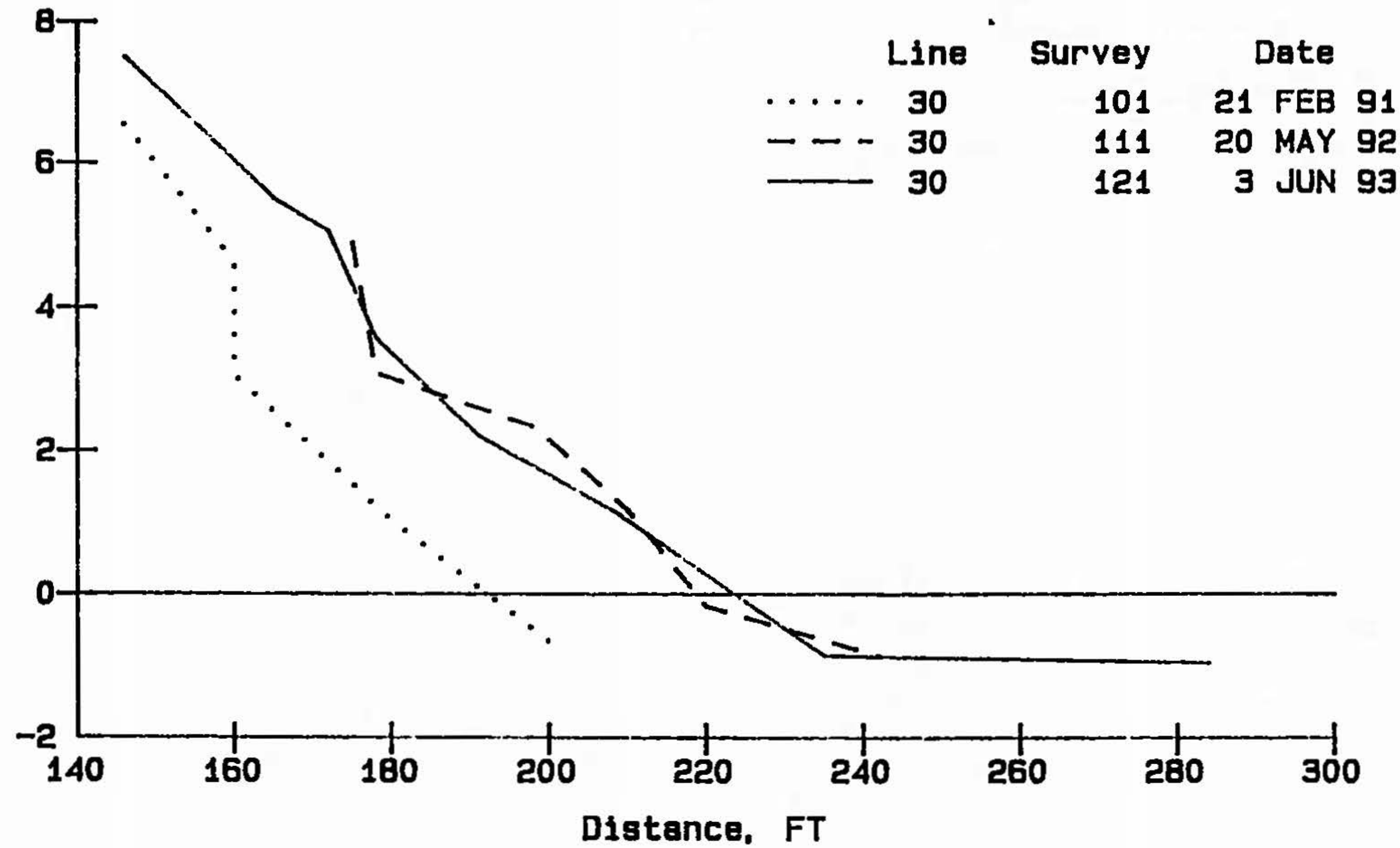
180
200
220
240
260
280
300
320



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30 111 20 MAY 92
30 121 3 JUN 93
Elevation, FT
Distance, FT
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6
4
2
0
-2
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160
180
200
220
240
260
280
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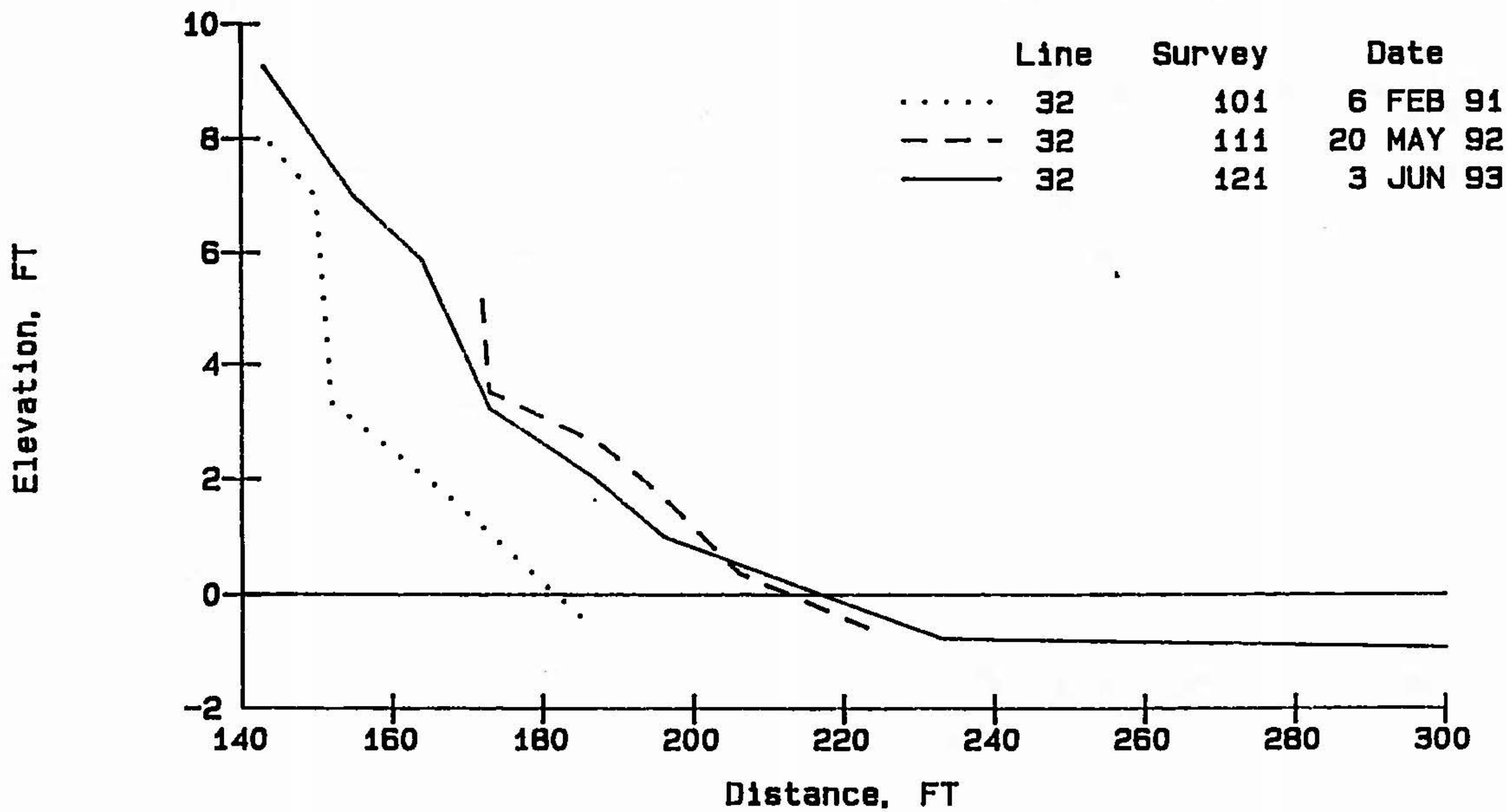

Line
Survey
Date
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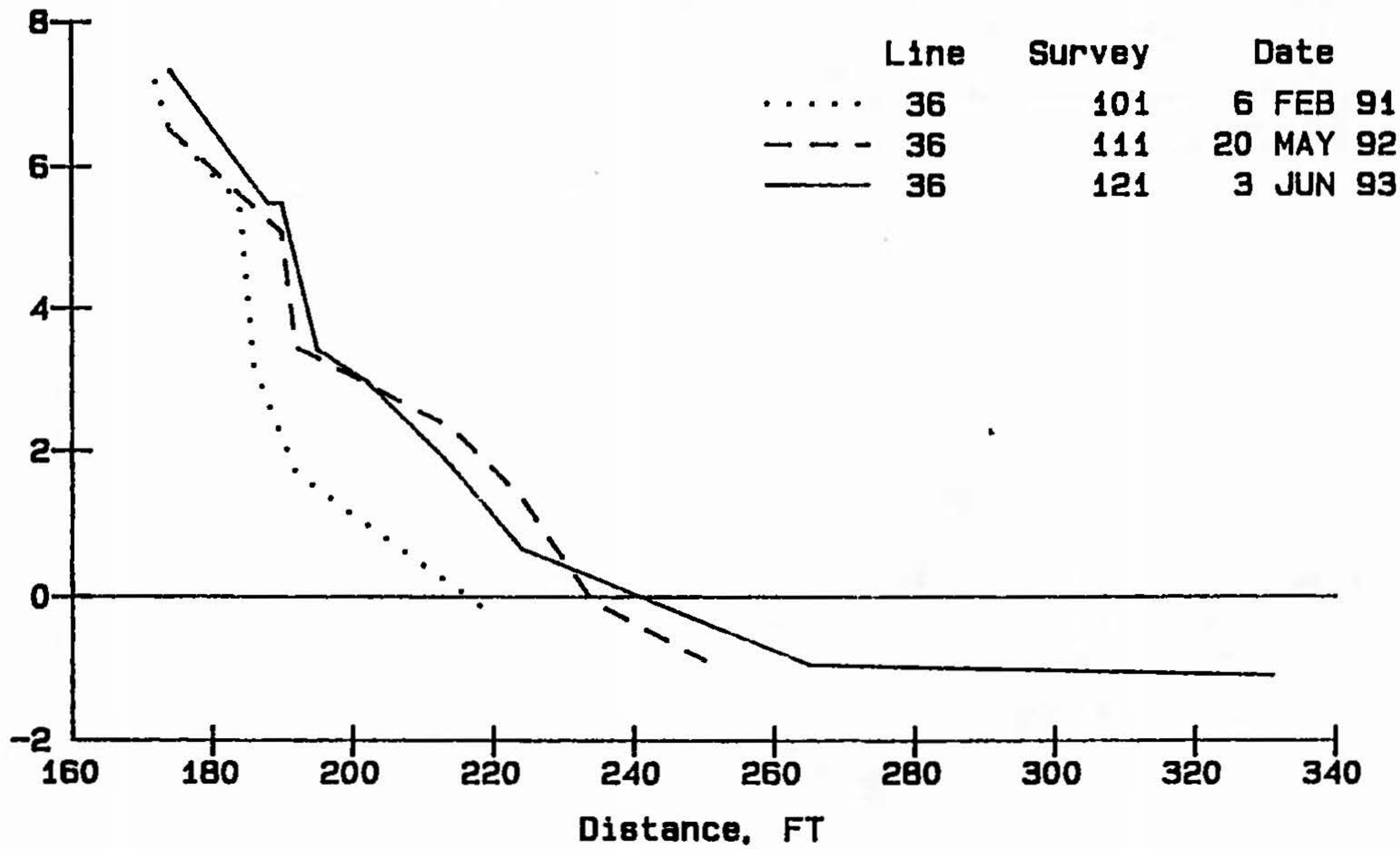
101
6 FEB 91
32
111
20 MAY 92
32
121
3 JUN 93
10
8
6
4
2
0
-2
140
160
180
200
220
240
260
280
300
Elevation, FT
Distance, FT


Line Survey Date
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36 121 3 JUN 93
Elevation, FT
Distance, FT
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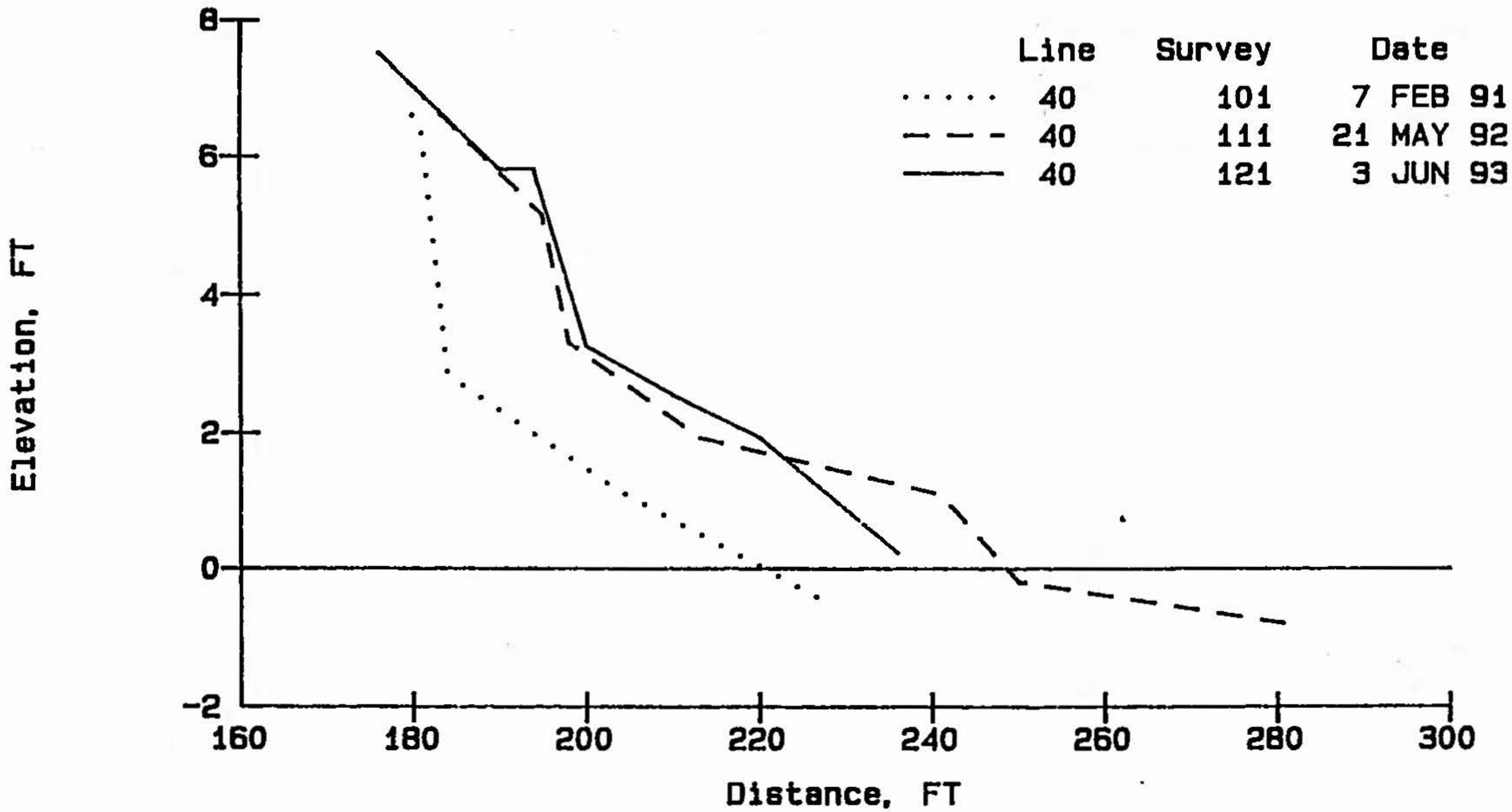
6
4
2
0
-2
160 180 200 220 240 260 280 300 320 340


Line Survey Date
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40 111 21 MAY 92
40 121 3 JUN 93
Elevation, FT
Distance, FT
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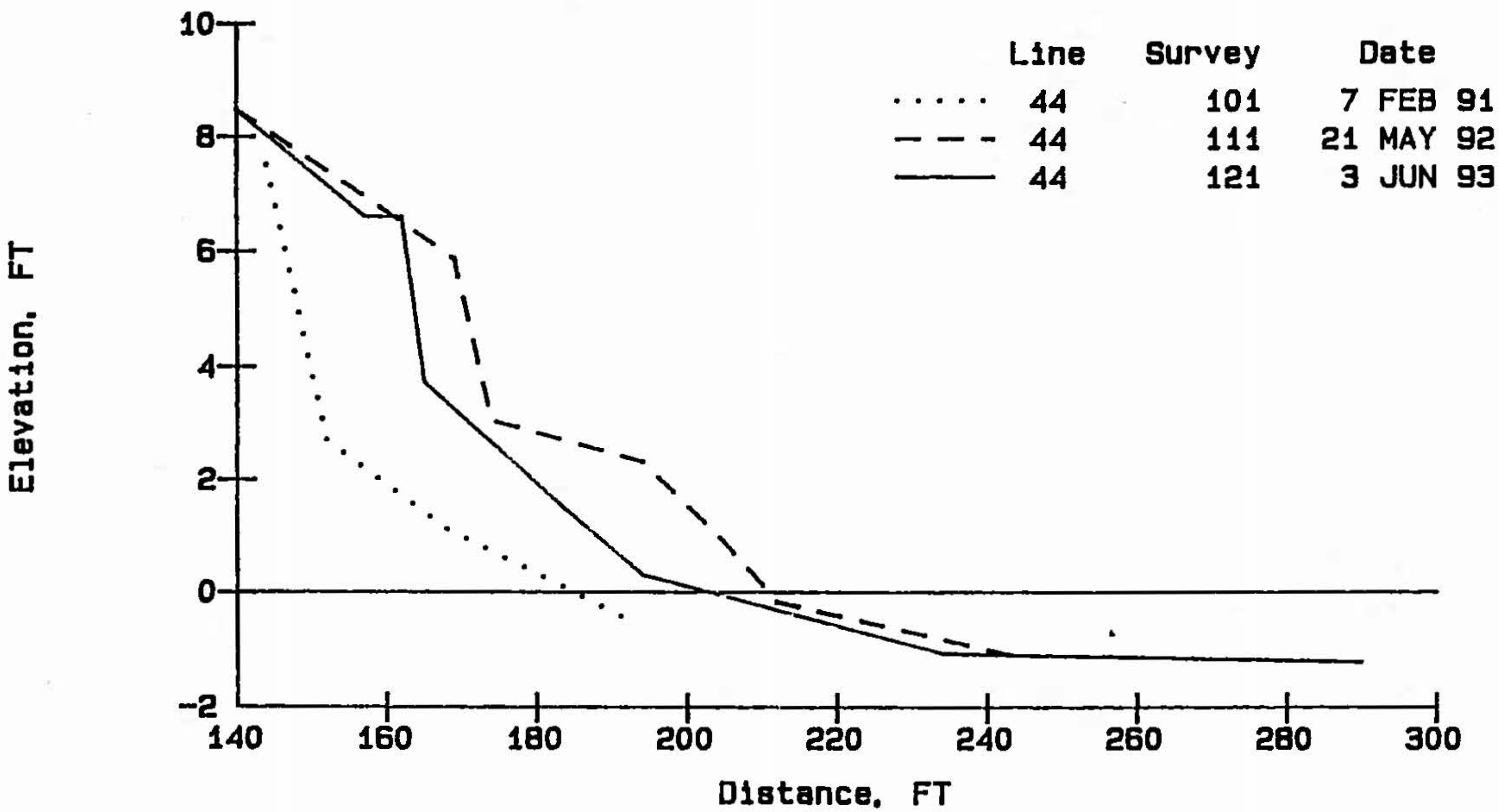
6
4
2
0
-2
160
180
200
220
240
260
280
300



Line Survey Date
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44 111 21 MAY 92
44 121 3 JUN 93
Elevation, FT
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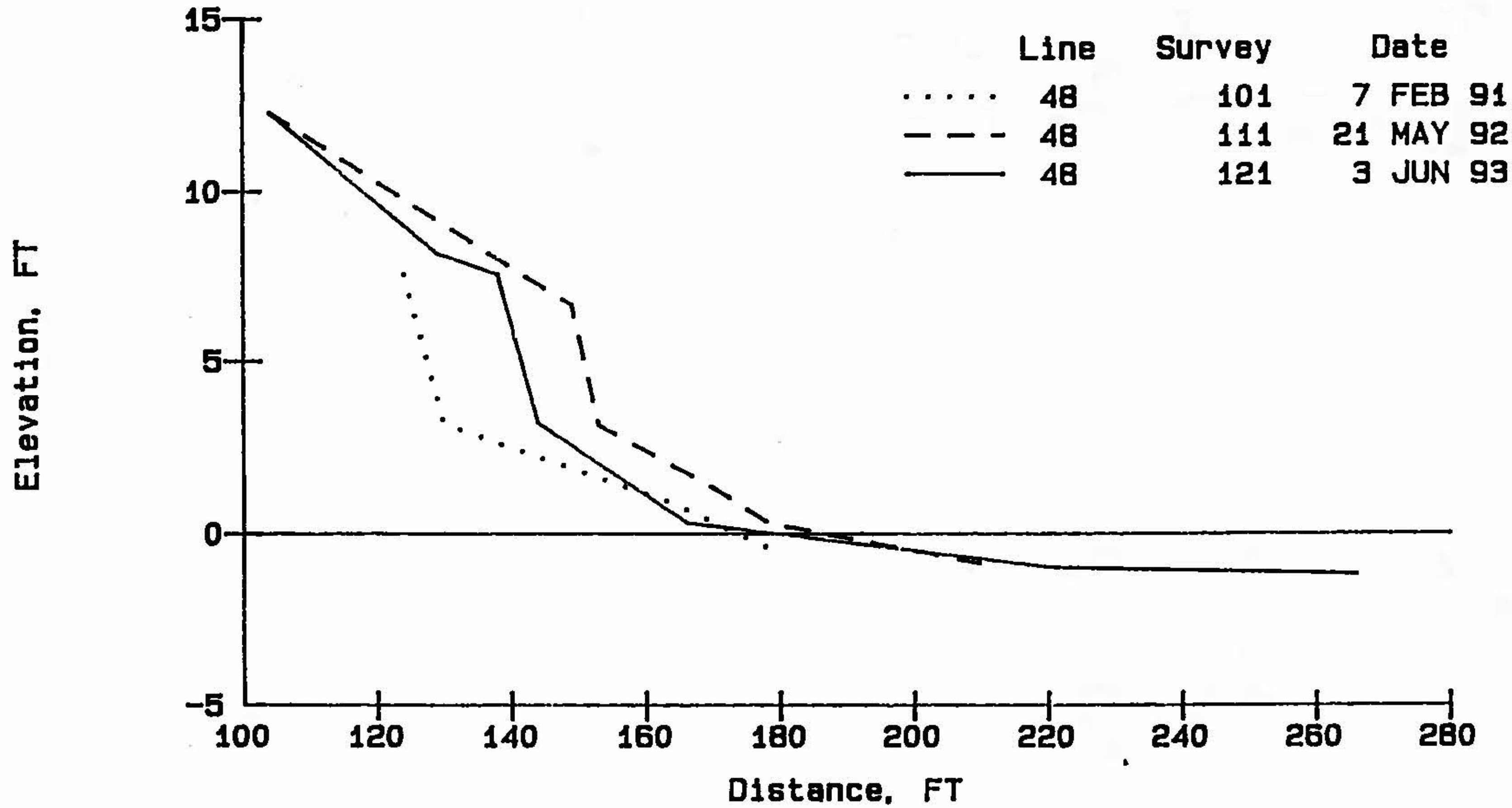
6
4
2
0
-2
140
160
180
200
220
240
260
280
300
Distance, FT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48 121 3 JUN 93
15
10
5
0
-5
Elevation, FT
100
120
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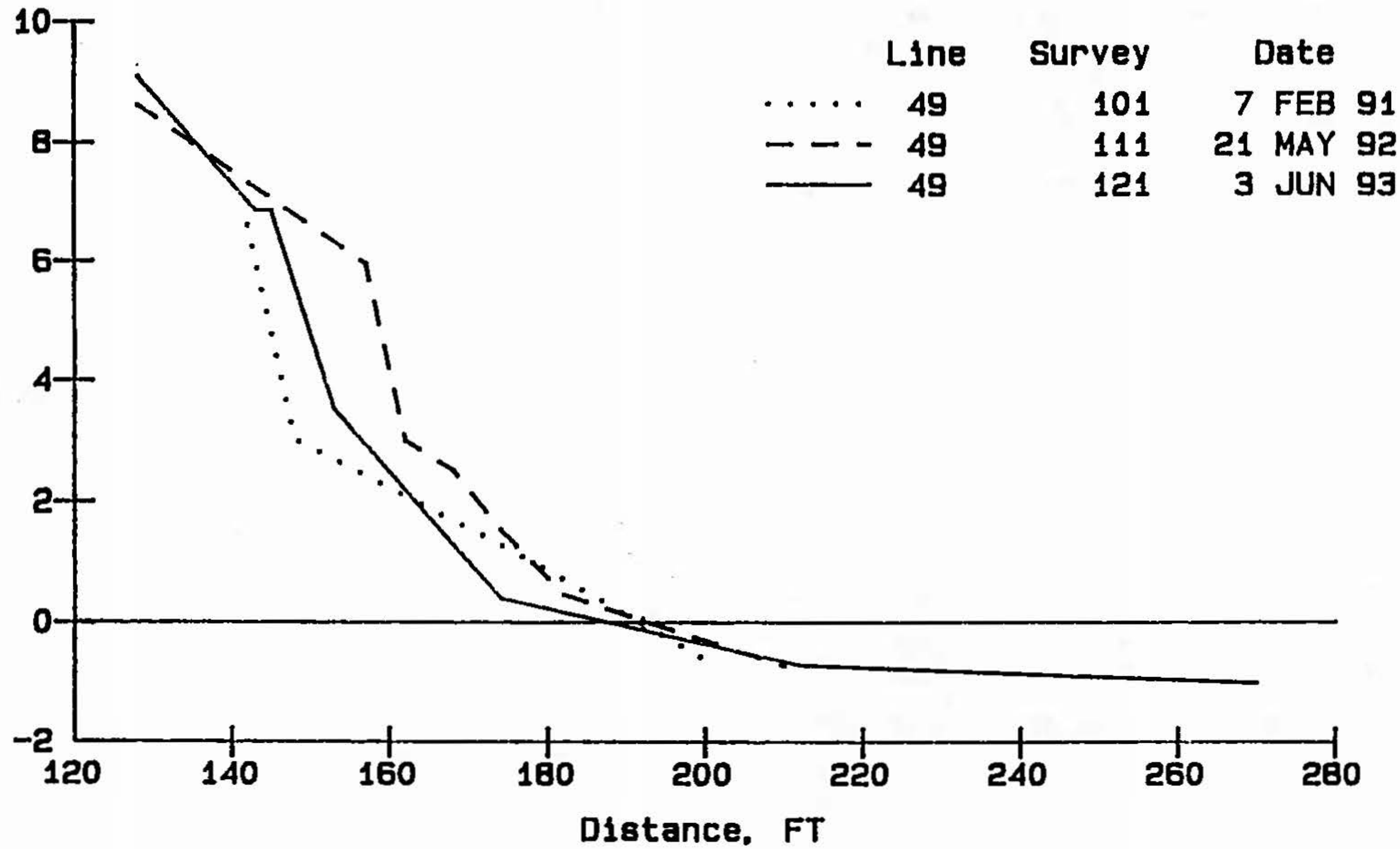
220
240
260
280
Distance, FT



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Elevation, FT
Distance, FT
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6
4
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0
-2
120
140
160
180
200
220
240
260
280

APPENDIX A(ii):

HART AND MILLER BEACH PROFILE DATA:
Analysis of Profile Changes.

PROFILE 24

Profile 24 Survey 121(920520) and Profile 24 Survey 131(930603)
Start Distance = 214.00 FT, Ending Distance = 335.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
1	310.39	-.43	3.13	.88	3.13	3.13
END	335.00	-.95	-.15	-.16	2.98	3.28

Volume Change: Above Datum= 3.00 YD3/FT, Below Datum= -.02 YD3/FT
The Shoreline changed 15.34 FT, from 289.37 FT to 304.71 FT

Profile 24 Survey 100(910206) and Profile 24 Survey 131(930603)
Start Distance = 214.00 FT, Ending Distance = 288.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	288.00	.36	2.89	1.05	2.89	2.89

Volume Change: Above Datum= 3.26 YD3/FT
The Shoreline changed 21.96 FT, from 282.75 FT to 304.71 FT

PROFILE 28

Profile 28 Survey 121(92/05/20) and Profile 28 Survey 131(93/06/03)
Start Distance = 170.00 FT, Ending Distance = 249.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	249.00	-.86	-4.76	-1.63	-4.76	4.76

Volume Change: Above Datum= -4.06 YD3/FT, Below Datum= -.69 YD3/FT
The Shoreline changed -21.60 FT, from 238.14 FT to 216.54 FT

Profile 28 Survey 100(91/02/06) and Profile 28 Survey 131(93/06/03)
Start Distance = 170.00 FT, Ending Distance = 230.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	230.00	-.77	-2.27	-1.02	-2.27	2.27

Volume Change: Above Datum= -2.13 YD3/FT, Below Datum= -.14 YD3/FT
The Shoreline changed -6.92 FT, from 223.46 FT to 216.54 FT

PROFILE 30

Profile 30 Survey 121(92/05/20) and Profile 30 Survey 131(93/06/03)
Start Distance = 175.00 FT, Ending Distance = 242.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	242.00	-.89	-2.42	-.98	-2.42	2.42

Volume Change: Above Datum= -1.94 YD3/FT, Below Datum= -.48 YD3/FT
The Shoreline changed -10.21 FT, from 218.73 FT to 208.52 FT

Profile 30 Survey 100(91/02/21) and Profile 30 Survey 131(93/06/03)
Start Distance = 150.00 FT, Ending Distance = 200.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	200.00	-.01	1.47	.99	1.47	1.47

Volume Change: Above Datum= 1.40 YD3/FT
The Shoreline changed 16.40 FT, from 192.12 FT to 208.52 FT

PROFILE 32

Profile 32 Survey 121(92/05/20) and Profile 32 Survey 131(93/06/03)
Start Distance = 172.00 FT, Ending Distance = 224.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	224.00	-.70	-1.61	-.84	-1.61	1.61

Volume Change: Above Datum= -1.51 YD3/FT, Below Datum= -.10 YD3/FT
The Shoreline changed -4.76 FT, from 212.66 FT to 207.90 FT

Profile 32 Survey 100(91/02/06) and Profile 32 Survey 131(93/06/03)
Start Distance = 146.00 FT, Ending Distance = 186.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	186.00	.31	2.23	1.68	2.23	2.23

Volume Change: Above Datum= 2.56 YD3/FT
The Shoreline changed 26.09 FT, from 181.81 FT to 207.90 FT

PROFILE 36

Profile 36 Survey 121(92/05/20) and Profile 36 Survey 131(93/06/03)
Start Distance = 174.00 FT, Ending Distance = 250.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	250.00	-.89	-3.36	-1.19	-3.36	3.36

Volume Change: Above Datum= -3.25 YD3/FT, Below Datum= -.11 YD3/FT
The Shoreline changed -6.66 FT, from 233.58 FT to 226.91 FT

Profile 36 Survey 100(91/02/06) and Profile 36 Survey 131(93/06/03)
Start Distance = 174.00 FT, Ending Distance = 220.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
1	186.34	3.08	-.71	-1.56	-.71	.71
END	220.00	.01	.62	.50	-.09	1.33

Volume Change: Above Datum= -.07 YD3/FT
The Shoreline changed 10.52 FT, from 216.39 FT to 226.91 FT

PROFILE 40

Profile 40 Survey 121(920521) and Profile 40 Survey 131(930603)
Start Distance = 176.00 FT, Ending Distance = 238.16 FT
(Data extrapolated to Datum. Extrapolated cells and values affected by extrapolation marked with *)

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
1	222.75	1.64	.39	.22	.39	.39
END*	238.16	.59	-.32	-.57	.06	.71

Volume Change: Above Datum= -.18 YD3/FT*
The Shoreline changed -10.44 FT*, from 248.60 FT* to 238.16 FT

Profile 40 Survey 100(910207) and Profile 40 Survey 131(930603)
Start Distance = 180.00 FT, Ending Distance = 228.00 FT
(Data extrapolated to Datum. Extrapolated cells and values affected by extrapolation marked with *)

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	228.00	.28	4.08	2.29	4.08	4.08

Volume Change: Above Datum= 4.22 YD3/FT*
The Shoreline changed 17.63 FT*, from 220.54 FT* to 238.16 FT

PROFILE 44

Profile 44 Survey 121(92/05/21) and Profile 44 Survey 131(93/06/03)
Start Distance = 152.00 FT, Ending Distance = 244.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	244.00	-1.12	-4.21	-1.23	-4.21	4.21

Volume Change: Above Datum= -3.75 YD3/FT, Below Datum= -.46 YD3/FT
The Shoreline changed -13.09 FT, from 210.85 FT to 197.76 FT

Profile 44 Survey 100(91/02/07) and Profile 44 Survey 131(93/06/03)
Start Distance = 152.00 FT, Ending Distance = 192.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	192.00	-.14	2.54	1.72	2.54	2.54

Volume Change: Above Datum= 2.51 YD3/FT
The Shoreline changed 12.85 FT, from 184.91 FT to 197.76 FT

PROFILE 48

Profile 48 Survey 121(92/05/21) and Profile 48 Survey 131(93/06/03)
Start Distance = 124.00 FT, Ending Distance = 210.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
1	209.23	-.85	-4.90	-1.55	-4.90	4.90
END	210.00	-.87	.00	.00	-4.90	4.90

Volume Change: Above Datum= -4.70 YD3/FT, Below Datum= -.20 YD3/FT
The Shoreline changed -12.66 FT, from 186.53 FT to 173.88 FT

Profile 48 Survey 100(91/02/07) and Profile 48 Survey 131(93/06/03)
Start Distance = 124.00 FT, Ending Distance = 180.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
1	148.91	1.89	1.79	1.94	1.79	1.79
2	173.56	.01	-.36	-.40	1.43	2.15
END	180.00	-.36	.05	.20	1.47	2.20

Volume Change: Above Datum= 1.43 YD3/FT, Below Datum= .05 YD3/FT
The Shoreline changed .23 FT, from 173.64 FT to 173.88 FT

PROFILE 49

Profile 49 Survey 121(92/05/21) and Profile 49 Survey 131(93/06/03)
Start Distance = 128.00 FT, Ending Distance = 210.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	210.00	-.75	-6.89	-2.27	-6.89	6.89

Volume Change: Above Datum= -6.44 YD3/FT, Below Datum= -.45 YD3/FT
The Shoreline changed -20.30 FT, from 192.77 FT to 172.47 FT

Profile 49 Survey 100(91/02/07) and Profile 49 Survey 131(93/06/03)
Start Distance = 142.00 FT, Ending Distance = 200.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	200.00	-.67	-2.73	-1.27	-2.73	2.73

Volume Change: Above Datum= -2.42 YD3/FT, Below Datum= -.31 YD3/FT
The Shoreline changed -19.18 FT, from 191.65 FT to 172.47 FT

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Twelfth Annual Interpretive Report for Project III: Benthic Studies

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

For:

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Tidewater Administration

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ABSTRACT

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 twelfth 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 1992 and April and August 1993.

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 30 species were collected from these seventeen infaunal stations. The most abundant species were the worms, *Scolecolepides viridis*, *Streblospio benedicti*, *Tubificoides sp.* and *Heteromastus filiformis*; the crustaceans, *Leptocheirus plumulosus* and *Cyathura polita*; and the clam, *Rangia cuneata*.

Species diversity (H') values were evaluated at each of the infaunal stations at the three sampling periods. The highest diversity value (3.478) was obtained for the reference station HM9, in April 1993. The lowest diversity value (1.685) occurred in December 1992 at the Back River station, HM26. For the three sampling dates, the overall highest diversity values (with only two stations under 2.5 and ten greater than 3.0) occurred in August 1993 and the lowest overall diversity occurred in December 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 reference stations, the combined nearfield and reference stations and the combined zinc enriched stations in December only. No significant differences were found in April or August.

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. We were unable to reach reference station R5 in April due to rough sea conditions. The epifaunal populations at both the nearfield and reference stations were very similar over all three sampling periods and as previously reported the amphipod, *Corophium lacustre*, was one of the most abundant organisms present at all nearfield and reference stations sampled during the Twelfth Year. The encrusting bryozoans, *Victorella pavida* and *Membranipora tenuis* were the next most frequently observed species on the pilings.

The results of the 12th monitoring year studies again reveal that no adverse effects on the benthic populations have been observed which could be attributed to the maintainance and operation of the Hart-Miller Island Dredged Material Containment Facility. We have continued to monitor the 4 zinc enrichment stations (G5,G25, HM12, G84) established in the 9th year of sampling as a result of Maryland Geological Survey's findings of zinc enriched sediments in the vincinity of HMI. During this the fourth 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.

INTRODUCTION

The results of the benthic population studies conducted during the twelfth 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 twelfth 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.

5. To provide selected species of benthic invertebrates for chemical analysis of organic and metal concentrations by an

outside laboratory (Artesian Laboratories, Inc. in Newark, Delaware), in order to ascertain various contaminant levels of organisms and to follow if there is any possible bioaccumulation occurring.

METHODS AND MATERIALS

Three cruises were conducted during the twelfth monitoring year on December 14, 1992, April 1, 1993 and August 2, 1993. 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 twelfth 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. 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. Surface and Bottom temperatures were determined with a Hydrolab Surveyor 3 Multiparameter Water Quality Logging system to the nearest 0.01°C. Salinity for the surface and bottom waters was also determined with the Surveyor 3 to a tenth of a 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 singlelinkage 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 HMI. The most abundant species this year were the annelid worms, *Scolecolepides viridis, Streblospio benedicti, Tubificoides sp.* and *Heteromastus filiformis;* the crustaceans, *Leptocheirus plumulosus* and *Cyathura polita* and the clam, *Rangia cuneata* (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 *L. plumulosus* and *R. cuneata* had an increase in their range of numbers compared with the 11th year data; the range of *S. virdis* decreased slightly. The average numbers increased for all three species this 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. This year the most numerous organism at soft bottom stations and on shell bottom stations was the worm, *Tubificoides sp*.

Station HM26, at the mouth of the Back River has in past years usually had the most diverse annelid worm fauna. Once again that was the case this year; HM26 had the highest overall annelid diversity with 6 species in December, 5 in April and 7 species of worms in August. A diverse annelid fauna was also recorded this year at stations S3, S4, G5, G25, and HM12; like HM26 all of these stations had 7 species of worms in August (see

Tables 3, 4 and 5). In August, *Tubificoides sp.* was the most abundant worm at each of the above stations except for station G25, where the most numerous worm was *Strebospio benedicti*. The most abundant worm species at the nearfield, reference and zinc-enriched stations was *Tubificoides sp.* This year the total *Tubificoides sp.* population numbers (all station data combined) were over ten times that observed last year.

The worm, *S. viridis*, the clam, *R. cuneata* and the crustacean, *C. polita* occurred frequently at all three sets of stations, the nearfield, reference, and zinc enriched. This year, all three species were present at all stations and all dates sampled. These three species were not only the most frequently found but were also among the numerically most abundant organisms at the various stations (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, the worm, *Tubificoides sp.* was the most abundant species followed by *L. plumulosus*.

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 present at 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 2000 and 9000 individuals/m^2. The highest recorded value occurred at station HM26 in December (39,753 individuals/m^2) as a result of high concentrations of the worm, *Tubificoides sp.* (25,540 individuals/m^2) and the crustacean, *L. plumulosus* (7580 individuals/m2). The lowest recorded value occurred at station S1 in April (1640 individuals/m^2). There did not appear to be any consistent pattern in terms of the highs and lows at the

Not true. S. viridis has planktonic larvae. (Bochert + Bick, 1995.

reference or nearfield stations. 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).

Salinity and temperature (both surface and bottom) were recorded at various infaunal stations on all sampling dates (Table 6). In December the surface salinity ranged from 2.9 - 5.9 ‰ whereas in April the salinity varied between 0.1 and 1.0 ‰. In August, the surface salinity ranged from 6.4 - 8.9 ‰. The salinity ranges (surface) were somewhat higher than the previous years values in December and August, when the values were 1.0 - 8.0 ‰, 2.0 - 4.5 ‰, respectively, but lower than last years values of 0.5 - 6.0 ‰ for April. Nearly all the bottom salinities were higher than the surface salinities for all sampling dates; the bottom salinities ranges were as follows: December (3.2 - 8.8 ‰), April (0.1 - 5.5 ‰), August (6.6 - 9.3 ‰). This year the average temperatures for the surface were: 4.7°C in December, 9.3°C in April, and 26.8°C in August, compared with the previous year of 5.7, 8.9 and 23.3°C, respectively. The average bottom water temperatures were: 5.3°C in December, 8.8°C in April, and 26.3°C in August.

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 scattered throughout the three sampling months; seven stations had their highest values in August, while six stations were highest in April and four stations in December. Highest diversity values occurring in the summer months was postulated in the First Interpretive Report (Pfitzenmeyer *et al.*, 1982) and was frequently the case for a majority of the stations during the early years of the study. This year the summer (August) sampling period had the greatest number of stations exhibiting their peak diversity values, however highest diversity values for some of the stations were also recorded for December (S5, S6, S8) and April (S3, S4, HM9, HM26, G25, HM12). The overall highest diversity value (3.478) was recorded in April at HM9 while the lowest overall diversity value (1.685) was recorded in December for HM26.

The largest number of species recorded for any station was 23 at station S1 in December, followed by 22 at S1 and S4 in August. The lowest number of species, 10, was recorded in April at nearfield station S7.

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*. *Rangia* clams were most abundant during the August sampling period and there was a large set of *Rangia* observed at this time in the 5mm size class (1548 individuals). In December, the largest number of *Rangia* clams was recorded in the 5, 30, and 35 mm size classes. In April, most of the *Rangia* population was in the 25-40 mm size range. 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 twelfth year of studies, as was the case for the six previous years (sixth through eleventh) was *M. balthica* (see Figure 3). *M. balthica* was most abundant in the 15mm size class at the nearfield sampling stations over all three sampling periods. Highest populations densities were recorded in December when all size classses were present at all three station types. The overall population abundance of the 15mm size class at the nearfield stations dropped off during the August sampling period. In August similar numbers and size classes of *Rangia* were found at all three station types. Somewhat higher salinity and temperatures were recorded this August when compared with the eleventh year study.

M. mitchelli is the least abundant of the three clam species recorded in the vicinity of HMI (see Figure 4). The length frequency distribution and abundance pattern for *M. mitchelli* over the three sampling periods was quite similar to that observed in the previous four study years (eighth through eleventh). There was a slight decrease in the overall numbers of *M. mitchelli* from the previous year. As happened last year, 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 December. 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 1992 sampling period is presented in Figure 5. There is an initial joining of a nearfield and zinc-enriched station (S8 and G5, both silt/clay stations). The next six stations to join the initial pair of stations were also silt/clay stations (HM12, a zinc-enriched station, HM7 and HM22, two reference stations, and S3, S4, and S5, three nearfield stations). The last stations to join the dendrogram were HM26 and HM9 (silt/clay, reference stations), and S2 (a shell bottom, nearfield 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, 1993) 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 two stations to join the dendrogram were S1 and S7 (a sand, and a shell nearfield station respectively). The next ten stations to join the dendrogram were all silt/clay stations with representatives of all three different station types; this same trend occurred last year, in April. The last two stations to join the other groupings of stations were again as noted in December, S2, a shell station and HM26, a silt/clay 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 G84 and HM26. The clusters formed over these three sampling dates, during the 1992-93 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 1992, the stations sorted themselves out into three subsets (Table 10). The reference station, HM26 stood alone to form the first subset. The second subset was made up of all the other stations except for HM22. The third subset dropped station S6 and added station HM22. The second and third subsets in December obviously 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. The first subset consisted only of the Back River reference station, HM26. This isolation of HM26 in its own subset was consistent for all three sampling periods. As pointed out in previous reports and proposals HM26 is not a true reference station but is maintained in order to ascertain and track the potential effects of the Back River sewage treatment plant. Its isolation in a separate subset is consistent with findings of it being the last station to join the dendrograms in the previous section (see Figures 4, 5, and 6).

In April, five subsets were evident (Table 11). The first subset was comprised of two reference stations (HM26, HM16) and one zinc-enriched station(G84). The second subset consisted of two reference stations (HM16, HM9), one zinc-enriched station (G84) and one nearfield station (S6). All three of the other subsets were equally well mixed.

The analysis of the August 1993 data resulted in the occurrence of six subsets somewhat similar to those observed in the April sampling period, because the subsets, for the most part, again had a mixture of nearfield, reference, and zinc-enriched stations. Subset one consisted only of the Back River reference station (HM26) again. 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 only in December, at the reference stations, the combined nearfield and reference stations and for the combined zinc enriched and reference stations. No differences were found in any of the stations for April and August.

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). Overall, *Corophium lacustre* was the most abundant organism and the bryozoan, *Victorella pavida*, in general, was the second most abundant species. 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.

CONCLUSIONS AND RECOMMENDATIONS

For this the twelfth 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 ninth 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 seven years (eleventh through fifth year of monitoring). A total of 30 species (compared with 35, 32, 34, 31, 35, 30 and 26 for the eleventh through the fifth 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*, *Tubificoides sp.*, and *S. benedicti*, the crustaceans, *L. plumulosus* and *C. polita*, and the clam, *R. cuneata*. The oyster shell substrate stations, had two numerically dominant species (*Tubificoides sp*. and *S. benedicti*) in common with the soft bottom regions as well as three other numerically dominant species characteristic of oyster substrate stations, the worm, *H. filiformis* and the barnacle, *B. improvisus* and the bryozoan, *M. tenuis*. 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 reference (23,240) stations with slightly decreasing values observed for the nearfield stations (14,565) and zinc-enriched stations (12,275) over the three sampling periods.

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 December this year. The zinc-enriched clam populations appeared comparable to those observed at the reference and nearfield stations. The largest recruitment of young clams was observed in August for *Rangia cuneata*.

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 station, S2 and the Back River reference (silt/clay) station HM26 were frequently the last 2 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. However, HM26 continued to be separated from the majority of stations and for each time period occurred in its own subset. Friedman's non-parametric test indicated significant differences for the reference stations, the combined nearfield and reference stations and the combined zinc enriched and reference stations in December only.

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 bryozoans, *Victorella* and *Membranipora* 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 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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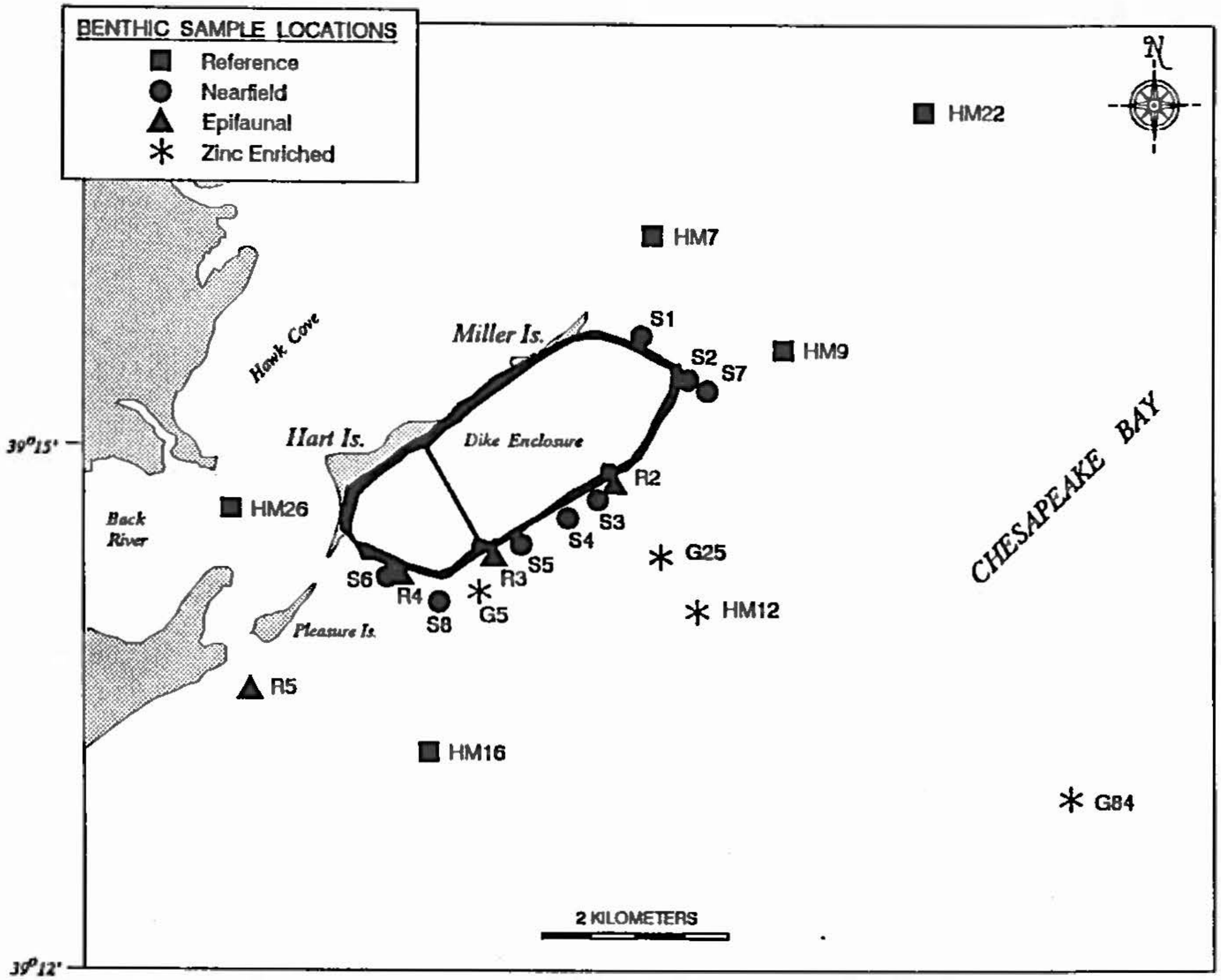

Figure 1. Benthic infaunal and epifaunal sampling station locations at HMI.
University of Maryland, Chesapeake Biological Laboratory designations.

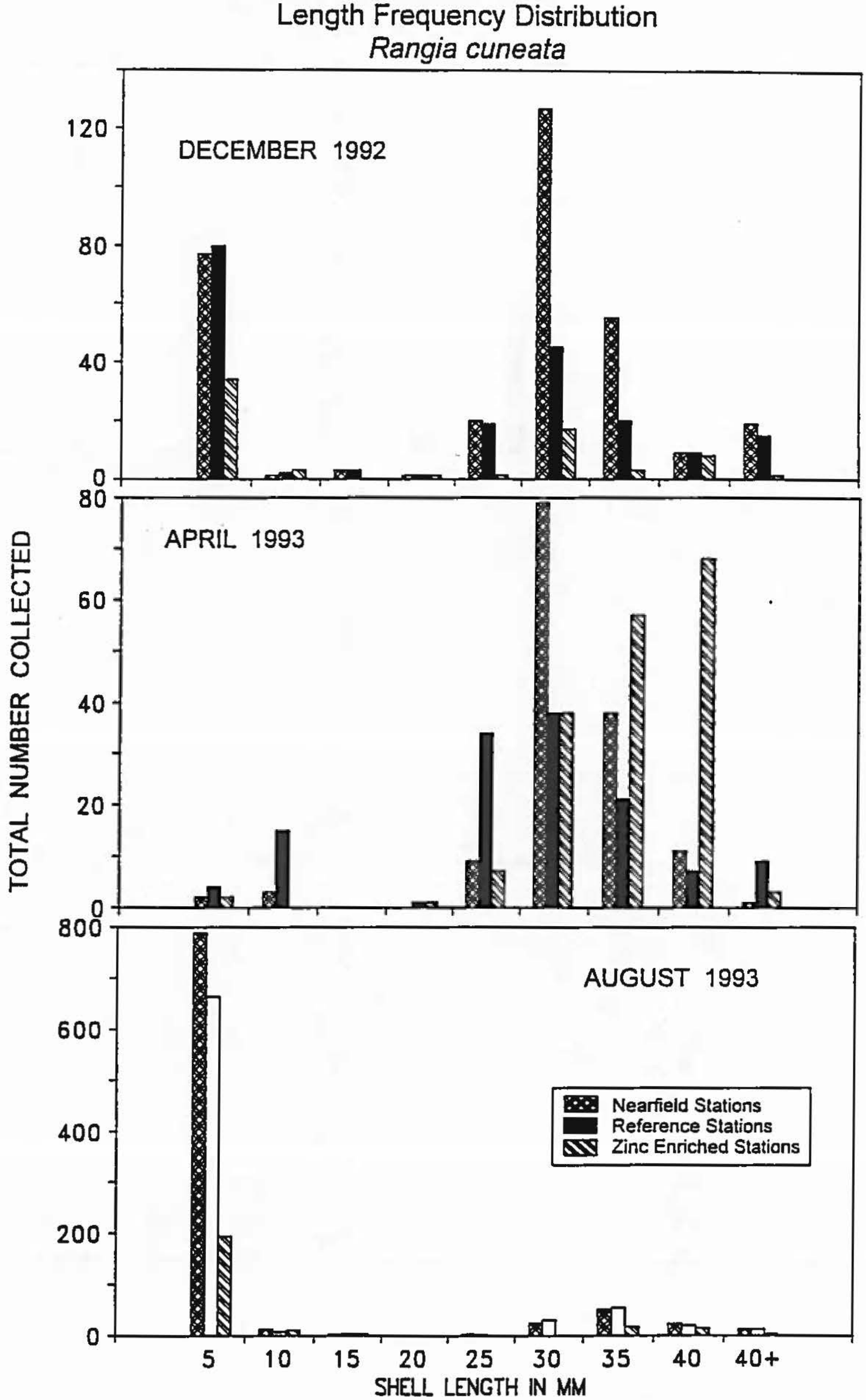

Figure 2. Length frequency distribution of the clam, *Rangia cuneata*, during the twelfth year of benthic monitoring studies at HMI.

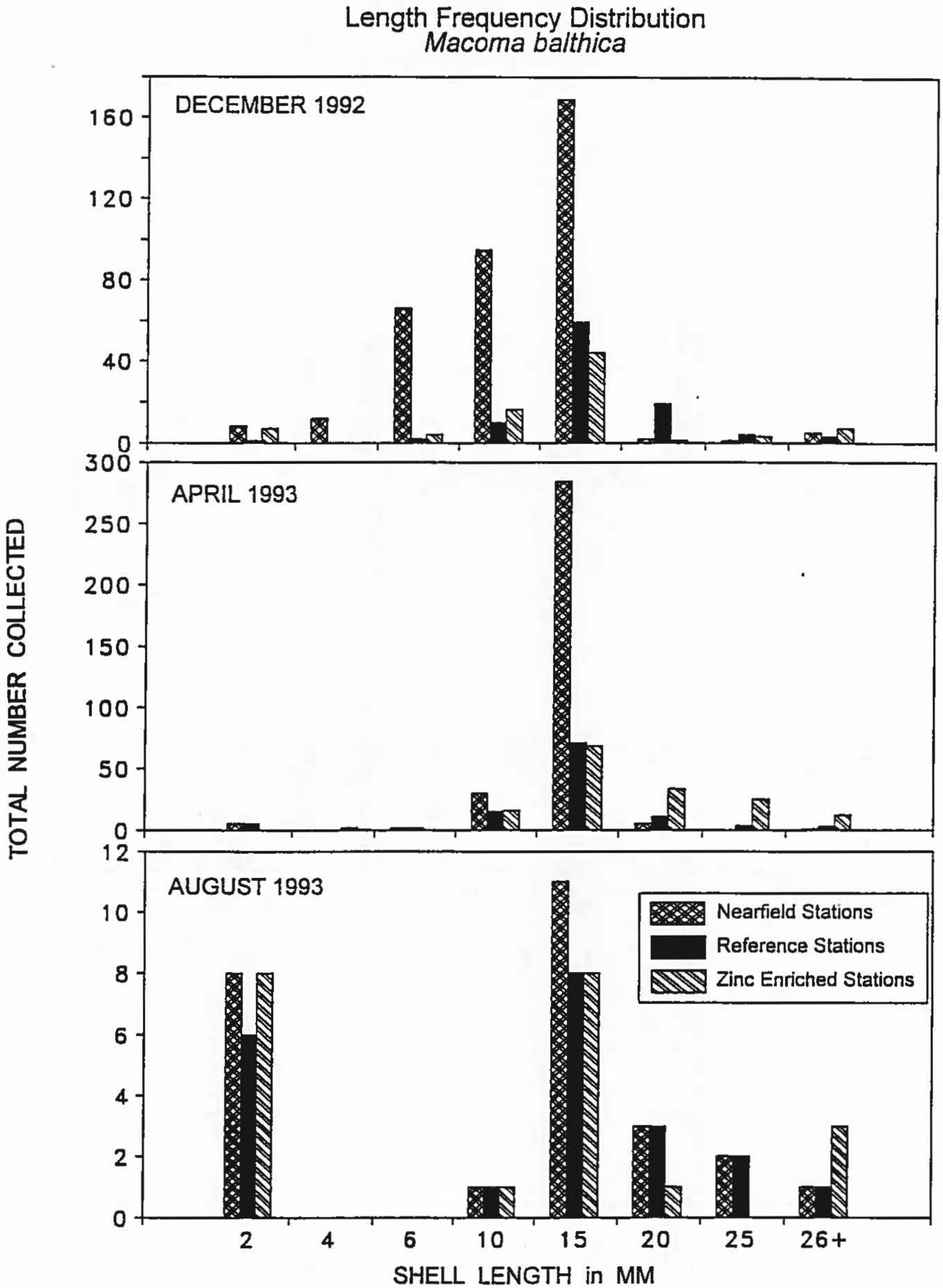

Figure 3. Length frequency distribution of the clam, *Macoma balthica*, during the twelfth year of benthic monitoring studies at the HMI.

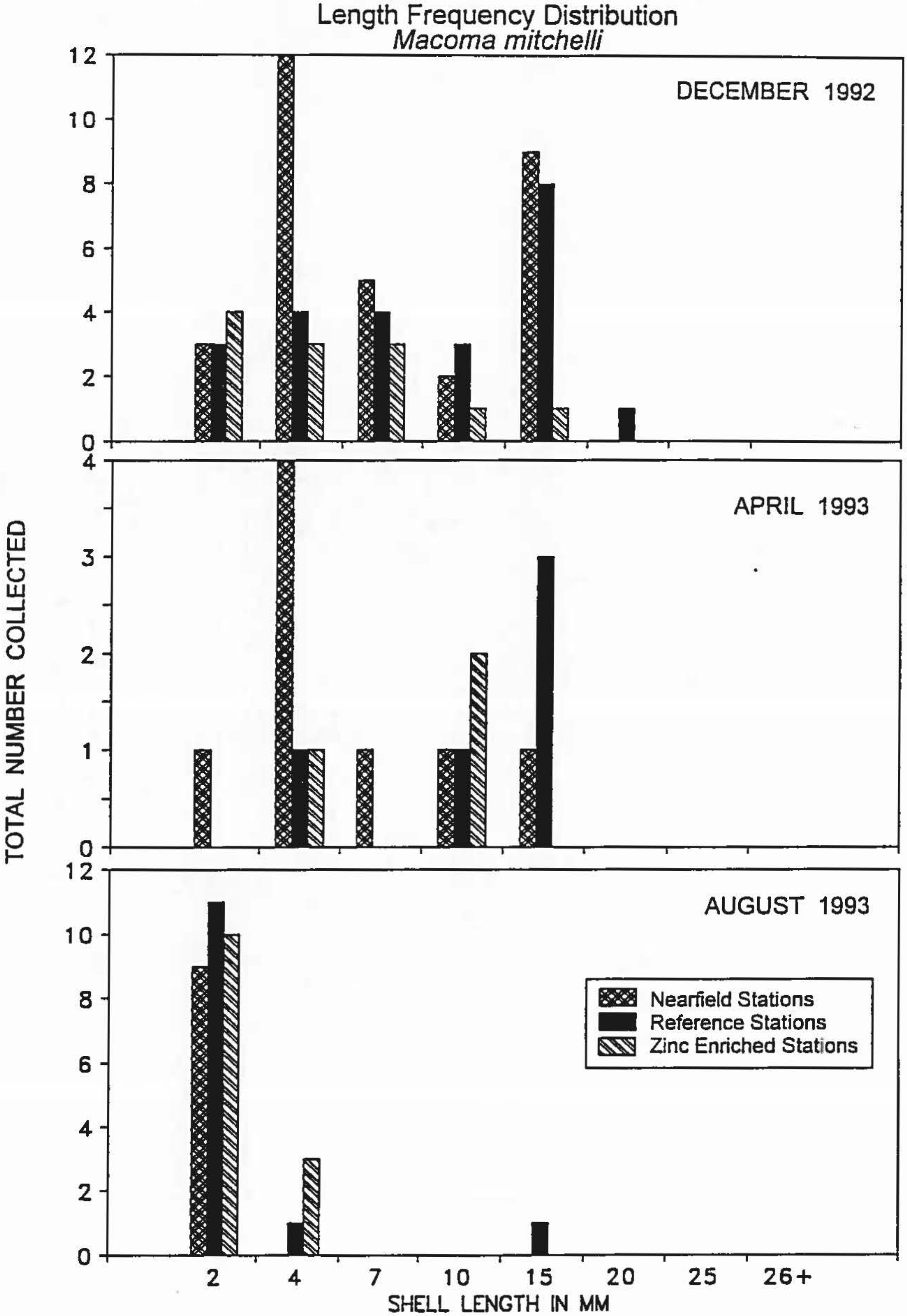

Figure 4. Length frequency distribution of the clam, *Macoma mitchelli*, during the twelfth year of benthic monitoring studies at HMI.

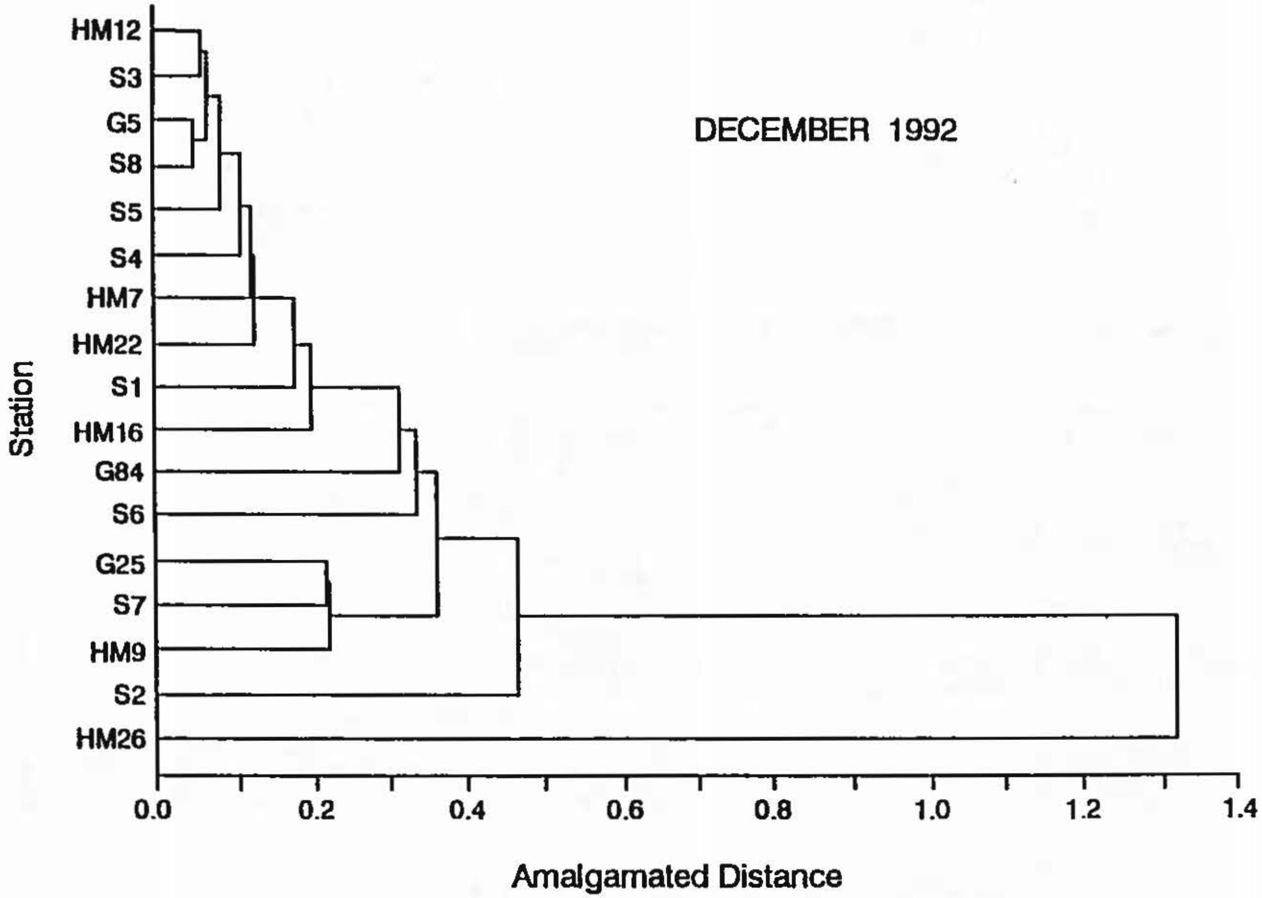

Figure 5: Cluster Analysis for all of the HMI Sampling Stations in December 1992 during the Twelfth Year of Benthic Studies.

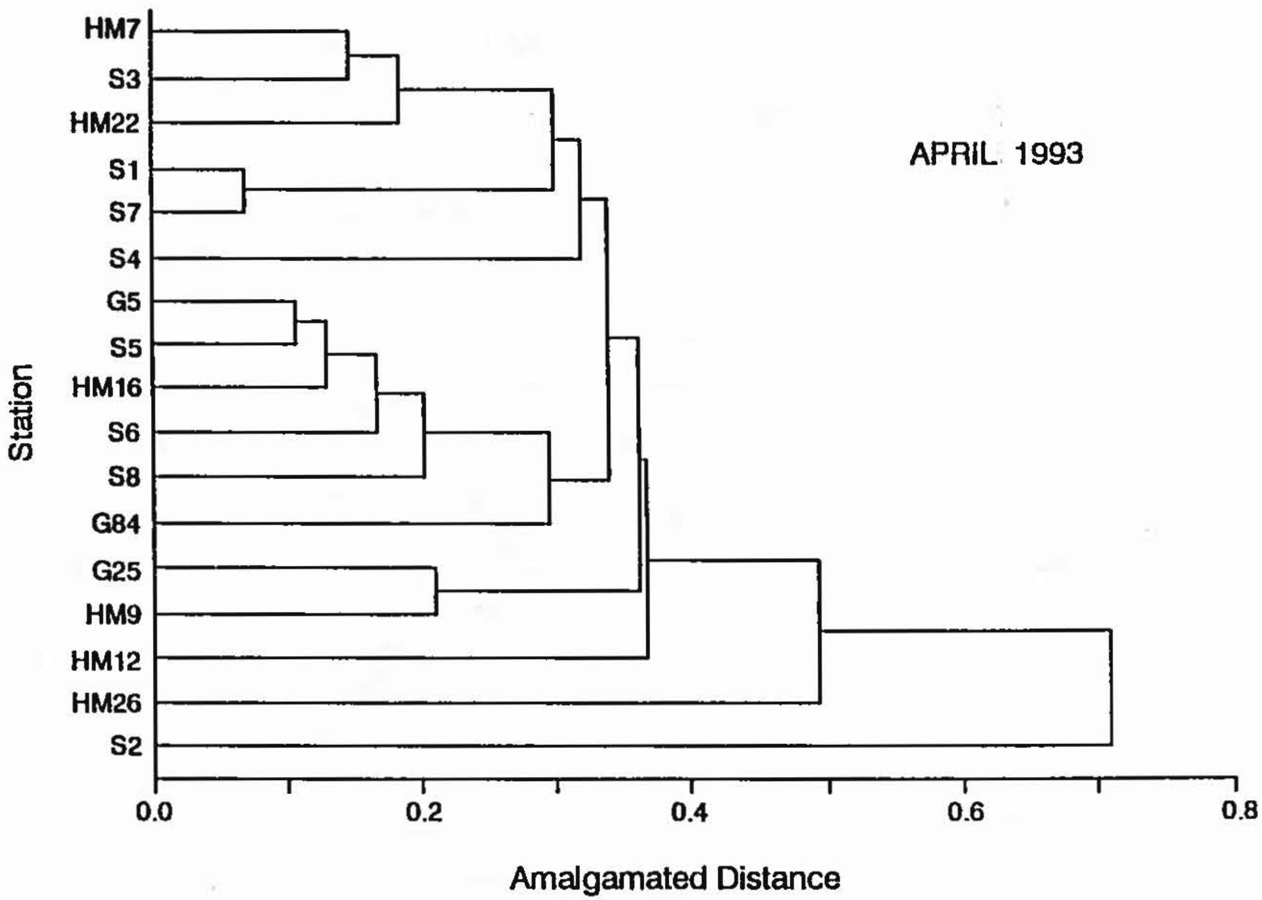

Figure 6: Cluster Analysis for all of the HMI Sampling Stations in April 1993 during the Twelfth Year of Benthic Studies.

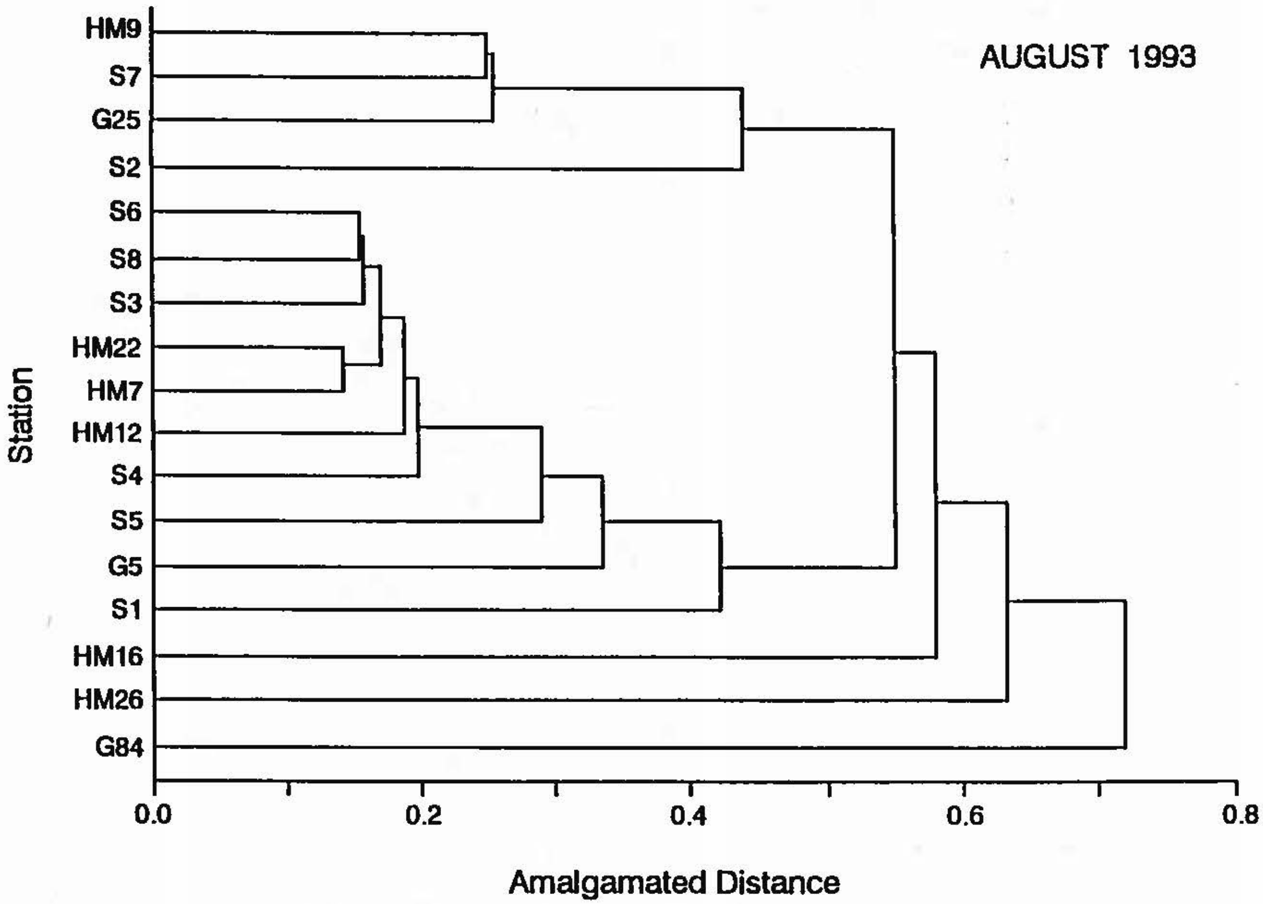

Figure 7: Cluster Analysis for all of the HMI Sampling Stations in August 1993 during the Twelfth Year of Benthic Studies.

TABLE 1. Relative abundances (#/m2) of three of the most abundant species of benthic organisms which occur at the HMI Reference Stations (HM7, HM9, HM16, HM22, HM26) over the twelve year study period from August 1981 to August 1993.

	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	Dec.1992 Apr.,Aug. 1993
Scolecolepides viridis													
Range/m2	0-1825	0-288	0-264		11-153	7-1287	13-447	0-657	20-3420	27-9393	7-2313	20-880	60-693
Avg./m2	229	121	69	546	92	398	179	178	998	2012	231	231	277
Leptocheirus plumulosus													
Range/m2	0-2960	0-5749	7-6626		20-441	7-1293	7-3312	0-3693	0-2474	87-2820	0-3607	0-2740	0-7580
Avg./m2	832	1459	2259	614	272	308	1111	398	327	829	808	1064	1392
Rangia cuneata													
Range/m2	0-46	0-99	0-135		0-75	0-273	13-3007	0-2267	0-580	13-12420	0-9000	0-853	73-2487
Avg./m2	9	9	22	455	27	102	687	359	123	1587	1647	289	484

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

STATION	December 1992	April 1993	August 1993
NEARFIELD SOFT BOTTOM (S3,4,5,6,8)			
	Tubificoides sp.	Leptocheirus plumulosus	Streblospio benedicti
	Leptocheirus plumulosus	Tubificoides sp.	Rangia cuneata
	Streblospio benedicti	Cyathura polita	Tubificoides sp.
NEARFIELD SHELL BOTTOM (S2,7)			
	Balanus improvisus	Scolecolepides viridis	Streblospio benedicti
	Tubificoides sp.	Balanus improvisus	Tubificoides sp.
	Membranipora tenuis	Membranipora tenuis	Heteromastus filiformis
REFERENCE SOFT BOTTOM (HM7,16,22)			
	Leptocheirus plumulosus	Leptocheirus plumulosus	Rangia cuneata
	Cyathura polita	Tubificoides sp.	Tubificoides sp.
	Tubificoides sp.	Cyathura polita	Membranipora tenuis
REFERENCE SHELL BOTTOM (HM9)			
	Tubificoides sp.	Tubificoides sp.	Streblospio benedicti
	Membranipora tenuis	Membranipora tenuis	Tubificoides sp.
	Balanus improvisus	Scolecolepides viridis	Rangia cuneata
BACK RIVER REFERENCE SOFT BOTTOM (HM26)			
	Tubificoides sp.	Leptocheirus plumulosus	Streblospio benedicti
	Leptocheirus plumulosus	Tubificoides sp.	Rangia cuneata
	Streblospio benedicti	Cyathura polita	Tubificoides sp.
ZINC ENRICHED SOFT BOTTOM (G5,25,64,HM12)			
	Tubificoides sp.	Leptocheirus plumulosus	Streblospio benedicti
	Leptocheirus plumulosus	Tubificoides sp.	Scolecolepides viridis
	Cyathura polita	Heteromastus filiformis	Tubificoides sp.

TABLE 3: Number of benthic organisms per m squared (m2) found at the Reference Stations during the Twelfth Year (December 1992 - August 1993) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	HM7 (X1F6389)			HM9 (X1F5297)			HM16 (X1F3325)			HM22 (X1G7689)			HM26 (X1F5145)			TOTALS
			Dec	Apr	Aug	Dec	Apr	Aug	Dec	Apr	Aug	Dec	Apr	Aug	Dec	Apr	Aug	
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2	40	13	20	47	13	93	47	73	113	7	7	40	40	27	60	640
ANNELIDA (worms)	Heteromastus filiformis	3	320	347	40	633	287	460	453	833	160	87	107	73	213	180	27	4220
	Nereis succinea	5				267	107	293	7					13	27	33	73	820
	Eteone heteropoda	8							7	20	93						7	127
	Polydora ligni	9			73	40		187			7			313	47		40	707
	Scolecolepides viridis	10	187	260	100	133	693	593	60	80	93	460	693	307	160	273	67	4160
	Streblospio benedicti	11	47		260	153	13	2187	427	93	207	80		200	3940	20	9620	17247
	Limnodrilus hoffmeisteri	13																0
	Tubificoides sp.	14	413	293	227	3147	987	653	767	1907	807	333	507	313	25540	4560	1767	42220
	Capitella capitata	15																0
MOLLUSCA (mollusks)	Ischadium recurvus	16																0
	Congeria leucophaeta	17				80	67	67						40	20		7	280
	Macoma balthica	19	20	33		47	60	33	220	393	67		13	13	367	253	27	1547
	Macoma mitchelli	20	13		13	27			60	27	47			27	53	7		273
	Rangia cuneata	21	273	100	653	247	267	627	93	73	587	260	313	733	427	113	2487	7253
	Mya arenaria	22					13											13
	Hydrobia sp.	23	27		33						180			7			13	260
	Doridella obscura	25																0
ARTHROPODA (crustaceans)	Balanus improvisus	27		7		893	300	127	27									1353
	Balanus subalbidus	28																0
	Leucon americanus	29																0
	Cyathura polita	30	520	373	147	380	393	353	747	700	407	327	353	220	393	333	240	5887
	Cassidinidea lunifrons	31				13												13
	Edotea triloba	33						20	7	20		7	7	7	27	113	13	220
	Gammarus palustris	35																0
	Leptocheirus plumulosus	36	220	140	60		333	7	2327	3513	293	13	327	27	7580	5313	727	20880
	Corophium lacustre	37		13			7		7	7	7				193	87		320
	Gammarus daiberi	38																0
	Gammerus tigrinus	39					20						13					33
	Melita nitida	40				47	147	13	67	67	20	7			393	200	147	1107
	Chirodotea almyra	41			13										7			20
	Monoculodes edwardsi	42	167	67	13	53	287	13	320	133		73	173	27	320	113	33	1793
	Chironomid sp.	43			53						33			27			227	340
	Rithropanopeus harrisi	44	13			67	153	80	20	20			13	7			7	380
COELENTERA (hydroids)	Garvela franciscana	47																0
PLATYHELMIA (flatworms)	Stylochus ellipticus	48		7														7
BRYOZOA (bryozoans)	Membrania tenuis	49				1407	853	500	127	13	1160			13	7			4060
	Victorella pavida	50																0
	TOTAL NUMBERS		2260	1653	1707	7680	5000	6307	5787	7973	4280	1653	2527	2407	39753	11627	15587	116200

TABLE 4A: Number of benthic organisms per m squared (m2) found at the Nearfield Stations during the Twelfth Year (December 1992-August 1993) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	S1 XIF 5710 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	13		13	7	0	7	107	20	113	67	93	73
ANNELIDA (worms)	Heteromastus filiformis	3	293	7	180	200	40	667	387	433	187	180	167	153
	Nereis succinea	5	47		293	120	7	533			7	7	53	33
	Eteone heteropoda	8									7			33
	Polydora ligni	9	13		853	60		53			87			120
	Scolecolepides viridis	10	1213	827	207	47	60	147	287	487	340	273	253	440
	Streblospio benedicti	11	307		847	33		1407	187		880	73		507
	Limnodrilus hoffmeisteri	13												
	Tubificoides sp.	14	3633	7	407	867	140	793	1827	547	340	407	393	507
	Capitella capitata	15												
MOLLUSCA (mollusks)	Ischadium recurvus	16												
	Congeria leucophaeta	17	27		113	20	7	27			13			13
	Macoma balthica	19	153		7	20	7		400	580	33	273	287	27
	Macoma mitchelli	20	7						47		7			
	Rangia cuneata	21	733	27	1260	113	260	73	167	140	1033	140	407	1200
	Mya arenaria	22												
	Hydrobia sp.	23	80		7	7			13					27
	Doridella obscura	25												
ARTHROPODA (crustaceans)	Balanus improvisus	27	27	13	40	3213	1153	513				27	347	13
	Balanus subalbidus	28						7						
	Leucon americanus	29												
	Cyathura polita	30	787	267	260	87	67	253	687	693	400	580	500	400
	Cassidinidea lunifrons	31				27	27							
	Edotea triloba	33	33		47				27	33		20	13	13
	Gammarus palustris	35												
	Leptocheirus plumulosus	36	140	107	7	7	7		793	573	13	80	527	7
	Corophium lacustre	37	260		73	53	27			7			13	
	Gammarus daiberi	38												
	Gammarus tigrinus	39	7	13										
	Melita nitida	40	13		13	47	60	327						13
	Chirodotea almyra	41	7	7	53			13		7	7			
	Monoculodes edwardsi	42	113	360	20	80	27		267	220	13	107	193	13
	Chironomid sp.	43									27			13
	Rithropanopeus harrisi	44	73		27	127	73	220	7			13	27	33
	Gammarus mucronatus	45								7				
COELENTERA (hydroids)	Garvela franciscana	47												
PLATYHELMIA (flatworms)	Stylochus ellipticus	48			13									7
BRYOZOA (bryozoans)	Membranipora tenuis	49	200	7	573	1420	607	1140		20		80	180	173
	Victorella pavida	50												
	TOTAL NUMBERS		8180	1640	5313	6553	2567	6180	5200	3767	3507	2327	3453	3820

TABLE 4B: Number of benthic organisms per m squared (m2) found at the Nearfield Stations during the Twelfth Year (December 1992-August 1993) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	S5 XIF4420 Dec	S5 Apr	S5 Aug	S6 XIF4327 Dec	S6 Apr	S6 Aug	S7 XIG5405 Dec	S7 Apr	S7 Aug	S8 XIF4124 Dec	S8 Apr	S8 Aug	TOTALS ALL STATIONS ALL DATES
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2	100	73	27	107	67	113		7	80	67	20	60	1233
ANNELIDA (worms)	Heteromastus filiformis	3	473	220		913	353	227	613	47	820	73	213	47	6893
	Nereis succinea	5	13	13		13			413		327				1860
	Eteone heteropoda	6	7		13	20							7	13	100
	Polydora ligni	9						7			140				1333
	Scolecolepides viridis	10	120	60	13	553	473	153	107	1113	407	140	93	67	7880
	Streblospio benedicti	11	260	7	1433	1967		1407	67		1553	120		1033	12087
	Limnodrilus hoffmeisteri	13													0
	Tubificoides sp.	14	2773	1573	1093	5613	1827	627	1640		833	533	320	527	27227
	Capitella capitata	15													0
MOLLUSCA (mollusks)	Ischadium recurvus	16													0
	Congeria leucophaeta	17							67		47				333
	Macoma balthica	19	500	580	40	660	460	33	33	7	7	347	273	27	4753
	Macoma mitchelli	20	13	7	7	113	33	33				27	20	13	327
	Rangia cuneata	21	33	27	193	173	27	1267	707	60	620	80	13	720	9473
	Mya arenaria	22				7									7
	Hydrobia sp.	23			27			20						67	247
	Doridella obscura	25													0
ARTHROPODA (crustaceans)	Balanus improvisus	27							627		293				6267
	Balanus subalbidus	28													7
	Leucon americanus	29													0
	Cyathura polita	30	500	413	127	440	573	493	160	373	293	393	547	207	9500
	Cassidinidea lunifrons	31							27	13	7				100
	Edotea triloba	33		20		120	40		7		13		7	7	400
	Gammarus palustris	35													0
	Leptocheirus plumulosus	36	907	1593	167	4227	2900	47	7	307	13	353	1240	167	14207
	Corophium lacustre	37		7		240	20		7		7		7		720
	Gammarus daiberi	38													0
	Gammarus tigrinus	39				7									27
	Melita nitida	40	7	13	7	93	27	13	127		40		7	7	813
	Chirodotea almyra	41				7	7	7		7					120
	Monoculodes edwardsi	42	220	160		87	153		107	273	7	113	47	13	2593
	Chironomid sp.	43			13			73						33	160
	Rhithropanopeus harrisi	44	7			27	20	7	173		173	13	7		1027
	Gammarus mucronatus	45													7
COELENTERA (hydroids)	Garveia franciscana	47													0
PLATYHELMIA (flatworms)	Stylochus ellipticus	48									27				47
BRYOZOA (bryozoans)	Membranipora tenuis	49		20		87	7		1153		1020	7	60		6753
	Victorella pavida	50													0
	TOTAL NUMBERS		5933	4787	3180	15473	6987	4527	6040	2207	6726	2267	2880	3007	116520

TABLE 5: Number of benthic organisms per m squared (m2) found at the Zinc Enriched Stations during the Twelfth Year (December 1992 - August 1993) of Benthic Studies at HMI.

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
			X1F4221			X1F4405			X163570 / X162560			X1F5805			
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2	67	93	60	67	47	33		147	33	93	40	120	580
ANNELIDA (worms)	Heteromastus filiformis	3	193	420	40	373	347	207	87	1367	47	287	333	167	3213
	Nereis succinea	5			60	167	120	247	13	13	7	7	253	80	907
	Eteone heteropoda	8	7		7			7		20	73			13	127
	Polydora ligni	9			47			40			7		7	80	180
	Scolecolepides viridis	10	260	53	33	80	253	193	307	400	1473	33	593	127	3807
	Streblospio benedicti	11	173		653	60	7	1373	67	107	1060	140		547	4187
	Limnodrilus hoffmeisteri	13													0
	Tubificoides sp.	14	580	1153	280	567	267	267	20	1453		1507	1160	900	8153
	Capitella capitata	15													0
MOLLUSCA (mollusks)	Ischadium recurvus	16													0
	Congeria leucophaeta	17				7		7			27		7		47
	Littoridinops sp.	18													0
	Macoma balthica	19	193	293	7	87	47	20	33	647	47	240	53	67	1733
	Macoma mitchelli	20	33	20				27	20		27	27		33	187
	Rangia cuneata	21	87	13	160	167	260	480	73	13	153	153	887	813	3260
	Mya arenaria	22											7		7
	Hydrobia sp.	23				7		7						67	80
	Doridella obscura	25													0
ARTHROPODA (crustaceans)	Balanus improvisus	27				480	153	173				13	120		940
	Balanus subalbidus	28													0
	Leucon americanus	29							see X153520						0
	Cyathura polita	30	647	473	320	367	320	307	93	600	453	367	247	287	4480
	Cassidinidea lunifrons	31													0
	Edotea triloba	33			7			7		20	7	33	73	13	160
	Gammarus palustris	35													0
	Leptocheirus plumulosus	36	607	1493	353	27	440	7	1333	4753	587	687	353	200	10840
	Corophium lacustre	37				7			7						13
	Gammarus daiberi	38													0
	Gammarus tigrinus	39				7	13			20			60		100
	Melita nitida	40	20	33	13	13	107	107					60		353
	Chirodotea almyra	41							7		27				33
	Monoculodes edwardsi	42	193	247	7	140	147		100	13	47	147	113	7	1160
	Chironomid sp.	43			20									7	27
	Rithropanopeus harrisi	44	7	7	73	73	80	153					113	7	513
COELENTERA (hydroids)	Garveia franciscana	47													0
PLATYHELMIA (flatworms)	Stylochus ellipticus	48													0
BRYOZOA (bryozoans)	Membranipora tenuis	49		7	53	1033	813	840			20	7	307		3080
	Victorella pavida	50													0
	TOTAL NUMBERS		3067	4307	2193	3727	3420	4500	2160	9573	4093	3740	4787	3533	49100

TABLE 6: Salinity (in 0/00), temperature (in oC), and depth (in ft.) data for the benthic sampling stations on the 3 collection dates during the Twelfth Year of Benthic studies at HMI.

CBL STA. ID	STATE STA. #	DECEMBER 92 DEPTH	DECEMBER 92 TEMP.	DECEMBER 92 SAL.	APRIL 93 DEPTH	APRIL 93 TEMP.	APRIL 93 SAL.	AUGUST 93 DEPTH	AUGUST 93 TEMP.	AUGUST 93 SAL.
R1	XIF4811	*NS	NS	NS	NS	NS	NS	NS	NS	NS
R1	XIF4811	NS	NS	NS	NS	NS	NS	NS	NS	NS
R2	X1F4813	**NR	NR	NR	0	10.84	0.2	0	27.81	6.5
R2	X1F4813	NR	NR	NR	11	9.51	0.2	10	26.42	7.1
R3	X1F4514	NR	NR	NR	NR	NR	NR	NR	NR	NR
R3	X1F4514	NR	NR	NR	NR	NR	NR	NR	NR	NR
R4	XIF4518	NR	NR	NR	NR	NR	NR	0	27.4	6.6
R4	XIF4518	NR	NR	NR	NR	NR	NR	7.5	27.41	6.6
R5	XIF3638	NR	NR	NR	NS	NS	NS	NR	NR	NR
R5	XIF3638	NR	NR	NR	NS	NS	NS	NR	NR	NR
S1	XIF5710	0	4.45	3.1	0	10.08	0.2	0	26.6	6.5
S1	XIF5710	7	4.39	3.2	8	9.05	0.2	8	26.59	6.6
S2	XIF5406	0	4.51	3.4	0	9.61	0.2	0	26.59	6.6
S2	XIF5406	12	5.23	5.8	14	9.07	0.4	14	26.49	6.8
S3	XIF4811	0	4.64	4.2	0	9.45	0.2	0	26.79	6.6
S3	XIF4811	18	5.55	6.6	18	9.14	0.4	17	26.21	8.3
S4	XIF4715	0	4.68	4.3	0	9.77	0.2	0	26.92	7.1
S4	XIF4715	15	5.76	7.6	16	9.02	0.5	16	26.19	8.5
S5	XIF4420	0	4.7	4.2	0	9.19	0.4	0	26.86	8.3
S5	XIF4420	20	5.66	7.4	20	8.89	0.7	22	26.16	9
S6	XIF4327	0	4.66	4.4	0	9.08	0.1	0	26.45	6.7
S6	XIF4327	10	4.61	4.8	12	9.41	1.4	12	26.42	8.5
S7	XIG5405	0	4.44	3.3	0	9.06	0.1	0	26.6	6.8
S7	XIG5405	14	5.27	5.9	15	8.99	0.4	16	26.44	7
S8	XIF4124	0	4.54	4.4	0	8.94	0.5	0	26.7	7.8
S8	XIF4124	16	5.03	5.6	15	9.4	1.4	16	26.03	9.1
HM7	XIF6388	0	4.69	3.7	0	9.97	0.3	0	26.93	6.4
HM7	XIF6388	12	4.76	4.4	13	9.55	1.5	12	26.33	7
HM9	XIF5297	0	5.01	4.9	0	9.01	0.1	0	26.97	7.3
HM9	XIF5297	17	5.44	5.9	18	8.41	0.3	18	26.4	7.5
HM12	XIF5805	0	5.18	5.4	0	8.17	0.1	0	26.59	8.9
HM12	XIF5805	18	6.03	8.3	18	7.36	0.1	18	26.04	9
HM16	XIF3325	0	4.89	4.5	0	8.88	0.4	0	26.65	7.9
HM16	XIF3325	18	5.88	7.9	19	8.74	0.6	20	26.07	9.3
HM22	XIG7689	0	4.45	2.9	0	9.82	0.1	0	26.7	7.1
HM22	XIG7689	12	5.35	5.7	14	8.18	0.1	13	26.56	7.1
HM26	XIF5145	0	4.26	3.9	0	10.65	1	0	27.43	6.6
HM26	XIF5145	18	4.52	4.7	16	10.08	1.6	16	26.33	7.3
G5	XIF4221	0	4.55	4.3	0	8.95	0.5	0	26.75	8.3
G5	XIF4221	17	4.79	5.5	18	9.12	0.9	17	26.1	9
G25	XIF4405	0	4.89	4.4	0	8.99	0.2	0	26.73	8
G25	XIF4405	18	6	8.2	18	8.92	0.6	18	26.12	8.9
G84	XIG3570	0	5.66	5.9	0	7.06	0.3	0	26.56	8.5
G84	XIG3570	12	6.46	8.8	20	5.92	5.5	13	26.12	8.5

*NS= NOT SAMPLED **NR= NOT RECORDED

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 1992. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for the Twelfth Year of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINANCE FACTOR S.I.
NEARFIELD					
S1	Sand	23	1227	2.823	0.242
S2	Shell	20	983	2.371	0.307
S3	Silt/Clay	14	780	2.924	0.184
S4	Silt/Clay	15	349	3.237	0.136
S5	Silt/Clay	15	890	2.521	0.266
S6	Silt/Clay	21	2321	2.675	0.230
S7	Shell	18	906	3.128	0.153
S8	Silt/Clay	13	304*	3.074	0.146
REFERENCE					
HM 7	Silt/Clay	13	339	3.047	0.144
HM 9	Shell	18	1152	2.786	0.228
HM16	Silt/Clay	19	868	2.864	0.213
HM22	Silt/Clay	11	248	2.647	0.189
BACK RIVER REFERENCE					
HM26	Silt/Clay	19	5963	1.685	0.459
ZINC ENRICHED					
G5	Silt/Clay	14	460	3.103	0.143
G25	Silt/Clay	19	559	3.249	0.144
G84	Silt/Clay	13	324	2.052	0.409
HM12	Silt/Clay	15	561	2.760	0.221

* only two grabs

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 1993. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for the Twelfth Year of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINANCE FACTOR S.I.
NEARFIELD					
S1	Sand	11	246	2.000	0.333
S2	Shell	16	385	2.499	0.274
S3	Silt/Clay	14	565	3.028	0.137
S4	Silt/Clay	15	518	3.461	0.103
S5	Silt/Clay	16	718	2.464	0.245
S6	Silt/Clay	16	1048	2.461	0.260
S7	Shell	10	331	2.080	0.319
S8	Silt/Clay	16	432	2.541	0.250
REFERENCE					
HM 7	Silt/Clay	12	248	2.843	0.164
HM 9	Shell	19	750	3.478	0.114
HM16	Silt/Clay	17	1196	2.416	0.273
HM22	Silt/Clay	12	379	2.752	0.174
BACK RIVER REFERENCE					
HM26	Silt/Clay	15	1744	1.949	0.365
ZINC ENRICHED					
G5	Silt/Clay	13	646	2.560	0.222
G25	Silt/Clay	16	513	3.442	0.116
G84	Silt/Clay	14	1436	2.280	0.301
HM12	Silt/Clay	19	718	3.373	0.131

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 1993. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for the Twelfth Year of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINANCE FACTOR S.I.
NEARFIELD					
S1	Sand	22	797	3.313	0.134
S2	Shell	16	927	3.188	0.135
S3	Silt/Clay	17	525	2.814	0.187
S4	Silt/Clay	22	573	3.135	0.164
S5	Silt/Clay	13	477	2.050	0.330
S6	Silt/Clay	16	679	2.666	0.211
S7	Shell	21	1009	3.341	0.126
S8	Silt/Clay	16	451	2.686	0.216
REFERENCE					
HM 7	Silt/Clay	14	256	2.873	0.204
HM 9	Shell	18	946	3.142	0.168
HM16	Silt/Clay	17	642	3.189	0.149
HM22	Silt/Clay	19	361	3.114	0.160
BACK RIVER REFERENCE					
HM26	Silt/Clay	19	2338	1.864	0.422
ZINC ENRICHED					
G5	Silt/Clay	18	329	3.106	0.162
G25	Silt/Clay	20	675	3.190	0.158
G84	Silt/Clay	17	614	2.572	0.232
HM12	Silt/Clay	18	530	3.120	0.158

TABLE 10. The Ryan-Einot-Gabriel-Welsch Multiple F test of significance among mean number of individuals per station for stations sampled in December 1992. Subsets show groupings of stations different at (P<0.05). Stations in a separate vertical row and column are significantly different from others. Twelfth Year of Benthic Studies at HMI.

DECEMBER 1992

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

ANALYSIS OF VARIANCE

SOURCE	D.F	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB.
BETWEEN GROUPS	16	9701974	606373	14.3	0.0001
WITHIN GROUPS	34	1397780	42357		
TOTAL	50	11099754			

TABLE 11. The Ryan-Einot-Gabriel-Welsch Multiple F test of significance among mean number of individuals per station for stations sampled in April 1993. Subsets show groupings of different stations (P<0.05). Stations in a separate vertical row and column are significantly different from others. Twelfth Year of Benthic Studies at HMI.

APRIL 1993

SUBSET	STATION NUMBERS																	
1	HM26	G84	HM16															
2		G84	HM16	S6	HM9													
3			HM16	S6	HM9	S5	HM12	G5	S3									
4				S6	HM9	S5	HM12	G5	S3	S4	G25	S8	S2	HM2	S7			
5					HM9	S5	HM12	G5	S3	S4	G25	S8	S2	HM2	S7	HM7	S1	

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB.
BETWEEN GROUP	16	970587	60662	9.36	0.0001
WITHIN GROUPS	34	220417	6483		
TOTAL	50	1191004			

TABLE 12. The Ryan-Einot-Gabriel-Welsch Multiple F test of significance among mean number of individuals per station for stations sampled in August 1993. Subsets show groupings of stations different at ($P<0.05$). Stations in a separate vertical row and column are significantly different from others. Twelfth Year of Benthic Studies at HMI.

AUGUST 1993

SUBSET	STATION NUMBERS																
1	HM26																
2		S7	HM9	S2	S1	S6	G25	HM16	G84								
3			HM9	S2	S1	S6	G25	HM16	G84	S4	HM1	S3					
4				S2	S1	S6	G25	HM16	G84	S4	HM1	S3	S5	S8			
5					S1	S6	G25	HM16	G84	S4	HM1	S3	S5	S8	HM22	G5	
6						S6	G25	HM16	G84	S4	HM1	S3	S5	S8	HM22	G5	HM7

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	16	1181934	73871	23.09	0.0001
WITHIN GROUPS	34	108781	3200		
TOTAL	50	1290715			

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 Twelfth 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, G84, HM12.)

	SOURCE	D.F.	CHI-SQUARE	CHI-SQUARE (0.05)
DEC 1992				
	NEARFIELD	4	8.16	9.49
	REFERENCE	2	7.82 *	5.99
	ZINC ENRICHED	3	5.70	7.82
	NEARFIELD & REFERENCE	7	17.44 *	14.07
	ZINC ENRICHED & REFERENCE	6	16.87 *	12.59
APR 1993				
	NEARFIELD	4	6.20	9.49
	REFERENCE	2	2.86	5.99
	ZINC ENRICHED	3	1.55	7.82
	NEARFIELD & REFERENCE	7	13.55	14.07
	ZINC ENRICHED & REFERENCE	6	7.58	12.59
AUG 1993				
	NEARFIELD	4	2.49	9.49
	REFERENCE	2	2.36	5.99
	ZINC ENRICHED	3	1.61	7.82
	NEARFIELD & REFERENCE	7	8.98	14.07
	ZINC ENRICHED & REFERENCE	6	7.39	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 Twelfth Year of Benthic Studies at HMI.

	STATIONS R2-R4 DEPTH (M)		REFERENCE STATION R5 DEPTH (M)	
DEC 1992				
	1.0 m	2-3 m	1.0 m	2-3 m
	Membranipora	Corophium	B. subalbidus	Polydora
	Victorella	Victorella	Corophium	Corophium
	Polydora	Membranipora	G. tigrinus	Membranipora
	B. improvisus	Polydora	Victorella	Victorella
	Corophium	G. tigrinus	B. improvisus	B. improvisus
	B. subalbidus	B. improvisus		Rithropanopeus
APR 1993				
	1.0 m	2-3 m	1.0 m	2-3 m
	Membranipora	Membranipora	Not sampled	Not sampled
	G. tigrinus	B. improvisus		
	Victorella	Corophium		
	Corophium	Rithropanopeus		
	B. improvisus	G. tigrinus		
	B. subalbidus	Polydora		
AUG 1993				
	1.0 m	2-3 m	1.0 m	2-3 m
	Corophium	Polydora	Corophium	Corophium
	Nereis	Corophium	Victorella	Victorella
	Victorella	Nereis	Nereis	Garveia
	Polydora	B. improvisus	B. improvisus	Cordylophora
	Rithropanopeus	Victorella	Cordylophora	Nereis
	Garveia	Rithropanopeus	Garveia	

Ref. No. UMCEES CBL 94-102

Twelfth 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 populations and abundance of fish and benthos while physical studies have characterized the nature of currents and sediments. Chemical studies have measured levels of nutrients in the water column as well as 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. The Chesapeake Biological Laboratory of the University of Maryland, Center for Environmental and Estuarine Studies, is responsible for the collection and characterization of the biota samples under Project III: Benthic Studies. 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.

Chemical 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 Summer (August) and included both fish and benthic invertebrate tissue contaminant determinations. Beginning in the Eleventh Year (1992) and continuing to the present (Twelfth Year), data for contaminant burdens in biota were collected only in the Spring and include only benthic invertebrates. The present report focuses mainly on trends between the present study and the Tenth and Eleventh Years and follows up on recommendations in the previous two interpretive reports.

METHODS

Sampling and Chemical Analyses

Ten benthic stations were sampled for chemical analysis of biota. These represent a subset of the overall sampling stations for the benthos project (Figure 1). 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 S1, S2, S4, and S6 are designated as nearfield stations and are immediately adjacent to the facility. Stations HM16 and HM22 are designated as reference stations that are not immediately adjacent to HMI. It should be noted, however, that the flow descriptions described under the sedimentary project for the Tenth Year suggest that these designations may not necessarily indicate where contaminant burdens should be differentiable based on operation of HMI.

Biota samples were collected by the Chesapeake Biological Laboratory on April 1, 1993 using a 0.05 m2 Ponar grab. Biota were enumerated, identified to genus or species and measured prior to submission for metal and organic analyses. In the Tenth Year Interpretive Report, it was recommended that benthic samples be standardized according to size or age to reduce variability. This is the first year in which length or size class data for samples have been available. In Year Twelve, 22 composite samples of the benthic bivalves, *Macoma* sp. and *Rangia* sp., and the benthic isopod, *Cyathura polita* were collected.

Biota samples were collected and frozen in pre-cleaned glass containers with teflon lined lids until extraction and analyses were performed by a new contractor, Artesian Laboratories, Inc. (ALI). Biota were analyzed for seven metals (cadmium, chromium, copper, nickel, zinc, iron, manganese) and two classes of organic contaminants: chlorinated pesticides/PCBs and semivolatiles (phthalate esters, non-chlorinated pesticides and selected polycyclic aromatic hydrocarbons (PAHs)). This is the first year that tissues were analyzed for cadmium burdens.

Data Analysis

Several recommendations cited in previous years have been implemented in the Twelfth Year. Where possible, larger tissue samples were available and organisms were sorted into samples according to size distribution. This resulted in station replicates comprised of either smaller or larger sized organisms. At many stations, however, there were still insufficient organisms to make up one fully adequate composite tissue sample for analyses. This was particularly true for the *Cyathura* and *Macoma* samples, as noted by the contractor. Most sampling programs designed to determine contaminant differences among stations and or sampling years, incorporate a standardization protocol (e.g. size, age, sex, lipid content) in order to reduce unwanted variance (Popham and D'Auria, 1983; Lobel et al., 1991a). Sorting organisms according to size distributions allowed sample replication at five stations in the Twelfth Year. But since contaminant burdens are often correlated with size or age, having two replicates of different age groups may only increase variability within a site, as observed in the summary metal Appendix table (A2) of this report. High variability within a site due to different size-dependent tissue burdens or variable sediment content makes true among-station differences difficult to assess statistically. It may be preferable to have station replicates consisting of similar size classes when organisms are available at a particular site.

Analytical methods changed in the Twelfth Year, based on recommendations aimed at improving detection limits for certain organic contaminants. ALI used National Oceanic and Atmospheric Administration (NOAA) National Status and Trends (1993) tissue and extraction and cleanup methods, and Environmental Protection Agency (EPA) methods for organic contaminant analyses. From the information provided by ALI in the Twelfth Year Analytical Data Report (1995) it is unclear whether the EPA methods were applied to instrumental or data analyses. Complete listing of analyses methods, as provided by ALI, are given in Table 1. The contractor encountered several problems with these methods, which were compounded by frequent small sample volumes and the presence of sediment in the intestinal tract of some invertebrate samples. For certain classes of compounds, namely the phthalate esters and low molecular weight compounds, the methods provided were inadequate for trace compound recovery.

The Twelfth Year analytical tissue data were accompanied by extensive quality control (QC) data by the contractor relative to previous years. These data included replicated analyses of external standard reference material (SRM) (tissue 1566a from the National Institute of Standards and Technology, NIST) for metal analyses and internal QC including laboratory blanks, fortified blanks, replicated sample tissue matrix spike recoveries on two samples, surrogate spike recoveries, and replicate analyses on two samples for both metal and organic data. While these QC data results are discussed under the appropriate sections, the data are too large to include in total within the context of this interpretive report. One may find the entire data set in the accompanying Twelfth Year Analytical Data Report (1995).

Data were entered into Quatro Pro 5.0 for Windows for presentation and for summary purposes. The nature of the data set and the limited resources for conducting more exhaustive sampling and/or chemical analyses sensitive enough for some analytes precludes rigorous statistical analysis. Appropriate statistical tests are not generally available for this type of data. As in years past, the data set is characterized by small sample sizes, few appropriate replicates per site and a substantial number of non-detects with varying detection limits. While somewhat improved over previous years, there is still insufficient data to estimate both among-sample and within-sample variability so that statistically significant among station contrasts could be performed. Therefore, the data presentation is primarily a summarization of the analytical results in tabular format with appropriate summary statistics. Unusual or atypical results were noted and compared largely with Tenth and Eleventh Year data. The order and format used to present the current data is similar to the Tenth and Eleventh Years to facilitate between-year comparisons. Although not statistically significant, selected metal data for each genus was arranged according to station type, where data permitted, using data from similar size classes. It is believed that this presentation will aid in among station contrasts and facilitate observed trends in future years.

A summary of the benthic sample data is compiled in Appendix Table A1, which includes sample ID numbers, number of organisms, length distribution and weight per sample composite and analyses notes. In this report, chemical concentrations for metals are reported as µg/g (ppm) wet weight values and µg/kg (ppb) wet weight for organics. Since many bivalve sampling programs report dry weight values (e.g. NOAA's Mussel Watch), approximate comparisons can be made by decreasing dry 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-G. Individual sample summaries are provided in Appendix Table A2.

As in the previous three years, two tables have been provided as reference information from which to compare selected trace metal concentrations in Hart-Miller benthic 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 during the years 1984 - 1986. 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 eight-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 1981-1985 survey of Chesapeake Bay soft shell clams, *Mya arenaria* (Murphy, 1990) and 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.

Two important caveats should be kept in mind when comparing the present Twelfth Year HMI data set with these other two studies (Tables 3 and 4). First, the feeding habits of the species being compared differ. Both *Mytilus edulis* and *Mya arenaria* are filter feeders, while all the HMI invertebrates in this study are deposit feeders. Thus, the NOAA and Murphy data are reflective of water column conditions while the HMI data are more relevant to sedimentary environment conditions. Second, both of the comparative data sets are rather old. Metal loadings to this region of the Bay, at least from point sources, have generally declined since the early to mid-1980s (Warner et al. 1992). Hence, conclusions drawn from such comparisons may not be entirely appropriate.

QC Metal Data

The overall QC data for metals were good and within specified limits. The only problems encountered were for over-recovery for iron and zinc in one matrix spike (133% and 163%, respectively) and for iron, zinc and manganese in the other matrix spike (287%, 128%, and 1022%, respectively) of the internal QC samples. The contractor believes these over-recoveries were due to the presence of excessive sediment (which may have contained high ambient levels of these analytes) in the tissue samples. This led to difficulty in obtaining homogeneous subsamples and high recovery of these compounds compared to the relatively (unspecified) low levels used for the matrix spike. Since recovery of these compounds was excellent for their lab fortified blanks and within limits for their SRMs their explanations are reasonable and point to the difficulty of analyzing and interpreting the sediment-laden tissue data.

Rangia cuneata

Twelve *Rangia* samples were collected in the Twelfth Year, three samples from the reference areas, three from nearfield and six from zinc enriched stations.

Cadmium was detected in 75% of the Twelfth Year samples, all of which were near the low end of the detection limits (Table 2A). Detection limits varied according to sample digest weight and ranged between 0.2 and 0.8 (μg/g).

Chromium was detected in 83% of the samples from the Twelfth Year with detection limits ranging from 0.3 to 1.5 μg/g (Table 2B). Again, most of the detected values were close to or within the detection limit range and are similar to chromium levels found in soft shell clams in the Chesapeake. Chromium was detected in none of the samples in the Eleventh Year which carried higher detection limits of between 1 and 2 μg/g. In contrast, chromium was detected in 33% of the samples from the Tenth Year when one of two samples from the reference station (HM22) yielded the highest concentration of 66 μg/g.

Copper was detected in all the Twelfth Year *Rangia* samples with the highest concentration of 6.3 μg/g at station G5 from the zinc-enriched area (Table 2C). Copper concentrations were higher in the reference stations than in the near field stations. The lowest concentration occurred within the zinc-enriched area (G25) while the remaining copper concentrations from this area were similar to the elevated levels found at the reference stations. The range of copper concentrations for the Twelfth Year are only slightly higher than the Eleventh Year and are in contrast to the wide range of concentrations found in the Tenth Year. Copper concentrations were within the lower range of soft shell clams from the Chesapeake, and were above or within the highest sample range of the nationwide NOAA survey of the blue mussel (Tables 3 and 4).

Nickel was detected in all of the *Rangia* samples with a high value of 20.4 μg/g in one sample at Reference HM22 (Table 2D). *Rangia* samples from this same site carried the maximum nickel concentration in the Eleventh Year. As with copper, the highest nickel concentrations occurred in the reference stations, the lowest near field, with the zinc-enriched stations showing variable and intermediate values. In general, the range in nickel concentrations were similar to the Tenth and Eleventh year data. Detected nickel concentrations were generally 6-12 times higher than the highest sample concentrations in blue mussels nationwide (Table 3).

Zinc was detected in all samples with the highest value (145 μg/g) in one sample at Reference station HM16 (Table 2E). Elevated *Rangia* zinc concentrations at the two reference stations were within or above the range found at the zinc-enriched stations. The near field station concentrations were generally lower and similar to the mean zinc concentrations found by Murphy (1990) for Chesapeake soft shell clams (Table 4). The range of concentrations of zinc were 4-6 times higher than the previous two years, and reminiscent of the high values reported in years prior to the Tenth Year. Zinc concentrations were higher than the highest sample range found in blue mussels nationwide (Table 3).

***Macoma* sp.**

Six samples of *Macoma* were sampled in the Twelfth Year; three from the zinc enriched area, two from one reference station and one from a nearfield station. As noted by the contractor, these data should be viewed with caution since the presence of appreciable sediment in the gut contents of many samples caused analytical difficulties and likely do not reflect true tissue burdens for some analytes (Table A1).

Cadmium was detected in 83% of *Macoma* samples with the highest value (1.4 μg/g) found in one larger-sized replicate from the reference site HM16 (Table 2A). However, all values were very close to the detection limits and no among station differences are readily apparent.

Chromium was detected in all of the samples with the highest value (4.5 μg/g) found at the nearfield station (Table 2B). The lowest value occurred at the edge of the zinc enriched area (station G84) with the remaining values similar in magnitude. In contrast, chromium was found in 33% (two values) of all samples with a high of 8.2 μg/g at station G84 in the Tenth Year and nondetectable in the one *Macoma* sample in the Eleventh Year. It should be noted that the range of chromium values for both the Twelfth and Tenth years are well above the values typically found for Chesapeake soft shell clams (Table 4). However, the values are similar to those found in *Macoma* from Baltimore Harbor (Wright et al. 1986).

Copper was detected in all *Macoma* samples from the Twelfth Year with the highest value (59 μg/g) occurring in one replicate at the reference station HM16 (Table 2C). The greatest copper values are found in samples comprised of the largest size range, regardless of station (Table A2). When normalized, to some degree, by shell length, the remaining samples in the smaller size group (i.e. <21 mm) have similar values among the zinc enriched stations (15 and 17 (μg/g) and a value roughly twice as high at the nearfield station (29 (μg/g). The range of copper values found in *Macoma* for the Twelfth Year are similar to values obtained in the past two years, taking into account continuing problems with sediment in the samples and ignoring shell length normalization.

Nickel was present in all samples with the greatest value (6.1 μg/g) again in the largest size-class replicate at reference station HM16 (Table 2D). The remaining samples all had values within the range of 2.5 to 3.5 μg/g which is roughly twice as high as the highest ranges found nationwide in the blue mussel (Table 3). The frequency of detection for nickel was higher in the present survey over previous years making between-year comparisons difficult. This increased frequency may be due to larger sample sizes and/or lower detection limits.

Zinc distributions in *Macoma* followed those of copper and nickel. Zinc was detected in all samples with the largest burden (465 μg/g) in the replicate at reference station HM16 (Table 2E). The highest zinc burdens were again associated with samples from the largest size-class (Table A2). These values are 2-4 fold higher than the maximum *Macoma* zinc burden (130 μg/g) from the Tenth Year. In the Eleventh Year only one *Macoma* sample was taken and its zinc burden (29 μg/g) is well below the range currently reported. The remaining Twelfth Year samples of similar size-class did not show any strong trends reflecting among station differences, given the lack of shell-length normalized variance data for each station.

Cyathura polita

Four samples of *Cyathura* were collected for the Twelfth Year; three from zinc enriched stations and one from a nearfield station.

Cadmium was detected in 75% of the samples with the highest value (0.96 μg/g) at zinc enriched station G5 (Table 2A). Cadmium concentrations were nearly twice as high at zinc enriched stations than at the nearfield site, though all values were close to the detection limits for this analyte.

Chromium was detected only in one sample at the nearfield station and the value (2.1 μg/g) was just above the maximum detection limit (Table 2B). Chromium was not detected in any *Cyathura* samples from the Tenth or Eleventh Years. Detection limits were not generally different from previous years. In previous reports, chromium appeared in *Cyathura* most frequently from the nearfield stations.

Copper was detected in all samples of *Cyathura* and the highest value (120 μg/g) at a zinc enriched station was also the highest of all HMI tissue samples from the Twelfth Year (Table 2C). The lowest copper burden in *Cyathura* tissues is near the maximum value found in *Macoma* and seven and a half times the maximum burden in *Rangia* tissues from the Twelfth Year. Copper concentration at the nearfield station is within the range found among the zinc enriched stations. The range of copper concentrations in *Cyathura* for the Twelfth Year is an order of magnitude greater than those in the Eleventh Year but of similar magnitude to the Tenth Year.

Nickel was detected in half of the *Cyathura* samples, both within the zinc enriched area, and were generally much less than tissue burdens in the bivalves (Table 2D). The detection limits for nickel in *Cyathura* were somewhat higher than in the bivalves, which may be a reflection of the limited tissue digest weight available for analyses (Table A1).

Zinc was found in all of the *Cyathura* samples with a maximum value of 180 μg/g found at the zinc enriched station G5. Zinc burdens were greater at the zinc enriched stations than at the nearfield station. The range of *Cyathura* zinc concentrations are two to three times higher than those in the Eleventh Year but similar to the Tenth Year. Zinc concentrations in *Cyathura* were not generally higher than in the bivalves. Year-to-year fluctuations in zinc concentrations in *Cyathura* have been noted in previous reports, the reasons for which are unclear.

Summary of Selected Metal Distributions by Station

The distributions of copper, nickel, and zinc in the three types of benthic invertebrates from selected stations are presented in Figure 2. *Rangia* composite samples less than 31 mm and *Macoma* composite samples less than 21 mm in length were used in these comparisons in an attempt to exclude the atypically high values associated with the few large sized samples. All *Cyathura* data have been included since the size distribution among all samples was similar (Table A1). As noted previously, the *Macoma* data should be treated with caution due to abnormally high sediment in the tissues. Since tissue burdens between species vary at any one station, the best overall comparison of station differences may be obtained from the *Rangia* data, which contained the largest number of samples.

These data suggest several trends: that copper preferentially accumulates in *Cyathura*, nickel in *Rangia* and that zinc distributions show no particular species preferences. Zinc distributions at the zinc enriched stations are similar in magnitude to the reference stations. These limited data also suggest that tissues from the reference stations carry equal, if not greater, contaminant burdens than tissues from the nearfield stations, at least in the present sampling year.

It is unclear whether the observed contaminant levels in tissues at the reference sites reflect ambient upper Bay conditions or impacts from HMI, given the modeling study of pollutant dispersion surrounding HMI (Wang 1993) and the distribution of trace metals and fine sediment under the sedimentary environment report in the Tenth Annual Interpretive Report (1993). Based on these studies, it is plausible that the distribution of contaminants associated with HMI effluent or particles encompasses many of the designated reference stations. Depending on Susquehanna flow and under certain spillway operation and flow rates, a higher distribution of fine grained material originating from HMI would be found farther from the facility (i.e. in the direction of some reference sites). Since many contaminants preferentially associate with this fine grained material, some of the designated reference stations would be expected to carry higher contaminant burdens than the nearfield stations. If, for example, one examines the pattern of sediment zinc distributions surrounding HMI in the Tenth Year, it is clear that the location of environments affected by HMI operation is not a simple function of distance from HMI. In order to separate the effects of HMI from those of the surrounding environment, reference stations should be located in areas well-removed from possible influences from the facility.

Iron and Manganese

Iron and manganese were detected in substantial quantities in all tissue samples from the Twelfth Year (Tables 2F and 2E). As is typical from years past, the values are quite variable among station types and among species. As mentioned under the metals QC section, the variability in these data and high values are likely due to varying amounts of iron and manganese enriched sediments present in the guts of the animals at the time of sampling. The *Macoma* samples, which carried large sediment burdens, show excessively high iron values, indicative of enrichment.

It is important to note that the biota are not purged of gut contents at the time of sampling and thus all analytical results in the present sampling year as in years past, are presumed to reflect the combination of true tissue burdens as well as contamination from particles in the gut. 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 (Wright et al., 1986). Similarly, Lobel et al. (1991b) found the presence of sediment in the intestinal tract of aquatic organisms accounted for significant overestimation of some metal levels, particularly iron and manganese. In light of the continuing problems associated with sediment in the tissue samples, the monitoring program may wish to consider the benefits of purging or depurating samples prior to submission for chemical analyses.

Organic Contaminants

Table 5a,b is a listing of target organic analytes for the Twelfth Year and the reported detection limits for laboratory blanks as well as the range of detection limits for each type of tissue. The organics are grouped into two broad categories: Semivolatiles and Pesticides. The Pesticide grouping contains chlorinated pesticides and polychlorinated biphenyls (PCBs) while the Semivolatile group contains polycyclic aromatic hydrocarbons (PAHs), phthalate esters, and non-chlorinated pesticides. Detection limits were generally highest (i.e. least sensitive) in *Cyathura* samples and lowest in *Rangia*, though the semivolatile detection limits for *Macoma* contained some of the highest values cited.

In response to recommendations from previous years, the methods for chemical analyses of organics changed in the Twelfth Year to provide for more sensitive detection levels. The new contract lab, ALI, adopted NOAA methods (1993) used in the nationwide Mussel Watch monitoring program for their tissue extraction and cleanup steps. Tissue samples were outside the realm of matrices normally analyzed for organics by ALI and difficulties were encountered both in the methods and from the often minimal sample mass available (Table A1). Variable and minimal sample mass contributed to the variable and often high detection limits observed (Table 5). Also, the NOAA methods were not entirely appropriate for some classes of target analytes, namely the phthalate esters and some of the nonchlorinated pesticides, as these compounds are not target analytes monitored in the Mussel Watch program. Hence, while aimed at improving levels of detection, application of the new methods led to less sensitivity in several classes of analytes and problems in their QC samples. For the suite of compounds identical to both the HMI and Mussel Watch monitoring programs, ALI's detection limits were several orders of magnitude higher.

QC Organic Data

As mentioned previously, the extensive QC data submitted by ALI will not be extensively reviewed here. One may find all of the data and ALI's explanations for QC data results outside of the specified limits in the accompanying Twelfth Year Analytical Data Report (1994). ALI could not obtain an external quality control check on the organics because the tissue SRMs were on back order from NIST. While they did provide data results from an EPA standard tissue for pesticides, they failed to note which compounds were known to be present and their certified values. It also would have been helpful had they specified the levels at which they dosed their matrix spikes, laboratory fortified blanks, or surrogate spikes, instead of providing only percent recoveries. There were no external or internal QC data for PCBs.

The only organic analytes detected in the Twelfth Year samples were from the phthalate ester and the chlorinated pesticide classes. Thus, the remaining discussion of QC data will focus only on these classes of organics since the high detection limits precluded quantification of other analytes in the samples. Surrogate recoveries for chlorinated pesticides were low, averaging 56% and 28% for 4,4'dibromooctafluoro-biphenyl and dibutyl chlorendate, respectively. Matrix spike recoveries for chlorinated pesticides were also generally low or inprecise. None of the phthalate esters were recoverable from the laboratory fortified blanks and one matrix spike, while the second matrix spike showed low recoveries for only two of the six phthalate ester analytes. To compound the problem, the phthalate ester, bis (2-ethylhexyl) phthalate, was detected in the laboratory blank at levels close to those detected in some of the HMI samples. While the remaining detects of this compound were great enough to rule out laboratory contamination by the contractor, detection of these ubiquitous compounds in many studies are often suspect due to routine contamination from plastics.

Detected Organics in Benthic Samples

Organic contaminant burdens were detected in eight of the 22 samples submitted: in one *Cyathura*, three *Macoma* and four *Rangia* samples. The only analyte detected in all of these samples was the phthalate ester, bis (2-ethylhexyl) phthalate (Table 6). The DDT metabolite, 4,4'-DDE, was also detected at low levels (20 μg/kg) in one *Rangia* sample. In contrast, no organics were present above the (high) levels of detection in the Eleventh Year samples. The Tenth Year reported detectable PCBs in all samples, but with detection limits several orders of magnitude more sensitive than the present sampling year. In the present sampling year, the PCB detection limits for many tissue samples were well above the FDA action limit of 2,000 μg/kg wet wt. One *Rangia* sample also contained 4,4'-DDT burdens in the Tenth Year. In light of the QC problems with phthalate esters noted above, the phthalate burdens should be viewed with some caution. It is known, however, that Baltimore Harbor receives its largest quantifiable loading of any organic contaminant from bis (2-ethylhexyl) phthalate and that part of its source is derived from Back River effluent discharged to the Patapsco from cooling water operations (Warner et al., 1992). Phthalate esters have been sporadically detected in biota samples in previous HMI monitoring years, though not in the past two. Due to the widespread distribution, large bioaccumulation potential (Mayer et al., 1972) and toxicological effects (Wams, 1987) of phthalate esters, great care should be exercised in the collection and processing of samples in order to rule out confounding contamination issues.

CONCLUSIONS

Concentrations of trace metals in the benthic biota samples were characterized by high variability within station type (where replication permitted evaluation) as in previous years. Some of the variability within stations could be explained by the size class differences between replicates and the relative amount of sediment associated with the tissue samples. These factors were particularly relevant for the *Macoma* data and interfered with their interpretation. While it is assumed that sediment has always been present in tissue samples from previous years, this is the first year the contract lab specified which samples carried the greatest burdens and their associated analytical problems. This was also the first year in which cadmium was analyzed and it was detected in 73% of all samples at levels close to the detection limit. Chromium was detected more frequently, but in narrower concentration ranges, in the present year than in the Tenth Year, compared to no detects in the Eleventh Year. Though *Macoma* carried the highest burdens, within species, there were no strong trends in chromium levels among station type. As in the previous three monitoring years, copper concentrations were highest in *Cyathura*, and similar in range for all species as in the previous two years. Nickel concentrations were greatest in the *Rangia* samples and similar in range to the previous two years. Zinc concentrations were elevated in *Rangia* samples over the previous two years. In general, zinc distributions at the zinc enriched stations were similar in magnitude to the reference stations.

Despite (unsuccessful) efforts to improve detection limits, the frequency and number of organic analyte detection were quite low in the present monitoring year as in previous years. The high detection limits and complete loss of some analytes were due, in part, to minimal sample mass and application of recommended methods which were inappropriate for some classes of target organics. The only analyte detected, apart from a small pesticide burden in one sample, was the plasticizing agent, bis (2-ethylhexyl) phthalate. No conclusions can be drawn nor general trends observed from the organic data set in the present sampling year due to continuing problems with high and variable detection limits.

Another problem highlighted in the present monitoring year concerns the locations selected for reference stations in the HMI benthic monitoring program. One cannot necessarily exclude HMI facility operation as a contributing agent for the contaminant levels observed in samples from the reference stations, based on recently available data and results from hydrodynamic modeling studies. Should data sets with improved detection limits and appropriate replication become available in the future, it would still be difficult to statistically assess the impacts of the facility if many of the designated reference sites are potentially under the influence of HMI operation. It is strongly suggested that the monitoring program address the concerns raised over sampling locations in this, as well as in previous, interpretive reports.

RECOMMENDATIONS

1. Re-evaluate the sampling locations, particularly those for reference stations. Coordinate data from the sedimentary project, results from the hydrodynamic pollutant modeling study in the Tenth Year and knowledge of projected spillway operation to design a sampling scheme able to detect contaminant gradients around the facility and to find reference sites well-removed from the influences of HMI.

2. Adopt more sensitive analytical techniques for target organic analytes so that true contaminant differences can detected. With present methodology, only gross contamination, which often exceeds FDA action limits, is sporadically detected and no trends can be assessed. Since the associated costs of improved detection limits will be higher, monitoring studies could be performed less

frequently. It is questionable whether anything is to be gained from using less sensitive analytical techniques in intervening years.

3. Consult the contractor prior to sampling for proper collection methods and adequate tissue needs. True trace level determinations require extra sampling precautions to protect against contamination. Consider dropping *Cyathura* for organic analyses. There is rarely sufficient tissue mass to justify the cost and resulting high detection limits for these data.

4. Try to determine the minimum number of individuals needed to provide an adequate composite tissue sample for analyses after consultation with the contractor. Alternatively, a minimum of 5 grams wet weight per sample is suggested. Subdivide large samples of similar size class into enough replicates to provide for statistical comparisons. It would not be prudent to invest in more sensitive testing if there is still insufficient sample or replication to draw conclusions.

5. Consider using only *Rangia* as a monitoring species to eliminate problems with comparing contaminant levels from different species among stations. Allow flexibility in the selection of sampling locations so that only those sites with enough individuals to provide adequate tissue and replication are used.

6. Consider purging the samples of sediment prior to submission for analyses. The presence of sediment in the present year as in years past has confounded the interpretation of metal burdens in the benthic samples. Alternatively, adopt an experimental scheme recommended in the Ninth Year to evaluate the influence of sediment on the apparent concentration of contaminants in tissues by dividing a sample and analyzing purged and unpurged sets.

7. Reevaluate whether iron and manganese are really providing any information pertinent to the benthic monitoring program. While iron data are sometimes used to calculate enrichment in sediments, the data do not seem to be serving any purpose in the benthic biota data set. Alternatively, add arsenic to the analyte list or direct the costs associated with analysis of these metals to additional numerical or spatial coverage.

8. Decrease the number of target organic analytes. Consider dropping aldrin, endrin, ethyl and methyl parathion, linuran, malathion, trifluralin, atrazine, diazinon, beta BHC, naphthalene and alkylated naphthalenes as these compounds do not readily accumulate in sediments or biota or are not stable in estuarine environments. It is also questionable whether toxaphene should be kept as an analyte using the current analytical methodology.

9. With improved detection limits and new reference sites selected in the future, consider repeating the sediment toxicity tests performed in the Eleventh Year. These tests were inconclusive due to predation and/or mortality in the reference sediment. To complete the sediment quality triad concept (Chapman et al. 1987) it is important to have the same stations for sediment and tissue contaminant burdens, as for toxicity tests and benthic community assessments.

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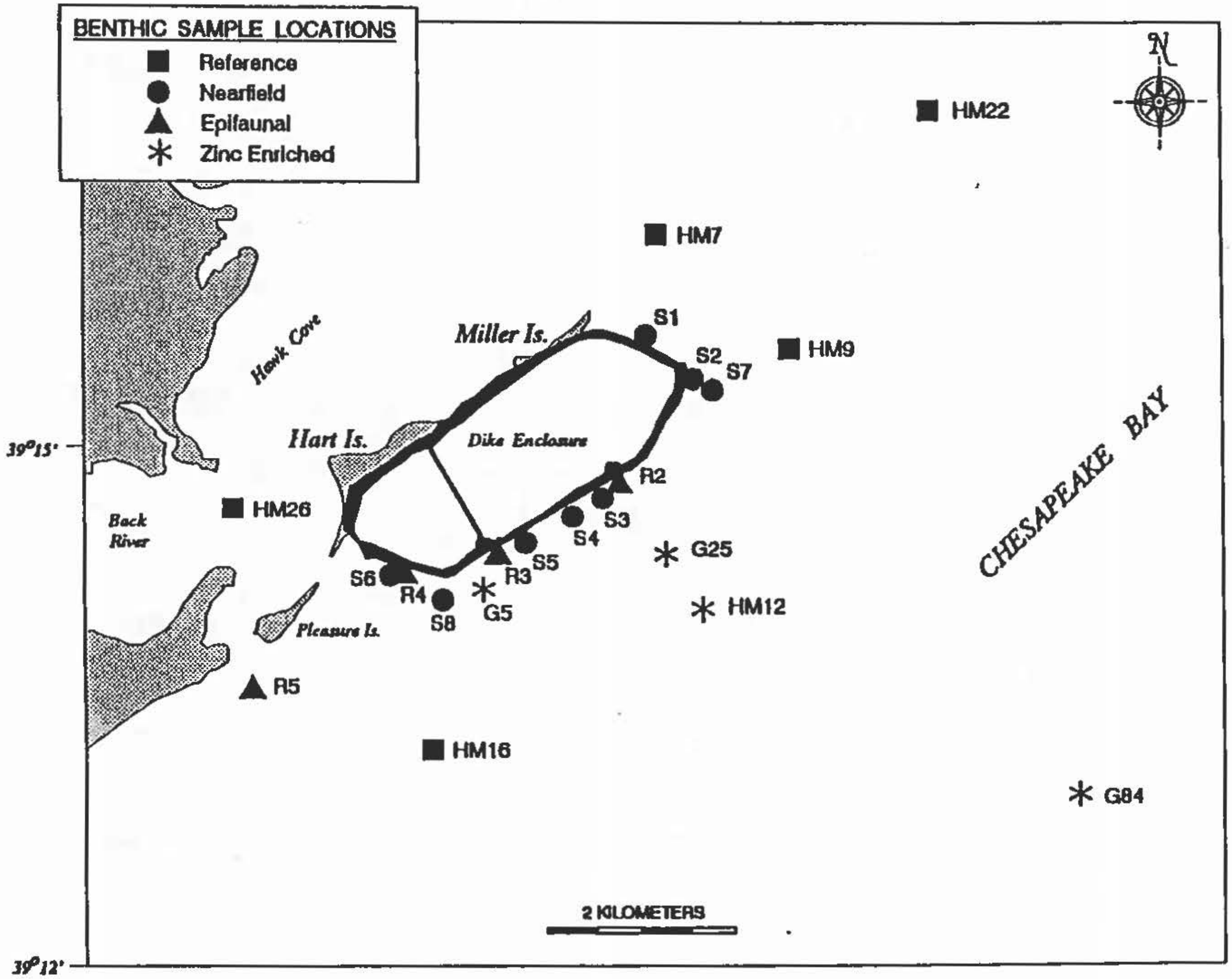

Figure 1. Benthic infaunal and epifaunal sampling station locations at HMI. University of Maryland, Chesapeake Biological Laboratory designations.

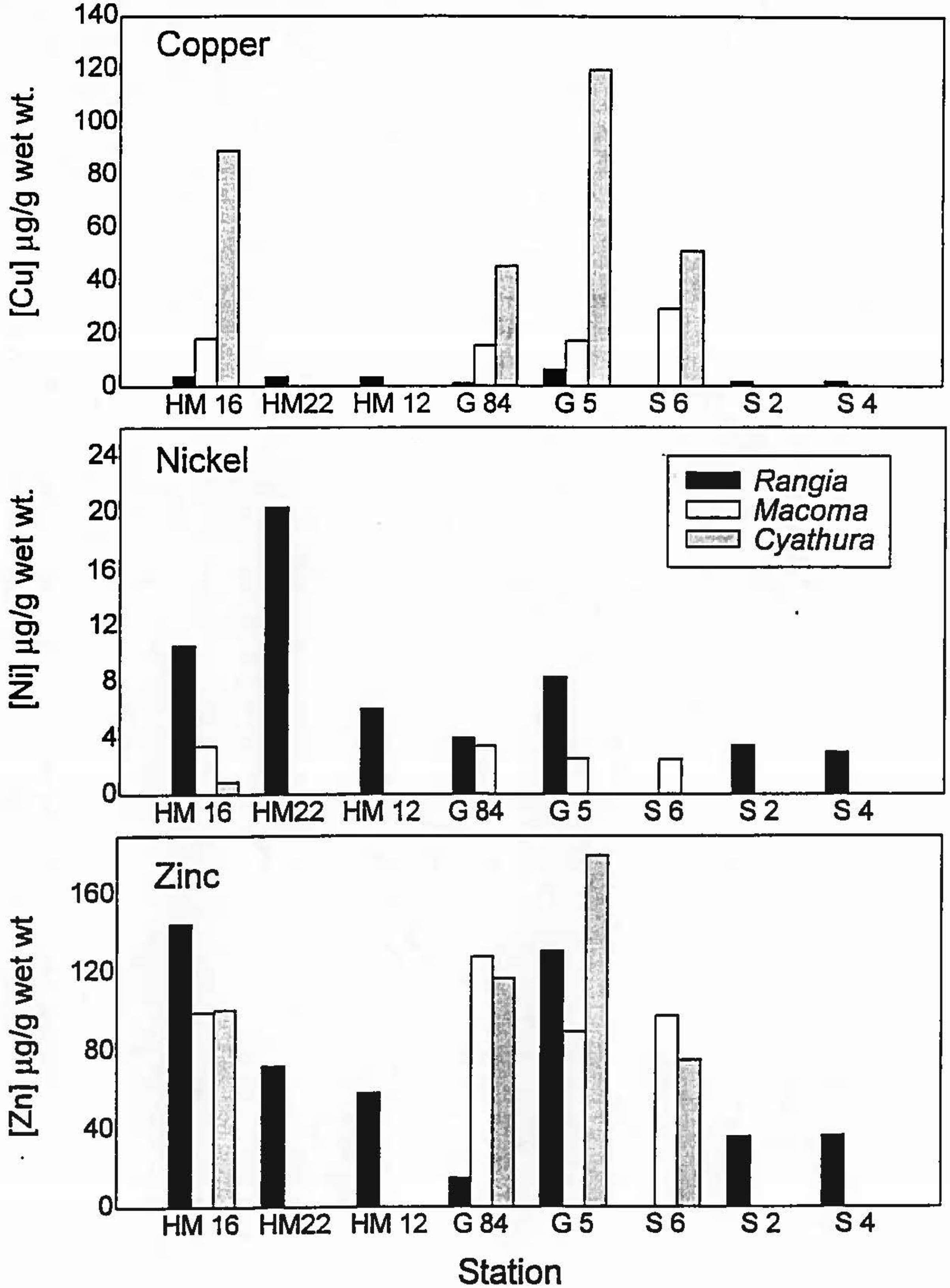

Figure 2. Selected tissue metal burdens by station.
(*Rangia* samples < 31mm; *Macoma* samples < 21 mm)

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

Parameter	Media	Method Number/Reference
Cadmium (Cd)	Tissues	(EPA 200.7) (EPA 1983)
Chromium (Cr)	Tissues	(EPA 218.2) (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 249.2) (EPA 1983)
Pesticides/PCBs	Tissues	NOAA NOS ORCA 71, 1993 (EPA 608)
Semivolatiles (Phthalate Esters, PAHs, etc.)	Tissues	NOAA NOS ORCA 71, 1993 (EPA 625)

Table 2A. Cadmium (ug/g wet wt.)

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/Max/Range
Cyathura	G 5	1	100	0.91	0.96	0.96	
Cyathura	G 84	1	0	1	ND	ND	
Cyathura	HM 16	1	100	0.53	0.79	0.79	
Cyathura	S 6	1	100	0.5	0.55	0.55	
Cyathura	All Stations	4	75	0.5, 2	0.96		0.55/ 0.96/ 0.41
Macoma	G 5	2	50	0.19, 1	0.41	<1, 0.41	
Macoma	G 84	1	100	0.19	0.22	0.22	
Macoma	HM 16	2	100	0.18, 0.83	1.39	0.24, 1.39	
Macoma	S 6	1	100	0.37	0.5	0.5	
Macoma	All Stations	6	83	0.18, 1	1.39		0.22/ 1.39/ 1.17
Rangia	G 5	1	0	0.83	ND	ND	
Rangia	G 25	2	50	0.17, 0.18	0.22	<0.17, 0.22	
Rangia	G 84	1	0	0.2	ND	ND	
Rangia	HM 12	2	100	0.17, 0.18	0.27	0..26, 0.27	
Rangia	HM 22	2	100	0.19, 0.20	0.29	0.2, 0.29	
Rangia	HM 16	1	0	0.77	ND	ND	
Rangia	S 1	1	100	0.2	0.33	0.33	
Rangia	S 2	1	100	0.19	0.25	0.25	
Rangia	S 4	1	100	0.19	0.24	0.24	
Rangia	All Stations	12	75	0.17, 0.83	0.33		0.2/ 0.33/ 0.13

Table 2B. Chromium (ug/g wet wt.)							
Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/Max/Range
Cyathura	G 5	1	0	1.8	ND	ND	
Cyathura	G 84	1	0	2	ND	ND	
Cyathura	HM 16	1	0	1.1	ND	ND	
Cyathura	S 6	1	100	1	2.11	2.11	
Cyathura	All Stations	4	25	1, 2	2.11		2.11
Macoma	G 5	2	100	0.38, 2	3.96	2.95, 3.96	
Macoma	G 84	1	100	0.38	1.66	1.66	
Macoma	HM 16	2	100	0.36, 1.7	3.95	3.78, 3.95	
Macoma	S 6	1	100	0.75	4.49	4.49	
Macoma	All Stations	6	100	0.36, 2	4.49		1.66/ 4.49/ 2.83
Rangia	G 5	1	100	1.7	1.79	1.79	
Rangia	G 25	2	100	0.36, 0.34	1.42	0.37, 1.42	
Rangia	G 84	1	0	0.39	ND	ND	
Rangia	HM 12	2	100	0.35, 0.36	0.48	0.43, 0.48	
Rangia	HM 22	2	100	0.4, 0.38	0.88	0.88, 0.88	
Rangia	HM 16	1	0	1.5	ND	ND	
Rangia	S 1	1	100	0.4	0.47	0.47	
Rangia	S 2	1	100	0.38	0.87	0.87	
Rangia	S 4	1	100	0.38	0.645	0.64	
Rangia	All Stations	12	83	0.34, 1.5	1.79		0.47/ 1.42/ 0.95

Table 2C. Copper (ug/g wet wt.)							
Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/Max/Range
Cyathura	G 5	1	100		120	120	
Cyathura	G 84	1	100		45.4	45.4	
Cyathura	HM 16	1	100		89.3	89.3	
Cyathura	S 6	1	100		51.2	51.2	
Cyathura	All Stations	4	100		120		45.4/ 120/ 74.6
Macoma	G 5	2	100		43	17.1, 43	
Macoma	G 84	1	100		15.4	15.4	
Macoma	HM 16	2	100		59	18.3, 59	
Macoma	S 6	1	100		29.2	29.2	
Macoma	All Stations	6	100		59		15.4/ 59/ 43.6
Rangia	G 5	1	100		6.34	6.34	
Rangia	G 25	2	100		3.1	2.83, 3.1	
Rangia	G 84	1	100		1.29	1.29	
Rangia	HM 12	2	100		3.4	3.06, 3.4	
Rangia	HM 22	2	100		3.86	3.4, 3.86	
Rangia	HM 16	1	100		4.02	4.02	
Rangia	S 1	1	100		2.52	2.52	
Rangia	S 2	1	100		1.75	1.75	
Rangia	S 4	1	100		1.88	1.88	
Rangia	All Stations	12	100		6.34		1.29/ 6.34/ 5.05

Table 2D. Nickel (ug/g wet wt.)							
Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/Max/Range
Cyathura	G 5	1	100		2.84	2.84	
Cyathura	G 84	1	0	2.8	ND	ND	
Cyathura	HM 16	1	100		0.88	0.88	
Cyathura	S 6	1	0	1.4	ND	ND	
Cyathura	All Stations	4	50		2.84		2.84
Macoma	G 5	2	100		2.65	2.56, 2.65	
Macoma	G 84	1	100		3.41	3.41	
Macoma	HM 16	2	100		6.08	3.46, 6.08	
Macoma	S 6	1	100		2.5	2.5	
Macoma	All Stations	6	100		6.08	6.08	2.5/ 6.08/ 3.58
Rangia	G 5	1	100		8.35	8.35	
Rangia	G 25	2	100		14.3	4.26, 14.3	
Rangia	G 84	1	100		4.02	4.02	
Rangia	HM 12	2	100		6.73	6.03, 6.73	
Rangia	HM 22	2	100		20.4	11.4, 20.4	
Rangia	HM 16	1	100		10.6	10.6	
Rangia	S 1	1	100		2.63	2.63	
Rangia	S 2	1	100		3.49	3.49	
Rangia	S 4	1	100		3.02	3.02	
Rangia	All Stations	12	100		20.4		2.63/ 20.4/ 17.77

Table 2E. Zinc (ug/g wet wt.)							
Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/Max/Range
Cyathura	G 5	1	100		180	180	
Cyathura	G 84	1	100		117	117	
Cyathura	HM 16	1	100		101	101	
Cyathura	S 6	1	100		75.3	75.3	
Cyathura	All Stations	4	100		180		75.3/ 180/ 104.7
Macoma	G 5	2	100		267	89.9, 267	
Macoma	G 84	1	100		128	128	
Macoma	HM 16	2	100		465	99.5, 465	
Macoma	S 6	1	100		97.8	97.8	
Macoma	All Stations	6	100		465		89.9/ 465/ 375.1
Rangia	G 5	1	100		131	131	
Rangia	G 25	2	100		49.8	44.6, 49.8	
Rangia	G 84	1	100		15	15	
Rangia	HM 12	2	100		69.4	58.6, 69.4	
Rangia	HM 22	2	100		72.5	47.2, 72.5	
Rangia	HM 16	1	100		145	145	
Rangia	S 1	1	100		24.8	24.8	
Rangia	S 2	1	100		36.3	36.3	
Rangia	S 4	1	100		36.7	36.7	
Rangia	All Stations	12	100		145		15/ 145/ 130

Table 2F. Iron (ug/g wet wt.)							
Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/Max/Range
Cyathura	G 5	1	100		463	463	
Cyathura	G 84	1	100		475	475	
Cyathura	HM 16	1	100		239	239	
Cyathura	S 6	1	100		233	233	
Cyathura	All Stations	4	100		475		233/ 475/ 242
Macoma	G 5	2	100		2290	1935, 2290	
Macoma	G 84	1	100		2000	2000	
Macoma	HM 16	2	100		2837	2773, 2837	
Macoma	S 6	1	100		2691	2691	
Macoma	All Stations	6	100		2837		1935/ 2837/ 902
Rangia	G 5	1	100		300	300	
Rangia	G 25	2	100		139	127, 139	
Rangia	G 84	1	100		67.8	67.8	
Rangia	HM 12	2	100		144	103, 144	
Rangia	HM 22	2	100		350	156, 350	
Rangia	HM 16	1	100		164	164	
Rangia	S 1	1	100		97.1	97.1	
Rangia	S 2	1	100		120	120	
Rangia	S 4	1	100		240	240	
Rangia	All Stations	12	100		350		67.8/ 350/ 282

Table 2G. Manganese (ug/g wet wt.)

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Min/Max/Range
Cyathura	G 5	1	100		394	394	
Cyathura	G 84	1	100		140	140	
Cyathura	HM 16	1	100		158	158	
Cyathura	S 6	1	100		110	110	
Cyathura	All Stations	4	100		394		110/ 394/ 284
Macoma	G 5	2	100		236	187, 236	
Macoma	G 84	1	100		178	178	
Macoma	HM 16	2	100		347	262, 347	
Macoma	S 6	1	100		194	194	
Macoma	All Stations	6	100		347	347	178/ 347/ 169
Rangia	G 5	1	100		63.3	63.3	
Rangia	G 25	2	100		156	109, 156	
Rangia	G 84	1	100		37.8	37.8	
Rangia	HM 12	2	100		206	179, 206	
Rangia	HM 22	2	100		158	125, 158	
Rangia	HM 16	1	100		86.8	86.8	
Rangia	S 1	1	100		87.4	87.4	
Rangia	S 2	1	100		120	120	
Rangia	S 4	1	100		104	104	
Rangia	All Stations	12	100		206		37.8/ 206/ 168

Table 3. Trace metal concentrations in the blue mussel, *Mytilus edulis,* 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 the soft shell clam, *Mya arenaria,* from the Chesapeake Bay and its tributaries: 1981-1985. From Murphy 1990. Data as µg/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: Semivolatile organics

Compound	BLANK*	Rangia	Macoma	Cyathura
	ug/kg	sample range: ug/kg wet wt.		
PAHs				
Naphthalene	500	230-34000	700-320000	4700-28000
Acenaphthylene	500	"	"	"
Acenaphthene	500	"	"	"
Fluorene	500	"	"	"
Phenanthrene	500	"	"	"
Anthracene	500	"	"	"
Fluoranthene	500	"	"	"
Pyrene	500	"	"	"
Chrysene	500	"	"	"
Benzo(a)anthracene	500	"	"	"
Benzo(b+k)fluoranthene	500	"	"	"
Benzo(a)pyrene	500	"	"	"
Dibenz(ah)anthracene	500	"	"	"
Indeno(1,2,3-cd)pyrene	500	"	"	"
Benzo(ghi)perylene	500	"	"	"
Phthalate esters				
Dimethyl phthalate	1000	570-84000	1800-800000	12000-69000
Diethylphthalate	1000	"	"	"
Di-n-butylphthalate	1000	"	"	"
Butylbenzylphthalate	1000	"	"	"
Bis(2-ethylhexyl)phthalate +	1000	"	"	"
Di-n-octyl phthalate	1000	"	"	"
Pesticides				
Atrazine	1000	570-84000	1800-800000	12000-69000
Trifluraline	1000	"	"	"
Linuron	1000	"	"	"
Methyl parathion	1000	"	"	"
Diazinon	1000	"	"	"
Ethyl parathion	1000	"	"	"
Malathion	1000	"	"	"

* Blank MDL based on 5 g sample size
+Blank = 4400ug/kg

Table 5b. LIMITS OF DETECTION: Pesticide organics				
Compound	BLANK*	Rangia	Macoma	Cyathura
	ug/kg	sample range		
a-BHC	4	7.3-220	10-290	100-220
b-BHC	4	"	"	"
g-BHC	4	"	"	"
Heptachlor	4	"	"	"
Aldrin	4	"	"	"
Heptachlor Epoxide	4	"	"	"
Dieldrin	4	"	"	"
4,4'-DDE	4	"	"	"
Endrin	4	"	"	"
4,4'-DDD	4	"	"	"
4,4'-DDT	4	"	"	"
Chlordane	100	180-5500	250-19000	2600-5500
Toxaphene	100	"	"	"
PCB-1016	100	"	"	"
PCB-1221	100	"	"	"
PCB-1232	100	"	"	"
PCB-1242	100	"	"	"
PCB-1248	100	"	"	"
PCB-1254	100	"	"	"
PCB-1260	100	"	"	"

* Blank MDL based on 5 g sample size

Table 6. Organic contaminant burdens in HMI Twelfth Year biota samples. Values in ug/kg wet wt.

Species	Station	Sample #	DEHP *	4,4-DDE
Cyathura	HM 16-1	93211	925000	
Macoma	G 5-4	93206	296000	
Macoma	G 84-3	93198	2300	
Macoma	S 6-2	93215	42000	
Rangia	G 25-2	93208	7900	
Rangia	G 84-1	93196	5800	
Rangia	HM 22-1	93202	785000	20
Rangia	S 1-1	93201	211000	

* Bis (2-ethylhexyl) phthalate (or diethylhexylphthalate, DEHP)

Table A1. Benthic Sample Descriptions and Notes, April 1993 Samples.								
Species	Station	Sample #	ALI sample #	# organisms in sample	size range mm	tissue wt g	digest wt. metals (g)	Analysis notes
Cyathura	G 5-1	93217	22	19	10-25	0.38	0.11	
Cyathura	G 84-2	93197	2	14	10-25	0.47	0.1	
Cyathura	HM 16-1	93211	16	14	15-20	0.8	0.19	
Cyathura	S 6-1	93215	20	20	10-25	0.88	0.2	
Macoma	G 5-3	93205	10	86	12-14	2.01	0.54	1,2
Macoma	G 5-4	93206	11	1	28	0.21	0.1	2
Macoma	G 84-3	93198	3	40	17-21	17.63	0.53	1,2
Macoma	S 6-2	93216	21	54	12-15	1.47	0.27	1,2
Macoma	HM 16-3	93213	18	40	15-18	1.65	0.57	1,2
Macoma	HM 16-4	93214	19	3	21-26	0.49	0.12	2
Rangia	G 5-2	93204	9	2	24, 32	0.69	0.12	
Rangia	G 25-1	93207	12	11	22-31	3.23	0.55	
Rangia	G 25-2	93208	13	2	45,48	3.37	0.58	
Rangia	G 84-1	93196	1	3	28-32	5.59	0.51	
Rangia	HM 12-1*	93209	14	14	30-36	10.46	0.58	
Rangia	HM 12-2	93210	15	6	24-28	1.8	0.5	
Rangia	HM 22-1	93202	7	9	31-41	5.03	0.5	
Rangia	HM 22-2	93203	8	17	25-29	3.39	0.53	
Rangia	HM 16-2	93212	17	2	30	0.75	0.13	
Rangia	S 1-1	93201	6	10	31-45	10.24	0.51	
Rangia	S 2-1	93200	5	30	26-32	16.88	0.53	
Rangia	S 4-1*	93199	4	26	25-33	18.45	0.53	1

1. Tissue samples contained excessive sediment
2. Presence of sediment in tissue sample led to poor replication or excessively high values for some metals
* Duplicated sample

Table A2. Summary of HMI Metal Analyses, April 1993 Samples									
Species	Station	Size range	Cd	Cr	Cu	Ni	Zn	Fe	Mn
		mm	ug/g wet wt.						
Cyathura	G 5-1	10-25	0.96	<1.8	120	2.84	180	463	394
Cyathura	G 84-2	10-25	<1	< 2	45.4	<2.8	117	475	140
Cyathura	HM 16-1	15-20	0.79	< 1.1	89.3	0.88	101	239	158
Cyathura	S 6-1	10-20	0.55	2.11	51.2	<1.4	75.3	233	110
Cyathura	All Stations	10-25	0.55-1	<1.1-2.1	45-120	0.9-2.8	75-180	233-475	110-394
Macoma	G 5-3	12-14	0.41	2.95	17.1	2.56	89.9	1935	236
Macoma	G 5-4	28	< 1	3.96	43	2.65	267	2290	187
Macoma	G 84-3	17-21	0.22	1.66	15.4	3.41	128	2000	178
Macoma	HM 16-3	15-18	0.24	3.78	18.3	3.46	99.5	2837	262
Macoma	HM 16-4	21-26	1.39	3.95	59.1	6.08	465	2773	347
Macoma	S 6-2	12-15	0.5	4.49	29.2	2.5	97.8	2691	194
Macoma	All Stations	12-28	0.4-1.4	1.7-4.5	17-59	2.5-6	98-465	1935-2837	178-347
Rangia	G 5-2	24, 32	< 0.83	1.79	6.34	8.35	131	300	63.3
Rangia	G 25-1	22-31	0.22	0.37	3.1	4.26	49.8	139	156
Rangia	G 25-2	45, 48	< 0.17	1.42	2.83	14.3	44.6	127	109
Rangia	G 84-1	28-32	<0.2	<0.39	1.29	4.02	15	67.8	37.8
Rangia	HM 12-1a	30-36	0.22	0.5	3.09	6.7	93.3	146	190
Rangia	HM 12-1b		0.31	0.47	3.04	6.76	45.5	142	221
Rangia	HM 12-2	24-28	0.27	0.43	3.4	6.07	58.6	103	179
Rangia	HM 22-1	31-41	0.2	0.88	3.4	11.4	47.2	350	158
Rangia	HM 22-2	25-29	0.29	0.88	3.86	20.4	72.5	156	125
Rangia	HM 16-2	30	<0.77	<1.5	4.02	10.6	145	164	128
Rangia	S 1-1	31-45	0.33	0.47	2.52	2.63	24.8	97.1	86.8
Rangia	S 2-1	26-32	0.25	0.87	1.75	3.49	36.3	120	87.4
Rangia	S 4-1a	25-33	0.25	0.8	1.8	3.22	40.3	325	116
Rangia	S 4-1b		0.23	0.49	1.95	2.83	33.1	154	92.4
Rangia	All Stations	22-48	0.2-0.3	0.4-1.8	1.3-6.3	2.6-20.4	15-131	67-350	38-190