Assessment of Impacts from the Hart-Miller Island Dredged Material Containment Facility, Maryland

Year 27 Exterior Monitoring Technical Report
(September 2008-August 2009)

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MDE

Chesapeake Biological Laboratory · Solomons

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MARYLAND DEPARTMENT OF NATURAL RESOURCES

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DEFINITION OF TERMS

Aliquot	A portion of a larger whole, (e.g., a small portion of a sample taken for chemical analysis or other treatment).
Amalgamation	In the chemical context amalgamation is the binding or dissolving of two metals to form an alloy with mercury typically being one of the metals.
Amphipod	Crustacean order containing laterally compressed members such as the sand hoppers.
Anion	A negatively charged ion, (e.g., Cl^- and CO_3^{2-}).
Anoxic	Deplete of oxygen, (e.g., ground water that contains no dissolved oxygen).
Bathymetric	Referring to contours of depth below the water's surface.
Benthic	Referring to the bottom of a body of water.
Benthos	The organisms living in or on the bottom of a body of water.
Bioaccumulation	The accumulation of contaminants in the tissue of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, pore water or dredged material.
Bioaccumulation factor	The degree to which an organism accumulates a chemical compared to the source. It is a dimensionless number or factor derived by dividing the concentration in the organism by that in the source.
Bioassay	A test using a biological system. It involves exposing an organism to a test material and determining a response. There are two major types of bioassays differentiated by response: toxicity tests which measure an effect (e.g., acute toxicity, sublethal/chronic toxicity) and bioaccumulation tests which measure a phenomenon (e.g., the uptake of contaminants into tissues).
Biogenic	Resulting from the activity of living organisms. For example, bivalve shells are biogenic materials.
Biomagnification	Bioaccumulation up the food chain, e.g., the route of accumulation is solely through food. Organisms at higher trophic levels will have higher body burdens than those at lower trophic levels.
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.
Box and Whisker Diagram	A graphical summary of the presence of outliers in data for one or two variables. This plot, which is particularly useful for comparing parallel batches of data, divides the data into four equal areas of frequency. A box encloses the middle 50 percent, where the median is represented as a vertical line inside the box. The mean may be plotted as a point. Horizontal lines, called whiskers, extend from each end of the box. The lower (left) whisker is drawn from the lower quartile to the smallest point within 1.5 interquartile ranges from the lower quartile. The other whisker is drawn from the upper quartile to the largest point within 1.5 interquartile ranges from the upper quartile. Values that fall beyond the whiskers, but within 3 interquartile ranges (suspect outliers), are plotted as individual points. Far outside points (outliers) are distinguished by a special character (a point with a + through it). Outliers are points more than 3 interquartile ranges below the lower quartile or above the upper quartile.
Brackish	Salty, though less saline than sea water. Characteristic of estuarine water.
Bryozoa	Phylum of colonial animals that often share one coelomic cavity. Encrusting and branching forms secrete a protective housing (zooecium) of calcium carbonate or chitinous material. Possess lophophore feeding structure.
Bulk sediment chemistry	Results of chemical analyses of whole sediments (in terms of wet or dry weight), without normalization (e.g., to organic carbon, grain-size, acid volatile sulfide).
Cation	A positively charged ion, (e.g., Na^+ and Mg^{2+}).
Congener	A term in chemistry that refers to one of many variants or configurations of a common chemical structure (e.g., polychlorinated biphenyls [PCBs] occur in 209 different forms with each congener having two or more chlorine atoms located at specific sites on the PCB molecule).
Contaminant	A chemical or biological substance in a form that can be incorporated into, onto or be ingested by and that harms aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment, and includes but is not limited to the substances on the 307(a)(1) list of toxic pollutants of the Clean Water Act promulgated on January 31, 1978 (43 FR 4109).

Contaminated material	Material dredged from Baltimore Harbor, originating to the northwest of a line from North Point to Rock Point. Material shows high concentrations of metals, PCBs, organics, etc.
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).
Depurate	To cleanse or purify something, especially by removing toxins.
Desiccation	The process 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)	An organism or a group of organisms that by their size and/or numbers constitute the majority of the community.
Dredge	Any of various machines equipped with scooping or suction devices used in deepening harbors and waterways and in underwater mining.
Dredged material containment	A disposal method that isolates the dredged material from the environment. Dredged material containment is placement of dredged material within diked confined disposal facilities via pipeline or other means.
Dredged Material Containment Facility (DMCF)	A diked area, either in-water or upland, used to contain dredged material. The terms confined disposal facility (CDF), dredged material containment area, diked disposal facility, and confined disposal area are used interchangeably.
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 the bottom.
Fine-grained material	Sediments consisting of particles less than or equal to 0.062 mm in diameter.
Flocculation	An agglomeration of particles bound by electrostatic forces.

Flocculent layer	The transition zone between water column and sediment column. The material in the layer is gelatinous and highly mobile; composed primarily of water with organic matter and fine Clay sized particles. The thickness of the layer varies seasonally and as a function of the flow of water over the sediment-water interface. In the Chesapeake Bay, the flocculent layer is generally less than a centimeter thick, and can be absent in areas of high flow.
Freshet	A sudden overflow of a stream resulting from a heavy rain or a thaw. A stream of fresh water that empties into a body of salt water.
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 differential adsorption. A detector records separate peaks as various compounds are released (eluted) from the column.
Gravity core	A sample of sediment from the bottom of a body of water, obtained with a cylindrical device, used to examine sediments at various depths.
Gyre	A circular motion. Used mainly in reference to the circular motion of water in each of the major ocean basins centered in subtropical high-pressure regions.
Hydrodynamics	The study of the dynamics of fluids in motion.
Hydrography	The scientific description and analysis of the physical condition, boundaries, flow, and related characteristics of oceans, rivers, lakes, and other surface waters.
Hydrozoa	A class of coelenterates that characteristically exhibit alternation of generations, with a sessile polypoid colony giving rise to a pelagic medusoid form by asexual budding.
Hypoxic	A partial lack of oxygen.
Infauna	Benthic animals living within bottom material.
Isopleths	Lines on a graph or map connecting points that have equal or corresponding values with regard to certain variables.
Leachate	Water or any other liquid that may contain dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material.
Ligand	Lewis bases that bind by coordinate covalent bonds to transition metals to form complexes.

Littoral zone	The benthic zone between the highest and lowest normal water marks; the intertidal zone.
Mesohaline	Moderately brackish estuarine water with salinity ranging from 5 – 18 parts per thousand
Metalloid	An element with properties intermediate between non-metals and metals. There are seven metalloids; Boron, Silicon, Germanium, Arsenic, Antimony, Tellurium, Polonium.
Mixing zone	A limited volume of water serving as a zone of initial dilution in the immediate vicinity of a discharge point where receiving water quality may not meet quality standards or other requirements otherwise applicable to the receiving water. The mixing zone may be defined by the volume and/or the surface area of the disposal site or specific mixing zone definitions in State water quality standards.
Nephelometric turbidity unit (NTU)	A unit of measurement of the amount of light scattered or reflected by particles within a liquid.
Oligohaline	Water with salt concentrations ranging from 0.5 to 5.0 parts per thousand, due to ocean-derived salts
Open water disposal	Placement of dredged material in rivers, lakes or estuaries via pipeline or surface release from hopper dredges or barges.
Polycyclic aromatic hydrocarbons	Polycyclic aromatic hydrocarbons (PAHs) are a group of over 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat.
Pollution Sensitive Taxa	Organisms that are sensitive to pollution.
Pore Water	The water filling the space between grains of sediment.
QA	Quality assurance, the total integrated program for assuring the reliability of data. A system for integrating the quality planning, quality control, quality assessment, and quality improvement efforts to meet user requirements and defined standards of quality with a stated level of confidence.

QC	Quality control, the overall system of technical activities for obtaining prescribed standards of performance in the monitoring and measurement process to meet user requirements.
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.
Reflux	A technique involving the condensation of vapors in a closed system, and the return of this condensate to the system from which it originated. The process allows a solvent and reagent to be heated continuously at or near the boiling point without the loss of the solvent or reagent.
Salinity	The concentration of salt in a solution. Full strength seawater has a salinity of about 35 parts per thousand (ppt). Normally computed from conductivity or chlorinity.
Secchi depth	The depth at which a standard, black and white Secchi disk disappears from view when lowered into water.
Sediment	Material, such as sand, silt, or clay, suspended in or settled on the bottom of a water body.
Seine	A large fishing net made to hang vertically in the water by weights at the lower edge and floats on the top.
Sigma	A measure of standard deviation away from the mean of a normally distributed data set. One sigma accounts for approximately 68 percent of the population that makes up the set. Two sigma accounts for approximately 95 percent of the population while three sigma accounts for 99 percent.
Slag	The fused vitreous material left as a residue by the smelting of metallic ore.
Spectrophotometer	An instrument used in chemical analysis to measure the intensity of color in a solution.
Spillway	A channel for an overflow of water.
Standard Deviation	A statistical measure of the variability of a population or data set. A high standard deviation indicates greater variance around the mean of a data set where as a low standard deviation indicates little variance around the mean.
Substrate	A surface on or in which a plant or animal grows or is attached.

Supernatant	The clear fluid over sediment or precipitate.
Total suspended solids (TSS)	A measurement (usually in milligrams per liter or parts per million) of the amount of particulate matter suspended in a liquid.
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.
Turbidity	The property of the scattering or reflection of light within a fluid, as caused by suspended or stirred-up particles.
Turbidity maximum	A zone in a water body where turbidity is typically the greatest, resulting from the influx of river-borne sediments, and flocculation of clay particles due to prevailing salinity patterns.
Water Quality Certification	A state certification, pursuant to Section 404 of the Clean Water Act, that the proposed discharge of dredged material will comply with the applicable provisions of Sections 301, 303, 306 and 307 of the Clean Water Act and relevant State laws.
Water quality standard	A law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body.

PROJECT I : SUMMARY REPORT FOR THE HART-MILLER ISLAND DREDGED MATERIAL CONTAINMENT FACILITY YEAR 27

(September 2008 – August 2009)

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MDE thanks Ms. Darlene Wells, Principal Investigator for Project II with Maryland Geological Survey (MGS) and Stephen Ryswick; and Dr. Andrew Heyes, Principal Investigator for Project IV with the Chesapeake Biological Laboratory (CBL). Ms. Wells is responsible for analyzing for metals and characterizing physical parameters in surficial sediment samples and writing the Project II report. Mr. Ryswick assists with the report, compiles the Project II data report and schedules and conducts the field work. MDE gives special recognition and thanks to Dr. James Hill who was the Principal Investigator for Project II for many years. Dr. Hill's contributions and work have proven to be invaluable in understanding the dynamic processes that take place in the sedimentary environment around HMI. Dr. Heyes is responsible for analyzing tissue samples for metals and organic contaminants. In addition to tissue analysis his laboratory analyzes sediment samples for organic contaminants and a suite of metals not analyzed by MGS. Dr. Heyes interprets the data and writes the Project IV Technical report and compiles the data report.

MDE would like to thank all the members of the HMI Exterior monitoring Program's Technical Review Committee and Mr. Thomas Kroen, Chairmen of the HMI Citizens Oversight Committee and the committee members for their useful comments and suggestions throughout the project year. Special thanks to the Maryland Port Administration for their continued

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INTRODUCTION

The Hart-Miller Island Dredged Material Containment Facility (HMI-DMCF) was designed to receive dredged material from navigation channel maintenance and improvement activities in the Baltimore harbor and its approaches.

The State of Maryland contracted for the construction of a diked area connecting the remnants of Hart and Miller Islands during 1981-1983. A notice to proceed was issued on September 1, 1981 to the Great Lakes Dredge and Dock Company and the facility, encompassing approximately 1,100 acres was completed in 1983. The original dike was built to 18' above mean low water, resulting in a capacity of 50.4 million cubic yards (mcy) of dredged material. The area was further divided into a North and South Cell by a 4,300 foot interior cross-dike. HMI is located in the Chesapeake Bay at the mouth of the Back River, to the northeast of Baltimore Harbor and began receiving dredged material in 1984.

In response to the need for additional capacity, between August 1986 and August 1987, coinciding with HMI Exterior Monitoring Year 6[1], the dike surrounding HMI was raised to 28' above mean low water. HMI continued to receive dredged material with placement mainly in the South Cell, which was completed on October 12, 1990 after which efforts were initiated to convert it into a wildlife refuge. Placement of dredged material was then diverted to the North Cell and within only a few years there was concern again regarding capacity. In January of 1996 State Port officials requested that the exterior dike surrounding the North Cell be raised to 44'; doing so would extend the facility's life by 10 to 13 years.

As of January 1, 2010 placement of dredged material in HMI-DMCF will no longer be permitted as stated in the Annotated Code of Maryland Environmental Article 5-1103. At this time, like the South Cell, efforts will commence to convert HMI North Cell into a wildlife refuge. Two committees, The North Cell Habitat Development Working Group and The North Cell Habitat Development Team, representing more than ten organizations and groups including the Citizens Oversight Committee, have developed a preliminary design for the conversion of the North Cell.

HMI Year 27 marks the last full year of dredged material placement activities at HMI. Dredged material placement will occur during HMI Year 28; however, only between August 1, 2009 and December 31, 2009. With the cessation of dredged material inflow HMI will enter a new phase of extensive material drying and crust management. These operations introduce oxygen into the dredged material which triggers chemical processes that can result in contaminants leaching from the sediment into the discharge. Prior to the start of the Year 27 monitoring and in anticipation of the closure and operational changes at HMI, Maryland Department of the Environment (MDE) and the Principle Investigators (PIs) met to discuss the possible revision of the exterior monitoring design. The idea or concept was that data obtained

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[1] HMI Exterior Monitoring Years are referenced by the year capitalized followed by the specific year, e.g., Year 9, Year 10 etc.

from monitoring Years 27 and 28 prior to closure would serve as baseline to be compared to monitoring results post closure, January 1, 2010.

HMI EXTERIOR MONITORING DESIGN IN ADVANCE OF FACILITY CLOSURE

In anticipation of the January 1, 2010 closure of HMI in terms of no longer receiving dredged material and entering a new phase of development, MDE, PIs, and other stakeholders met to discuss the need to create a different monitoring design. The change in design would address different needs in external monitoring based on the potential effects due to operational changes and management of the dredged material, post closure.

Studies have shown that there are three distinct regions of influence surrounding HMI; the region of Back River influence to the north and west of the facility, the region of Patapsco River/Baltimore Harbor influence to the south of the facility, and the region of HMI influence east of the facility. The HMI influence to the east of the facility was the impetus for developing the new monitoring design.

Historically, the primary discharge point was Spillway 007 on the northern tip of HMI (Summary Figure 1-1). The primary discharge point being proposed in a number of North Cell restoration concepts would be Spillway 009 on the east side and toward the center of HMI. Although during crust management and dewatering effluent limitations for metals will be adhered to according to the discharge permit, some metals will likely be present in the discharge. Utilizing Spillway 009 will potentially result in elevated metals concentration (within permit limits) in the region east of HMI.

Since the potential effect HMI will have on the external environment is a primary concern it was felt that increasing the density of the monitoring stations on the east side would be most prudent. Rather than adding sites to the existing number a decision was made to relocate a number of sites and remove a couple located outside the HMI zone of influence. Stations MDE-35 and 04, outside the HMI zone of influence, were removed. Stations MDE-28, 31, 32 and 37 in the Hawk Cove area representing environmental conditions of Back River, and MDE-24 on the southern tip also outside the HMI zone of influence were chosen for relocation while MDE-27 and MDE-30 were retained as sentinel sites. The five relocated stations were renamed to stations MDE-45 through 49 and then strategically located in the HMI influenced region to fill gaps of spatial coverage (Summary Figure 1-1). In addition to the five relocated stations, MDE-50 and MDE-51 were established and will serve as additional reference sites. The changes made to the monitoring design will not in any way compromise the objectives of the exterior monitoring program.[2]

Summary Figure 1-1 shows the new sampling design and the parameters which were monitored. For Year 27, Maryland Geological Survey (MGS) analyzed sediment for physical and chemical properties, Maryland Department of the Environment (MDE) sampled the benthic organisms at 22 sites, and from 16 sites Chesapeake Biological Laboratory (CBL) collected the brackish water clam *Rangia cuneata* for tissue analysis and sediment for analysis of metals and metalloids.

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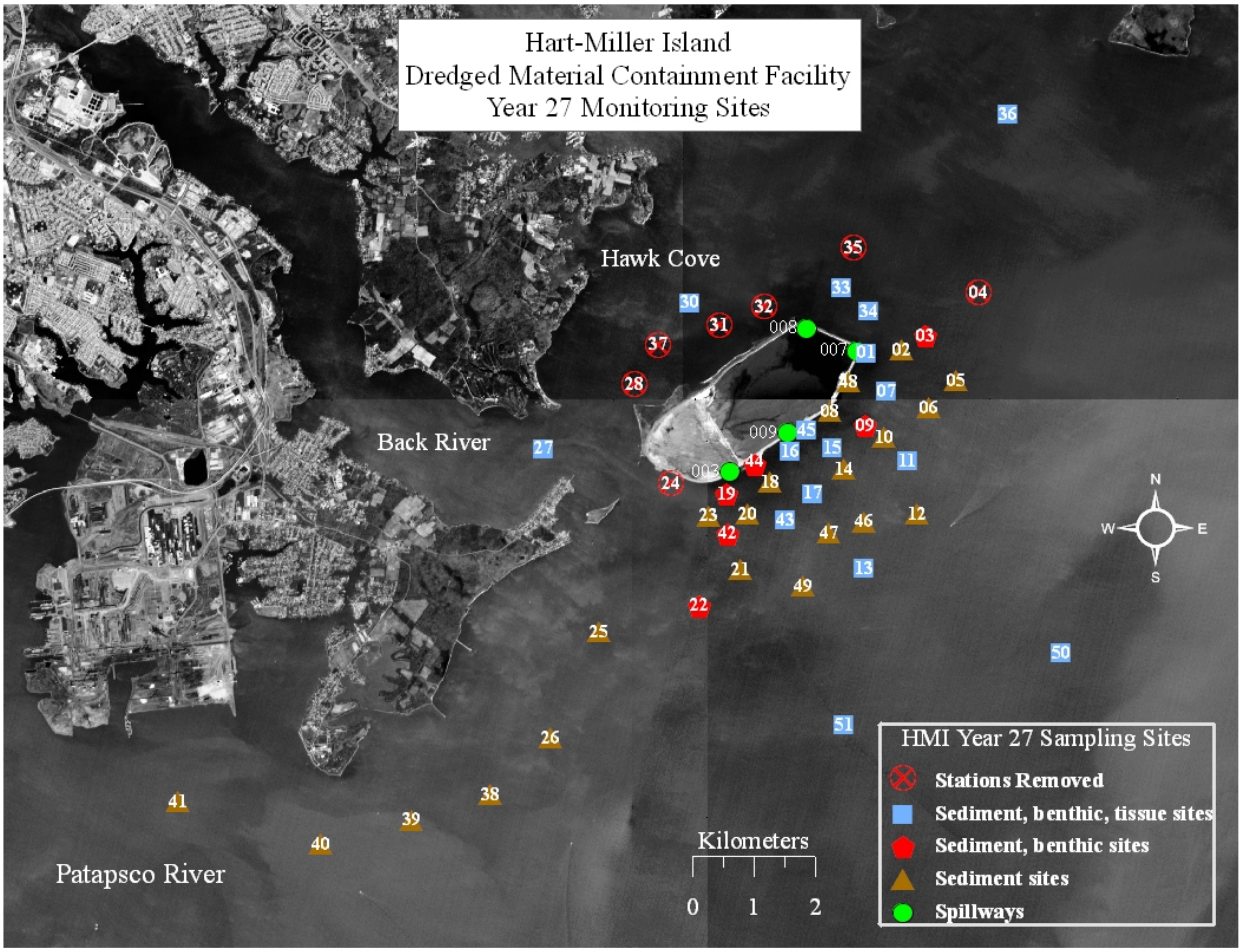
[2] For a more detailed explanation of the new sampling design see “Scientific Rationale for Relocating Hart-Miller Island Exterior Monitoring Stations in Advance of Facility Closure”



Summary Figure 1-1. Year 27 Hart-Miller Island post-closure monitoring locations.

HMI PROJECT SUMMARIES

PROJECT II: Sedimentary Environment

The Coastal and Estuarine Geology Program of the MGS has been involved in monitoring the physical and chemical behavior of near-surface sediments around HMI since the early project planning stages. As part of this year's exterior monitoring program, MGS collected bottom sediment samples from 43 stations on both September 8, 2008 (Cruise 57), and on April 16, 2009 (Cruise 58). Survey geologists then analyzed the following parameters: (1) grain size composition (relative proportions of sand, silt, and clay) and (2) total elemental concentrations of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), cadmium (Cd), lead (Pb), phosphorous (P), carbon (C), nitrogen (N), and sulfur (S).

Sediment Grain Size Composition

Changes in grain size of the exterior sediments surrounding HMI are largely dependent upon amount, quality, and timing of discharge from particular spillways, and the interaction of the discharge with the tides and currents in the receiving waters and the existing grain size distribution patterns. Basically, the depositional environment in the vicinity of HMI was unchanged between Year 26 and Year 27. The areas of high sand content are generally found around the perimeter of the dike in shallow waters and diminish with distance from HMI. The area extending off the northeast tip of HMI has the highest sand content typically around 90 percent. The sand distribution in this same area, although still around 90 percent, shifted slightly in September 2008 from the April 2008 sampling, and by April 2009, except for MDE-33 located approximately 2,500 feet off the northeast tip, sand content fell below 90 percent indicating a minor increase in silt/clay. MDE-50, a new site located 3.5 miles southeast of HMI was 93 percent sand. Otherwise, there were no significant changes in sand content around HMI in Year 27.

The mud portion of sediment is made up of very fine particles of clay, and the slightly larger particles of silt. The fine (mud) fraction of the sediments around HMI is generally richer in clay than in silt. Muddy sediments predominate around HMI; however, compared to the distribution of sand the distribution of clay:mud ratios has tended to be more variable over time. The reason for this variability is due to the fact that the silt and especially the clay fractions remain suspended for longer periods of time resulting in greater opportunity to eventually settle far removed from the actual source. Also, the finer grains are more likely to become re-suspended and re-located as a result of storm events. Sand, being larger, heavier particles will settle more quickly, closer to the source, and is less likely to become re-suspended.

In Year 27 station MDE-41, at the mouth of Baltimore Harbor, continued to be clay-rich (clay:mud ratio > 0.50) which is consistent with the previous two years. Of those sites in proximity to HMI a clay-rich area southeast of HMI was present both September 2007 and September 2008 but then diminished slightly in size in the April sampling of both years. This pattern is likely due to seasonal changes. For example, the spring time period often has higher turbulence due to weather while the late summer early fall period preceding sampling events are comparatively calm with lower flow. The less turbulent waters offer greater opportunity for the finer silt-clay particles to settle on the bottom.

Silt-rich sediments (clay:mud ratio < 0.50) were generally found immediately adjacent to the walls of the dike, commonly in the vicinity of spillways. During both Year 26 and Year 27 monitoring, the area adjacent to the walls of the dike to the south remained silt-rich.

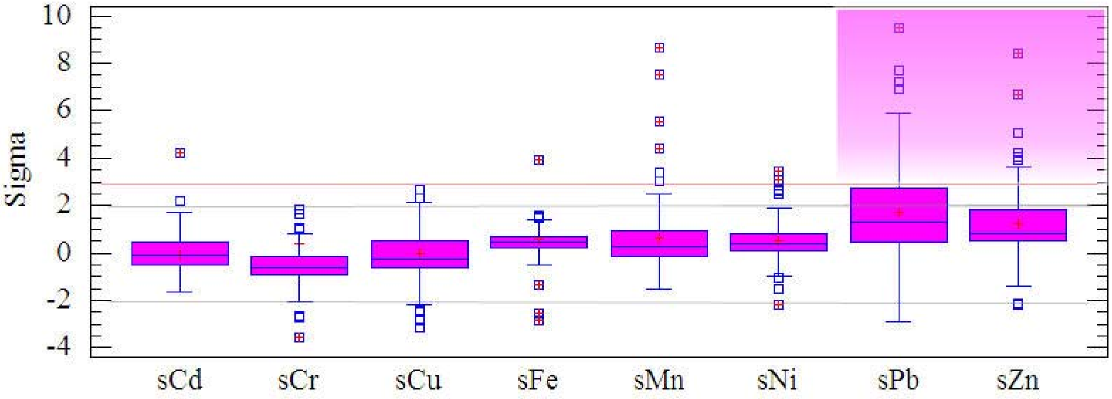
Analysis of Trace Metals

The sediment samples collected by MGS were analyzed for metals including Fe, Mn, Zn, Cu, Cr, Ni, Cd, and Pb. The concentrations were then compared to the Effects Range Low (ERL) and Effects Range Median (ERM), which are proposed criteria put forward by National

Oceanic and Atmospheric Administration (NOAA) (Buchman, 2008) to gauge the potential for deleterious biological effects. The ERL and ERM are explained in detail in Appendix I. Basically, concentrations between the ERL and ERM may have adverse impacts to benthic organisms and those exceeding the ERM are likely to have adverse biological effects. Of the eight metals, Cr, Cu, Ni, Pb and Zn were found at some sites with concentrations that exceeded the ERL while at other sites concentrations for Zn and Ni were high enough to exceed the ERM. This comparison is somewhat useful; however, it does not take into consideration the unique characteristics and composition (i.e., grain size) of the Bay sediments around HMI.

MGS developed a mathematical procedure that normalizes the metals concentrations based on percent composition of sand and mud (clay:silt) fraction. The resulting calculations are given as multiples of sigma levels (standard deviation) above and below zero, which is a reference baseline for background levels typical of the Bay region around HMI. When the data are normalized, Pb and to a lesser extent Zn, have samples significantly enriched compared to the baseline (Summary Figure 1-2). Based on work done by the University of Maryland during Year 25 monitoring the most probable conditions where the metals affect the infaunal communities are:

1. When the sigma level exceeds +2 [indicating enriched metals concentrations over baseline] and;
2. When the metals level exceeds the ERL with increased probability as the level exceeds the ERM [showing absolute concentrations that have exhibited adverse effects in other systems].



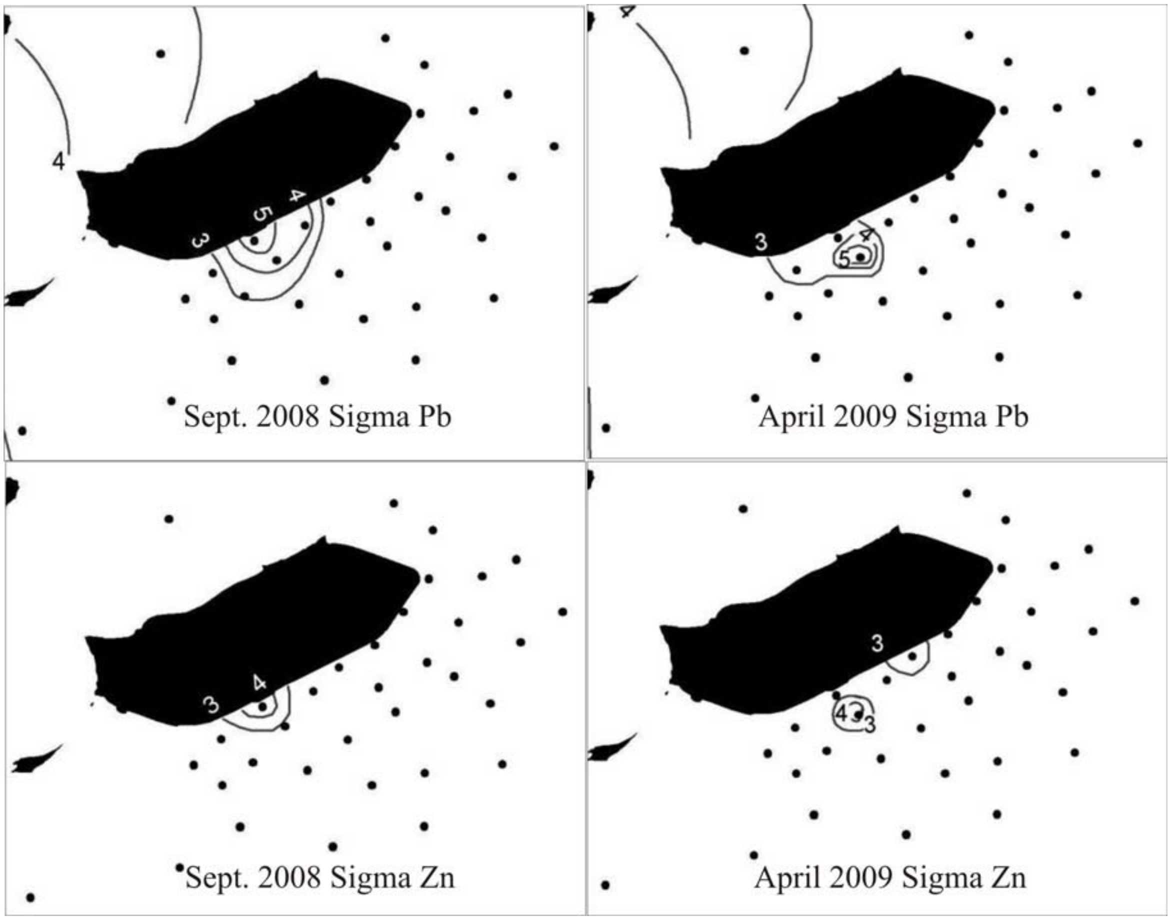
Summary Figure 1-2. Year 27 concentration of metals at HMI relative to baseline values. Metal concentrations greater than 2 standard deviations (horizontal blue lines) are considered elevated above baseline.

The results for Year 27 were similar to Year 26 where all of the metals except Pb and Zn were found to be within the range expected for normal baseline behavior in the area (Summary Figure 1-2). In Year 27 levels for Pb and Zn dropped slightly compared to Year 26; however, 25 percent of the Pb samples still exceeded the baseline levels (i.e., > 3 sigma levels), and 11 percent of the samples had Zn levels that exceeded the baseline.

Pb and Zn distribution around HMI

Since the eighth monitoring year (1988 – 89), increased metal levels (specifically Zn) have been noted in bottom sediments east and south of Spillway 007 (Summary Figure 1-1); similarly since the start of monitoring Pb in Year 15 (1995 – 96), elevated levels of Pb have been found in the same areas, but with generally higher relative loadings.

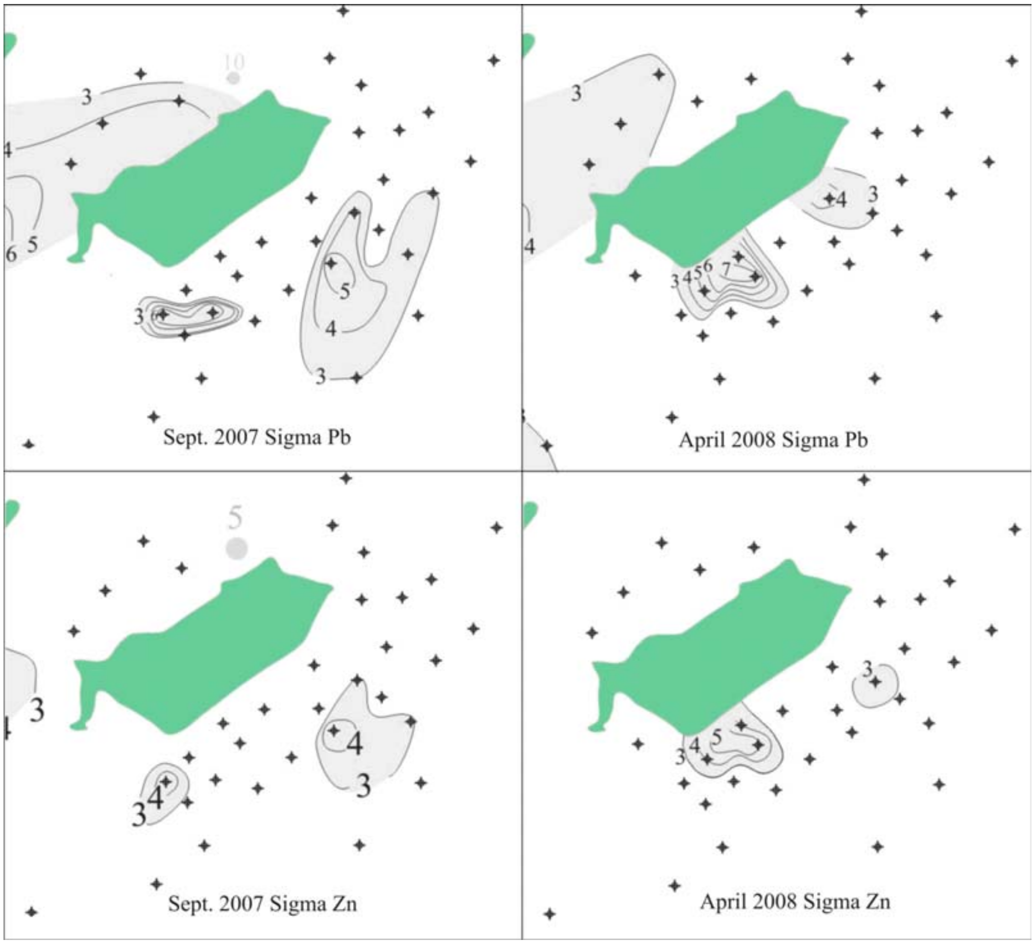
For the purpose of this summary only the distribution of Pb and Zn around HMI will be discussed; the distribution due to the contribution of Baltimore Harbor and Back River are discussed in detail in Appendix II. Summary Figure 1-3 shows the sigma levels for Pb and Zn for Year 27 fall and spring monitoring periods in the area adjacent to HMI. Data that fall within +/-2 sigma are considered within normal baseline variability. Data within the 2 to 3 sigma range are transitional, and data >3 sigma are significantly elevated above background. The isopleths in Summary Figure 1-3 identify those areas that are significantly elevated above baseline levels.



Summary Figure 1-3. Fall 2008 and spring 2009 distribution of Pb and Zn around HMI. Values are expressed in multiples of Sigma.

Pb and Zn levels adjacent to HMI were lower compared to the previous year. The spatial extent of Pb enrichment has not changed significantly; the extent for the enrichment for both cruises was confined to a single area around the South Cell discharge point Spillway 003. The area of Zn enrichment was confined to one site (MDE-44) in the fall 2008. In April 2009 Zn enrichment was still confined but to site MDE-18 while enrichment at MDE-44 dropped below 3 sigma. Both sites MDE-18 and 44 are adjacent to the South Cell Spillway 003. In April a second site MDE-45, which was added to this year's monitoring design, yielded Zn enrichment over 3 sigma. This site is adjacent to the North Cell Spillway 009 (Summary Figure 1-1).

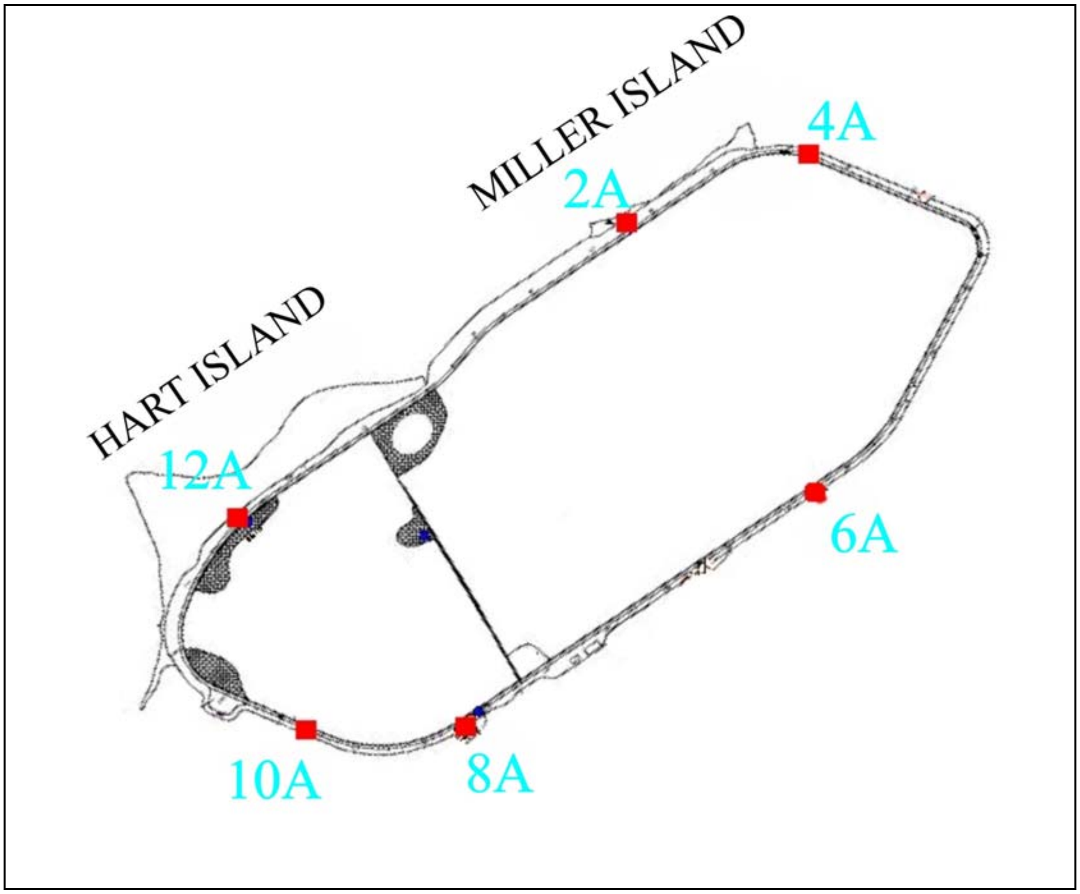
Given the reduced activity of the HMI facility, there appeared to be less impact, in terms of level of enrichment and spatial extent, on the sediments adjacent to the facility. Due to the timing of the discharges from the South Cell, the September sampling was slightly more impacted than the sediments collected in the spring (Summary Figure 1-3). Both Pb and Zn show elevated levels for both cruises, localized in the area of the South Cell discharge. The influence of the North Cell discharge appeared to be minimal for both cruises. Overall when compared to Year 26 the trend for material from the North Cell appears to be diminishing toward background levels; the South Cell although still showing enrichment also showed a downward trend in levels (Summary Figure 1-3 and Summary Figure 1-4).



Summary Figure 1-4. Fall 2007 and spring 2008 distribution of Pb and Zn around HMI. Values are expressed in multiples of Sigma.

Groundwater Monitoring Wells

Groundwater samples from six wells were collected in June and December 2008, as part of the on-going HMI external monitoring effort and as a continuation of the groundwater studies completed in 2003 (URS), and 2005 (Hill). The North and South Cells each have three monitoring wells (Summary Figure 1-5).



Summary Figure 1-5. Groundwater sampling wells locations.

All wells were found to be anoxic or hypoxic with dissolved oxygen (DO) levels less than 1.01 mg/l. However, due to sulfide interference with the DO probe it is more likely that the wells were anoxic, i.e., without oxygen. When oxygen is not available, anaerobic respiration occurs with nitrates being used preferentially as the primary oxidant and ammonium is formed as a byproduct. Ammonium was found as the dominant form of nitrogen which is consistent with the anoxic nature of the groundwater. In situ sulfides were not measured due to the limitations of the instrumentation.

North Cell Wells 2A, 4A and 6A

With the exception of the June 2008 sampling results of Well 4A, the groundwater in the North Cell Wells shows a reducing environment based on the depletion in sulfate in comparison to predicted concentrations. The predicted levels are calculated from the chloride concentration based on conservative mixing between rainwater and seawater. The amount of sulfate is either removed from the water as a result of sulfate reduction (– excess sulfate) or added to the water as the result of sulfide oxidation in the sediment solids (+ excess sulfate). Oxidation of sulfides can increase the potential for acidic conditions which in turn can mobilize metals and acid soluble nutrients and trace organic compounds in the sediments.

Alkalinity concentrations and pH in Well 6A were found to be higher than Wells 2A and 4A, and alkalinity concentrations in both 6A and 4A were higher than the three South Cell wells. The higher concentrations suggest that the alkalinity in these wells, and especially in 6A, had not been neutralized by acid production.

Overall most metal concentrations are lower in the North Cell wells. This indicates metals are not being leached from the sediment by acid or change in oxidation state. Acid produced by sediment oxidation can liberate metals; most of the trace metals measured except As were near or below the detection limits.

Total dissolved nitrogen (as ammonium), was found to be about three times higher in Well 6A compared to the other wells. This is due to the reducing processes that dominate the groundwater infiltrating this well. Ammonium is produced as a byproduct of anaerobic respiration; since the water in this well has not undergone an oxidative stage, ammonium is higher. Wells 2A and 4A were similar in concentration to South Cell Wells 8A and 10A.

Overall, the North Cell wells exhibit behavior typical of anoxic pore waters that have not been exposed to oxidized sediment. In this area of the North Cell, the groundwater is replenished with water from dredged material input which maintains the anaerobic state of the sediments, which is necessary to keep acidic conditions from developing.

South Cell Wells 8A, 10A and 12A

The wells in the South Cell have higher levels of excess sulfate indicating the waters infiltrating them have been exposed to oxidized sediments. Sediments are oxidized when exposed to air during periods of crust management or in the case of the South Cell when the pond is drained down to create mudflats, and with the upland areas (location of Well 12A) that are never submerged. This would indicate that rainwater rather than pond water is the major source of water infiltrating these wells compared to the North Cell. This is also evident in that chloride (typically high in Bay water) is in lower concentrations in these wells, especially Well 12A where chloride was less than 100 mg/l and salinity measured less than 1 ppt. Bay water in this region is generally over 5 ppt.

Ammonium, which is a by-product of anaerobic respiration (without oxygen), in Well 12A was near 0 mg/l indicating the availability of oxygen, which in turn increases the opportunity for oxidation of mineral sulfides. Ammonium levels in Wells 8A and 10A were more similar to those found in North Cell Wells 2A and 4A.

PROJECT III: Benthic Community Studies

Year 27 was the first year to utilize the revised monitoring station design, which was created to address post-closure needs. Stations MDE-24 and 28 west of HMI, and MDE-35 north of HMI were removed from the sampling grid and replaced with MDE-11, 15, and newly established station MDE-45 all of which are on the east side of HMI. Also, stations MDE-50 and 51 were established as additional reference sites (Summary Figure 1-1). Twenty-two stations were sampled on September 10, 2008 and on April 17, 2009 to monitor aquatic invertebrate communities surrounding HMI. Organisms living in sediments close to the facility (Nearfield, South Cell Restoration Baseline, and Back River/Hawk Cove stations) were compared to those located away from the influence of the facility (Reference stations). Water quality parameters, including dissolved oxygen concentrations, salinity, temperature, pH, conductivity, and secchi depth were measured *in situ.*

Water Quality

The water quality parameters measured during the September 2008 sampling cruise showed minimal variations between surface and bottom conditions indicating that the water column was well mixed and not stratified. This condition did not persist in spring of 2009 where the water column was found to be varied with stratification apparent at some stations. However, this is not an unfavorable condition and is often typical where brackish and fresh water converge and temperatures differ.

Dissolved oxygen (DO) is a criterion established to protect aquatic life, and for which a threshold of 5.0 ppm has been determined and published in the Maryland Code of Regulations. During both the fall 2008 and spring 2009 sampling bottom-water DO concentrations exceeded the water quality standard of 5.0 ppm at all stations with the exception of MDE-51 where the DO concentration for the spring sampling was recorded at 4.18 ppm.

Like DO, measures of bottom-water temperature and salinity are important and relevant to benthic macroinvertebrate health. In Year 27, bottom-water temperature did not vary much between stations during both fall 2008 and spring 2009 sampling events. In September 2008 the average temperature was only 0.22°C lower than the 22-year fall average of 24.46°C. In April 2009 the average bottom-water temperature was 2.71°C below the 11-year spring average of 11.80°C. Salinity values also did not vary considerably between September and April. The fall average salinity for all stations was 8.10 ppt and was within the range of the historical average of 6.17 ppt. The spring 2009 salinity was 7.80 ppt which was considerably above the long term average of 3.16 ppt.

Benthic Macroinvertebrate Community

Taxa Richness and Dominance

For Year 27 the total number of taxa found around HMI during both fall 2008 and spring 2009 sampling was 36. This is comparable to the 11-year average of 39 taxa. During the fall sampling 31 different taxa were found and 30 different taxa during the spring sampling. *Argulus sp*. (fish lice), *Cassidinidea ovalis* (Isopod – pillbug, sowbug), *Gobiosoma bosc* (small fish), *Victorella pavida* (bryzoans), *Chironomus sp*. (midges), and *Polydora cornuta* (mudworm) were found only in the fall, while Ostracoda (small crustacean), *Platyhelminthes sp*. (flatworms), and *Mya arenaria* (soft-shell clams) were only found in the spring.

Nearfield stations MDE-03 and MDE-34 had the highest number of taxa in September 2008 and newly established Reference station MDE-50 had the fewest number at 10 taxa. Overall, average taxa richness was highest at the Nearfield stations but did not vary greatly between station types, i.e., Nearfield, Reference, Back River/ Hawk Cove and South Cell Exterior. In April 2009, the greatest taxa richness (21) was found at Reference station MDE-13. The lowest taxa richness (11) was found at Reference stations MDE-01 and 33.

Several taxa were clearly dominant. The worms *Marenzelleria viridis, Heteromastus filiformis,* and Naididae, the clam *Rangia cuneata,* and the arthropods *Leptocheirus plumulosus* and *Apocorophium lacustre* were among the dominant taxa on both sampling dates. Between September 2008 and April 2009 abundance varied greatly for certain taxa. For example, the per meter square average abundance for *Macoma balthica* in the fall was 345.6 and was the seventeenth most abundant taxa. In the spring the count for *M. balthica* was 5196.0 per meter square and was the fifth most abundant taxa. *Streblospio benedicti* decreased from the fifth most abundant in the fall to the fifteenth most abundant taxa in the spring. Total abundance (excluding Bryozoa and Copepoda) was higher at most stations in April 2009 than September 2008, primarily due to the spring recruitment of the worms *Naididae sp*. and *M. viridis*. Spring recruitment and natural predation may also be a cause for the difference in *M. balthica* and *S. benedicti* between fall and spring.

Benthic Index of Biotic Integrity

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI), (Weisberg et al. 1997), a multi-metric index of biotic condition that evaluates summer populations (specific for July 15th to September 30th timeframe) of benthic macroinvertebrates, was calculated for all stations sampled during the September 2008 cruise.

The B-IBI is calculated using different metrics, and the metrics used are dependent upon the salinity. In the fall of 2009 the salinity was 8.10 ppt which is considered low mesohaline and under such conditions the individual metrics used are; 1) Shannon-Wiener species diversity index (SWDI), 2) Total infaunal abundance, 3) Relative abundance of pollution-indicative taxa, and 4) Relative abundance of pollution-sensitive taxa. Relative abundance of pollution-sensitive taxa is used as a substitute to percent biomass of pollution-sensitive taxa. The following is a brief summary of the findings of the four metrics of the September sampling followed by a discussion of the B-IBI results.

Species Diversity

Species diversity was examined using the SWDI, which measures diversity on a numerical scale from 0 to 4. A lower score indicates an unbalanced benthic community dominated by only one or two species whereas a higher score suggests a balanced, diverse benthic community.

SWDI values for the 22 stations sampled in September 2008 ranged from a high of 3.11 at the Nearfield station MDE-07 located on the northeast side of HMI to 2.04 at MDE-27 located at the mouth of Back River. MDE-27 is likely not influenced by HMI rather predominantly influenced by Back River. Station MDE-50, a reference site located approximately 3.5 miles southeast and beyond the influence of HMI had the second to lowest score of 2.16. Nearfield sites had the highest SWDI average of 2.74 (n=12) with Reference sites having the second highest average SWDI of 2.65 (n=5). The SWDI average for the three South Cell Exterior Monitoring stations was 2.50.

Total Infaunal Abundance

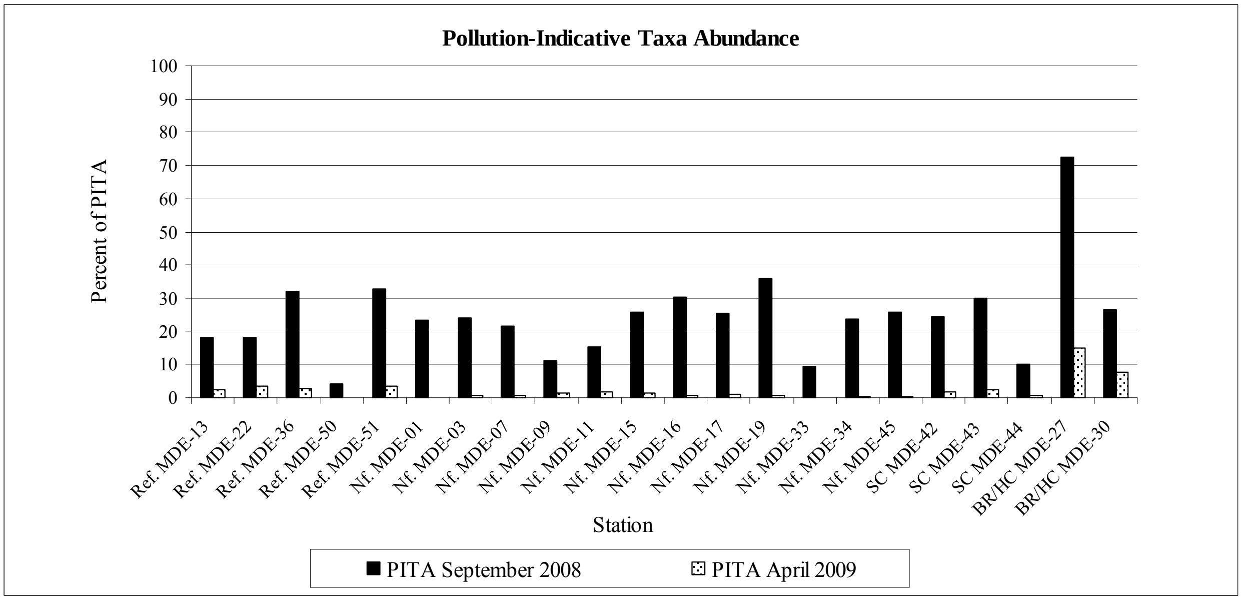
Infaunal organisms are those that live below the surface of the sediment as opposed to on the surface of the sediment, or epifaunal. Total infaunal abundance per meter square (#/m^2) is a calculation derived by multiplying the average infauna of three Ponar grab samples by a conversion factor. In September 2008, total infaunal abundance ranged from 454 individuals/m^2 found at the Reference site MDE-50 to 7,795 individuals/m^2 at MDE-34, a Nearfield site located on the northern end of HMI. Overall, Nearfield stations (n=12) had the highest average total infaunal abundance at 2,910.9 individuals/ m^2 while the South Cell Exterior Monitoring stations had the lowest at 1,369 individuals/m^2. Back River stations (n=2) had the second highest average infaunal abundance at 2,634 individuals/m^2; however, that was primarily due to a high number of Naididae worms collected at MDE-27. The average infaunal abundance of the five Reference sites equaled 2,153 individuals/m^2.

Relative abundance of pollution-indicative taxa

Pollution-indicative taxa are species that are typically tolerant of pollution. They are often small in size, have rapid growth, high reproductive potential, and short life-span, (Versar, Inc. 2002). In Year 27 during the September sampling five taxa were found that are designated as “pollution-indicative” according to Alden et al. (2002). The five taxa were Chironomids of the Genera *Coelotanypus* and *Chironomus*, the polychaete worms *S. benedicti* and *E. heteropoda*, and oligochaete worms of the family Naididae.

In September 2008 station MDE-50 had the lowest percent of pollution-indicative taxa abundance (PITA) at 4.23 percent. MDE-27 at the mouth of Back River had the highest PITA at

72.44 percent while MDE-19 located approximately 900 feet south of the South Cell Spillway 003 had the second highest PITA at 35.84 percent. The high percent PITA found at Station MDE-27 (over twice that of MDE-19) was primarily due to the high count of oligochaete worms of the family Naididae, (Summary Figure 1-6). In terms of station type, the lowest average PITA was 21.11 percent at the Reference stations, followed by 21.45 percent at the South Cell Exterior Monitoring stations, and 22.65 percent at Nearfield stations. The Back River/Hawk Cove stations (MDE-27 and 30) had the highest average PITA at 49.42 percent; however, MDE-30 was more consistent with all other stations and the high average is simply due to the high PITA found at MDE-27, (Summary Figure 1-6).



Summary Figure 1-6. Percent abundance comprised of pollution indicative species (PITA), HMI Year 27 September 2008 and April 2009

Relative abundance of pollution-sensitive taxa

Species identified as being sensitive to pollution are those that tend to grow slowly and are relatively long-lived and thus tend to characterize undisturbed, mature communities, (Versar, Inc. 2002). Of those organisms collected in September 2008 four taxa were designated as "pollution-sensitive" according to Alden et al. (2002); they were the polychaete worm *M. viridis,* the bivalves *R. cuneata* and *M. balthica,* and the isopod crustacean *C. polita.*

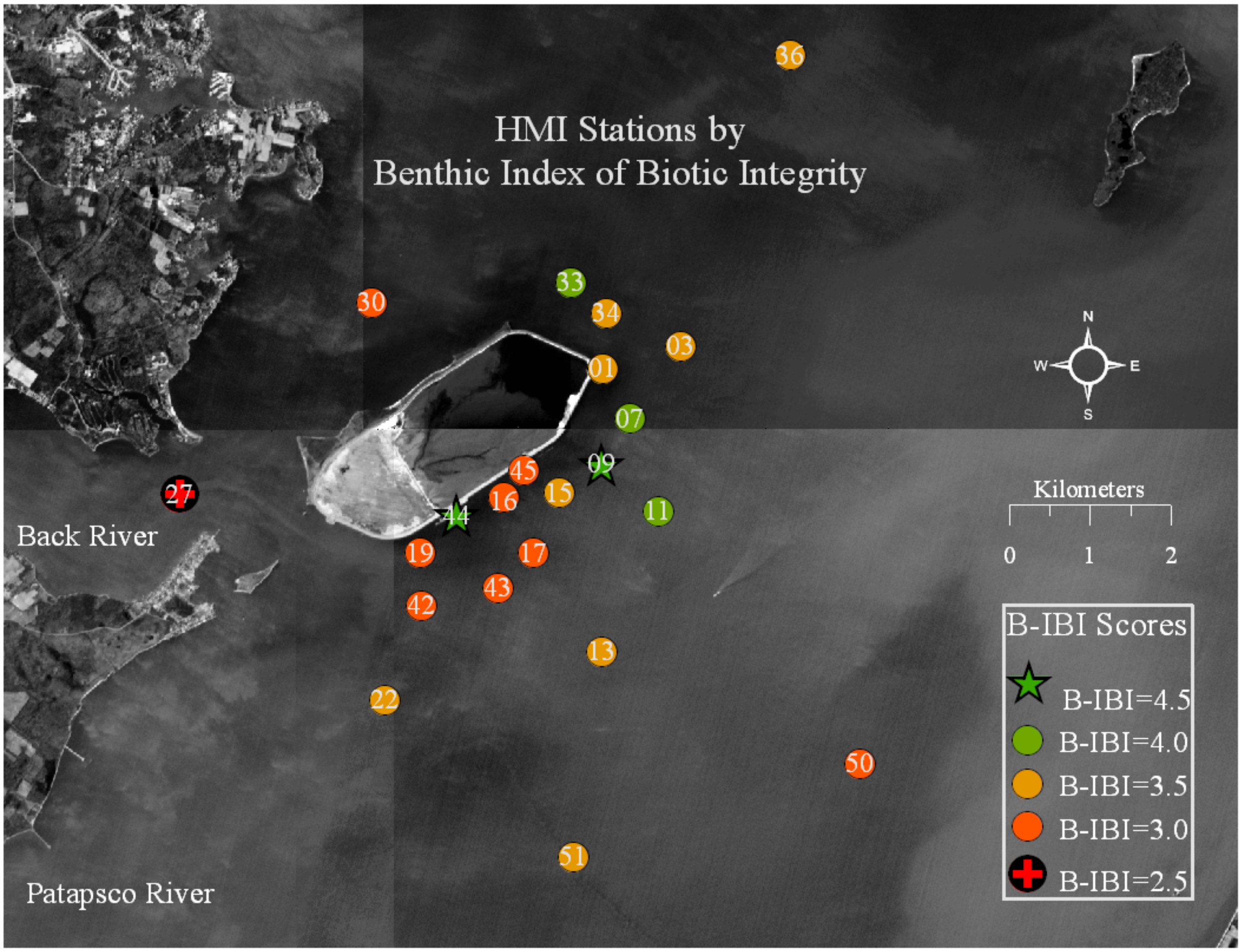
For the September 2008 sampling the Nearfield station MDE-17, centrally located and approximately 3,300 feet out from the east side of HMI, had the lowest pollution-sensitive taxa abundance (PSTA) at 2.72 percent; Nearfield station MDE-01 had the highest PSTA at 50.16 percent. The Back River station MDE-27 which had the highest percent PITA had a PSTA of 10.38 percent which marginally fell within the 50th percentile of all 22 sites. Station MDE-19 often a degraded site like MDE-27, fell within the twenty-fifth percentile with a PSTA of 9.68 percent.

In terms of station types the Nearfield and South Cell Exterior Monitoring stations for the September sampling had similar average PSTA percentages at 22.70 and 22.66 percent respectively. However, station MDE-44, one of the three South Cell Exterior Monitoring stations, had a rather high individual percentage (45.03 percent) that considerably increased the overall average of the three stations. Percent PSTA for South Cell Exterior Monitoring stations MDE-42 and 43 was 11.37 percent and 11.57 percent respectively; nearly 4 times lower than MDE-44. Another measure of central tendency is the "median" which if used in this case would result in the South Cell Exterior Monitoring stations having the lowest overall PSTA percentage. The average for the Reference stations was 19.83 percent while Back River/Hawk Cove stations had the lowest average PSTA at 16.11 percent.

Benthic Index of Biotic Integrity Results

B-IBI scores range from one to five with one considered as deviating greatly from reference conditions, and five approximating reference conditions. A B-IBI score greater than or equal to three represents a benthic community that is not considered stressed by *in situ* environmental conditions. The 22 benthic stations studied during Year 27 were compared to this benchmark. It should be noted that existing conditions at those sites around HMI classified as "Reference" sites are not necessarily equal in high quality to the reference sites originally used for calibrating the B-IBI. The HMI Reference sites were selected and compared to because they were considered outside the potential influence of HMI operations.

In Year 27 there was an increase in overall B-IBI scores at individual stations when compared to the previous two monitoring years. With the exception of the Back River station MDE-27 all stations in Year 27 met or exceeded the benchmark criteria of 3.0, (Summary Figure 1-7). The five Reference sites MDE-51, 50, 36, 22 and 13 although meeting the benchmark, comparatively had low scores; environmental factors unrelated to HMI operations are likely the cause. The cluster of eight sites on the north and northeast side of HMI (MDE-11 north to MDE-33) all had high B-IBI scores between 3.5 and 4.5. MDE-44 a South Cell Exterior Monitoring station and Nearfield station MDE-09 had the highest score. MDE-45, 43, 42, 19, 17 and 16, all closely located to one another and in the vicinity of the South Cell and Spillway 009 in the North Cell, comparatively had the lowest B-IBI scores, (Summary Figure 1-7).



Summary Figure 1-7. HMI stations by B-IBI scores.

In summary, Year 27 showed an increase in overall B-IBI scores. Starting with Year 25 through Year 27 Summary Table 1-1 shows those sites that have failed in any one year. The Back River site MDE-27 failed each year. MDE-30, north of Back River, but still potentially influenced by Back River, showed slight improvement. MDE-19, which historically often had a low B-IBI score showed improvement. SC MDE-44, 43 and 42, established in Year 22 to increase spatial coverage on the south side of HMI to monitor potential effects of effluent from the South Cell Spillway 003, all showed improvement.

Stations	Year 25	Year 26	Year 27
BR/HC MDE-27	**2.67**	**2.33**	**2.50**
BR/HC MDE-30	**2.33**	**2.33**	**3.00**
Nf. MDE-17	**2.67**	**3.00**	**3.00**
Nf. MDE-19	**2.67**	**2.33**	**3.00**
Nf. MDE-35	**2.67**	**3.00**	**N/A**
Ref. MDE-13	**2.67**	**3.00**	**3.50**
SC MDE-42	**4.33**	**2.33**	**3.00**
SC MDE-43	**3.67**	**2.33**	**3.00**
SC MDE-44	**2.67**	**3.00**	**4.50**

Summary Table 1-1. Comparison of failing sites in Years 25, 26 and 27.

In summary, the average B-IBI score of all sites monitored for Year 27 was 3.41, a slight improvement compared to Year 25 and 26, (3.37 and 3.00 respectively). Overall 95 percent of the sites met or exceeded the benchmark of 3.00. A more detailed comparison of present to historical results is given in Appendix III.

PROJECT IV: Analytical Services

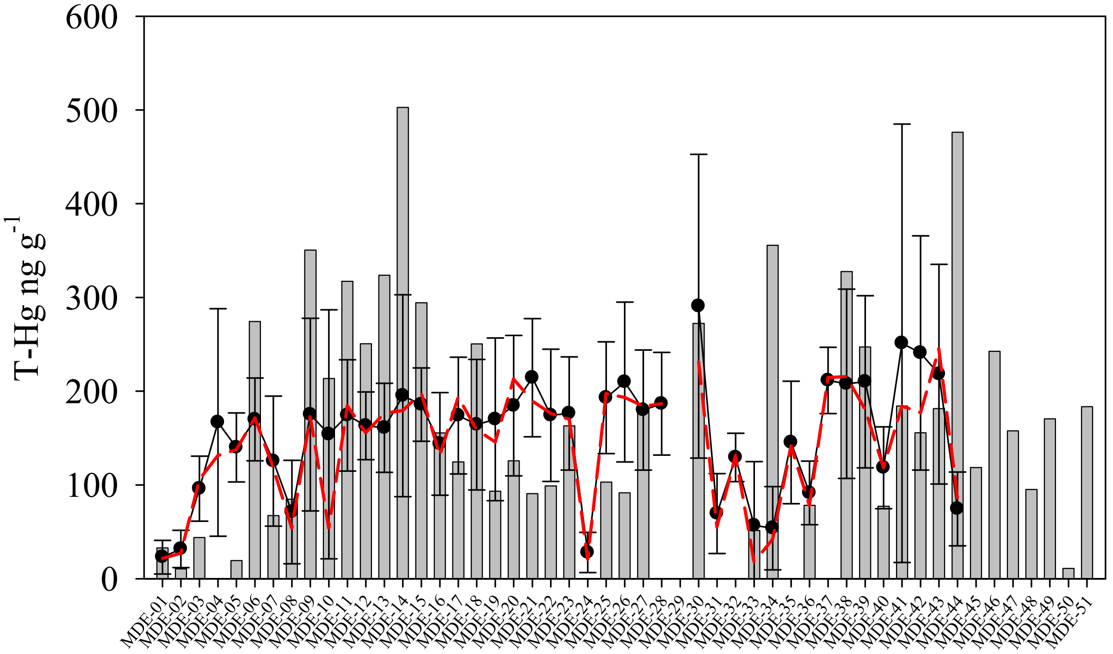
For Year 27 exterior monitoring at HMI, CBL collected the clam *Rangia cuneata* both in the fall 2008 and spring 2009. A total of 16 sites were sampled; however, not all were visited during both sampling events (Summary Figure 1-1). In addition to clams, sediment samples were concurrently collected and analyzed for trace metals. Analysis was not conducted for polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs), which are measured every other year as a cost saving measure during the inflow stage. Long-term trend analysis will not be compromised due to this slight data gap. During the dewatering phase annual sampling has been resumed in response to a significant change in operations. In addition as part of the annual sediment survey, CBL conducted analysis for concentrations of target trace elements in surface sediments collected in September 2008 around HMI by MGS. Metal analysis focuses on those metals and metalloids not measured by MGS, specifically total mercury (T-Hg), methylmercury (MeHg), silver (Ag), and metalloids selenium (Se) and arsenic (As).

Metals in Sediment

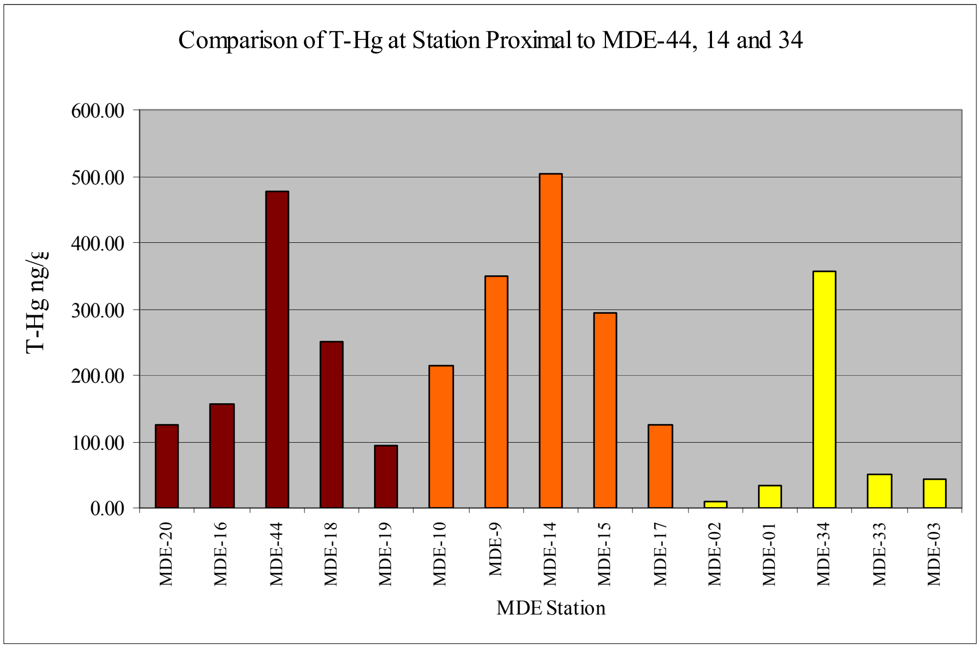
Concentrations of As in the sediments collected around HMI in the fall 2008 were toward the high side as seen over previous years. Concentrations were near the running mean at the majority of the sites with several sites exceeding the historical mean by greater than 5 ug g^{-1}. An explanation for the exceedance cannot be offered at this time especially since the sites were found to be spatially diverse. Selenium was also generally higher than previous years but lies within the standard deviation of the historical average. Concentrations of Ag in the sediments collected in the fall of 2008 were lower than the median and average concentrations collected around HMI in previous years.

Concentrations of T-Hg in sediment fell within the standard deviation of measurements made between 1998 and 2007, and were comparable to the concentrations of T-Hg in sediments typically found in the main stem of the Chesapeake Bay which range from 0.2 to 250 ng g^{-1} dry weight (Heyes et al. 2006). Concentrations of T-Hg at three stations, MDE-14, 34, and 44 were much higher than in past years (Summary Figure 1-8). Sites MDE-16, 18, 19 and 20 with T-Hg concentrations within a standard deviation of the running mean are proximal to MDE-44 however, do not exhibit the same extreme elevated concentration above the range observed in past years. The same holds true for sites proximal to MDE-14 and MDE-34 (Summary Figure 1-9). It is not likely given that MDE-16, 18, 19, and 20 having T-Hg concentration within the running mean, and being within the area of influence of South Cell Spillway 003, that the elevated concentration seen at MDE-44 is due to effluent from Spillway 003. There is no obvious explanation for the elevated concentrations at these three sites.

Concentrations of MeHg in sediment collected in the fall of 2008 ranged from 0.01 to 1.4 ng g^{-1} dry weight. These concentrations are comparable to the rest of the Chesapeake Bay (Heyes et al. 2006). The percent of mercury that occurred as MeHg was generally less than 1 percent.



Summary Figure 1-8. T-Hg concentrations in sediment, expressed as dry weight concentration, collected by MGS in the fall of 2008 (bars) and the 1998-2007 mean (circles) with standard deviation (error bars) and the 1998-2007 median (dashed line).



Summary Figure 1-9. Comparison of T-Hg at sites proximal to MDE-44, 14 and 34.

Metals in Clam Tissue

The clam *Rangia cuneata* was collected from 12 sites in the fall (September) of 2008 and 13 sites in spring (April) of 2009. Note, not all the benthic sites can be examined annually because of the cost, thus sites are selected from the 22 MDE sites to provide broad coverage while maintaining some between-year overlap of sites. In the fall of 2008 the sites monitored were MDE-01, 11, 15, 16, 17, 27, 34, 36, 43, 45, 50, 51 (Summary Figure 1-1; Sediment, benthic, tissue sites). With the exception of sites MDE-45 and 50, concentrations of metals and metalloids in clams collected in the fall of 2008 were similar to, or lower than, the historic running averages and medians observed at each of the selected sites. MDE-45 and 50 are 2 of 7 sites added to the sampling design and were found to have high concentrations of As and Se in the clams collected as compared to other HMI sites. Site MDE-45 also had high concentrations of T-Hg in clams. With Year 27 being the first year for collecting data at these locations there is no historical information to compare the data with and help explain the high concentrations. The fact that concentrations of As and Se in sediments collected from MDE-45 and 50 were found to be normal makes interpreting and explaining the high concentrations in clam tissue more difficult.

Sites sampled in April 2009 were MDE-01, 07, 13, 15, 17, 27, 30, 33, 34, 36, 43, 45, and 51 (Summary Figure 1-1; Sediment, benthic, tissue sites). In April 2009, concentrations of Cd, Pb, T-Hg and MeHg in clams were close to their historical levels. However, the concentration of As in clams was on average 4 times higher than historical levels, and the concentration of Se was 2 times higher. In past years elevated concentrations of Ag have been observed in clams collected in the spring as opposed to the fall; this trend was not seen in the fall 2008 to spring 2009 period. In fact Ag was much lower in April 2009 compared to historic values. As was the case for Ag in past years, the elevated As and Se concentrations were also seen at the reference site (MDE-36) which suggests a Bay wide issue and they were not related to operations at the HMI facility.

Of the 12 sites sampled for clams in the fall 9 were visited again in the spring. T-Hg was about the same with concentrations slightly higher in clams in the spring at all sites except MDE-45 where the inverse was seen. Concentration of T-Hg in clams collected from MDE-45 in the spring of 2009 was much lower than the concentration measured in the fall of 2008, 41.3 ug g^{-1} and 142.2 ug g^{-1} respectively. The concentrations of T-Hg in clams from MDE-45 collected in the fall of 2009 appear to have been anomalous. It is recommended that the site should be sampled again in 2010.

PROJECT I SUMMARY AND RECOMMENDATIONS

Although a Zn as well as Pb signature in sediments surrounding HMI has been detected over the long-term record, construction and operation at the HMI-DMCF has produced no long-term biological impacts to surrounding aquatic communities. As an example of this, at station MDE-44 located approximately 1,200 feet from Spillway 003 in the South Cell, (with the exception of April 2009 when Zn was 2.9 sigma) Pb and Zn were significantly enriched both September 2008 and April 2009 while the B-IBI indicated a healthy benthic community with a score of 4.5. Likewise, six stations all in the vicinity of Spillway 009 and the South Cell (with the exception of MDE-27 Back River station) although comparatively having the lowest scores of all sites, still met the benchmark B-IBI score of 3.0. A few of these sites were within the enriched zones. It cannot be stated definitively that the enrichment of Zn and Pb is the cause of the lower B-IBI scores of the sites in the vicinity of the South Cell; however, given the results it is recommended that close monitoring of the effluent from Spillway 003 (and in the future Spillway 009) be continued.

The South Cell discharge operations (and to a lesser extent Spillway 009 in the North Cell) did appear to have an effect on the exterior sedimentary environment, which is evident in the enrichment of Pb and Zn. However, although the spatial area was similar to the previous year the level of enrichment has some what diminished. It appears that there has been a diminishing trend over the past two years.

Although Spillway 009, which was utilized more than Spillway 008 during the last monitoring year, could possibly be contributing to some of the enrichments of Pb and Zn in exterior sediments on the southeast side of HMI, it appears that facility operation did not have any adverse effects to the biota or the sedimentary environment on the northeast and north end of HMI. This is evident in that enrichment levels are below 3 sigma and B-IBI scores were all between 3.5 and 4.5.

Results from MDE-27 and 30, retained in the monitoring design to track the potential effects of Back River, showed no enrichment of metals except for Pb. The gradient of Pb enrichment decreases further away from the mouth of Back River indicating that the source is from Back River and not HMI operations.

Year 27 was the first year using the revised sampling design and in general the PIs are satisfied with the change. The additional sites in closer proximity to HMI will serve to strengthen, reinforce and help make the data for all Projects more robust. However, the PIs have reservations regarding reference sites MDE-50 and 51 located 2.8 and 3.5 miles southeast of HMI, respectively. MDE-50 is high in sand content making it difficult to collect representative benthic grab samples, and it has been difficult for CBL to collect clams at both sites and in particular MDE-50. Water quality and in particular DO has shown to be some what suppressed at MDE-51. These sites were selected as reference sites and should be relatively free of *in situ* problems. Consequently it has been considered by the PIs to relocate them to areas that would yield samples more meaningful for comparison to those samples collected at sites within the potential influence of HMI. In the future PIs will be discussing the possible changes and present any recommendations to all stakeholders.

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APPENDIX 1: SEDIMENTARY ENVIRONMENT (PROJECT II)

(September 2008 - August 2009)

Technical Report

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EXECUTIVE SUMMARY

The Coastal and Environmental Geosciences 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 DMCF) from the initial planning stages of construction of the facility to the present. As part of this year's exterior monitoring program, MGS collected bottom sediment samples from 43 sites on both September 8, 2008 and April 16, 2009. The sediment samples were analyzed for various physical and chemical properties of the samples: (1) grain size composition (relative proportions of sand, silt, and clay) and (2) total elemental concentrations of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), cadmium (Cd), lead (Pb), phosphorous (P), carbon (C), nitrogen (N), and sulfur (S).

For exterior bottom sediments sampled during Year 27, average grain size composition, reported as percent sand and as clay:mud ratios, varied little compared to previous year data. The pattern of the grain size distribution varied slightly from one cruise to the next, and from the previous year's monitoring. Some of the variation is attributed to seasonal effects. In general, sediment distribution is consistent with the findings of previous monitoring years, dating back to 1988, two years following the initial release of effluent from HMI.

Generally, results of the elemental analyses are statistically similar to the previous year data. With regard to the NOAA Effects Range Low (ERL) and Effects Range Medium (ERM) values, this year's data show that:

1. At most sampling sites, concentrations of Cr, Cu, Ni, Pb, and Zn in the sediment exceed the Effects Range Low (ERL) values; and
2. Ni and Zn exceed the Effects Range Medium (ERM) values at some sites.

ERL and ERM are proposed criteria put forward by National Oceanic and Atmospheric Administration (Buchman, 2008) to gauge the potential for deleterious biological effects. These criteria are based on a statistical method of termed preponderance of evidence. Because this method does not allow for unique basin conditions or does not take into account grain size induced variability in metal concentrations in the sediment, MGS used a grain size normalization technique to assess changes in the sediments that may be attributed to HMI DMCF. The grain size normalization procedure is a means to correct the deficiencies of the NOAA guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When normalized, the data show that certain sediment samples are significantly enriched with Pb and Zn compared to the baseline levels.

In the areas adjacent to effluent spillways, sediment contained slight enrichment levels of Pb and Zn (i.e., 3 to 5 sigma levels). The September sampling cruise had higher levels, and a greater spatial extent as compared to the April sampling. The levels and spatial extent of the enriched sediment were lower than previous years, which is attributed to the reduced operations activity at the HMI Facility. Volumes of both material placement into the Facility and effluent discharge from the Facility were considerable lower than previous years. Material placed in the

North Cell was approximately half of the volume placed during the previous year. Discharges at > 10 mgd from the North Cell were done in two distinct periods, corresponding to material placement. The first period was well before the fall 2008 sampling, and the second at the time of the spring 2009 cruise. During the nine months between the major discharge periods, there were sporadic discharges at < 10 mgd, but none immediately prior to the sampling cruises. Total discharge from the North Cell was approximately a tenth of the volume from the previous monitoring year and most of the discharge was through Spillway 009. Given the amount and timing of the discharges, it is not surprising to see little effect in the sediments adjacent to the spillways for the North Cell.

Total discharge from the South Cell was 97 million gallons, approximately half of the volume discharged during the previous year. Discharge was over two discrete periods: July-August, 2008 and January-February, 2009. Daily discharge rates were very low (< 5 mgd). Generally, the low flow periods are due to a number of factors such as reduced rain events or pond level management which may result in oxidation of sediments. It is when the sediments are exposed to air that oxidation of sulfides may occur potentially creating acid conditions when water is reintroduced. The acidic condition can mobilize certain metals which are reflected in enrichment in the exterior sediments. Although these conditions existed in the South Cell, the low volume of effluent and timing of the discharges may have contributed in the lower levels of enrichment of Pb and Zn in sediments adjacent to Spillway 003.

Although this year’s monitoring documents a drop in enrichment of Pb and Zn around the HMI facility, the elevated levels remain above background levels. These persistent enriched levels indicate a need for continued monitoring in order to detect if the levels increase to a point where action is required, to document the effect that operations has on the exterior environment (for future project design), and to assess the effectiveness of any amelioration protocol implemented by the Maryland Port Administration (MPA) and Maryland Environmental Service (MES) to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MPA and MES is important in this endeavor.

INTRODUCTION

Since 1981, the Maryland Geological Survey (MGS) has monitored the sedimentary environment in the vicinity of Hart-Miller Island Dredged Material Containment Facility (HMI DMCF). HMI is a man-made enclosure in northern Chesapeake Bay, named for the two natural islands that form part of its western perimeter.

Designed specifically to contain material dredged from Baltimore Harbor and its approach channels, the oblong structure was constructed of sediment dredged from the facility 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 as well as channels in Baltimore Harbor, near commercial docks, which generally have local sources of material of concern, and deposited inside the facility also differ from recently deposited sediments in the region. Much of the material generated by channel deepening is fine-grained and enriched in trace metals and organic constituents. In addition, oxidation of the sediment placed in the facility produces effluent enriched in metals. Oxidation occurs when the sediments are exposed to aerated conditions; this occurs during periods of dewatering and crust management. These differences in sediment properties and discharge from the facility have allowed the detection of changes attributable to construction and operation of the facility.

Previous Work

Events in the history of the 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 earlier reports (Kerhin et al. 1982a, l982b; 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 facility 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 (Wells and Kerhin, 1983; 1985).

For a number of years after HMI began operating, no major changes were observed in the surrounding sedimentary environment. Then, in April 1989, more than two years after the first release of effluent from the facility, anomalously high Zn values were detected in samples collected near Spillway 007 (Hennessee et al., 1990b). Zn levels rose from the regional average enrichment factor of 3.2 to 5.5. Enrichment factors are the ratios of concentrations, in this case Zn to Fe, which are in turn normalized to the same ratio in a standard reference material (continental crustal rock); this number is dimensionless. Effluent discharged during normal operation of the facility was thought to be the probable source of the enrichment of Zn accumulating in the sediments. This was confirmed by use of the Upper Bay Model (Wang, 1993), a numerical, hydrodynamic model, which was used to predict the dispersion of discharge from the facility, coupled with discharge records from the spillways. From the discharge records it was noted that there is a significant increase in metal loading to the exterior sediments during periods of low discharge (<10 million gallons per day (MGD)); periods of higher discharge rates corresponded to lower metal levels in the exterior sediments.

The factors that influence the metals loadings to the exterior sediments are circulation patterns in the northern Bay and the rate and the nature of discharge from the facility. The results of the hydrodynamic model pertinent to a discussion of contaminant distribution around HMI follow (see the *Year 10 Technical Report* for details):

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 007 and 009 travel in a narrow, highly concentrated band up and down the eastern side of the dike. This explains the location of areas of periodically high metal concentrations east and southeast of the facility.

3. Releases from Spillway 008 are spread more evenly to the north, east, and west. However, dispersion is not as great as from Spillways 007 and 009 because of the lower shearing and straining motions away from the influence of the gyre.

4. 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.

5. Discharge from the HMI spillways 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 facility; the higher the discharge, the higher the concentration in the plume outside the facility.

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 facility was examined, as reported in the *Year 11 Technical Report*. As a result of this examination, a model was constructed to predict the general trend in the behavior of Zn as a function of discharge rate from the facility. 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 the MES. The behavior of this model supports the hypothesis of metal contamination during low flow conditions. Sediments discharged from the facility are the source of metals that enrich the exterior sediments. When exposed to the atmosphere, these sediments oxidize in a process analogous to acid mine drainage (i.e., sulfide minerals oxidize to produce sulfuric acid, which leaches acid-soluble metals, nutrients, and organic compounds that are released with the discharged waters). Since the initial detection of Zn, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, in the vicinity of the facility higher than expected levels of Zn and Pb have persisted to the present. Figure 1-1, in addition to showing the sampling sites for Year 27, shows zones which indicate influence of sources of material to the exterior sedimentary environment based studies conducted on elevated metal levels found in previous monitoring years. These influences are noted in the figure as:

1. *Reference* - representing the overall blanketing of sediment from the Susquehanna River;

2. *Back River* - Gradients showing the sewage treatment plant as a source carried by the river have varied through time; the sites in this zone encompass the area that has shown the influence from this source. Further documentation of this source was done in the Year 16 Technical Report, where samples were collected upstream beyond the sewage treatment plant. These samples clearly showed a continuous gradient from the plant down Back River approaching HMI;

3. *HMI* - The area of influence from the facility is divided into two zones, (a) the proximal zone, which shows the most consistent enrichment levels through time, and (b) the distal zone, which is affected primarily during extended periods of dewatering and crust management, and;

4. *Baltimore Harbor* – Sites in the southern portion of the area have consistently shown a gradient, indicating that Baltimore Harbor is a source of metals in the area south of HMI. The consistent pattern seen in the monitoring studies is base level values near HMI, which increase towards Baltimore Harbor. This pattern supports the results of a hydrodynamic model analyses performed in conjunction with the 1997 sediment characterization of Baltimore Harbor and Back River (Baker et al., 1998). During Year 22 monitoring, near record rainfall levels in the area strongly influenced the hydrodynamic flow, resulting in the incursion of Baltimore Harbor material into the HMI zone. This sampling period was the only time in the 22 years of monitoring that this occurred.

HMI will stop accepting dredged material December 31, 2009 and facility operations will then shift to dewatering and long-term crust management in preparation for environmental restoration activities. Past monitoring studies have shown that, during periods of extended crust management and dewatering when discharge volume is decreasing, metal concentrations in the discharge tend to increase. Therefore, metals concentrations in the sediments in the region of HMI influence to the east of the facility are expected to increase during post-closure operation phase. In anticipation of these changes, a modified sediment sampling scheme was implemented, starting this monitoring year, to provide better coverage in targeted areas south and east of the facility (Rowe and Hill, 2008). Figure 1-1 shows the changes in the sampling scheme.

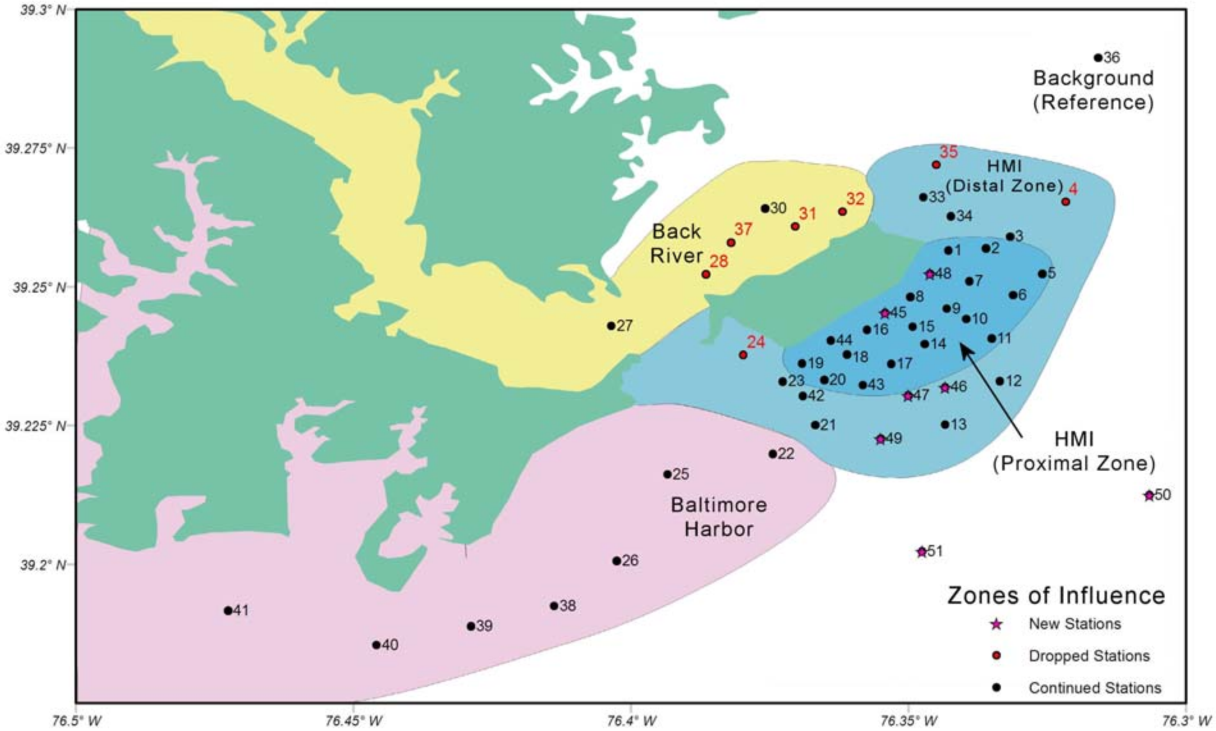


Figure 1-1. Sampling locations for Year 27. Contours show zones of influence found in previous studies. Stations 38 – 41 were added in Year 18 to measure the influence of Baltimore Harbor. Starting with this monitoring year, four stations in the Back River zone have been dropped and additional stations added in the proximal and distal zones, and southeast of the facility beyond the HMI zone of influence.

Facility Operations

Certain activities associated with the operation of HMI have a direct impact on the exterior sedimentary environment. Local bay floor sediments are sensitive, both physically and geochemically, to the release of effluent from the facility. Events or operational decisions that affect the quality or quantity of effluent discharged from the facility account for some of the changes in exterior sediment properties observed over time. For this reason, facility operations during the periods preceding each of the Year 27 cruises are summarized below. Information, which was provided by Cassandra Carr and Amanda Peñafiel of MES, covered the period from April 1, 2008 to April 30, 2009.

Between April 1, 2008 and April 30, 2009, 2.74 million cubic yards of dredged material were place in the North Cell, about half the amount as the previous monitoring year. Placement was not uniform but sporadic with the bulk of material placed after March 6, 2009, just prior to the spring sampling (Cruise 58) (Figure 1-2). Additional water input occurs from precipitation, which is the primary source of water to the South Cell. Figure 1-3 compares the monthly rainfall for HMI and Baltimore Washington International Airport (BWI) for the period between April 2008 and April 2009. The monthly averages recorded at HMI are comparable to BWI data with respect to trend. Monthly precipitation prior to Cruise 57 generally was above average until late August to early September when it was below average; the months preceding Cruise 58 were below average.

Also shown in Figure 1-3 is the average monthly discharge for the Susquehanna River at Conowingo Dam. As noted earlier flow from the Susquehanna River influences the dispersion of material around HMI. The River flow was largely seasonal, with higher flow during the winter and spring (wet) and low flow during the summer and early fall (dry). The flow rate was not influenced by local precipitation. The Susquehanna River average flow was 39,737 cubic feet per second (cfs) for the monitoring period (5/1/08-4/30/09), with the high seasonal average of 43,764 cfs and low seasonal average of 11,412 cfs. The seasonal averages were very similar to the high and low flow rates used in the hydrodynamic model to predict the dispersion of discharge from the facility (Wang, 1993).

Discharge from the North Cell was sporadic throughout the monitoring year (Figure 1-4). Highest discharges (>10 mgd) corresponded to the two periods of material placement, one at the beginning of the monitoring and the second at the end, around the time of the April 2009 sampling (Cruise 58). From June 2008 and March 2009, discharges were intermittent and less than 10 mgd. Spillways 008 and 009 were used for discharge with 89% of the total discharge coming from Spillway 009. There was no recorded discharge from Spillway 007 during the monitoring year. Total discharge from the North Cell was approximately a tenth of the volume from the previous monitoring year.

Total discharge from the South Cell was 97 million gallons, approximately half of the volume discharged during the previous year (Figure 1-5). Water from the South Cell was discharged as needed for dewatering and to regulate the water levels in the South Cell habitat area. Discharge was over two discrete periods: July-August, 2008 and January-February, 2009. Daily discharge rates were very low (< 5 mgd). There were no other recorded discharges during the monitoring year.

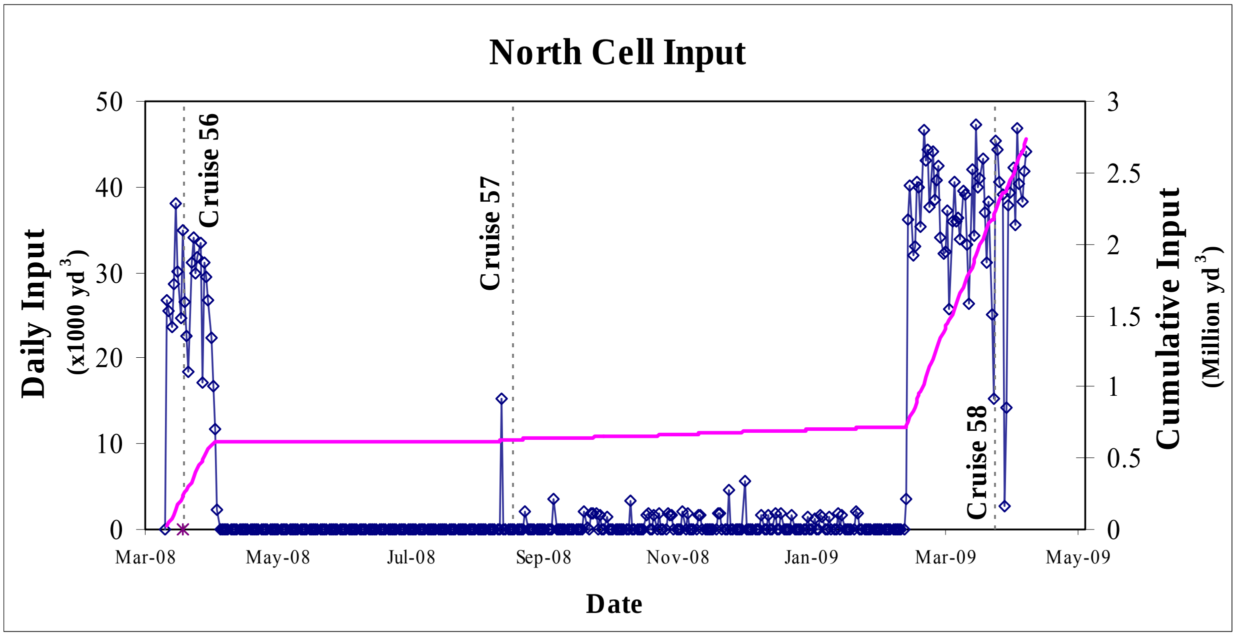


Figure 1-2. Dredged material inputs into HMI between April, 2008 and May, 2009. Blue circles indicate daily input, and Pink line indicate cumulative input.

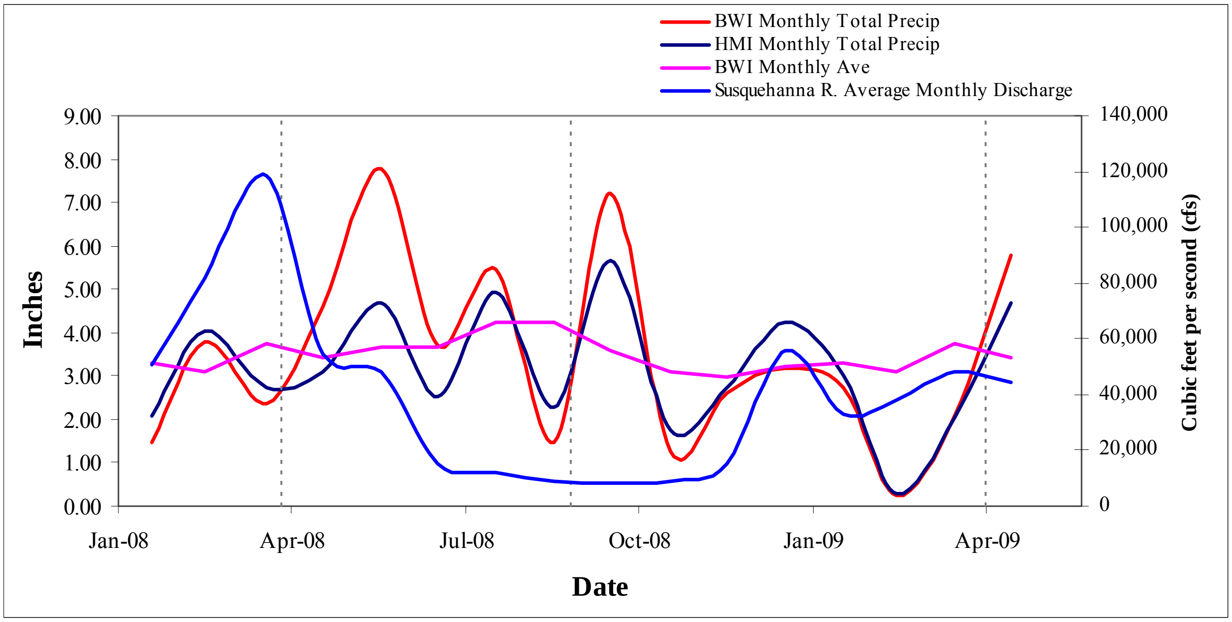


Figure 1-3. Comparison of monthly precipitation data collected at HMI Facility and at the National Weather Service (NWS) Station at BWI with the average monthly discharge of the Susquehanna River. The BWI data were obtained from the Maryland State Climatologist Office website. BWI monthly averages were based on monthly precipitation data from 1871 to 2009. Susquehanna River data were obtained from the USGS website. Vertical dotted lines indicate the dates of sampling events (Cruises 56, 57, and 58, respectively).

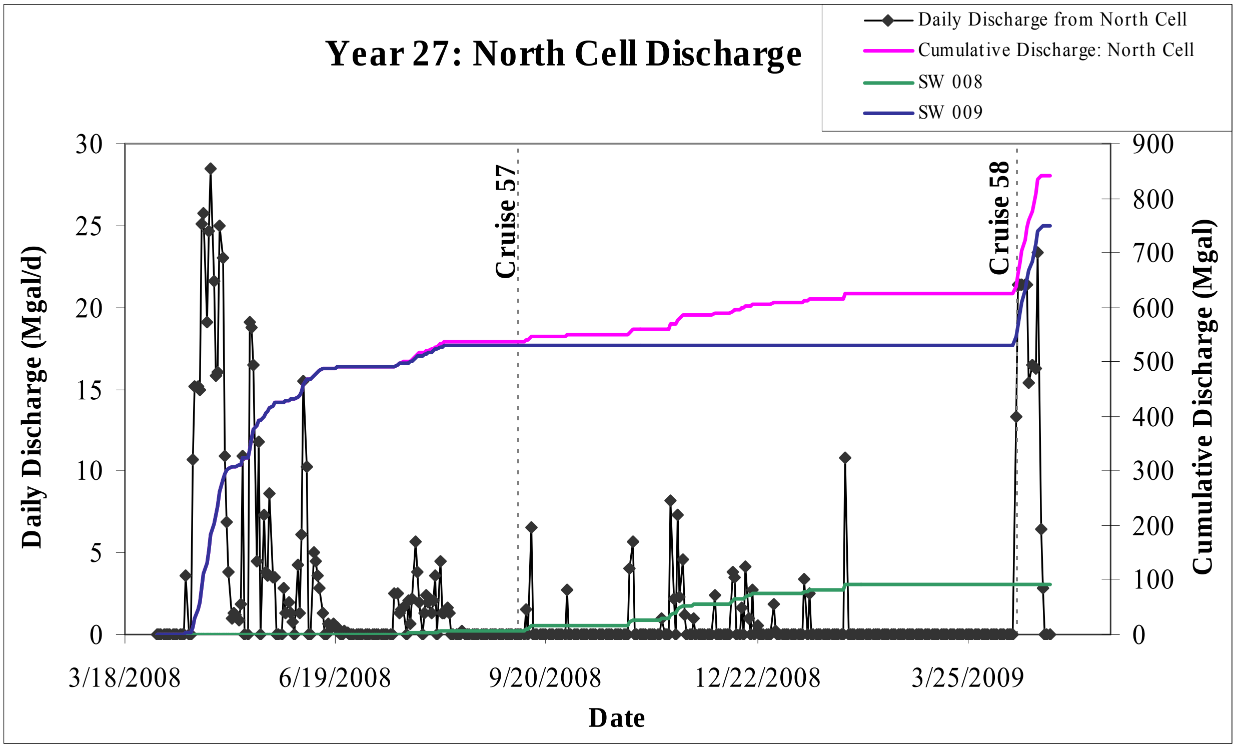


Figure 1-4. Daily and cumulative discharge from the North Cell Spillways 008 and 009; daily discharge amounts are the total of Spillways 008 and 009. The sediment sampling events are marked by the vertical lines.

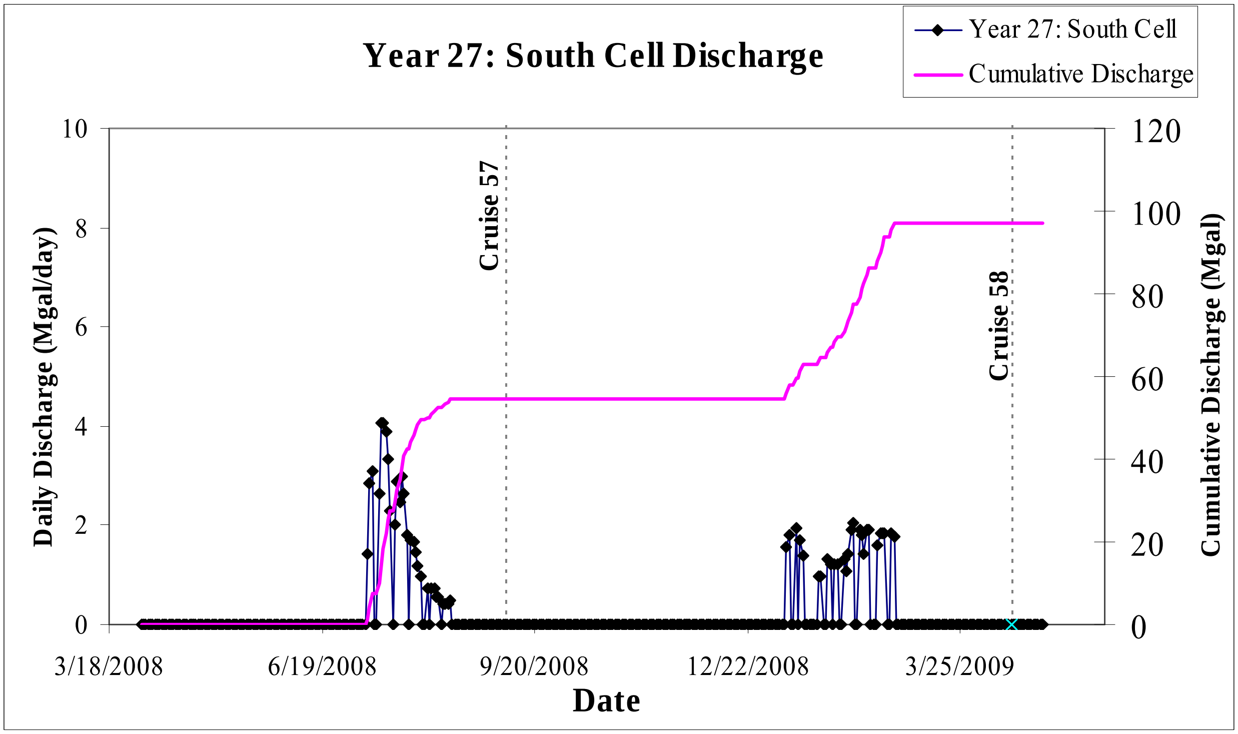


Figure 1-5. Daily and cumulative discharge from the South Cell Spillway 003.

OBJECTIVES

As in the past, the main objectives of the Year 27 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 historically elevated metals concentrations was again of particular interest.

METHODS AND MATERIALS

Field Methods

The information presented in this report is based on observations and analyses of surficial sediment samples collected around HMI during two cruises aboard the *R/V Kerhin.* The first cruise took place on September 8, 2008, and the second, on April 16, 2009.

Sampling sites (Figure 1-1) were located in the field by means of a Leica Model MX412B differential global positioning system (GPS) with a built-in beacon receiver. According to the captain, Rick Younger, the repeatability of the navigation system, that is, the ability to return to a location at which a navigation fix has previously been obtained is between 5-10 m (16-33 ft). Where replicates were collected, the captain repositioned the vessel between samples to counteract drifting off station during sample retrieval. The captain recorded station coordinates and water depth at most sites. Target and actual coordinates (latitude and longitude - North American Datum of 1983) of Year 27 sample locations are reported in the companion *Year 27 Data Report*.

Using a dip-galvanized Petersen sampler (maximum depth of penetration = 38 cm or 15 inches), crewmembers collected undisturbed samples, or grabs, of surficial sediments at 43 sites, MDE-1 through MDE-51 excluding MDE-04, 24, 28, 29, 31, 32, 35 and 37, for both Year 27 cruises.

At 39 stations for both the fall and the spring cruises, a single grab sample was collected, described lithologically, and split. Triplicate grab samples were collected at the remaining four stations (MDE-2, MDE-7, MDE-9 and MDE-30) and, likewise, described and split. MGS analyzed one split for grain size composition, a suite of trace metals, and carbon/sulfur/nitrogen. The Chesapeake Biological Laboratory (CBL) analyzed the second split collected for a different suite of trace metals. Field descriptions of samples are included as appendices in the *Year 27 Data Report*.

Using plastic scoops rinsed with deionized water, the crew took sediment sub-samples from below the flocculent layer, usually several centimeters from the top, and away from the sides of the sampler to avoid possible contamination by the sampler itself. MGS's sub-samples were placed in 18-oz Whirl-Pak^{TM} bags and refrigerated. They were maintained at 4^{o}C until they could be processed in the laboratory. CBL's splits were handled in much the same way, except that they included the floc layer and were frozen instead of refrigerated. CBL's samples are only collected for the fall sampling of each monitoring year. Therefore, the spring sampling procedure does not include a split.

Laboratory Procedures

Textural Analyses

In the laboratory, sub-samples 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:

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

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 65^{o}C, and reweighing it. The difference between total wet weight (Wt) and dry weight equals water weight (Ww). Bulk density was also determined from water content measurements.

The relative proportions of sand, silt, and clay were determined using the sedimentological procedures described in Kerhin et al. (1988). The sediment samples were pre-treated with hydrochloric acid and hydrogen peroxide to remove carbonate and organic matter, respectively. Then the samples were wet sieved through a 62-µm mesh to separate the sand from the mud (silt plus clay) fraction. The finer fraction was analyzed using the pipette method to determine the silt and clay components. Each fraction was weighed; percent sand, silt, and clay were determined; and the sediments were categorized according to Pejrup's (1988) classification (Figure 1-6).

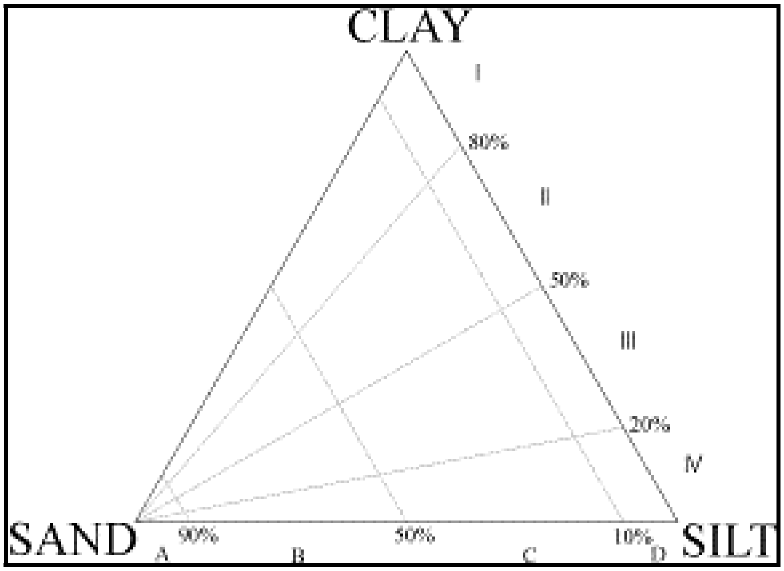


Figure 1-6. Pejrup's Diagram (1988) classification of sediment type.

Pejrup's diagram, developed specifically for estuarine sediments, is a tool for graphing a three-component system summing to 100%. Lines paralleling 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

Trace elements were analyzed by *Activation Laboratories Inc*. (ActLab). The quality assurance and quality control of ActLab has proved to meet MGS standards and requirements. In addition to the nine elements historically measured by MGS (Fe, Mn, Zn, Cu, Cr, Ni, Pb, Cd, and total P), forty-one (41) additional elements were analyzed. Samples were prepared and ground in-house and sent to ActLab for analyses using both a four acid “near total” digestion technique followed by analysis on an Inductively Coupled Argon Plasma Spectrometer (ICAP), and Neutron Activation Analysis (NAA). In addition to the standards and blanks used by ActLab, National Institute for Standards (NIST) and Chesapeake Research Consortium (CRC) standard reference materials were inserted as blind samples for analyses; 1 in every 8 samples.

Results of the analyses of the Standard Reference Materials reported by ActLab are presented in the *Year 27 Data Report.* Both the accuracy and precision of the Actlabs analyses are in excellent agreement with the standard reference materials.

Carbon-Sulfur-Nitrogen Analysis

Sediments were analyzed for carbon, total nitrogen, and sulfur (CNS) contents using a Carlo Erba NA1500 analyzer. This analyzer uses complete combustion of the sample followed by separation and analysis of the resulting gasses by gas chromatographic techniques employing a thermal conductivity detector. The NA1500 Analyzer was configured for CNS analysis using the manufacturer's recommended settings. As a primary standard, 5-chloro- 4-hydroxy- 3-methoxy- benzylisothiourea phosphate is used. Blanks (tin capsules containing only vanadium pentoxide) were run at the beginning of the analyses and after 12 to 15 unknowns (samples) and standards. Replicates of every fifth sample were also run. As a secondary standard, a NIST reference material was run after every six to seven sediment samples. The recovery of the SRM was excellent with the agreement between the NIST certified values and MGS's results well within the one standard deviation of replicate analyses. Results of the SRMS are presented in the *Year 27 Data Report.*

RESULTS AND DISCUSSION

Sediment Distribution

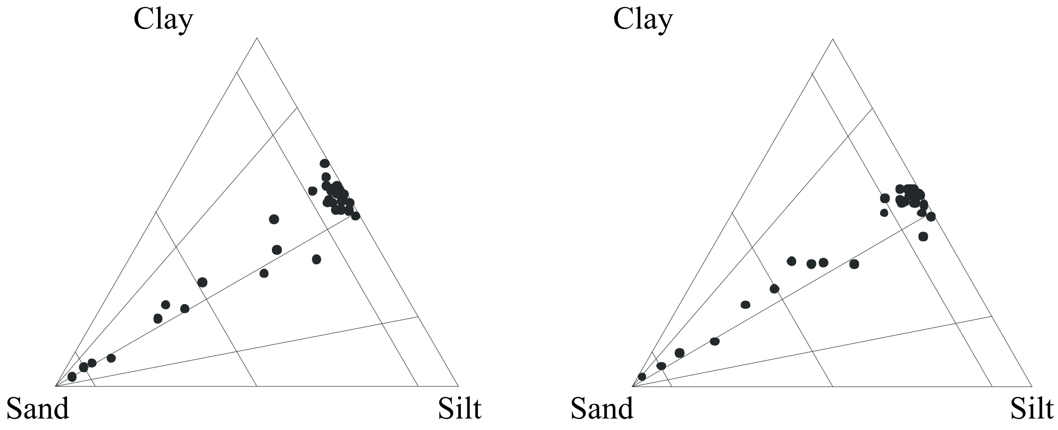
The monitoring effort around HMI is based on the identification of long-term trends in sediment distribution and on the detection of changes in those trends. The sampling scheme, revised in Year 17 and expanded in Year 18, established a new baseline against which any future changes in the sedimentary environment will be measured. Through Year 19, results of all cruises beginning with Year 17 were reported and compared. Starting with Year 20, results of the current year were discussed with respect to the preceding year. Therefore, for this report, the current Year 27 results are discussed with respect to the preceding Year 26 results.

Thirty-six of the sampling sites visited during Year 27 yielded results that can be compared to those measured during Year 26. The grain size composition (proportions of sand, silt, and clay) of the 36 samples is depicted as a series of Pejrup's diagrams in Figure 1-7. Within a diagram, each solid circle represents one sediment sample. Related statistics, by cruise, are presented in Table 1-1.

Table 1-1. Summary statistics for Years 26 - 27, for 36 sediment samples common to all four cruises.

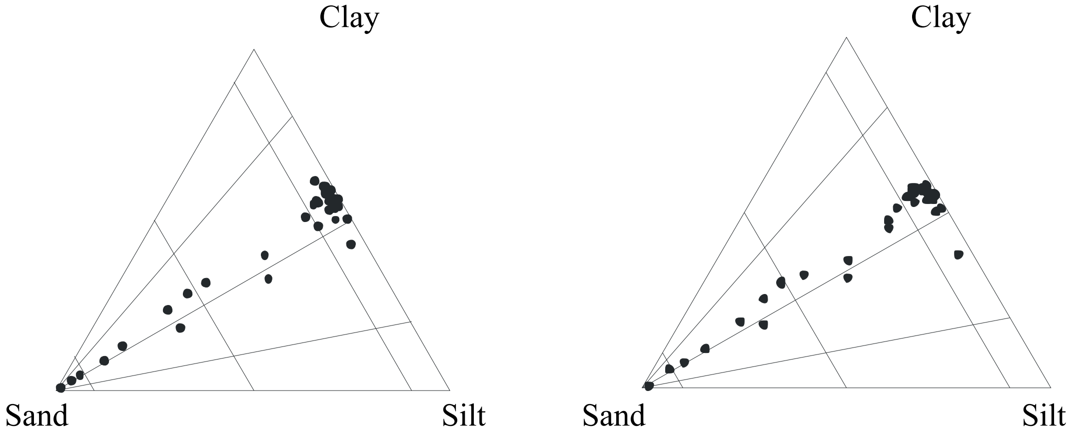
Variable	Sept 2007 Cruise 55	Apr 2008 Cruise 56	Sept 2008 Cruise 57	Apr 2009 Cruise 58
Sand (%)				
Mean	20.83	20.95	22.30	22.36
Median	4.00	4.06	4.18	5.23
Minimum	0.62	0.49	0.61	0.52
Maximum	94.38	95.98	97.99	98.13
Range	93.77	95.48	97.38	97.60
Count	**36**	**36**	**36**	**36**
Clay:Mud				
Mean	0.55	0.56	0.56	0.56
Median	0.56	0.56	0.57	0.57
Minimum	0.44	0.45	0.44	0.40
Maximum	0.65	0.67	0.63	0.61
Range	0.21	0.22	0.19	0.22
Count	**36**	**36**	**36**	**36**

The ternary diagrams show similar distributions of sediment type. The samples range widely in composition, from very sandy (>90% sand) to very muddy (<10% sand). Muddy sediments predominate; at least three-fourths of the samples contain less than 10% sand. All of the points fall fairly close to the line that extends from the sand apex and bisects the opposite side of the triangle (clay:mud = 0.50). In general, points lie above the 0.50 line, indicating that the fine (muddy) fraction of the sediments contain more clay than silt.



(a) September 2007 (Cruise 55)

(b) April 2008 (Cruise 56)



(c) September 2008 (Cruise 57)

(d) April 2009 (Cruise 58)

Figure 1-7. Pejrup diagrams showing the grain size composition of sediment samples collected in Years 26 and 27 from the 36 sampling sites common to all four cruises: (a) September 2007, (b) April 2008, (c) September 2008, and (d) April 2009.

Based on the summary statistics (Table 1-1), average grain size composition, reported as % sand and as clay:mud ratios, varied little over the four sampling periods. The mean percentage of sand varied less than 2% for the four samplings. The mean clay:mud ratio was 0.55 for sampling Cruise 55 and increased slightly to 0.56 for Cruise 56 and remained at 0.56 for the two sampling cruises of this monitoring year.

Sandy sediments are associated with the shallower areas around the diked facility. (Figure 1-8). The grain-size distribution of bottom sediments around HMI is depicted in contour maps showing (1) the percentage of sand in bottom sediments and (2) the clay:mud ratios. In Figure 1-9 and Figure 1-10, three contour levels represent 10%, 50%, and 90% sand, coinciding with the parallel lines in Pejrup's diagram (Figure 1-6). Generally, sand content diminishes with distance from the containment facility. Scattered around the perimeter of the dike, the sandiest sediments (>50% sand) are confined to relatively shallow (<15 ft) waters.

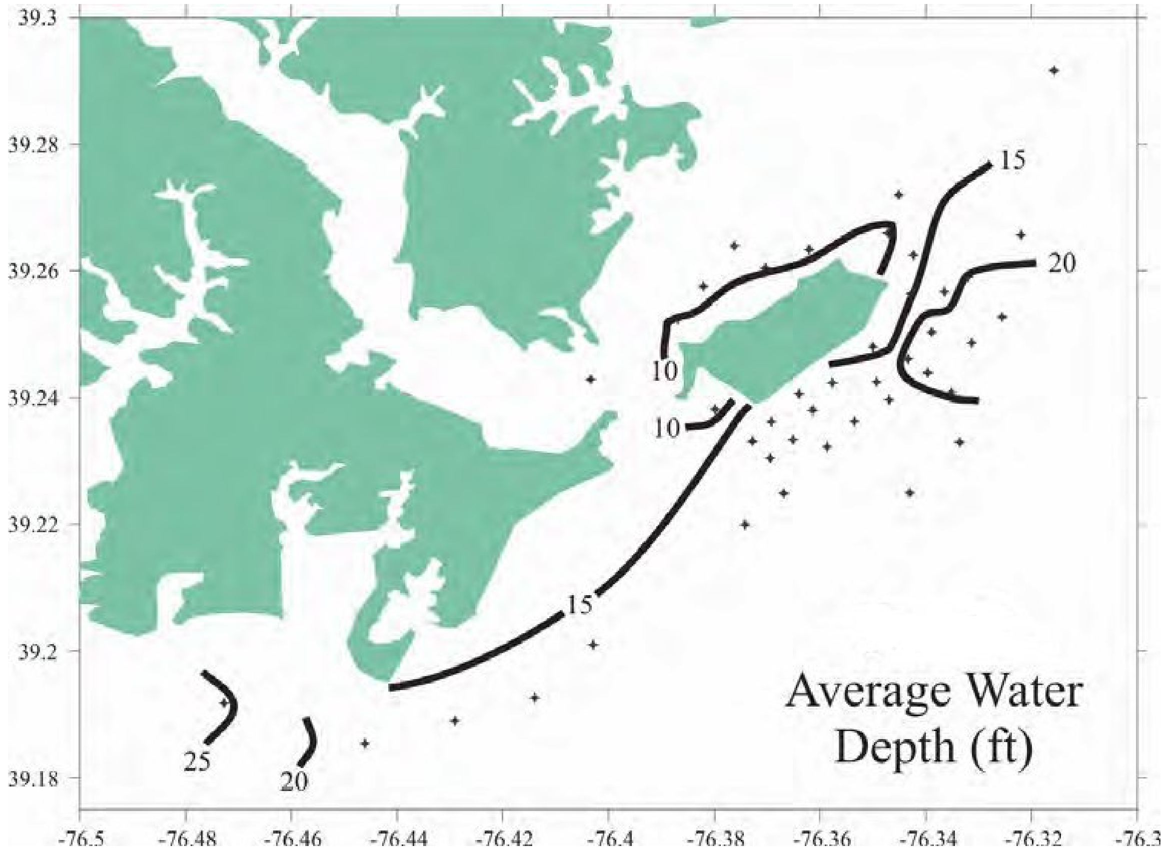


Figure 1-8. Average water depths around HMI and vicinity. Contour interval = 5 ft.

Broadest north and west of the facility, the shoals are the erosional remnants of a larger neck of land. The once continuous landmass has been reduced to a series of islands, including Hart and Miller, extending from the peninsula that now forms the south shore of Back River. However, not all shallow water samples are sandy. In particular, several of the shallow water samples from Hawk Cove (e.g., MDE-30) contain less than 10% sand. Sand distribution maps for Years 26 and 27 are similar in appearance (Figure 1-9 and Figure 1-10). Sand contents continue to be highest near the perimeter of HMI in shallow water depths. At the northeast end of the facility, the broad sand area as defined by the 90% contour changed slightly based on September 2008 sampling. By April 2009, sand content in the area dropped below 90%, indicating a slight increase in silt/clay. Otherwise, no significant changes in sand content occurred during monitoring Year 27. In general, the distribution of sand around HMI has remained largely unchanged since November 1988, two years after the first release of effluent from the dike. It should be noted that one of the newly added stations southeast of the facility (MDE-50) contains more than 90% sand.

Compared to the distribution of sand, the distribution of clay:mud ratios has tended to be slightly more variable over time (Figure 1-11 and Figure 1-12). It also may be noted that some of the differences in spatial variability may be due to the change in sampling scheme. The fine (mud) fraction of the sediments around HMI is generally richer in clay than in silt. That is, the clay:mud ratio usually exceeds 0.50, as shown in the ternary diagrams in Figure 1-7. However, slight variations in the most clay-rich (clay:mud ratio ≥ 0.60) and in the most silt-rich (clay:mud ratio < 0.50) of the fine fractions are evident (Figure 1-11 and Figure 1-12). MDE-41, at the mouth of Baltimore Harbor, continued to be clay-rich for all of the four samplings. A clay-rich area south of HMI was present in both September 2007 and September 2008, but diminished in size in the April sampling of both years. This pattern may be due to seasonal changes. The April samplings occur during a period of higher turbulence due to weather whereas the September samplings take place after a comparatively quiet, low flow summer during which more clay size sediment accumulated on the bottom. This may also explain the overall increase in finer fraction seen at the northeast end of the facility.

Silt-rich sediments (clay:mud ratio < 0.50) are generally found immediately adjacent to the walls of the dike, commonly in the vicinity of spillways. The silt-rich areas were consistent during both Year 26 and Year 27 monitoring with regards to the area adjacent to the walls of the dike to the south remaining silt-rich.

Understanding the specific reasons for these variations in grain size is difficult. They involve the amount, quality, and timing of discharge from particular spillways and the interaction of the effluent with tides and currents in the receiving waters. Those, in turn, are influenced by flow from the Susquehanna River. Based on the similarities between the fine fraction results from Year 26 and Year 27, one may conclude that the depositional environment in the vicinity of HMI was unchanged over this period. While there were a larger number of clay-rich sites in September sampling, there was a subsequent decrease in April sampling for the previous and this monitoring year. The grain size distribution of Year 27 samples is largely consistent with the findings of past monitoring years.

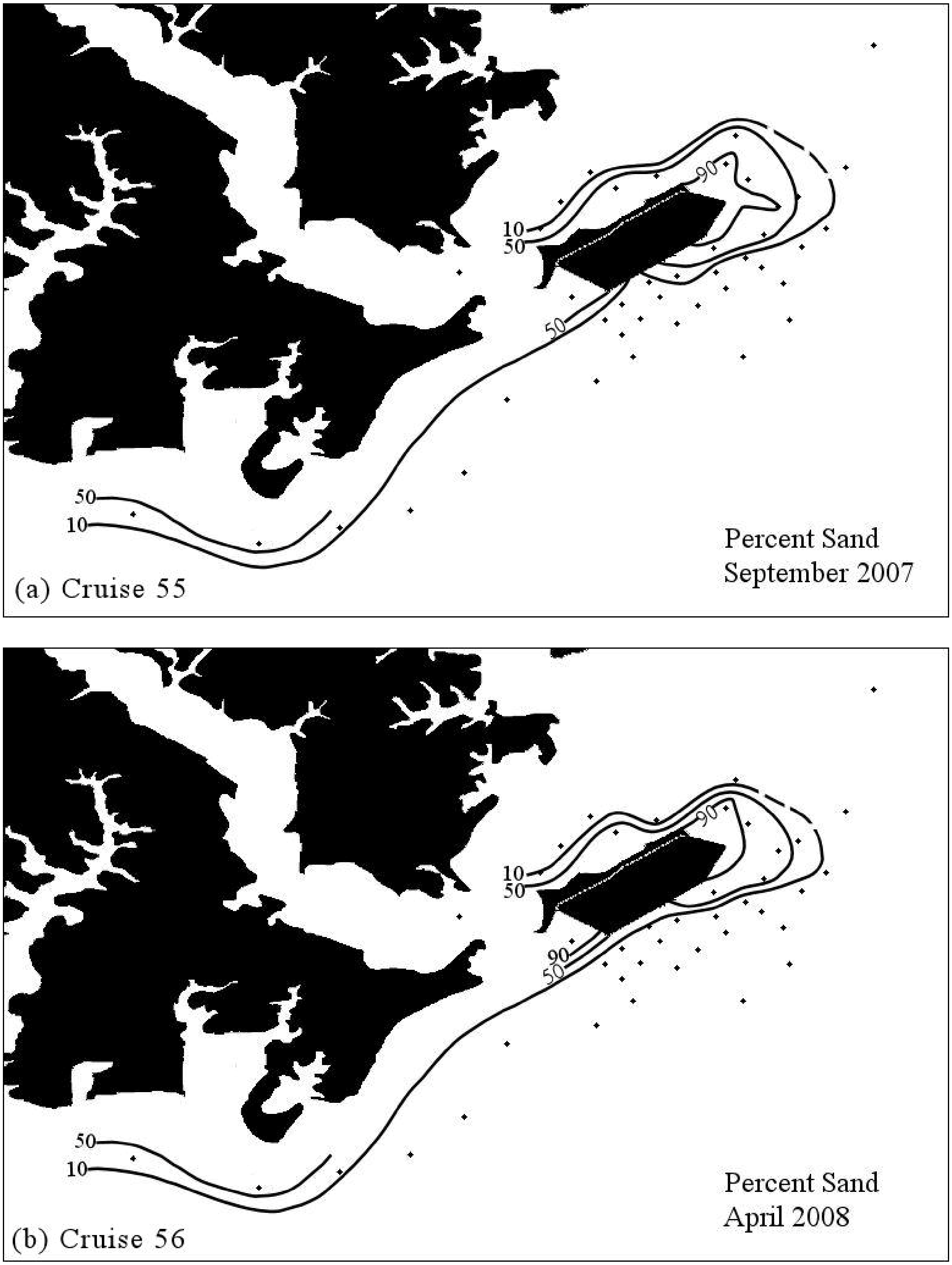


Figure 1-9. Sand distribution for Monitoring Year 26: (a) September 2007 (Cruise 55), (b) April 2008 (Cruise 56). Contour intervals are 10%, 50%, and 90% sand.

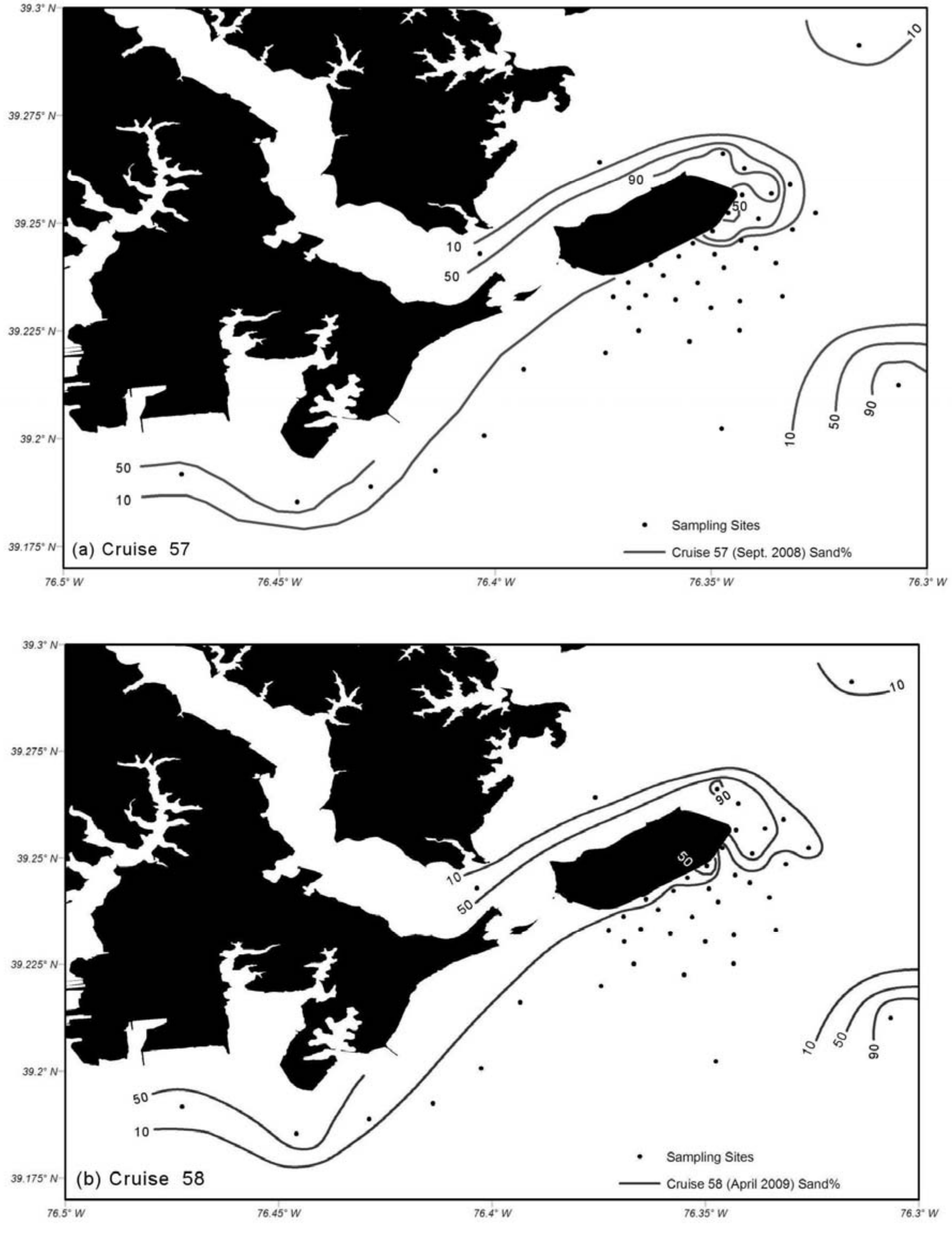
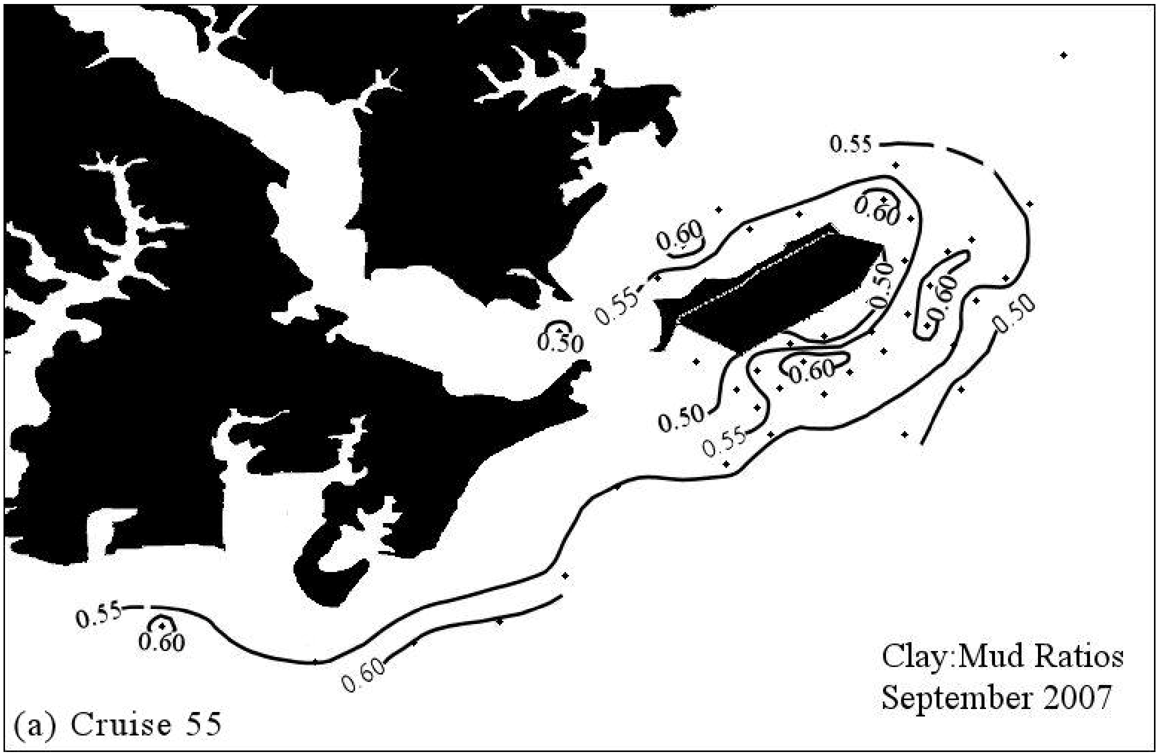


Figure 1-10. Sand distribution for Monitoring Year 27: (a) September 2008 (Cruise 57), (b) April 2009 (Cruise 58). Contour intervals are 10%, 50%, and 90% sand.



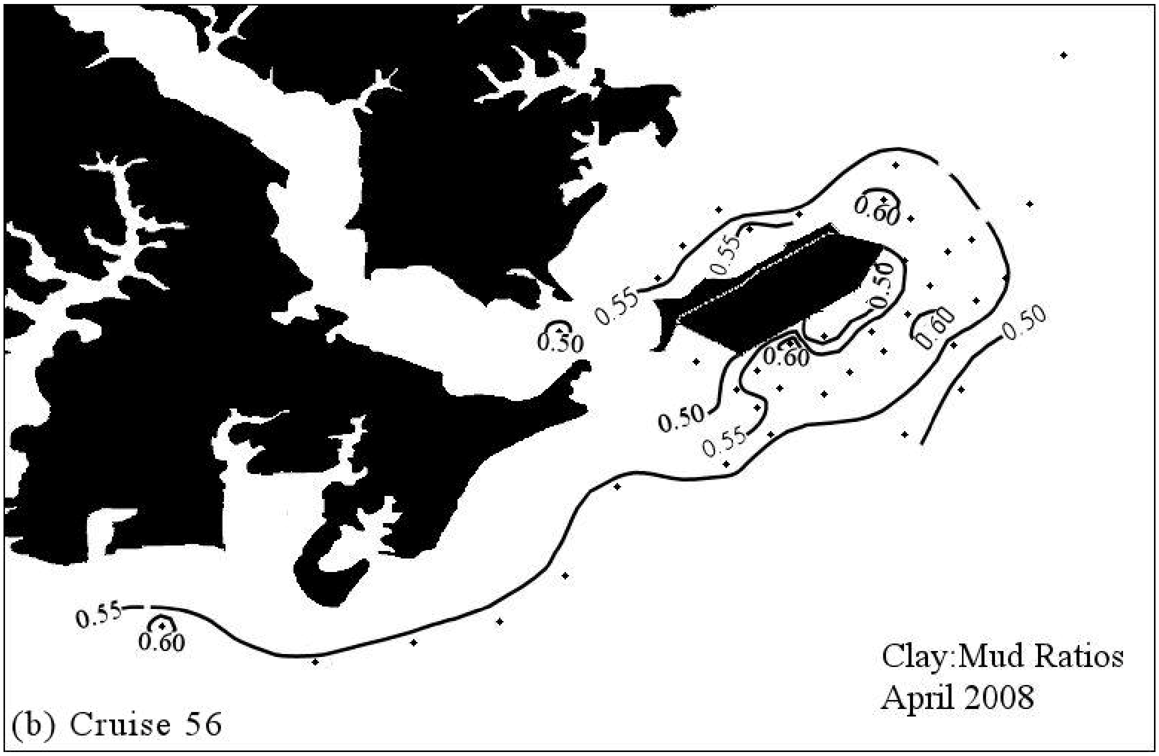


Figure 1-11. Clay;Mud rations for Monitoring Year 26: (a) September 2007 (Cruise 55), (b) April 2008 (Cruise 56). Contour intervals are 0.50, 0.55, and 0.60.

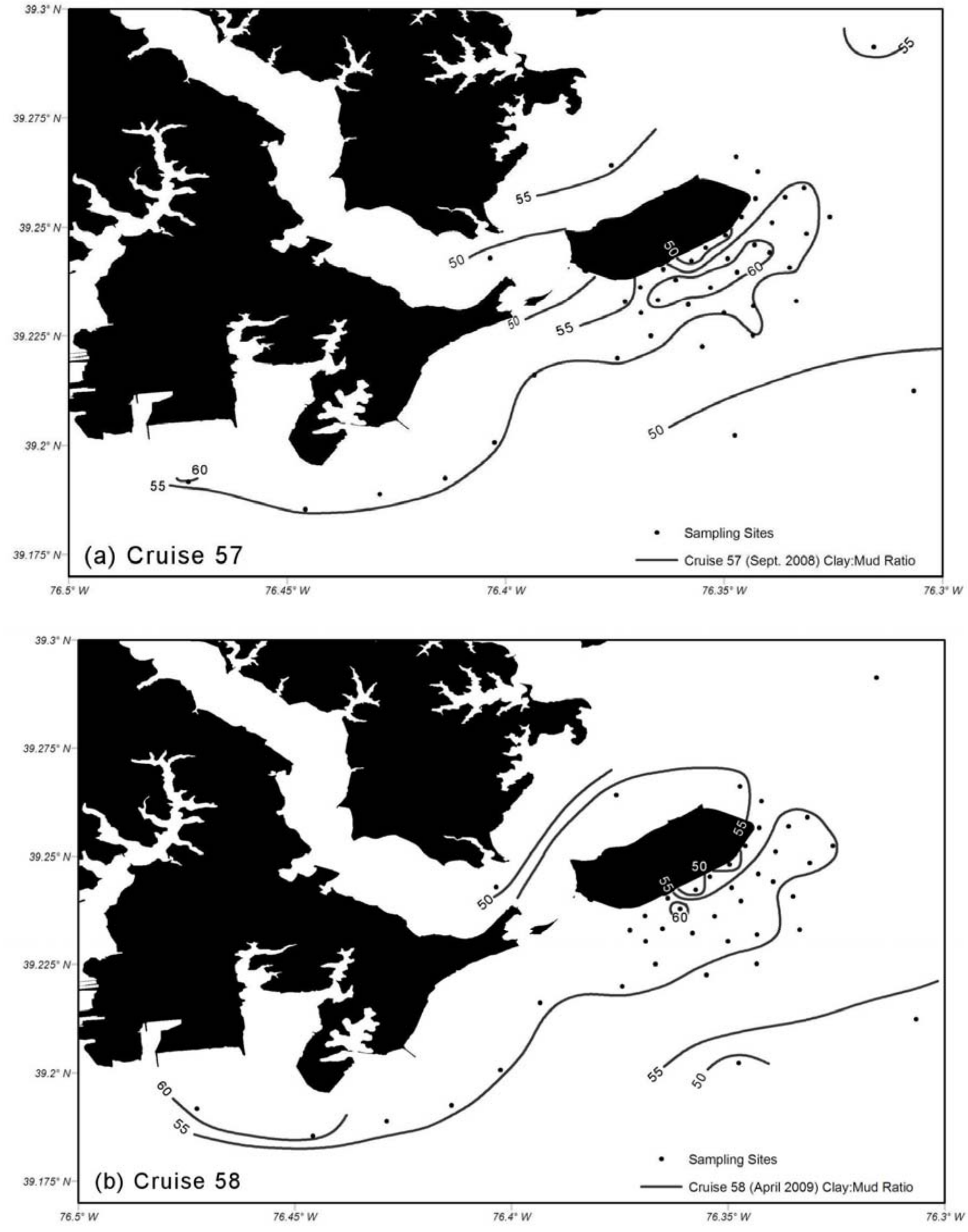


Figure 1-12. Clay:Mud ratios for Monitoring Year 27: (a) September 2008 (Cruise 57), (b) April 2009 (Cruise 58). Contour intervals are 0.50, 0.55, and 0.60.

Elemental Analyses

Interpretive Technique for Trace Metals

Previous monitoring years have focused on eight trace metals 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:

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

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 1-2. The correlations are excellent for Cr, Fe, Ni, Zn, and Pb 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. The poor relationship with regard to Cd is due to the baseline being established at or near the detection limit; however, the relationship is still significant. Baseline levels for Cd and Pb were determined from analyses of 30 samples collected in a reference area on the eastern side of the Northern Bay. The baseline was established as part of a study examining toxic loading to Baltimore Harbor.

Table 1-2. 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**	**Pb**	**Cd**
a	25.27	668	0.553	15.3	12.3	44.4	6.81	0.32
b	71.92	218	1.17	0	18.7	0	4.10	0.14
c	160.8	4158	7.57	136	70.8	472	77	1.373
R^2	0.733	0.36	0.91	0.82	0.61	0.77	0.88	0.12

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. A metal concentration can be predicted by substituting the least squares coefficients from Table 1-2 for the constants in equation 2, and using the measured grain size at the site of interest. These predicted values can then be used to determine variations from the regional norm due to deposition; to exposure of older, more metal-depleted sediments; or to loadings from anthropogenic or other enriched sources.

The following equation was used to examine the variation from the norm around HMI.

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

Note: Zn is used in the equation because of its significance in previous studies, however any metal of interest could be used.

In Equation 3, the differences between the measured and predicted levels of Zn are normalized to predicted Zn levels. This means that, compared to the regional baseline, a value of zero percent excess metal is at the regional norm, positive values are enriched, and negative values are depleted. Direct comparisons of different metals in all sediment types can be made due to the method of normalization. As useful as the % Excess Metal values are, alone they do not give a complete picture of the loading to the sediments; natural variability in the samples as well as analytical variations must be taken into account. As result of the normalization of the data, Gaussian statistics can be applied to the interpretation of the data. Data falling within ±2σ (±2 standard deviations) are within normal background variability for the region. Samples with a value of ±3σ can be within accepted background variability, but are considered marginal depending on the trends in the distribution. Any values falling outside this range indicate a significant perturbation to the environment. The standard deviation (σ) of the baseline data set (the data used to determine the coefficients in Equation 2) is the basis for determining the sigma level of the data. Each metal has a different standard deviation, as reflected in the R^2 values in Table 1-2. The sigma level for Zn is ~30% (e.g. 1σ = 30%, 2σ = 60%, etc.).

General Results

A listing of the summary statistics for the elements analyzed is given in Table 1-3. Generally, the statistics are very similar to the previous year except for the anomalously high Cr value of 1,110 ppm which was measured from MDE-41 sampled during the fall 2008 cruise. The sample contained the maximum values for Cu, Fe and Mn. MDE-41 is the upstream-most sample site in the Baltimore Harbor Zone of Influence and has consistently been high in metals. However, for both sampling cruises this year, the samples collected at this site also contain significant gravel (10%), a portion of which may have been 'slag' which would explain the high metal contents.

With regard to Effects Range Low (ERL) and Effects Range Medium (ERM) values list in Table 1-3, it also should be noted:

1. At most sampling sites, concentrations of Cr, Cu, Ni, Pb, and Zn in the sediment exceed the ERL values; and
2. Ni and Zn exceed the ERM values at some sites.

ERL and ERM are proposed criteria put forward by National Oceanic and Atmospheric Administration (Buchman, 2008) to gauge the potential for deleterious biological effects. Sediments with concentrations below the ERL are considered baseline concentrations with no expected adverse effects. Concentrations between the ERL and ERM may have adverse impacts to benthic organisms, while values greater than the ERM have probable adverse biological effects. These criteria are based on a statistical method of termed preponderance of evidence. The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional difference. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, certain samples are significantly enriched in Pb and to a lesser extent in Zn, compared to the baseline (Figure 1-13). Based on work done by the University of Maryland during the Year 25 monitoring year, the most probable conditions where the metals affect the infaunal communities are:

1. When the sigma level exceeds +2 [indicating enriched metals concentrations over baseline] and;
2. When the metals level exceeds the ERL with increased probability as the level exceeds the ERM [showing absolute concentrations that have exhibited adverse effects in other systems].

Table 1-3. Summary statistics for elements analyzed. Both sampling cruises are included in summary. All concentrations are in ug/g (ppm) unless otherwise noted.

	%P	**Cd**	**Cr**	**Cu**	**%Fe**	**Mn**	**Ni**	**Pb**	**Zn**
Ave	0.071	0.85	103	41	4.29	2526	75	51	303
Std	0.027	0.36	116	19	1.60	1173	33	25	150
Min	0.003	0.3	5	2	0.24	244	6	3	17
Max	0.109	2	1110	100	7.96	6660	154	115	785
n	86	76	86	86	86	86	86	86	86
ERL	n/a	1.3	81	34	n/a	n/a	21	47	150
#>ERL	n/a	5	65	84	n/a	n/a	79	53	70
ERM	n/a	9.5	370	270	n/a	n/a	52	218	410
#>ERM	n/a	0	1	0	n/a	n/a	65	0	17

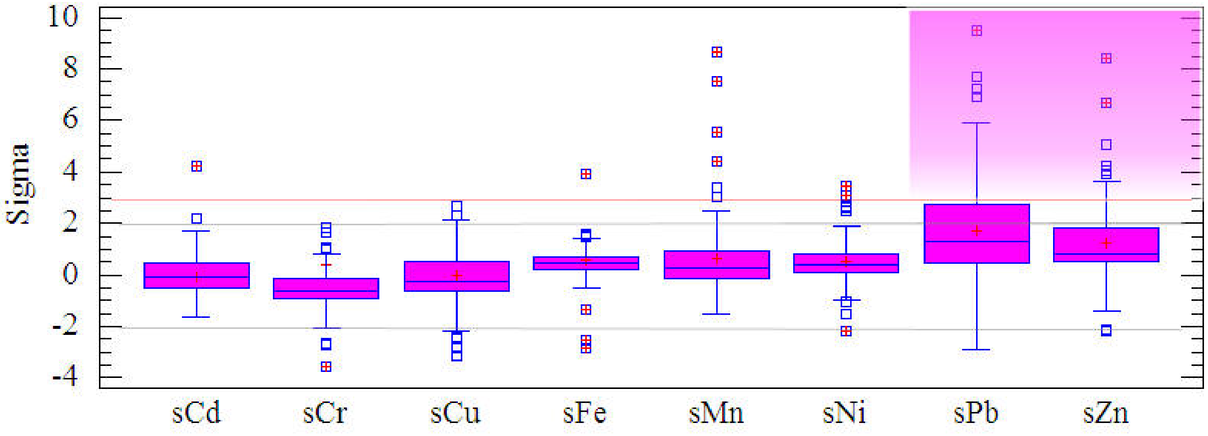


Figure 1-13. A box and whisker diagram showing the range of the data for both the fall and spring cruise.

The values presented in Table 1-3 are the measured concentrations of metals in the sediment, not normalized with respect to grain size variability, as outlined in the preceding *Interpretive Techniques* section. Figure 1-13 shows the variation of the data from the predicted baseline behavior for each of the elements measured. The values are in units of multiples of standard deviations from the norm; zero values indicate measurements that are identical to the predicted baseline behavior, values within plus or minus two (2) sigma are considered to be within the natural variability of the baseline values. For both sampling cruises, all of the metals except Pb and Zn are within the range expected for normal baseline behavior in the area. Approximately 25% of the samples contain Pb significantly exceeding the baseline levels (i.e., >3 sigma levels), and 11% of the samples contain Zn levels exceeding the baseline. However, overall levels for Pb and Zn have dropped compared to previous monitoring years. Most of the samples with elevated metal levels are in the Baltimore Harbor Zone of influence.

Metal Distributions

Since the eighth monitoring year, increased metal levels (specifically Zn) have been noted in bottom sediments east and south of Spillway 007; similarly since the Pb was added to the monitoring protocol (Year 15), elevated levels of Pb have been found in the same areas, but with generally higher relative loadings. The results of previous monitoring studies have shown that the areal extent and magnitude of metals loadings to the exterior sedimentary environment is controlled by three primary factors. These factors are:

1. *Discharge rate* - Controls the amount of metals discharged to the external sedimentary environment. Discharge from HMI at flows less than 10 MGD contribute excess metals to the sediment (see *Year 12 Interpretive Report*). The high metal loading to the exterior environment may be the result of a low pond level, which allows exposure of the sediment to the atmosphere. When the sediments are exposed to atmospheric oxygen, naturally occurring sulfide minerals in the sediment oxidize to produce sulfuric acid, which leaches metals and other acid-soluble chemical species from the sediment. At discharge rates greater than 10 MGD, the water throughput (input from dredged material inflow to release of excess water) submerges the sediment within the facility, minimizing atmospheric exposure, and dilutes and buffers any acidic leachate. As a result, higher discharge rates produce metal loadings that are close to background levels.

2. *Flow of freshwater into the Bay from the Susquehanna River* - The hydrodynamic environment of the Bay adjacent to HMI is controlled by the mixing of freshwater and brackish water south of the area. Details of the hydrodynamics of this region were determined by a modeling effort presented as an addendum to the *Year 10 Interpretive Report* (Wang, 1993). The effects of Susquehanna flow to the contaminant distribution around HMI follow;
   a. 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;
   b. 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; and
   c. Discharge from the facility 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 facility; the higher the discharge, the higher the concentration in the plume outside the facility.

3 *The positions of the primary discharge points from the facility* - The areal distribution of the metals in the sediment also depends on the primary discharge locations to the Bay. The effects of discharge location were determined as part of the hydrodynamic model of the region around HMI. The effects of discharge location are:

  a. Releases from Spillways 007 and 009 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; and
  b. Releases from Spillway 008 are spread more evenly to the north, east, and west. However, dispersion is not as great as from Spillways 007 and 009 because of the lower shearing and straining motions.

The 3-D hydrodynamic model explains the structure of the plume of material found in the exterior sediments, and the functional relationship of contaminants to discharge rate accounts for the magnitude of the loading to the sediments.

Figure 1-14 shows the sigma levels for Pb for Year 27 monitoring periods in the study area adjacent to HMI; sigma levels for Zn are shown in Figure 1-15. Sigma levels are the multiple of the standard deviation of the baseline data set. Data that falls within +/-2 sigma are considered within normal baseline variability. Data within the 2-3 sigma range are transitional; statistically one sample in 100 would normally be expected to occur, in a small data set. The occurrence of two or more spatially contiguous stations in this range is significant. Any sample >3 sigma is significantly elevated above background. As shown in Figure 1-1 there are three primary areas of interest that will be referred to as: Back River, Baltimore Harbor, and HMI.

Back River - The Back River influence is seen for Pb even though only two sites within this zone were sampled this monitoring year. As with previous years, Pb continues to be discharged by Back River during both of the sampling periods, having slightly higher levels in the fall, compared to the spring Cruise. The spatial extent is similar for both cruises. Based on the two sites, Zn concentrations were within background levels for both sampling cruises.

Baltimore Harbor - Elevated levels of Pb and Zn extend into the area southwest of HMI. The levels for both metals are clearly isolated from the HMI zone of influence adjacent to the island. Both metals showed similar enrichment values as compared to Year 26. There was a seasonal shift in level of enrichment with slightly higher values in the fall.

HMI – Pb and Zn levels adjacent to the HMI were lower compared to the previous year. The spatial extent of Pb enrichment has not changed significantly; the extent for the enrichment for both cruises was confined to a single area around the South Cell discharge point. The area of Zn enrichment was confined to one site (MDE-44) in the fall 2008. In April 2009 Zn enrichment was still confined but to site MDE-18 while enrichment at MDE-44 dropped to below 3 sigma. Both sites MDE-18 and 44 are adjacent to the South Cell Spillway 003. In April a second site MDE-45, which was added to this year's monitoring design, yielded Zn enrichment over 3 sigma. This site is adjacent to the North Cell Spillway 009.

Given the reduced activity of the HMI facility, there appeared to be less impact, in terms of level of enrichment and spatial extent, on the sediments adjacent to the facility. Due to the timing of the discharges from the South Cell, the September sampling was slightly more impacted than the sediments collected in the spring. Both Pb and Zn show elevated levels for both cruises, localized in the area of the South Cell discharge. The influence of the North Cell discharge appeared to be minimal for both cruises. The trend for material from the North Cell appears to be diminishing toward background levels.

The spatial extent and the levels found in the Baltimore Harbor and Back River zones vary according to seasonal weather changes, which influence the hydrodynamic conditions and sediment loading, and activity within those sources. Commonly the late summer - early fall levels are higher than the spring sampling for the Baltimore Harbor and Back River zones; this is the case for this monitoring year.

The HMI zone, prior to Year 22 monitoring, was clearly independent of Baltimore Harbor and Back River inputs. In the monitoring Years 22 and 23 an enriched area extended into the HMI region. In Year 22 near record rainfall caused the Baltimore Harbor influence to extend into the HMI region for the first time since the construction of the dike. This effect intensified during Year 23, due to continuing climatic factors. The influence of the Harbor diminished in the Year 24 monitoring, with the separation complete in the April 2006 sampling period. During Year 24 rainfall was below normal thus minimizing flow from Baltimore Harbor. The separation of the Baltimore Harbor zone from the HMI zone was maintained for Year 25 and continued through Year 27 by the low to average rainfall in the periods prior to sampling.

In regard to the long-term trend of the data, the highest levels of Zn enrichment in the HMI zone are comparable to the Year 25 monitoring. The data from this monitoring year are shown in Figure 1-16 as the solid points, which show a downward trend compared to last year. Viewed in context, there appears to be a general trend, starting in 2002, of increasing metal levels as dewatering operations proceed.

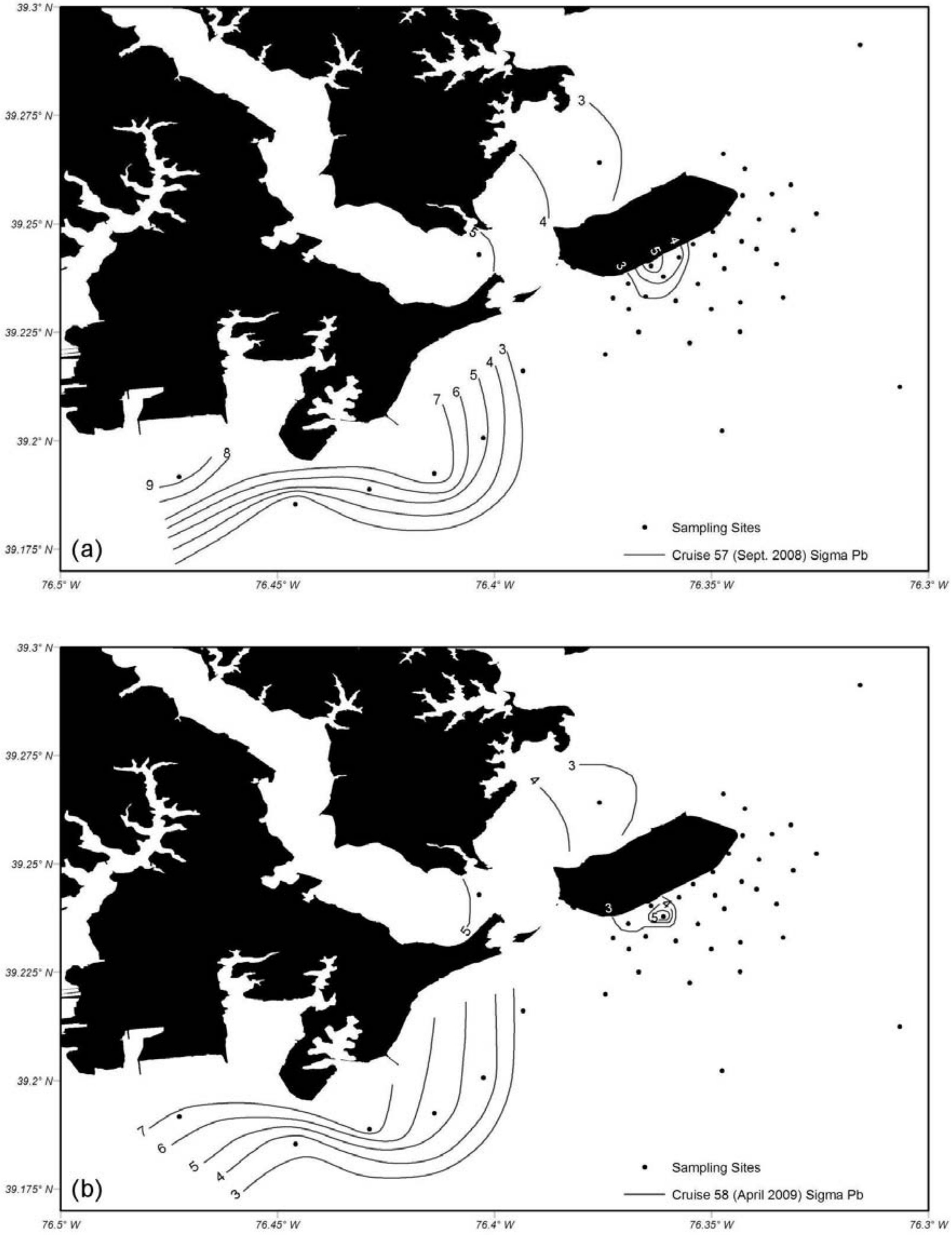


Figure 1-14. Distribution of Pb in the study area for the fall and spring sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (values less than 3 not shown), >3 = significantly enriched.

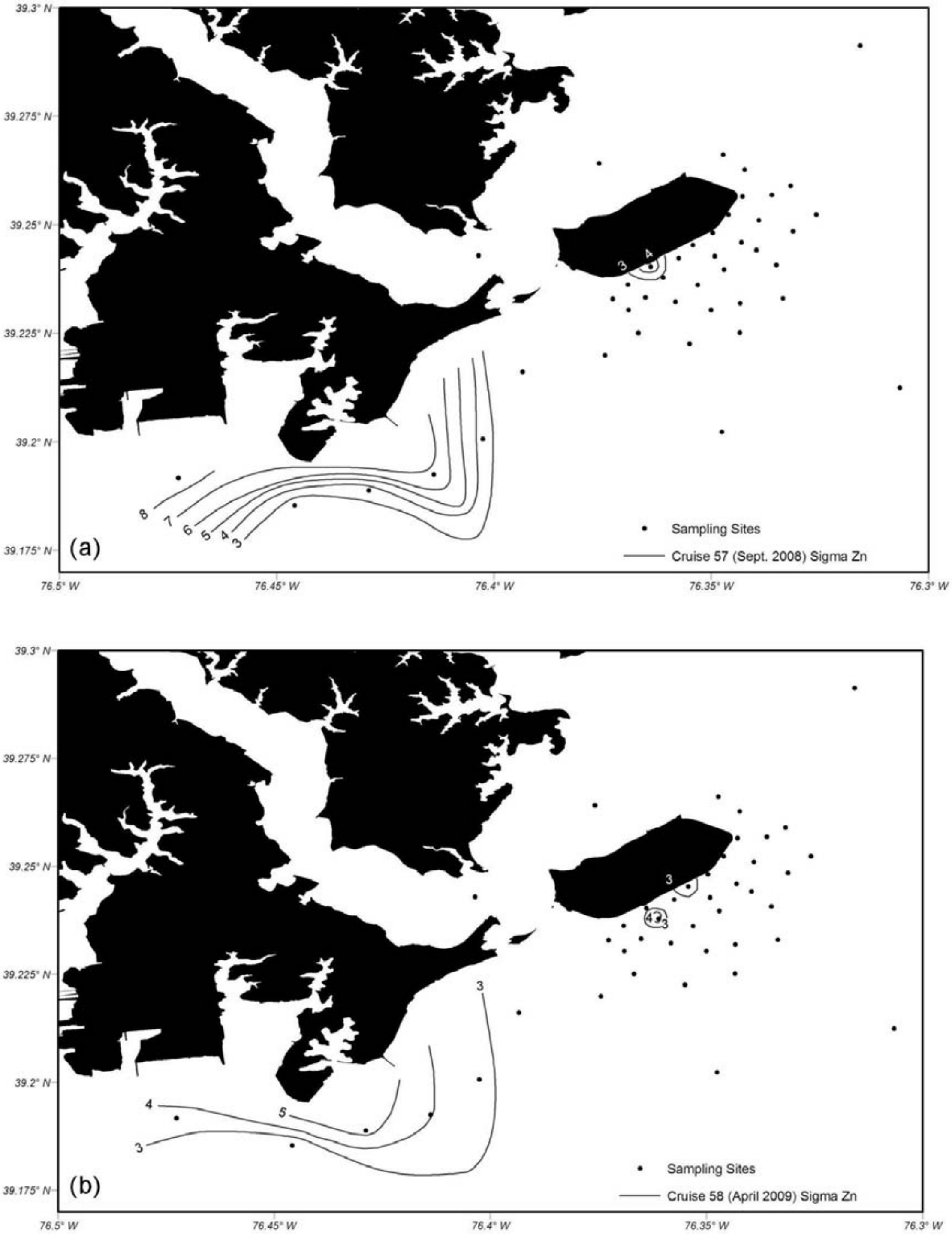


Figure 1-15. Distribution of Zn in the study area for the fall and spring sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional(values less than 3 not shown), >3 = significantly enriched.

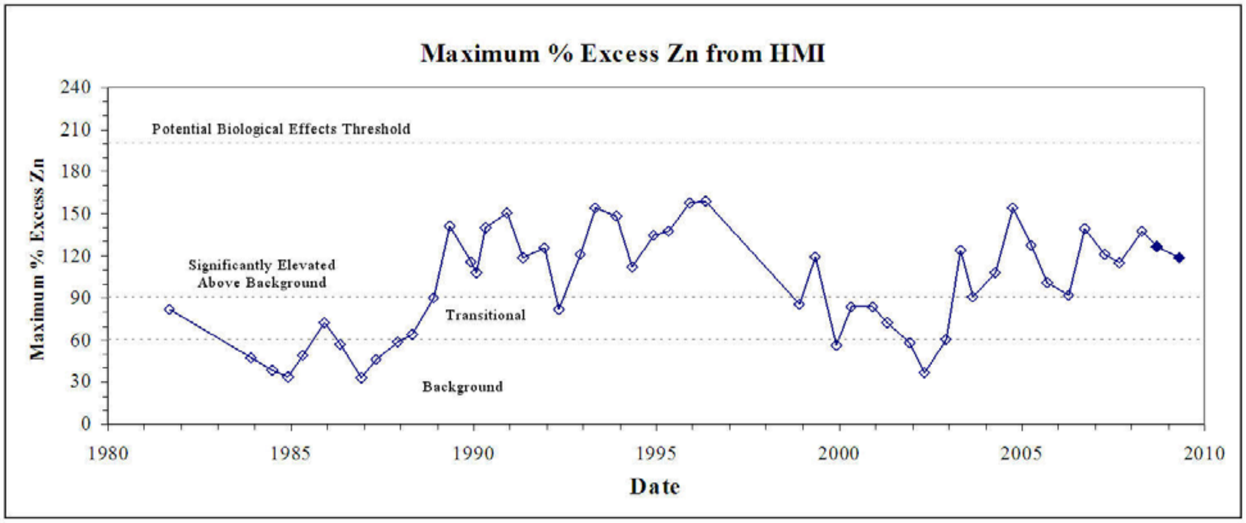


Figure 1-16. Record of the maximum % excess Zn for all of the cruises for which MGS analyzed the sediments. The filled points are the data from this year's study Cruises 57 and 58).

SUMMARY AND RECOMMENDATIONS

The grain size distribution of the Year 27 sediment samples does not show any clear trends in sedimentation patterns from cruise to cruise. This is due to the complexity of the environmental conditions and source of material to the area. The clay:mud ratios show that the depositional environment was similar during Year 26 and Year 27. The general sediment distribution pattern is consistent with the findings of previous monitoring years dating back to 1988 (the second year after the start of release from HMI) and no significant changes occurred during Year 27.

Elemental analyses data indicate that the sediments are very similar to the previous year except for the anomalously high Cr value measured at a sampling site in the Baltimore Harbor Zone of Influence; the same site had consistently been high in metals in previous years. Based on summary statistics, the elemental data show that:

1. At most sampling sites, concentrations of Cr, Cu, Ni, Pb, and Zn in the sediment exceed the ERL values; and
2. Ni and Zn exceed the ERM values at some sites.

ERL and ERM are proposed criteria put forward by National Oceanic and Atmospheric Administration (Buchman, 2008) to gauge the potential for deleterious biological effects. Sediments with concentrations below the ERL are considered baseline concentrations with no expected adverse effects. Concentrations between the ERL and ERM may have adverse impacts to benthic organisms, while values greater than the ERM have probable adverse biological effects. These criteria are based on a statistical method of termed preponderance of evidence.

The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional difference. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, Pb, and Zn have significantly enriched samples compared to the baseline.

In regard to potential adverse benthic effects the overlap of enrichment and concentration can be used as an indicator of potential biological impacts: based on the intensity of the effect (enrichment based on sigma level, and concentrations exceeding ERL or ERM), Zn>Ni>Pb; in regard to the number of samples, Pb>Zn>Ni. Most of the samples with potential benthic effects due to high concentrations of Ni are in the Back River and Baltimore Harbor Zones of Influence. From the preliminary toxicology work done in Year 25, enrichments of Zn and Pb are probably the most significant in influencing benthic communities as a result of HMI operations. Pb enriched samples are associated with the three local sources HMI, Baltimore Harbor and Back River. Zn on the other hand shows enrichment from Baltimore Harbor and HMI. The two sampling sites in Back River showed no enrichment for Zn. Material from the Harbor did not influence the sediments in the HMI zone.

In the area affected by facility operations, Pb and Zn showed enriched levels, but less, both in terms of sigma levels and spatial extent, than previous years. This reduced impact may be due to the limited operations activity at the HMI facility during the monitoring year. Material placed in the North Cell was approximately half of the volume placed during the previous year. Discharges at > 10 mgd from the North Cell were done in two distinct periods, corresponding to material placement. The first period was well before the fall 2008 sampling, and the second at the time of the spring cruise. During the nine months between the major discharge periods, there were sporadic discharges at < 10 mgd, but none immediately prior to the sampling cruises. Total discharge from the North Cell was approximately a tenth of the volume from the previous monitoring year and most of the discharge was through Spillway 009. Given the amount and timing of the discharges, it is not surprising to see little effect in the sediments adjacent to the spillways for the North Cell.

Total discharge from the South Cell was 97 million gallons, approximately half of the volume discharged during the previous year. Discharge was over two discrete periods: July-August, 2008 and January-February, 2009. Daily discharge rates were very low (< 5 mgd). Due to conditions previously discussed, periods of low flow can result in the mobilization of certain metals, which are reflected in the enrichment of the exterior sediments. Although these conditions existed in the South Cell, the low volume of effluent and timing of the discharge may have resulted in the lower levels of enrichment of Pb and Zn observed in sediments adjacent to the spillway.

Although this year’s monitoring documents a drop in enrichment of Pb and Zn around the HMI facility, the elevated levels remain above background levels. These persistent enriched levels indicate a need for continued monitoring. The metal levels in the exterior sediments continued to show a consistent response to the operations of the facility. Currently, the facility is actively accepting material in the North Cell, but the amount of material accepted is declining as the facility reaches its capacity (in order to maximize the remaining capacity additional material will be accepted up to December 31, 2009). Consequently, the volume of effluent is declining, but crust management and dewatering operations will increase which may lead to higher metal levels in the effluent. Exposure of dredged material to the air is likely to result in the mobilization of metals associated with those sediments and ultimately the metals are released in the effluent. Continued monitoring is needed in order to document the effect that operations has on the exterior environment (for future project design), and to assess the effectiveness of any amelioration protocol implemented by MES and MPA to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MES and MPA is important in this endeavor.

In order to assess the potential influence of Baltimore Harbor on the HMI exterior sediments better, the transect of sampling sites, originating at the mouth of the Patapsco River leading out from the Baltimore Harbor should be maintained, at least temporarily. Further, since the South Cell has been converted to an upland wetlands, the addition sample locations near the discharge point should be maintained to assess this new operation of the facility as part of the on-going monitoring program.

In regard to discharge monitoring from the spillways, which follows the discharge permit, a re-evaluation of the sampling frequency and protocols is needed if comparison of the data with historical records is considered important.

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APPENDIX 1A: HMI GROUNDWATER MONITORING WELLS 2008 (PROJECT II)

INTRODUCTION

Groundwater samples from six wells were collected in June and December 2008, as part of the on-going HMI external monitoring effort and as a continuation of the groundwater studies completed in 2003 (URS, 2003), and 2005 (Hill, 2005). The number of wells was equally divided between the North and South Cells as seen in Figure 1-17: North Cell 2A, 4A & 6A; South Cell 8A, 10A & 12A. These wells were part of 34 wells installed around the facility dike between 2001 and February 2002 for a groundwater study. The purpose of the study was to identify 1) the direction and rate of groundwater flow from the facility to the surrounding Bay, and 2) physical and chemical reactions controlling the mobilization of contaminants from the facility. The 6 wells (*i.e.,* 'A' wells) were installed to depths to monitor the shallow saturated groundwater zone (URS, 2003); depths of the wells range from -4 ft to -16.6 ft North American Vertical Datum of 1988 (NAVD88) (Table 1-4).

Table 1-4. Elevation and depth of well data for the HMI Wells sampled for groundwater monitoring. Data is from URS, 2003. Elevation referenced to NAVD88 datum which is approximately mean sea level.

Well ID	Date Installed	Elevation, ft (Top of well casing)	Depth of well, ft	Elevation, ft (Bottom of well)
2A	12/12/2001	19.28	35	-15.72
4A	1/6/2002	21.48	30	-8.52
6A	1/4/2002	21.41	30	-8.59
8A	12/19/2001	21.07	30	-8.93
10A	12/18/2001	20.98	25	-4.02
12A	12/15/2001	13.60	25	-11.40

The South Cell has been converted to its' intentional use as an upland wetlands, and has not received any "new" dredged material since 1990. The North Cell on the other hand is actively receiving material and will continue to do so until December 31, 2009. The following summarizes the data based on the interpretive methods detailed in the 2005 HMI well study report (Hill, 2005).

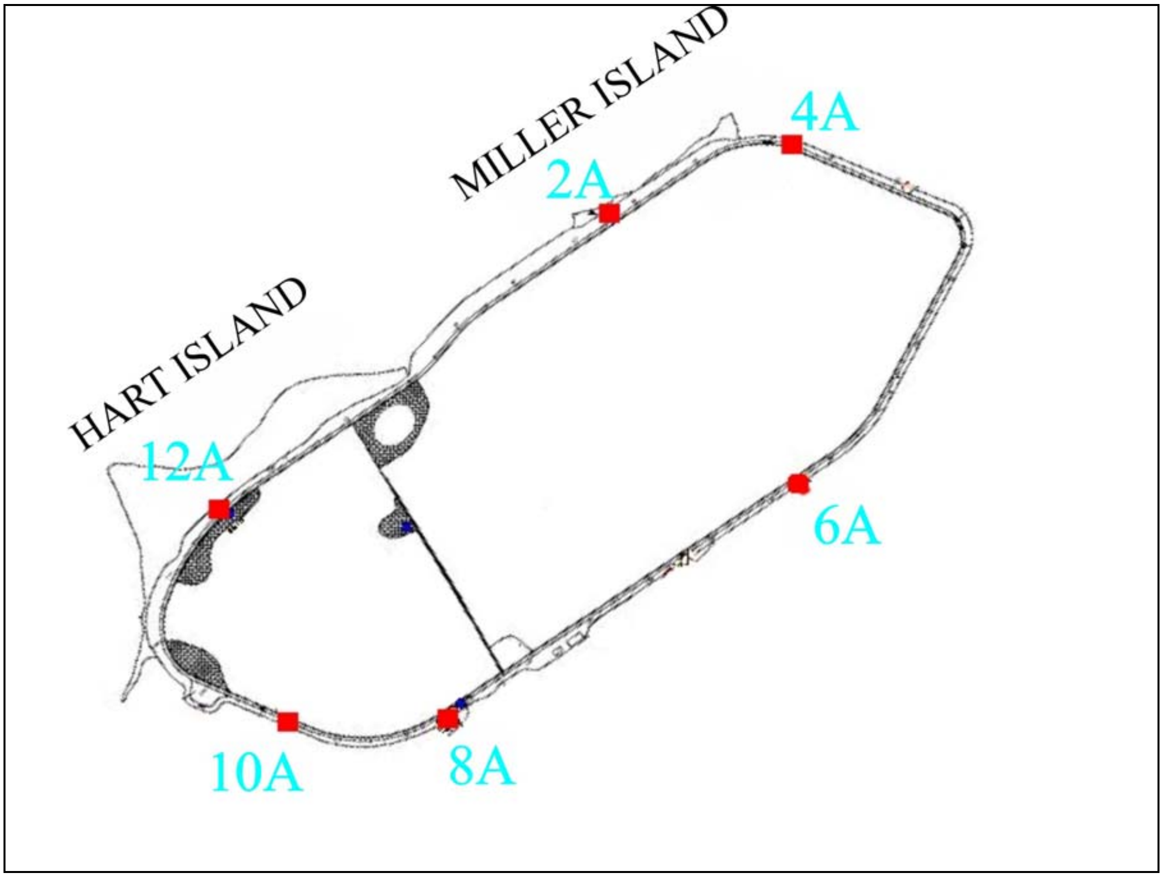

Figure 1-17. Groundwater sampling wells locations.

SUMMARY OF WELL DATA

All of the wells are anoxic or hypoxic, with dissolved oxygen (DO) levels less than 1.01 mg/l. Some of the levels may be the result of sulfide interference with the DO probe. DO levels have been consistently low since 2006 (Figure 1-18 and Figure 1-19).

Due to limitations in the instrumentation used to get *in situ* measurements, no sulfide measurements were taken. These measurements are not necessary, but their absence limits the information on the degree of anoxia and the processes occurring. URS (2003) found that sulfide concentrations in HMI groundwater were consistently at or below detection. The low sulfide levels were due to there being precipitated out of solution and thus could not be detected by the instruments used. Dissolved sulfide binds with many metals and restricts their mobility.

The dominant form of nitrogen in all of the wells appears to be ammonium, since nitrate is below detection. Nitrate is used preferentially once oxygen is consumed as the primary oxidant, and ammonium ion is a by-product of anaerobic respiration. This is consistent with the anoxic/hypoxic nature of the groundwater.

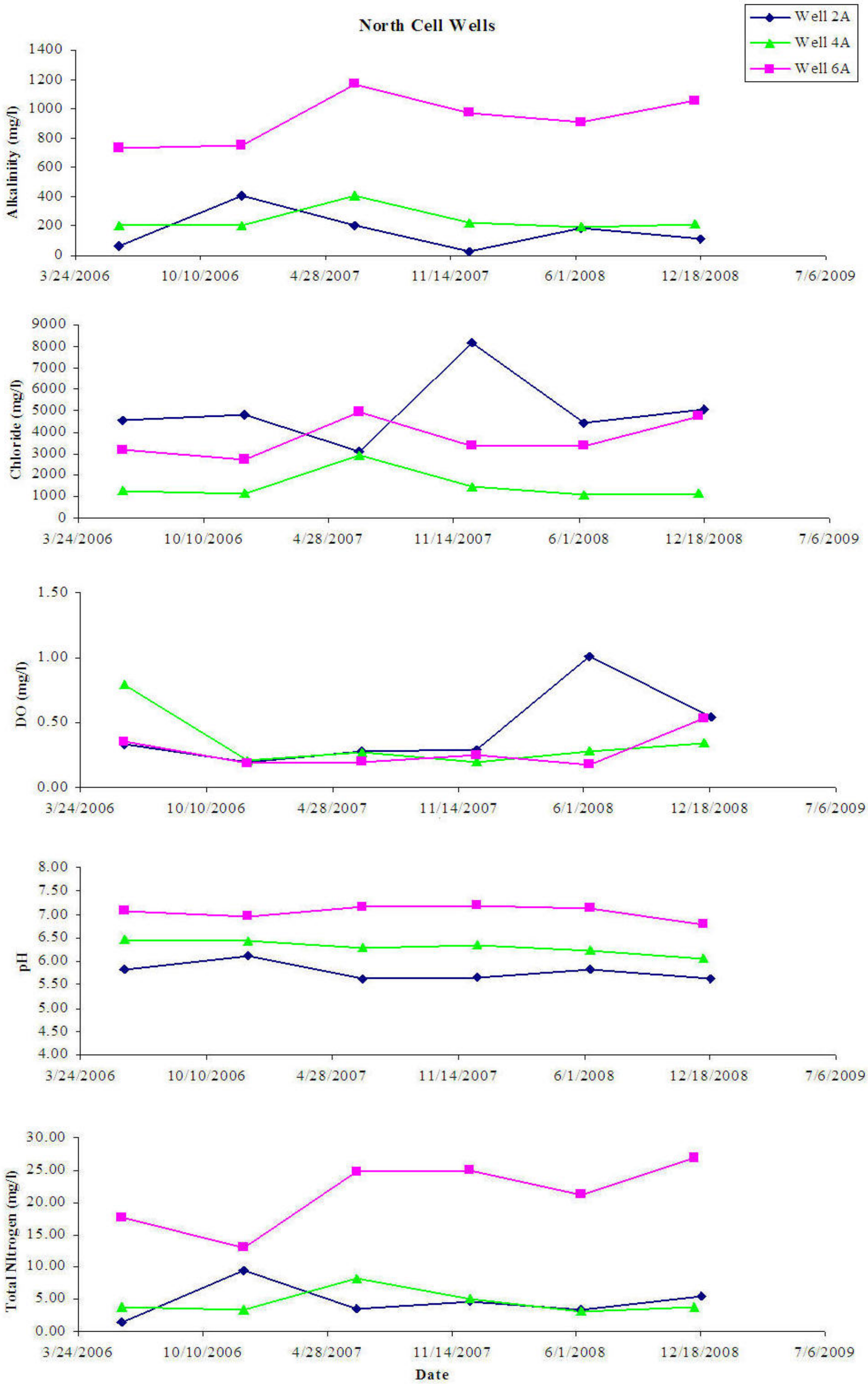

Figure 1-18. Trend plots for specific parameters measured in groundwater samples collected since 2006 from North Cell wells.

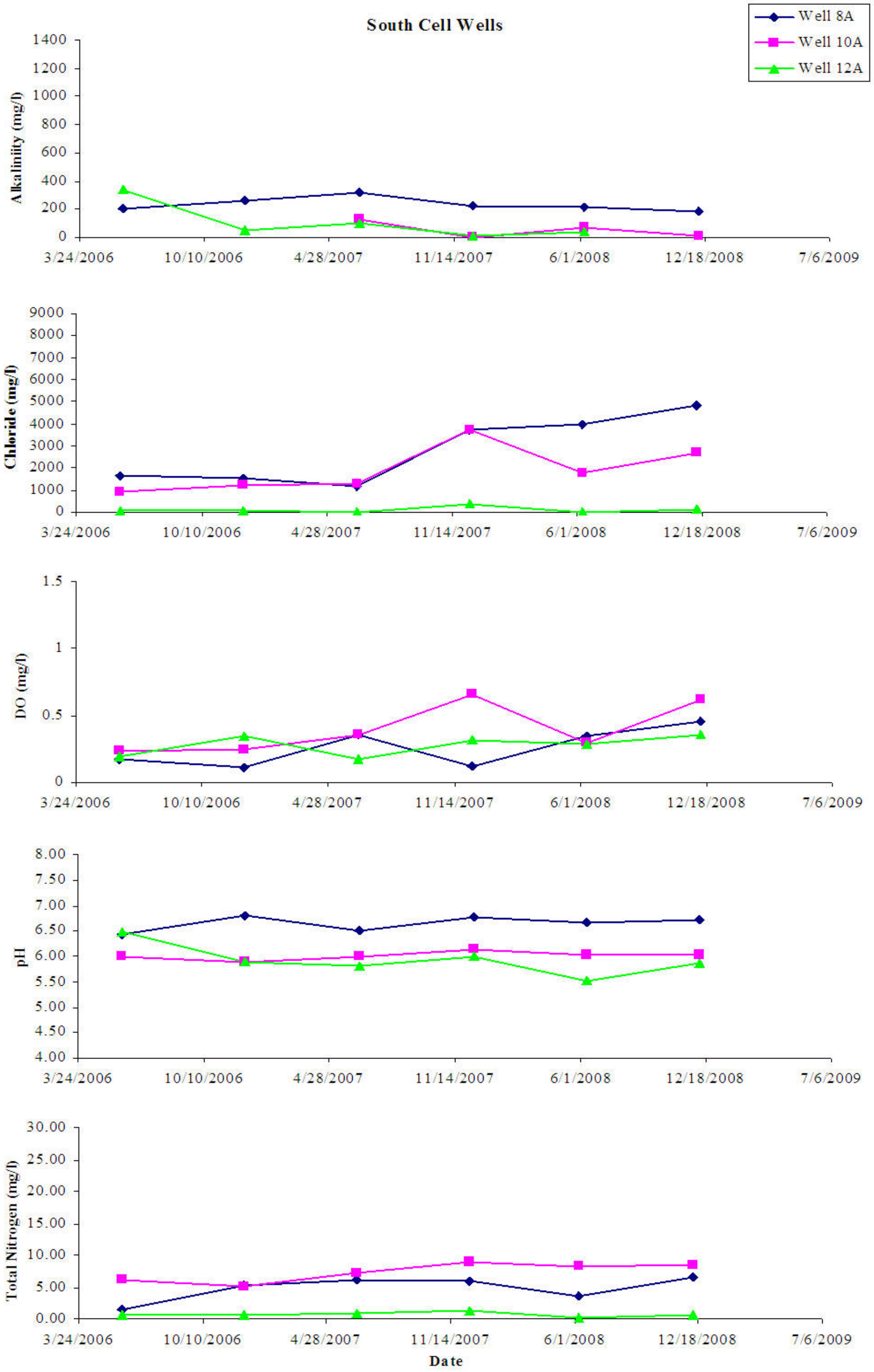

Figure 1-19. Trend plots for specific parameters measured in groundwater samples collected since 2006 from South Cell wells.

North Cell Wells 2A, 4A and 6A

Based on the depletion in sulfate in comparison to predicted concentrations, the groundwater shows a reducing environment in the North Cell wells for both sampling events except for Well 4A, where the June 2008 sampling yielded a positive excess sulfate value, while the chloride remained the same. The predicted levels are calculated from the chloride concentration based on conservative mixing between rainwater and seawater. Figure 1-20 shows the chloride (Cl^-) concentration as a function of the amount of sulfate either removed from the water as a result of sulfate reduction (– excess sulfate) or added to the water as the result of sulfide oxidation in the sediment solids (+ excess sulfate).

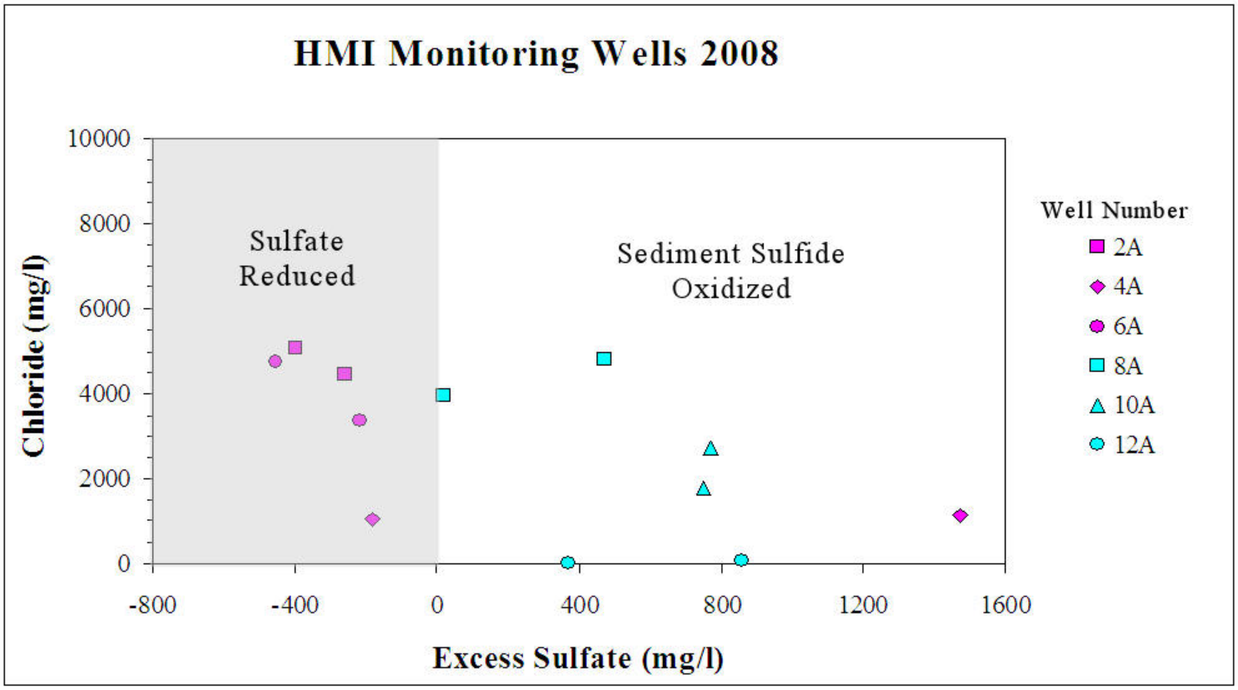

Figure 1-20. Groundwater chloride concentrations as a function of excess sulfate (the difference of the measured sulfate concentrations minus the predicted concentrations).

Alkalinity concentrations and pH in Well 6A are higher than the other two wells in the North Cell and the wells in the South Cell (Figure 1-18 and Figure 1-19). The higher concentrations suggest that the alkalinity in this well had not been neutralized by acid production. The pH values for Well 6A also are higher than both the North and South Cell wells

With the exception of higher Fe in Well 2A, most metal concentrations are generally lower in the North Cell wells since they are not leached from the sediment by acid or change in oxidation state (Figure 1-21). Acid produced by sediment oxidation can dissolve mineral species and the change in oxidation state that produced the acid can destabilize minerals and make them more soluble. Most of the trace metals measured [except As] were near or below the detection limits.

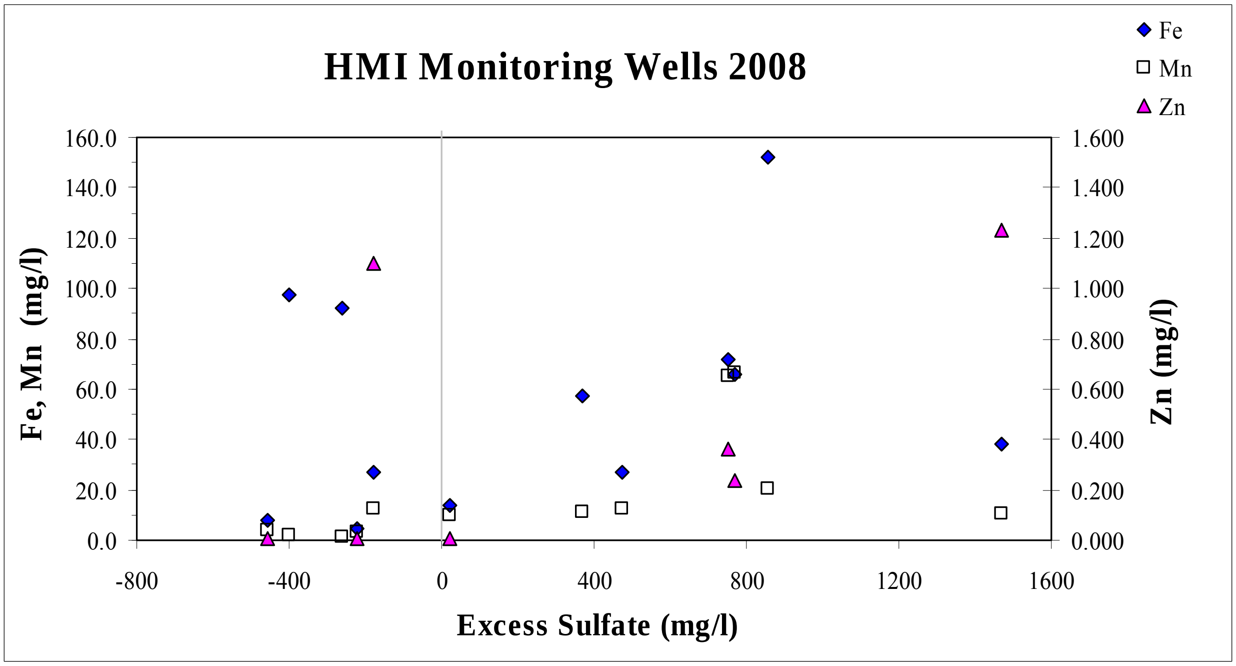

Figure 1-21. Fe, Mn and Zn concentrations as a function of excess sulfate. Note samples below detection limits are not shown.

The major cations are near the predicted conservative mixing concentrations. Since acid generally is not being generated, there is minimum mineral dissolution (specifically calcium carbonate) or ion exchange. Hydrogen ion from acid is preferentially bound on ion exchange sites in the sediment releasing other adsorped cations (*e.g.* K+). The linear relation in the positive excess sulfate region is due to the process of acid production being directly related to neutralization and ion exchange (Figure 1-22).

Total dissolved nitrogen (as ammonium) on average, is about three times higher in Well 6A compared to the other wells, both in North and South Cells. This is due to the reducing processes that dominate these groundwaters. Ammonium is produced as a by-product of anaerobic respiration. Since the water in this well has not undergone an oxidative stage, ammonium is higher.

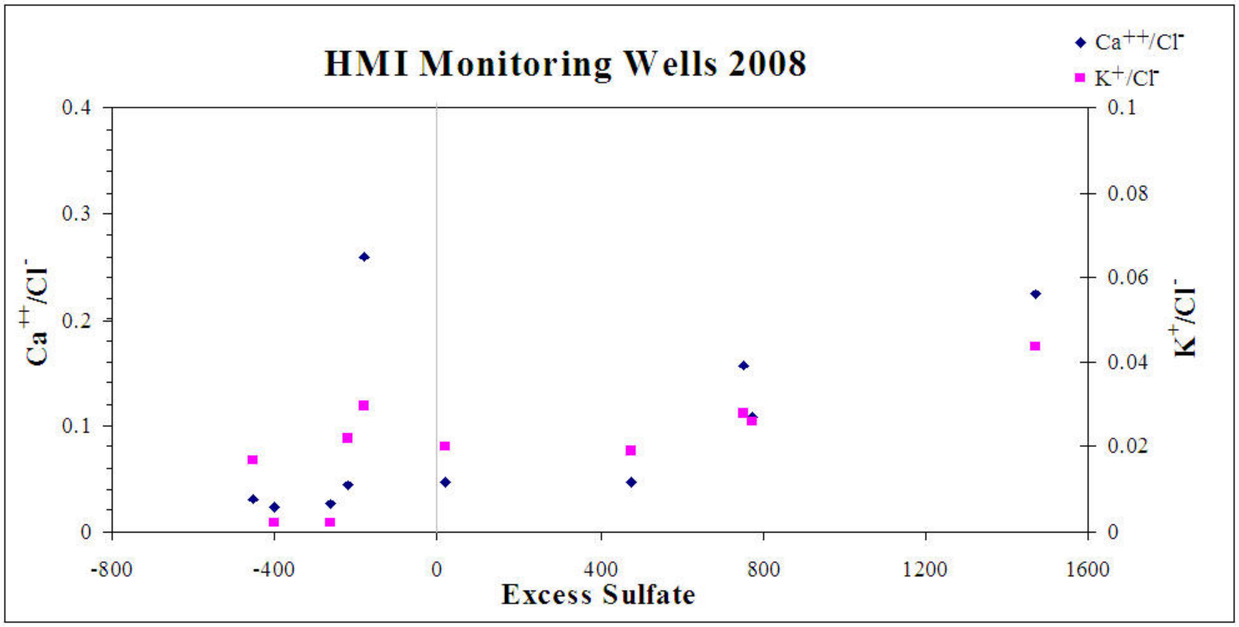

Figure 1-22. The ratios of K^+/Cl^- and Ca^{++}/Cl^- as a function of excess sulfate. For reference, the ratio for both of these cations in seawater is ~0.02. The ratios for Well 12A plotted in the + excess sulfate side of the graph, but way off the chart: the ratios were very high due to the extremely low chloride concentrations (Ca^{++}/Cl^- = 3.5 and 1.3; K^+/Cl^- = 0.93 and 0.2, for June and December samplings, respectively).

The groundwater from the North Cell wells overall exhibit behavior typical of anoxic pore waters that have minimum exposure to oxidized sediment. The groundwater is replenished with water from dredged material input which maintains the anaerobic state of the sediments in these areas of the North Cell. Well 6A, in particular, stands out from the other two North Cell wells. This well consistently had the lowest DO and Oxidation Reduction Potential (ORP) (Eh) indicating constant anoxic environment. This well also had the highest levels of alkalinity, pH, and total nitrogen (assumed to be mostly ammonia). The high alkalinity may be a result of algal activity in the ponds created in the north cell, producing high pH water, which eventually percolated into the shallow groundwater at Well 6A. This well is near Spillway 009 where effluent water is channeled for discharge.

South Cell Wells 8A, 10A & 12A

The waters in the South Cell wells have been exposed to oxidized sediments, thus the higher levels of excess sulfate (Figure 1-20). Total nitrogen (ammonium) and alkalinity are lower, while metals and cations are higher than in the waters in the North Cell wells. Chloride concentrations generally are low, especially in Well 12A where chloride was less than 100 mg/l and salinity measured less than 1 ppt.

Based on the above, rainwater appears to be a major source of water to these wells. The waters in Well 12A, in particular, appear to be almost entirely fresh water. The sediments in the

South Cell are, to some extent, exposed to the atmosphere. The exposure of the sediment is providing the oxygen to oxidize the sulfide in the sediments that are the source of water for the wells. The entire South Cell has on-going sediment oxidation.

PROCESSES OPERATING IN HMI GROUNDWATER

Figure 1-23 shows a hypothetical cross section of HMI at the South Cell. Hydrodynamically, there are five areas to consider:

1. *The surface sediments of the interior of the cell.* Here if the sediment is kept inundated the sediment and the associate pore fluids would be anoxic and would have the characteristics of normal Bay sediments. This is the situation in the North Cell. However in the South Cell circumstance, the material for the most part is sub-areal with rain water being the primary source of water to the system. The occluded water native to the dredged material is diluted by the fresh rain water; this lowers the dissolved load derived from dilution of sea water in the Bay waters. Since the hydrated sediment is exposed to atmospheric oxygen, aerobic process is in operation. One of the most significant reactions is the oxidation of the naturally occurring sulfide minerals (primarily iron monosulfides and pyrite) that produces sulfuric acid. The acidified waters have sulfate concentrations in excess of conservative mixing. The oxidation of the sulfide minerals significantly increases the levels of Fe and Mn, and the free acid can react with the sediment to release other metals and acid soluble nutrients and trace organic compounds. This acidified water is either entrained in surface water run off or infiltrates into the sediment in the dike forming the groundwater flow through the dike. The surface water is monitored and controlled by MES under a MDE issued permit.

2. *Dredged sediment in the dike.* When the acidified waters infiltrate into the dredged sediment they enter an organic rich environment that is isolated from the atmosphere. Here several processes occur: the acid is neutralized by naturally occurring material such as shell material which contains calcium carbonate; acid and metals are bound by ion exchange processes; the reduction in acidity causes precipitation of insoluble metal compounds (with anions such as phosphate, and carbonate), and; reduction occurs which removes oxygen and changes the environmental conditions waters are in. The flow of water through the dike is relatively fast compared to the rate of reduction since the concentrations of sulfate are high relative to conservative mixing (this is shown as the positive Excess Sulfate in the preceding figures). If strongly reducing conditions existed all of the sulfate would be reduced and the sulfide produced would be significantly removed by sulfide mineral formation as in the North Cell.

3. *Movement through the dike walls.* The dike walls are made of clean sands, thus are relatively inert; however they act as a mechanical filter. As a filter the dike retains the fine sediment placed in the dike, and removes the precipitates that form as the water reacts in the contained sediment. Eventually as with any filter, it would be expected that

the filter (i.e. the dike walls) will become plugged as material is trapped along the flow lines. This is the area where the sampling wells are located. The groundwaters sampled at this point reflect changes in the water chemistry resulting from transport through the three zones outlined above.

4. *Mixing with Bay water*. As the groundwater travels the dike as a result of the hydraulic gradient it will encounter and mix with Bay water within the dike wall. The water from the dike is more dilute than bay water so there will be some degree of floating, or riding over, of the less dense dike water on top of the more saline water Bay water. The Bay water is aerated and slightly alkaline. This water will react with the dike water oxidizing the reduced water and precipitating iron oxy-hydroxides and other redox sensitive species. These precipitates are effective in scavenging trace metals and phosphate.

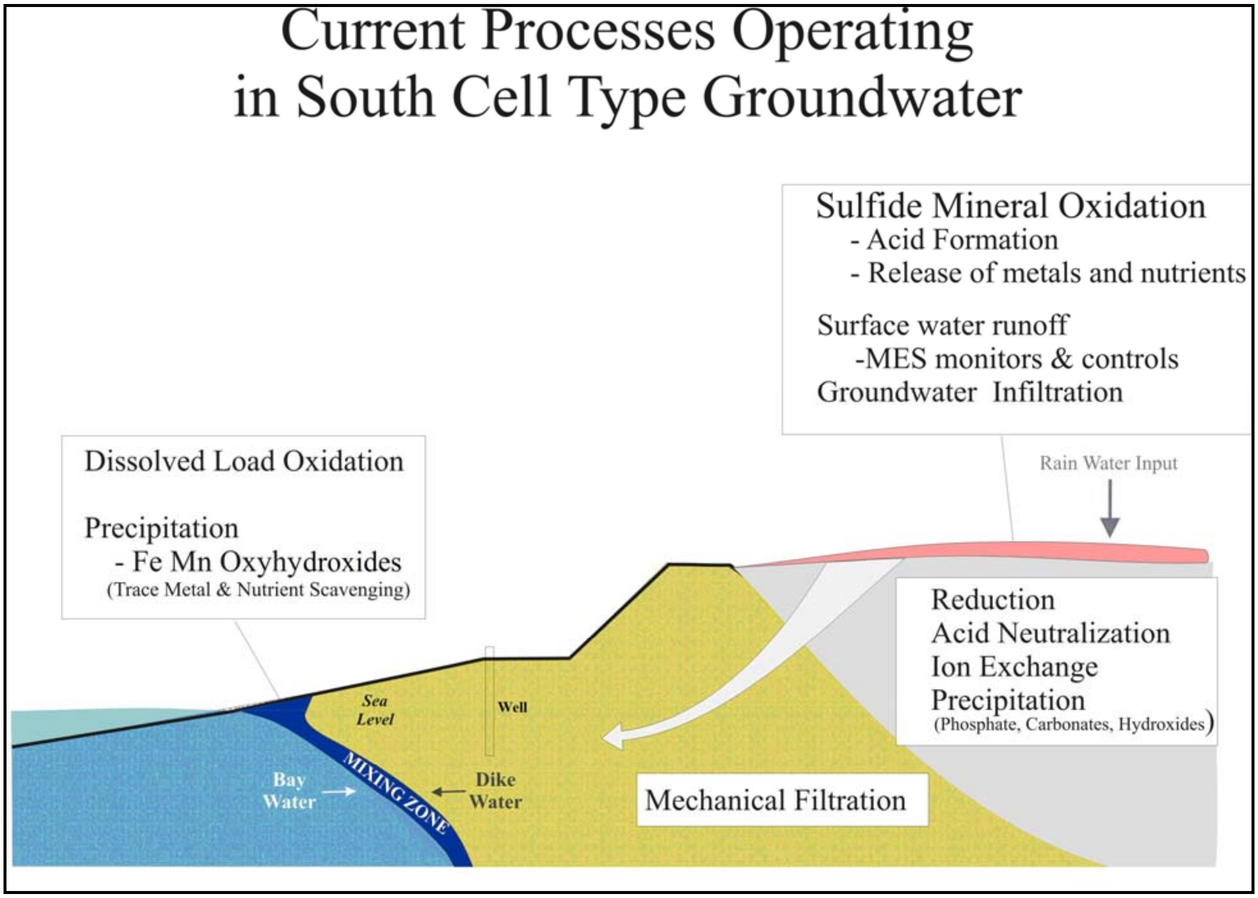

Figure 1-23. Schematic presentation of the processes which produce the groundwater similar to those found in the South Cell wells.

As noted the sampling wells are located in the sandy matrix of the dike walls which act as a filter for the groundwater. Groundwaters are anaerobic for all of the sampling wells; the South Cell type wells have undergone an initial oxidation stage that the North Cell has not. However, it should be noted that the behavior of measured parameters in each well within the two cells is slightly different reflecting the heterogeneous material contained in the dike wall and source material that affected transport rates and chemistry of the groundwaters.

Table 1-5 is a summary of the trace metal data for the groundwaters sampled in 2008; listing the number of samples, the number below detection, the maximum and minimum concentration and the EPA Maximum Concentration Level in drinking water (MCL) (U.S. EPA, 2002). For the most part, the concentrations of the metals are low.

Table 1-5. Monitoring Wells Trace Metal Analyses for 2008 (two sampling periods). Values in mg/l, unless otherwise indicated.

North Cell Wells						
	n	**n<dl**	**dl**	**Min**	**Max**	**MCL**
Al	6	6	0.050	0.00	0.00	0.05 - 0.2*
As	6	0	0.010	0.008	0.03	0.010
Cd	6	6	0.002	0.00	0.00	0.005
Cr (total)	6	6	0.005	0.00	0.00	0.100
Cu	6	6	0.005	0.00	0.00	1.300
Fe	6	0		4.93	97.70	0.300*
Pb	6	6	0.010	0.00	0.00	0.00
Mn	6	0		1.63	12.70	0.050*
Zn	6	2	0.005	0.007	1.23	5.00*
Ag	6	6	0.001	0.00	0.00	0.100*
South Cell Wells						
	n	**n<dl**	**dl**	**Min**	**Max**	**MCL**
Al	6	6	0.050	0.00	0.00	0.05 - 0.2*
As	6	0	0.010	0.01	0.02	0.010
Cd	6	6	0.002	0.00	0.00	0.005
Cr (total)	6	3	0.005	0.01	0.02	0.100
Cu	6	6	0.005	0.00	0.00	1.300
Fe	6	0		13.70	152.00	0.300*
Pb	6	6	0.010	0.00	0.00	0.00
Mn	6	0		9.58	66.40	0.050*
Zn	6	3	0.005	0.01	0.36	5.00*
Ag	6	6	0.001	0.00	0.00	0.010*

Note:
MCL – EPA Maximum Concentration Levels for Inorganics in Drinking Water
*Values followed by * are Secondary Maximum Concentration Levels (SMCL)*
North Cell Wells – Maintained Pore water behavior
South Cell Wells – Oxidation at Surface followed by neutralization and partial reduction

The North Cell samples are the lowest with all of the metals except Fe, Mn, and As below detection. The South Cell has more metals at detectable concentrations; however they are still low with respect to the MCL. Fe and Mn are the only metals with concentration that exceed the MCL; these are not considered a health risk but affect the taste and quality of the water. These metals precipitate from solution in aerobic conditions, so as the water mixes with Bay water further down the flow line these metals will precipitate as metal oxyhydroxides. The metal rich precipitate will cement the sands and make the dike more impermeable with time.

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URS Corporation, 2003, Draft Groundwater Investigation Report December 2001 - June 2003 Hart-Miller Island Dredged Material Containment Facility Baltimore County, MD. Report Prepared For MD Environmental Service.

U.S. EPA, 2002, National Primary Drinking Water Regulations, EPA 816-F-02-013 (July 2002), Table of contaminants and MCLs downloaded from U.S. EPA website: http://permanent.access.gpo.gov/lps21800/www.epa.gov/safewater/mcl.html.

APPENDIX 2: BENTHIC COMMUNITY STUDIES (PROJECT III)

(September 2008 – August 2009)

Technical Report

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January 2010

EXECUTIVE SUMMARY

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI-DMCF) was studied for the twenty-seventh consecutive year under Project III of the HMI Exterior Monitoring Program. Benthic communities living close to the facility [Nearfield, South Cell Exterior Monitoring (formerly called South Cell Restoration Baseline), and Back River/Hawk Cove stations] were compared to communities located at some distance from the facility (Reference Stations). Water quality parameters, including dissolved oxygen concentrations, salinity, temperature, pH, conductivity, and secchi depth were measured *in situ.* Twenty-two stations (12 Nearfield, 5 Reference, 2 Back River/Hawk Cove, and 3 South Cell Exterior Monitoring stations) were sampled on September 10, 2008 and on April 17, 2009. In Year 27 two established Nearfield stations were dropped (MDE-24 and MDE-35) but three new Nearfield stations were added (MDE-11, MDE-15, MDE-45). In addition two new Reference stations were added (MDE-50 and MDE-51) and one established Back River Station was dropped (MDE-28).

A total of 36 benthic macroinvertebrate taxa were identified during Year 27. Several taxa were clearly dominant. The worms *Marenzelleria viridis, Heteromastus filiformis,* and Naididae sp.[3], the clam *Rangia cuneata,* and the arthropods *Leptocheirus plumulosus* and *Apocorophium lacustre* were among the dominant taxa on both sampling dates. Taxa abundance varied greatly for certain taxa between the two seasons in Year 27 (September 2008 and April 2009). The clam *Macoma balthica* increased from the seventeenth most abundant taxa in the fall to the fifth most abundant taxa in the spring, while the worm *Streblospio benedicti* decreased from the fifth most abundant to the fifteenth most abundant taxa. Polychaete taxa richness was similar for the two cruises. Total abundance (excluding Bryozoa and Copepoda) was higher at most stations in April 2009 than September 2008, primarily due to the spring recruitment of the worms Naididae sp. and *M. viridis*.

Species diversity was examined using the Shannon-Wiener diversity index (SWDI). Diversity was higher in September 2008 than in April 2009 at all stations. The proportion of pollution sensitive taxa (PSTA) and pollution indicative taxa (PITA) was calculated for both cruises. The PSTA percentage was higher in April, while PITA percentages were lower in April, due to the large recruitment of the pollution sensitive species *Marenzelleria viridis*.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI, Weisberg et al. 1997, Llanso, 2002), a multi-metric index of biotic condition that evaluates summer populations (July 15th to September 30th timeframe) of benthic macroinvertebrates, was calculated for all stations sampled in September 2008. Overall, the Year 27 B-IBI scores increased from Year 26. Twenty one stations met or exceeded the benchmark criteria of 3.0, and only one station (Back River station MDE-27) failed to meet the benchmark.

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[3] Tubificidae sp. is now described as Naididae sp. due to a reclassification brought about by the International Commission on Zoological Nomenclature. (Case 3305)

The Friedman's nonparametric ANOVA test found significant differences in the benthic macroinvertebrate communities among the four station types. The B-IBI scores supported this result. This was primarily due to impaired infauna assemblages of Back River stations, specifically MDE-27. This station is subject to heavy sediment loading and relatively fresher waters than experienced at the other stations. In general, the cluster analyses indicated that Back River sediment loading was influencing most of the stations around HMI, but there was no indication of benthic community impact resulting from Back River (except for MDE-27) or HMI dredging operations.

INTRODUCTION

Annual dredging of the shipping channels leading to the Port of Baltimore is necessary to maintain safe navigation. An average of 4-5 million cubic yards of Bay sediments is dredged each year to maintain access to the Port. This requires the State of Maryland to develop environmentally responsible placement sites for dredged material. In 1981, the Hart-Miller Island Dredged Material Containment Facility (HMI-DMCF) was constructed to accommodate the dredged material management needs for the Port of Baltimore and specifically the need to manage contaminated sediments dredged from Baltimore's Inner Harbor.

HMI is a 1,140-acre artificial island surrounded by a 29,000-foot long dike constructed along the historical footprints of Hart and Miller Islands at the mouth of the Back River. A series of four spillways are located around the facility’s perimeter that discharge excess water released from on-site dredged material disposal operations.

As part of the environmental permitting process for dredged material containment facilities, an exterior monitoring program was developed to assess environmental impacts associated with HMI. Various agencies have worked together since the inception of this program to monitor for environmental impacts resulting from facility construction and operation. Studies were completed prior to and during the early construction period to determine baseline environmental conditions in the HMI vicinity. The results of post-construction monitoring have then been compared to this baseline, as well as to inter-seasonal and inter-annual data. Benthic monitoring is no longer a permit requirement, but is continued voluntarily by the Maryland Port Administration (MPA). Since HMI will no longer receive dredged material as of December 31, 2009, Year 28 will represent the culmination of monitoring data collected during 28 years of dredged disposal operations, beginning with the pre-operational phase in 1981. Since Year 17, the Maryland Department of the Environment (MDE) has been responsible for all aspects of benthic community monitoring. Post closure monitoring is expected to begin in Year 28 and continue through at least Year 30.

The goals of the Year 27 benthic community monitoring were:

- To monitor the benthic community condition; using, among other analytical tools, the Chesapeake Bay Benthic Index of Biological Integrity (B-IBI; Llanso 2002), and to compare the results at Nearfield stations to present local reference conditions;

- To monitor other potential sources of contamination to the HMI region by sampling transects along the mouth of Back River;

- To facilitate trend analysis by providing data of high quality for comparison with HMI monitoring studies over the operational phase of the project; and,

- To monitor benthic community conditions in a transect leading away from the South Cell Spillway 003. This will help the State to assess any environmental effects resulting from the South Cell closure and restoration.

METHODS AND MATERIALS

MDE staff collected all macroinvertebrate and water quality samples in Year 27. Field sampling cruises were conducted on board the Maryland Department of Natural Resources vessel "*R/V Kerhin*". Twenty-two fixed benthic stations were monitored during both fall and spring cruises (Table 2-1; Figure 2-1). Environmental parameters recorded at the time of sample collection are included in Tables 2-2 through 2-5.

Table 2-1. Sampling stations (latitudes and longitudes in degrees, decimal minutes), 7-digit codes of stations used for Year 27 benthic community monitoring, and predominant sediment type at each station for September and April.

Station #	Latitude	Longitude	Sediment Type		Maryland 7-Digit Station Designation
			Fall	Spring	
Nearfield Stations					
MDE-01	39° 15.3948	-76° 20.5680	Shell	Sand	XIF5505
MDE-03	39° 15.5436	-76° 19.9026	Shell	Sand	XIG5699
MDE-07	39° 15.0618	-76° 20.3406	Silt/clay	Sand	XIF5302
MDE-09	39° 14.7618	-76° 20.5842	Shell	Silt/clay	XIF4806
MDE-11	39° 24.072	-76° 33.504	Silt/clay	Silt/clay	XIG4501
MDE_15	39° 24.281	-76° 34.921	Silt/clay	Sand	XIF4609
MDE-16	39° 14.5368	-76° 21.4494	Silt/clay	Silt/clay	XIF4615
MDE-17	39° 14.1690	-76° 21.1860	Shell	Silt/clay	XIF4285
MDE-19	39° 14.1732	-76° 22.1508	Silt/clay	Silt/clay	XIF4221
MDE-33	39° 15.9702	-76° 20.8374	Sand	Sand	XIF6008
MDE-34	39° 15.7650	-76° 20.5392	Sand	Sand	XIF5805
MDE-45	39° 24. 533	-76° 35. 423	Silt/clay	Silt/clay	N/A
Reference Stations					
MDE-13	39° 13.5102	-76° 20.6028	Silt/clay	Silt/clay	XIG3506
MDE-22	39° 13.1934	-76° 22.4658	Silt/clay	Silt/clay	XIF3224
MDE-36	39° 17.4768	-76° 18.9480	Sand	Silt/clay	XIG7589
MDE-50	39° 25.237	-76° 34.611	Sand	Sand	N/A
MDE-51	39° 22.263	-76° 35.507	Silt/clay	Silt/clay	N/A
Back River/Hawk Cove Stations					
MDE-27	39° 14.5770	-76° 24.2112	Silt/clay	Silt/clay	XIF4642
MDE-30	39° 15.8502	-76° 22.5528	Silt/clay	Silt/clay	XIF5925
South Cell Exterior Monitoring Stations					
MDE-42	39° 13.8232	-76° 22.1432	Silt/clay	Silt/clay	XIF3879
MDE-43	39° 13.9385	-76° 21.4916	Silt/clay	Silt/clay	XIF3985
MDE-44	39° 14.4229	-76° 21.8376	Silt/clay	Silt/clay	XIF4482

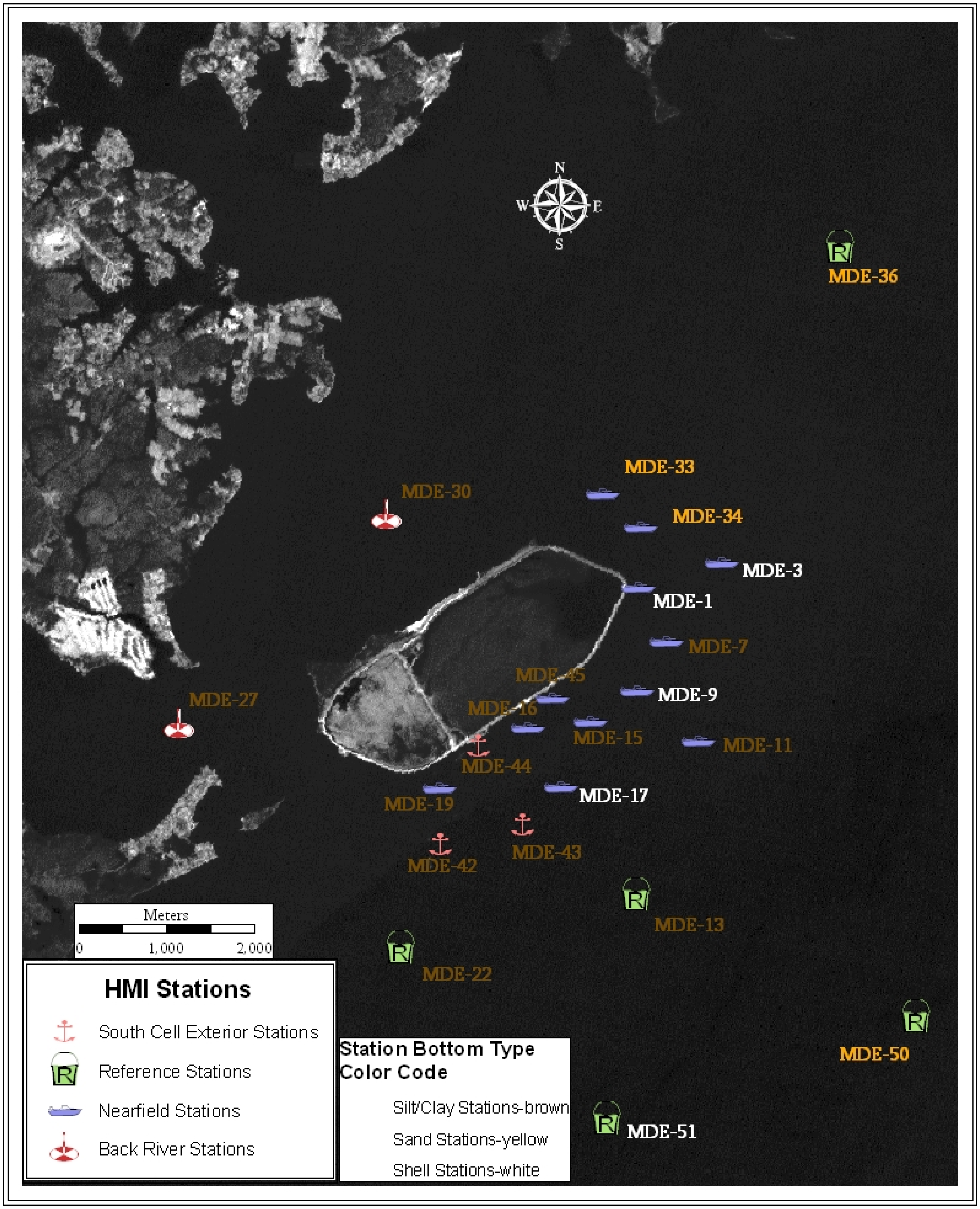

Figure 2-1. Year 27 benthic sampling stations for the HMI exterior monitoring program.

The majority of stations sampled during Year 26 were again sampled for Year 27. However, because of a change in the monitoring design stations MDE-24, 28, and 35 were not sampled; instead stations MDE-11, 15 and newly added stations MDE-45, 50, and 51 were sampled.[4] Stations were classified by location and dominant sediment type (Table 2-1). Stations were divided into four location groups (Nearfield stations, Reference stations, Back River/Hawk Cove stations, and South Cell Exterior Monitoring stations) and five sediment types (silt/clay, shell, detritus, gravel, and sand). All benthic community stations coincided with stations sampled by the Maryland Geological Survey (MGS) for sediment analysis. All stations were located using a differential global positioning system (GPS) navigation unit.

Temperature, depth, salinity, pH, conductivity, and dissolved oxygen (DO) were measured *in situ* using a Hydrolab Surveyor 4a multi-parameter water quality meter in September 2008 and April 2009. Water quality parameters were measured at approximately 0.5 m (1.6 feet) below the surface and 0.5 m above the bottom. The secchi depth was measured at all stations during both seasons.

All macroinvertebrate samples were collected using a Ponar grab sampler, which collects approximately 0.05 m^2 (0.56 ft^2) of bottom substrate. Three replicate grab samples were collected at each station. A visual estimate of the substrate composition [percent contributions of detritus, gravel, shell, sand, and silt/clay (mud)] was made at each station (Table 2-2 and Table 2-4) and the dominant sediment type for each station was derived from these percentages. Each replicate was individually rinsed through a 0.5 mm sieve on board the vessel and preserved in a solution of 10 percent formalin and Bay water, with Rose Bengal dye added to stain the benthic organisms.

In the laboratory, each benthic macroinvertebrate replicate was placed into a 0.5 mm sieve and rinsed to remove field preservative and sediment. Organisms were sorted from the remaining debris, separated into vials by major taxonomic groups, and preserved in 70 percent ethanol. All laboratory staff were required to achieve a minimum baseline sorting efficiency of 95 percent and quality control checks were performed for every sample to ensure a minimum 90 percent recovery of all organisms in a replicate sample.

Most organisms were identified to the lowest practical taxon using a stereo dissecting microscope. The number of specimens for each taxon collected in each replicate (raw data) is presented in the *Year 27 Data Report.* Members of the insect family Chironomidae (midges) were identified using methods similar to Llanso (2002). Where applicable, chironomids were slide mounted and identified to the lowest practical taxon using a binocular compound microscope. In cases where an animal was fragmented, only the head portion was counted as an individual taxon. All other body fragments were discarded. Individuals of the most common clam species (*Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*) were measured to the nearest millimeter. An independent taxonomist verified 10 percent of all samples identified.

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[4] For a detailed explanation of the new sampling design see "Scientific Rationale for Relocating Hart-Miller Island Exterior Monitoring Stations in Advance of Facility Closure"

Six major measures of benthic community condition were examined, including: total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa, the Shannon-Wiener diversity index (SWDI), taxa richness, and total abundance of all taxa (excluding Nematoda, Copepoda, and Bryozoa). Four of these measures (total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa and SWDI) were used to calculate the B-IBI for September 2008. The B-IBI is a multi-metric index of biotic integrity used to determine if benthic populations in different areas of the Chesapeake Bay are stressed (Llanso 2002). The B-IBI has not been calibrated for periods outside the summer index period (July 15 through September 30) and, thus, was not used with the April 2009 data. In addition to the above metrics, the numerically dominant taxa during each season and the length frequency distributions of the three most common clams (*R. cuneata*, *M. balthica*, and *M. mitchelli*) were examined.

Abundance measures were calculated based on the average abundance of each taxon from the three replicate samples collected at each station. Total abundance was calculated as the average abundance of epifaunal and infaunal organisms per square meter (#/m^2), excluding Bryozoa, which are colonial. Qualitative estimates (i.e., rare, common, or abundant) of the number of live bryozoan zooids are included in the *Year 27 Data Report*. Total infaunal abundance was calculated as the average abundance of infaunal organisms per square meter (#/m^2). Two different measures of total abundance were calculated because epifaunal organisms are not included in the calculation of the B-IBI (Ranasinghe et al. 1994).

For each station, data was converted to the base 2 logarithm in order to calculate the SWDI (H') (Pielou 1966). Taxa richness (number of taxa) was calculated for each station as the total number of taxa (infaunal and epifaunal) found in all three replicates combined. Infaunal taxa richness was calculated as the number of infaunal taxa found in all three replicates combined. The most abundant taxa at reference and monitoring stations were also determined.

To evaluate the numerical similarity of the infaunal abundances among the 22 stations, a single-linkage cluster analysis was performed on a Euclidean distance matrix comprised of station infaunal abundance values for all 22 stations. This analysis was performed separately for September 2008 and April 2009 data. Friedman's nonparametric test was used to analyze the differences of the 10 most abundant infaunal species among the Nearfield, Reference, Back River/Hawk Cove, and South Cell Exterior Monitoring stations for both September 2008 and April 2009. The statistical analyses were performed using SAS, Version 9.1 and Statistica, Version 6.0.

RESULTS AND DISCUSSION

Water Quality

Minimal variations between surface and bottom values for salinity, temperature, DO, conductivity, and pH values during the September 2008 cruise indicated that water column stratification was not a factor. However, during the April 2009 sample cruise widespread stratification was apparent. During this period conductivity differentials between surface and bottom readings were quite varied. For example, top and bottom water conductivity recorded at reference station MDE-51 located 2.8 miles southeast of HMI was 5,694 – 25,689 µmho/cm respectively for a difference of 19,995 µmho/cm as compared to reference station MDE-36 located within the influence of fresh water from the Gunpowder where top and bottom water conductivity recorded was 4,054 – 4,934 umho/cm respectively for a difference of 880 umho/cm, (Table 2-5).

Secchi depths were greater in September 2008 (Table 2-3, range=0.40 m-0.70 m, average = 0.52 m ± 0.08 m) than those in April 2009 (Table 2-5, range=0.25 m-0.60 m, average=0.42 m ± 0.07 m). Water quality and Secchi depth measurements provide a snapshot of the conditions prevalent at the time of sampling, but do not necessarily reflect the dominant conditions for the entire season.

The following discussion will be limited to bottom values for the first three parameters as bottom water quality measurements are most relevant to benthic macroinvertebrate health. In Year 27, bottom water temperatures did not vary much between stations during both sampling seasons. The September 2008 mean bottom water temperature (Table 2-3, mean=24.24°C ± 0.24°C, range= 23.86°C – 24.79°C) was 0.22ºC lower than the 22-year fall average of 24.46ºC. Bottom water temperatures were seasonably lower in April 2009 (Table 2-5) with a range of 7.77°C –10.49°C and an average of 9.09°C ± 0.68°C. April 2009 mean temperature was 2.71°C lower than the 11-year spring average of 11.80ºC.

The mean bottom DO concentration exceeded the water quality standard (5.0 ppm) to protect aquatic life (Maryland Code of Regulations COMAR) during both seasons. The September 2008 mean bottom DO (Table 2-3, mean=6.71 ppm ± 0.43 ppm, range=6.03 - 7.69 ppm) was 0.64 ppm lower than the 11-year fall average of 7.35 ppm. The April 2009 mean bottom DO (Table 2-5, mean=6.96 ppm ± 1.65 ppm, range=4.18 ppm - 9.73 ppm) was 3.12 ppm lower than the 11-year spring average of 10.08 ppm. Historically fall DO is 2.73 ppm lower than spring DO due to reduced oxygen solubility with elevated seasonal temperatures. This year there was only a 0.25 ppm difference in spring vs. fall mean bottom DO concentration. The lowest bottom DO value (4.18 ppm) occurred at Reference Station MDE-51 in April 2009. This reading was below the State standard of 5 ppm and was a consequence of atypical water column stratification observed in the upper Bay during this period (Table 2-5).

This region of the Bay typically ranges between the oligohaline (0.5 ppt – 5 ppt) and mesohaline (>5 ppt – 18 ppt) salinity regimes (Lippson and Lippson 1997). The 23-year mean bottom salinity is 6.17 ppt. Low mesohaline conditions (≥5-12 ppt.) were found during both the fall 2008 and the spring 2009 sampling seasons.

In Year 27 mean salinity values did not vary considerably between September (Table 2-3, mean=8.10 ppt, range = 7.07 ppt – 9.20 ppt) and April (Table 2-5, mean=7.82 ppt, range 2.70 ppt – 15.56 ppt). The fall salinity mean was within the historical salinity range (mean =6.17 ppt, ± 2.89 ppt). However, April 2009 mean salinity was much higher than the historical mean (3.16 ppt). In addition, spring within-season variability (± 3.02 ppt) was greater than historical within-season variability (mean variability = ± 0.56 ppt). This region of the Bay is subject to significant salinity fluctuations resulting from large inter-annual variation in rainfall in the watershed. In general, the Bay experiences relatively higher salinity values during the fall, because of dry summer conditions. In Year 27 the absence of the usual spring freshets, (i.e., lack of precipitation) resulted in salinity values that were atypically elevated, and also may have contributed to the high variability among stations because of a stratified water column that can occur during low rainfall conditions.

Table 2-2. Year 27 physical parameters measured *in situ* at all HMI stations on September 10, 2008.

						Wind Speed (knots)				Weather		Observed Bottom Sediment (%)				
MDE Station	**Time**	**Tide**	**Water Depth (m)**	**Wave Height (m)**	**Wind Direction**	**Min.**	**Max**	**Air Temp. (°C)**	**Cloud Cover (%)**	**Past 24 hrs.**	**Today**	**silt/clay**	**sand**	**shell**	**gravel**	**detritus**
MDE-01	11:49	Ebb	3.96	0.2	SE	0	5	22	40	5	1	15	40	45	0	0
MDE-03	11:39	Ebb	5.71	0.2	SE	0	5	22	40	5	1	0	30	35	30	5
MDE-07	11:32	Ebb	6.0	0.2	SE	0	5	22	40	5	1	35	30	30	0	5
MDE-09	11:21	Ebb	5.93	0.2	SE	0	5	22	40	5	1	45	0	50	0	5
MDE_11	11:11	Ebb	5.64	0.2	SE	0	5	20	40	5	1	70	0	25	0	5
MDE-13	10:22	Ebb	5.37	0.2	SE	0	5	18	70	5	1	55	0	45	0	0
MDE-15	10:10	Ebb	5.21	0.2	SE	0	5	18	70	5	1	75	0	25	0	0
MDE-16	9:51	Ebb	3.41	0.2	SE	0	5	20	70	5	1	65	0	35	0	0
MDE-17	9:22	Ebb	5.41	0.5	SE	5	15	19	70	5	1	15	40	45	0	0
MDE-19	9:31	Ebb	4.96	0.2	SE	0	5	21	60	5	1	90	0	10	0	0
MDE-22	8:45	Ebb	5.55	0.5	SE	5	15	19	70	5	1	90	0	10	0	0
MDE-27	13:03	Ebb	3.95	0.2	SE	0	5	22	40	5	1	60	0	10	0	30
MDE-30	12:51	Ebb	3.50	0.2	SE	0	5	23	40	5	1	70	0	30	0	0
MDE-33	12:14	Ebb	2.61	0.2	SE	0	5	23	40	5	1	5	70	25	0	0
MDE-34	12:05	Ebb	3.55	0.2	SE	0	5	23	40	5	1	0	50	45	0	5
MDE-36	12:30	Ebb	3.32	0.2	SE	0	5	23	40	5	1	0	80	20	0	0
MDE-42	8:59	Ebb	3.36	0.5	SE	5	15	19	70	5	1	95	0	5	0	0
MDE-43	9:12	Ebb	5.39	0.5	SE	5	15	19	70	5	1	85	0	15	0	0
MDE-44	9:40	Ebb	3.33	0.5	SE	5	15	21	60	5	1	97	0	3	0	0
MDE-45	9:59	Ebb	3.02	0.2	SE	0	5	21	70	5	1	85	0	15	0	0
MDE-50	10:53	Ebb	4.54	0.5	SE	0	5	19	70	5	1	0	95	4	0	1
MDE-51	10:34	Ebb	5.23	0.2	SE	0	5	19	70	5	1	80	0	20	0	0

Note: The weather code 1 stands for “Partly Cloudy” and 5 stands for “Light Rain”

Table 2-3. Year 27 water quality parameters measured *in situ* at all HMI stations on September 10, 2008.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp. (C)	Dissolved Oxygen (ppm)	pH	Secchi Depth (m)	Conductivity (µmos/cm)
Nearfield Stations									
MDE-01	XIF5505	Surface	0.50	7.28	24.02	7.53	7.91	0.5	12,675
		Bottom	3.46	7.37	24.03	7.43	7.86		12,825
MDE-03	XIG5699	Surface	0.50	7.54	24.03	7.02	7.75	0.6	13,154
		Bottom	5.21	7.80	24.01	6.81	7.67		13,502
MDE-07	XIF5302	Surface	0.50	7.55	24.26	7.10	7.86	0.5	13,127
		Bottom	5.50	7.91	24.13	6.41	7.65		13,701
MDE-09	XIF4806	Surface	0.50	7.77	24.19	6.86	7.76	0.5	13,280
		Bottom	5.43	8.15	24.19	6.70	7.64		14,099
MDE-11	XIG4501	Surface	0.50	8.36	24.26	6.86	7.76	0.6	14,438
		Bottom	5.14	8.43	24.27	6.79	7.72		14,544
MDE-15	XIF4609	Surface	0.50	7.95	24.16	6.58	7.65	0.5	13,811
		Bottom	4.71	8.19	24.20	6.43	7.60		14,151
MDE-16	XIF4615	Surface	0.50	7.64	24.02	6.85	7.69	0.5	13,403
		Bottom	2.91	7.96	24.03	7.29	7.65		13,764
MDE-17	XIF4285	Surface	0.50	8.43	24.37	6.23	7.60	0.5	14,538
		Bottom	4.91	8.43	24.37	6.42	7.60		14,530
MDE-19	XIF4221	Surface	0.50	8.49	24.55	6.31	7.65	0.5	14,641
		Bottom	4.46	8.66	24.79	6.03	7.64		14,960
MDE-33	XIF6008	Surface	0.50	7.29	24.28	7.66	7.97	0.5	12,706
		Bottom	2.11	7.30	24.25	7.69	7.93		12,716
MDE-34	XIF5805	Surface	0.50	7.25	24.31	7.28	7.95	0.7	12,626
		Bottom	3.05	7.25	24.24	7.20	7.86		12,630
MDE-45	N/A	Surface	0.50	7.49	23.91	6.94	7.72	0.4	13,078
		Bottom	2.52	7.63	23.86	6.96	7.71		13,282
Reference Stations									
MDE-13	XIG3506	Surface	0.50	8.47	24.30	6.51	7.72	0.6	14,617
		Bottom	4.87	8.48	24.31	6.58	7.71		14,627
MDE-22	XIF3224	Surface	0.50	9.18	24.65	6.64	7.80	0.5	15,754
		Bottom	5.05	9.18	24.65	6.46	7.79		15,755
MDE-36	XIG7589	Surface	0.50	6.95	24.07	7.42	7.84	0.7	12,150
		Bottom	2.82	7.50	23.93	6.74	7.63		12,843
MDE-50	N/A	Surface	0.50	9.13	24.11	6.45	7.72	0.6	15,675
		Bottom	4.14	9.13	24.13	6.56	7.71		15,684
MDE-51	N/A	Surface	0.50	9.19	24.33	6.18	7.65	0.5	15,764
		Bottom	4.73	9.20	24.51	6.19	7.65		15,772
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.50	6.47	24.64	9.41	8.78	0.4	11,331
		Bottom	3.45	7.58	24.18	6.25	7.78		13,163
MDE-30	XIF5925	Surface	0.50	6.98	24.27	7.25	7.89	0.5	12,189
		Bottom	3.00	7.07	24.10	7.10	7.83		12,283
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.50	8.79	24.65	6.26	7.71	0.5	15,129
		Bottom	2.86	8.78	24.66	6.34	7.70		15,104
MDE-43	XIF3985	Surface	0.50	8.43	24.43	6.25	7.61	0.5	14,549
		Bottom	4.89	8.43	24.45	6.33	7.61		14,553
MDE-44	XIF4482	Surface	0.50	7.71	23.98	6.91	7.74	0.6	13,245
		Bottom	2.83	7.73	24.08	6.93	7.69		13,467

Table 2-4. Year 27 physical parameters measured *in situ* at all HMI stations on April 17, 2009.

						Wind Speed (knots)				Weather		Observed Bottom Sediment (%)				
MDE Station	**Time**	**Tide**	**Water Depth (m)**	**Wave Height (m)**	**Wind Direction**	**Min.**	**Max.**	**Air Temp (ºC)**	**Cloud Cover (%)**	**Past 24 hrs.**	**Today**	**silt/clay**	**sand**	**shell**	**gravel**	**detritus**
MDE-01	11:51	Slack	4.46	0.02	NW	2	2	16	0	5	0	0	93	7	0	0
MDE-03	11:40	Slack	6.27	0.02	NW	2	2	16	0	5	0	20	55	20	0	5
MDE-07	11:26	Slack	6.42	0.02	NW	2	2	16	0	5	0	20	75	5	0	0
MDE-09	11:19	Slack	6.30	0.02	NW	2	2	16	0	5	0	65	0	20	0	15
MDE-11	11:11	Slack	6.18	0.02	NW	2	2	16	0	5	0	80	5	15	0	0
MDE-13	10:18	Slack	5.32	0.02	NW	2	2	14	0	5	0	60	5	30	0	5
MDE-15	10:03	Slack	5.64	0.02	NW	2	2	14	0	5	0	35	50	5	0	10
MDE-16	9:44	Slack	5.05	0.02	NW	2	2	12	0	5	0	83	0	10	0	7
MDE-17	9:10	Slack	5.66	0.02	NW	2	2	11	0	5	0	45	0	40	0	15
MDE-19	9:25	Slack	5.57	0.02	NW	2	2	11	0	5	0	80	0	15	0	5
MDE-22	8:30	Slack	5.91	0.02	NW	2	2	10	0	5	0	90	0	10	0	0
MDE-27	13:02	Slack	4.65	0.02	NW	2	2	16	0	5	0	80	0	12	0	8
MDE-30	12:46	Slack	4.03	0.02	NW	2	2	16	0	5	0	60	0	20	0	20
MDE-33	12:10	Slack	2.93	0.02	NW	2	2	17	0	5	0	0	75	10	0	15
MDE-34	12:00	Slack	2.92	0.02	NW	2	2	16	0	5	0	0	60	30	0	10
MDE-36	12:23	Slack	3.87	0.02	NW	2	2	17	0	5	0	45	35	10	0	10
MDE-42	8:50	Ebb	5.68	0.02	NW	2	2	11	0	5	0	90	0	10	0	0
MDE-43	9:00	Ebb	5.55	0.02	NW	2	2	11	0	5	0	60	10	20	0	10
MDE-44	9:37	Slack	5.52	0.02	NW	2	2	12	0	5	0	85	5	5	0	5
MDE-45	9:54	Slack	5.17	0.02	NW	2	2	13	0	5	0	75	0	5	0	20
MDE-50	10:50	Slack	4.92	0.02	NW	2	2	16	0	5	0	0	90	10	0	0
MDE-51	10:32	Slack	5.44	0.02	NW	2	2	14	0	5	0	85	0	10	0	5

Note: The weather codes 0 (zero) and 5 stand for “Clear” and “Light Rain”, respectively.

Table 2-5. Water quality parameters measured *in situ* at all HMI stations on April 17, 2009.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp. (C)	Dissolved Oxygen (ppm)	pH	Secchi Depth (m)	Conductivity (μmos/cm)
Nearfield Stations									
MDE-01	XIF5505	Surface	0.50	3.04	11.01	9.54	7.62	0.40	5,140
		Bottom	3.96	5.04	9.44	8.04	7.42		8,890
MDE-03	XIG5699	Surface	0.50	2.91	11.34	9.82	7.63	0.45	5,281
		Bottom	5.77	10.32	8.58	5.71	7.12		17,537
MDE-07	XIF5302	Surface	0.50	3.20	10.32	9.02	7.56	0.35	5,953
		Bottom	5.92	10.76	8.60	5.79	7.13		18,244
MDE-09	XIF4806	Surface	0.50	3.32	10.55	9.09	7.55	0.40	5,858
		Bottom	5.80	10.12	8.68	5.75	7.14		17,158
MDE-11	XIG4501	Surface	0.50	2.70	12.06	9.36	7.67	0.40	4,923
		Bottom	5.68	11.15	8.44	5.48	7.09		19,153
MDE-15	XIF4609	Surface	0.50	3.39	9.90	9.07	7.52	0.35	6,151
		Bottom	5.14	7.12	8.86	7.53	7.26		12,202
MDE-16	XIF4615	Surface	0.50	3.33	9.81	9.51	7.59	0.35	5,964
		Bottom	4.55	7.11	9.04	7.44	7.28		12,373
MDE-17	XIF4285	Surface	0.50	3.06	9.90	9.12	7.49	0.45	5,873
		Bottom	5.16	8.78	8.83	6.33	7.18		15,110
MDE-19	XIF4221	Surface	0.50	3.20	10.21	9.46	7.58	0.45	5,799
		Bottom	5.07	7.28	9.17	6.40	7.19		12,644
MDE-33	XIF6008	Surface	0.50	2.45	12.11	10.05	7.72	0.40	4,487
		Bottom	2.43	3.09	9.94	9.37	7.55		5,670
MDE-34	XIF5805	Surface	0.50	2.51	11.95	10.12	7.71	0.50	4,589
		Bottom	2.42	3.15	10.19	9.73	7.57		6,764
MDE-45	N/A	Surface	0.50	4.02	9.55	8.77	7.45	0.4	7,287
		Bottom	4.67	6.77	9.19	7.22	7.30		11,779
Reference Stations									
MDE-13	XIG3506	Surface	0.50	2.91	10.39	9.31	7.62	0.45	5,299
		Bottom	4.82	12.86	8.24	5.02	7.07		21,269
MDE-22	XIF3224	Surface	0.50	3.26	10.41	9.92	7.60	0.45	5,906
		Bottom	5.41	8.90	9.05	5.71	7.06		15,286
MDE-36	XIG7589	Surface	0.50	2.21	11.85	9.85	7.61	0.40	4,054
		Bottom	3.37	2.70	10.20	9.62	7.53		4,934
MDE-50	N/A	Surface	0.50	2.70	9.96	9.31	7.64	0.60	4,889
		Bottom	4.42	9.64	8.51	6.94	7.22		16,508
MDE-51	N/A	Surface	0.50	3.18	10.79	9.71	7.65	0.45	5,694
		Bottom	4.94	15.56	7.77	4.18	7.03		25,689
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.50	3.15	11.27	9.77	7.65	0.25	5,717
		Bottom	4.15	3.43	10.49	9.61	7.59		6,212
MDE-30	XIF5925	Surface	0.50	2.35	11.45	10.41	7.88	0.40	4,298
		Bottom	3.53	3.28	9.63	8.89	7.51		5,934
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.50	3.24	10.41	9.27	7.56	0.45	5,858
		Bottom	5.18	8.33	9.07	5.55	7.09		14,727
MDE-43	XIF3985	Surface	0.50	2.66	9.63	9.84	7.63	0.50	4,839
		Bottom	5.05	9.32	8.83	5.66	7.11		15,842
MDE-44	XIF4482	Surface	0.50	3.24	10.10	9.23	7.53	0.45	5,829
		Bottom	5.02	7.27	9.16	7.07	7.27		12,658

BENTHIC MACROINVERTEBRATE COMMUNITY

Taxa Richness and Dominance

A total of 36 taxa were found over the two seasons of sampling during Year 27. This is a decrease in species richness from the 11-year average of 39.6 taxa but not the lowest number found in a given year (32 taxa in Year 17).

The most common taxa groups were members of the phyla Arthropoda (joint-legged organisms), Annelida (segmented worms), and Mollusca/Bivalvia (shellfish having two separate shells joined by a muscular hinge). Seventeen taxa of Arthropoda were found in Year 27. This is similar to the 11-year mean of 17.7 taxa (range= 12-23 taxa). The most common types of arthropods were the amphipods (including *Leptocheirus plumulosus*) and the isopods (including *Cyathura polita*). Six taxa of annelid worms in the Class Polychaeta were found. This is 1.7 less than the 11-year mean of 7.6 taxa (range= 6-10 taxa). Polychaete taxa richness was comparable between April and September (5 vs. 6 taxa). Six species of bivalve mollusks were found. This is similar to the 11-year mean of 5.7 taxa (range= 4-7 taxa). Overall, bivalve mollusk average abundance was lower in September 2008 than in April 2009 (Table 2-6 and Table 2-7).

Glycinde solitaria, Amphicteis floridus (polychaetes), and *Balanus subalbidus* (a barnacle), were not found in Year 27. Ostracoda, *Platyhelminthes* sp., and *Mya arenaria* were only found in spring samples, while *Argulus* sp*., Cassidinidea ovalis, Gobiosoma bosc, Victorella pavida, Chironomus* sp., and *Polydora cornuta* were only found in fall samples. Year 27 is the first year since Year 21 that *Mya arenaria* was observed. *G. solitaria and Mulinia lateralis* have not been observed since the Year 21 sampling season. These species (and a few rarer ones) tended to only be found at Harbor Stations (MDE-38, MDE-39, MDE-40, and MDE-41), which have not been sampled since Year 21. The cessation of sampling Harbor stations partly accounts for any recent drop in the numbers of taxa found. Additionally, small inter-annual and inter-seasonal differences in taxa richness are likely a result of natural variation in salinity and spawning/recruitment typical in this dynamic region of the Chesapeake Bay.

Table 2-6. Average and total abundance (individuals per square meter) of each taxon found at HMI during the September 2008 sampling; by substrate and station type. Depending on site salinity, taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

Taxon	Average Abundance, All stations	Total Abundance, All stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Nemata	10.76	236.80	16.46	0.00	1.60	1.60	1.28	105.60	0.00
Carinoma tremaphoros	4.95	108.80	5.94	0.00	6.40	2.67	7.68	0.00	12.80
Bivalvia	13.96	307.20	4.57	8.00	52.80	8.00	33.28	12.80	6.40
Macoma sp.	2.04	44.80	2.29	0.00	3.20	0.00	2.56	9.60	4.27
Macoma balthica	**15.71**	**345.6**	**23.77**	**3.20**	**0.00**	**3.73**	**55.04**	**0.00**	**8.53**
Macoma mitchelli	28.51	659.20	33.83	24.40	24.00	25.07	25.60	60.80	36.27
Rangia cuneata	**255.42**	**5619.2**	**60.80**	**512.00**	**680.00**	**385.60**	**147.20**	**89.60**	**25.60**
Ischadium recurvum	2.91	64.00	0.00	11.20	4.80	5.33	0.00	0.00	0.00
Mytilopsis leucophaeata	75.93	1670.40	17.83	177.60	177.60	135.47	8.96	0.00	0.00
Amphicteis floridus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capitellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heteromastus filiformis	158.55	3488.00	146.74	305.60	52.80	178.67	222.72	44.80	46.93
Spionidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marenzelleria viridis	**147.78**	**3251.20**	**92.34**	**216.00**	**273.60**	**140.80**	**174.08**	**192.00**	**102.40**
Streblospio benedicti	250.76	5516.80	213.49	393.60	238.40	315.73	188.16	281.60	74.67
Polydora cornuta	144.58	3180.80	61.71	323.20	256.00	244.80	46.08	6.40	0.00
Boccardiella ligerica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nereididae	13.38	294.40	18.74	0.00	8.00	8.53	38.40	0.00	0.00
Neanthes succinea	47.13	1036.80	32.91	107.20	36.80	72.53	29.44	6.40	2.13

Table 2-6 – (continued)

Taxon	Average Abundance, All stations	Total Abundance, All stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Eteone heteropoda	29.09	640.00	18.74	44.80	49.60	38.40	26.88	9.60	8.53
Naididae sp.	389.24	8563.20	410.97	236.80	465.60	309.87	325.12	1283.20	217.60
Amphipoda	20.36	448.00	26.51	3.20	16.00	11.73	19.20	38.40	44.80
Gammaridea	11.64	256.00	16.46	3.20	3.20	10.67	2.56	32.00	17.07
Ameroculodes spp. complex	0.58	12.80	0.91	0.00	0.00	0.00	0.00	3.20	2.13
Leptocheirus plumulosus	337.16	7417.60	442.06	73.60	233.60	221.33	390.40	476.80	618.67
Gammarus sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Melitidae	1.45	32.00	1.83	0.00	1.60	2.13	1.28	0.00	0.00
Melita nitida	44.80	985.60	64.91	4.80	14.40	20.80	23.04	118.40	128.00
Corophiidae	19.49	428.80	19.20	33.60	6.40	30.40	11.52	0.00	2.13
Apocorophium lacustre	500.36	11008.00	372.11	804.80	644.80	774.93	339.20	6.40	0.00
Cyathura polita	**119.85**	**2636.80**	**120.23**	**187.20**	**51.20**	**130.13**	**103.68**	**64.00**	**142.93**
Edotia triloba	9.02	198.40	3.66	9.60	27.20	10.13	7.68	19.20	0.00
Chiridotea almyra	6.11	134.40	0.00	0.00	33.60	11.20	0.00	0.00	0.00
Cirripedia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Balanus improvisus	83.20	1830.40	68.11	217.60	1.60	124.27	67.84	0.00	0.00
Balanus subalbidus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhithropanopeus harrisii	6.69	147.20	5.49	16.00	1.60	10.13	5.12	0.00	0.00
Membranipora sp.	+	+	+	+	+	+	+	+	+
Chironomidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-6 – (continued)

Taxon	Average Abundance, All stations	Total Abundance, All stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Coelotanypus sp.	5.24	115.20	8.23	0.00	0.00	2.67	0.00	35.20	4.27
Chironomus sp.	1.75	38.40	1.83	1.60	1.60	2.13	0.00	3.20	2.13
Victorella pavida	23.27	512.00	0.00	128.00	0.00	42.67	0.00	0.00	0.00
Gammaridae	1.75	38.40	2.74	0.00	0.00	0.53	6.40	0.00	0.00
Copepoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiosoma bosc	0.29	6.40	0.46	0.00	0.00	0.53	0.00	0.00	0.00
Mysidacea	1.75	38.40	1.83	1.60	1.60	2.13	0.00	3.20	2.13
Cassidinidea ovalis	0.29	6.40	0.00	0.00	1.60	0.53	0.00	0.00	0.00
Argulus sp.	0.29	6.40	0.46	0.00	0.00	0.00	0.00	0.00	2.13

Note: Presence of *Membranipora* sp. is indicated by +

Table 2-7. Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 27 spring sampling, April 2009, by substrate and station type. Depending on salinity, taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Nemata	3.52	70.40	4.69	N/A	0.00	0.00	0.00	23.47	0.00
Carinoma tremaphoros	2.88	57.60	3.41	N/A	1.28	2.33	6.40	2.13	2.13
Bivalvia	654.08	13081.60	712.53	N/A	478.72	407.85	1273.60	746.67	844.80
Macoma sp.	109.44	2188.80	110.08	N/A	107.52	104.15	83.20	104.53	160.00
Macoma balthica	**259.84**	**5196.80**	**245.76**	**N/A**	**302.08**	**203.66**	**315.73**	**241.07**	**428.80**
Macoma mitchelli	48.64	972.80	49.07	N/A	47.36	36.07	81.07	72.53	38.40
Rangia cuneata	**105.28**	**2105.60**	**68.27**	**N/A**	**216.32**	**157.09**	**70.40**	**25.60**	**29.87**
Ischadium recurvum	4.80	96.00	0.43	N/A	17.92	8.73	0.00	0.00	0.00
Mytilopsis leucophaeata	62.40	1248.00	9.39	N/A	221.44	113.45	0.00	0.00	0.00
Capitellidae	2.88	57.60	3.84	N/A	0.00	4.07	4.27	0.00	0.00
Heteromastus filiformis	117.44	2348.80	108.37	N/A	144.64	114.04	192.00	91.73	81.07
Spionidae	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Marenzelleria viridis	**17280.00**	**345600.00**	**13056.85**	**N/A**	**29949.44**	**22630.98**	**9107.20**	**6796.80**	**16315.73**
Streblospio benedicti	12.16	243.20	15.79	N/A	1.28	1.75	14.93	40.53	19.20
Polydora cornuta	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Boccardiella ligerica	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Nereididae	16.64	332.80	16.21	N/A	17.92	29.09	4.27	0.00	0.00

Table 2-7 – (continued)

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Neanthes succinea	48.64	972.80	49.92	N/A	44.80	59.93	17.07	14.93	72.53
Naididae sp.	308.80	6176.00	379.73	N/A	96.00	198.40	149.33	1024.00	157.87
Amphipoda	204.16	4083.20	201.39	N/A	212.48	174.55	418.13	119.47	183.47
Gammaridea	177.28	3545.60	149.33	N/A	261.12	140.22	44.80	162.13	460.80
Ameroculodes spp. complex	2.88	57.60	3.84	N/A	0.00	3.49	2.13	2.13	2.13
Leptocheirus plumulosus	1147.20	22944.00	1197.23	N/A	997.12	918.11	1224.53	1907.20	1149.87
Gammaridae	2.88	57.60	0.85	N/A	8.96	4.07	4.27	0.00	0.00
Gammarus sp.	13.12	262.40	6.83	N/A	32.00	23.85	0.00	0.00	0.00
Melitidae	5.12	102.40	4.69	N/A	6.40	7.56	0.00	4.27	2.13
Melita nitida	51.52	1030.40	62.29	N/A	19.20	27.93	61.87	130.13	49.07
Corophiidae	33.92	678.40	4.69	N/A	121.60	59.93	0.00	0.00	6.40
Apocorophium sp.	8.00	160.00	9.81	N/A	2.56	12.22	0.00	0.00	8.53
Apocorophium lacustre	486.40	9728.00	119.89	N/A	1585.92	823.85	57.60	72.53	91.73
Cyathura polita	**90.88**	**1817.60**	**97.28**	**N/A**	**71.68**	**86.11**	**125.87**	**76.80**	**87.47**
Edotia triloba	6.40	128.00	6.40	N/A	6.40	8.73	6.40	4.27	0.00
Chiridotea almyra	1.60	32.00	0.85	N/A	3.84	1.75	2.13	0.00	2.13
Balanus improvisus	15.04	300.80	15.79	N/A	12.80	27.35	0.00	0.00	0.00
Rhithropanopeus harrisii	6.40	128.00	2.13	N/A	19.20	11.64	0.00	0.00	0.00
Membranipora sp.	+	+	+	N/A	+	+	+	0.00	+

Table 2-7 – (continued)

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Chironomidae	0.32	6.40	0.00	N/A	1.28	0.58	0.00	0.00	0.00
Coelotanypus sp.	1.60	32.00	2.13	N/A	0.00	1.16	2.13	4.27	0.00
Procladius (*Holotanypus*) sp.	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Copepoda	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Ostracoda	2.24	44.80	2.56	N/A	1.28	0.58	2.13	8.53	2.13
Mysidacea	1.28	25.60	1.28	N/A	1.28	0.58	2.13	0.00	4.27
Platyhelminthes sp.	0.32	6.40	0.43	N/A	0.00	0.00	2.13	0.00	0.00
Mya arenaria	8.32	166.40	5.97	N/A	15.36	13.38	6.40	0.00	0.00
Eteone heteropoda	11.52	230.40	14.93	N/A	1.28	2.91	14.93	29.87	21.33

Note: Presence of *Membranipora* sp. is indicated by +

Of the 36 taxa found in Year 27, twenty were considered truly infaunal, eleven were considered epifaunal, and the remaining five were considered too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 27 were worms from the family Naididae, the amphipod *L. plumulosus*, the polychaete worm *M. viridis*, the bivalve *R. cuneata*, and the isopod *C. polita*. The most common epifaunal species were the amphipods *A. lacustre* and *M. nitida,* and the isopod *E. triloba.*

Nearfield stations MDE-03 and MDE-34 had the highest number of taxa in September 2008 (20 taxa, Table 2-8). Two Nearfield stations (MDE-01 and MDE-16) and one Reference station (MDE-13) had 18 taxa. The station with the fewest number of taxa (10 taxa) in September was Reference station MDE-50 (Table 2-8). Overall, average taxa richness was highest at the Nearfield stations but did not vary greatly between station types (average taxa richness: Nearfield=16 taxa, Reference=15 taxa, Back River/Hawk Cove=14 taxa, South Cell Exterior Monitoring=13 taxa). It is important to note that there are 12 Nearfield stations, 5 Reference stations, 3 South Cell Exterior Monitoring stations and 2 Back River/Hawk Cove stations. So, higher taxa abundances at Nearfield stations may simply be an artifact of sample size. No trend of increasing/decreasing taxa richness associated with distance from HMI could be discerned.

Table 2-8. Summary of metrics for each HMI benthic station surveyed during the Year 27 September 2008 cruise. Total infaunal abundance and total abundance, excluding Polycladida, Nematoda, and Bryozoa, are individuals per square meter.

Station	Total Infauna	Total All	All Taxa	Infaunal Taxa	Shannon-Wiener	PSTA (%)	PITA (%)	B-IBI
Nearfield Stations								
MDE-01	3904.0	4000.0	18	13	2.79	50.16	23.28	3.50
MDE-03	3270.4	4147.2	20	13	3.04	22.50	24.07	3.50
MDE-07	1068.8	1081.6	14	13	3.11	41.32	21.56	4.00
MDE-09	3411.2	4262.4	17	13	2.88	26.83	11.07	4.50
MDE-11	3910.4	4083.2	17	11	2.83	14.40	15.38	4.00
MDE-15	697.6	697.6	12	12	2.88	26.61	25.69	3.50
MDE-16	4230.4	5017.6	18	13	2.51	2.72	30.26	3.00
MDE-17	2502.4	2976.0	16	12	2.68	2.56	25.32	3.00
MDE-19	1785.6	1875.2	14	12	2.48	9.68	35.84	3.00
MDE-33	678.4	697.6	14	10	2.50	29.25	9.43	4.00
MDE-34	7795.2	8780.8	20	14	2.84	28.81	23.81	3.50
MDE-45	1676.8	1792.0	13	12	2.29	17.18	25.95	3.00
MEANS	**2910.9**	**3284.3**	**16.1**	**12.3**	**2.74**	**22.70**	**22.65**	**3.59**
HISTORIC MEAN, n=27								**3.35**
Reference Stations								
MDE-13	3513.6	3916.8	18	13	2.66	4.37	18.21	3.50
MDE-22	1120.0	1126.4	13	13	2.82	22.86	18.29	3.50
MDE-36	3270.4	3379.2	17	12	2.90	45.99	32.09	3.50
MDE-50	454.4	620.8	10	9	2.16	7.04	4.23	3.00
MDE-51	2406.4	2502.4	15	13	2.68	18.88	32.71	3.50
MEANS	**2153.0**	**2309.1**	**14.6**	**12.0**	**2.64**	**19.83**	**21.11**	**3.40**
HISTORIC MEAN, n=27								**3.53**
Back River/Hawk Cove Stations								
MDE-27	4006.4	4326.4	16	12	2.05	10.38	72.20	2.50
MDE-30	1260.8	1267.2	12	11	2.80	21.83	26.40	3.00
MEANS	**2633.6**	**2796.8**	**14**	**11.5**	**2.42**	**16.11**	**49.30**	**2.75**
HISTORIC MEAN, n=27								**2.98**
South Cell Exterior Monitoring Stations								
MDE-42	1632.0	1913.6	15	13	2.31	11.37	24.31	3.00
MDE-43	1382.4	1446.4	12	11	2.69	11.57	30.09	3.00
MDE-44	1094.4	1177.6	12	10	2.51	45.03	9.94	4.50
MEANS	**1369.6**	**1512.5**	**13**	**11.3**	**2.50**	**22.66**	**21.45**	**3.50**
HISTORIC MEAN, n=5								**3.54**

In April 2009, the greatest taxa richness (21 taxa) occurred at Reference station MDE-13. The second greatest taxa richness (20 taxa) occurred at Nearfield station MDE-34. Overall, taxa richness increased from Year 26 when 17 spring taxa were recorded at one station and six stations had 16 taxa. The lowest taxa richness (11 taxa) from spring 2009 sampling was recorded at Nearfield stations MDE-01 and MDE-33. Overall, the average taxa richness was highest at Reference stations (16.6 taxa), while Nearfield stations averaged 14.8, South Cell Exterior Monitoring stations averaged 14.7, and Back River/Hawk Cove stations averaged 14.

Table 2-9. Summary of metrics for each HMI benthic station surveyed during the Year 27 April 2009 cruise. Total infaunal abundance and total abundance, excluding Polycladida, Nematoda, and Bryozoa, are individuals per square meter.

Station	Total Infauna	Total All	All Taxa	Infaunal Taxa	Shannon-Wiener	PSTA (%)	PITA (%)
Nearfield Stations							
MDE-01	51616.0	53004.8	11	9	0.50	93.27	0.06
MDE-03	11558.4	11955.2	13	9	0.71	90.92	0.61
MDE-07	33177.6	33926.4	17	12	1.16	82.85	0.64
MDE-09	23699.2	24320.0	19	13	0.62	93.41	1.54
MDE-11	14560.0	15558.0	17	15	1.21	84.84	1.71
MDE-15	24602.0	25574.0	13	11	0.72	90.43	1.38
MDE-16	20454.0	20787.0	13	9	0.45	95.56	0.66
MDE-17	10259.2	11769.6	16	13	0.99	85.15	1.00
MDE-19	6739.2	7443.2	13	11	2.07	64.20	0.66
MDE-33	37850.0	37907.0	11	9	0.44	95.23	0.03
MDE-34	41280.0	42860.8	20	13	0.97	89.09	0.47
MDE-45	31878.0	32806.0	15	13	0.53	95.78	0.42
MEANS	**25,639.5**	**26,492.7**	**14.8**	**11.4**	**0.86**	**88.40**	**0.77**
Reference Stations							
MDE-13	13555.0	14246.0	21	16	1.26	84.66	2.46
MDE-22	9811.2	11692.8	15	14	1.69	72.86	3.39
MDE-36	18131.0	18618.0	18	14	1.20	84.47	2.82
MDE-50	34342.4	36672.0	13	12	0.26	97.13	0.09
MDE-51	13670.4	15059.2	16	15	1.58	83.99	3.42
MEANS	**17,902.0**	**19,257.6**	**16.6**	**14.2**	**1.19**	**84.57**	**2.44**
Back River/Hawk Cove Stations							
MDE-27	17017.6	18035.2	16	10	1.67	64.99	15.12
MDE-30	5209.6	5388.8	12	10	1.79	61.67	7.49
MEANS	**11,113.6**	**11,712.0**	**14**	**10**	**1.73**	**63.33**	**11.31**

South Cell Exterior Monitoring Stations							
MDE-42	10752.0	12563.0	17	13	1.77	72.44	1.79
MDE-43	17235.0	19168.0	12	11	1.02	87.71	2.30
MDE-44	8358.4	8691.2	15	11	2.02	59.04	0.77
MEANS	**12,115.1**	**13,474**	**14.7**	**11.7**	**1.60**	**73.06**	**1.62**

Since the first benthic survey studies of the Hart-Miller Island area in 1981, a small number of taxa have been dominant. Year 27 was no exception. During both seasons, 7 taxa were consistently dominant: oligochaete worms of the family Naididae, the amphipods *L. plumulosus* and *A. lacustre*, the bivalve mollusk *R. cuneata*, the isopod *C. polita*, and the polychaete worms *M. viridis* and *H. filiformis.*

Several other taxa were among the most dominant in only one season. In September 2008, the polychaetes *S. benedicti, N. succinea,* and *P. cornuta*, the bivalve *M. leucophaeata*, and *B. improvisus* were within the most dominant taxa, but not in April 2009. Likewise, the bivalve *M. balthica* was among the most dominant in April 2009, but not in September 2008. The average abundance of each taxon (individuals per square meter) found at each station during September and April are provided in Table 2-10 through Table 2-13. These trends, both in overall abundance and seasonal variation are historically established.

Table 2-10. Average number of individuals collected per square meter at each station during HMI Year 27 late summer sampling, September 2008, stations MDE-1 to MDE-22. Depending on salinity, taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

	Station										
Taxon	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Nemata	0	0	0	0	19.2	0	0	0	0	0	0
Carinoma tremaphoros	0	0	6.4	0	0	0	0	0	0	0	19.2
Bivalvia	0	12.8	0	19.2	0	0	0	0	0	0	6.4
Macoma sp.	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	**6.4**	**0**	**12.8**	**0**	**0**	**12.8**	**12.8**	**0**	**6.4**	**0**	**96.0**
Macoma mitchelli	76.8	6.4	19.2	6.4	0	12.8	19.2	6.4	0	64.0	38.4
Rangia cuneata	**1344.0**	**262.4**	**243.2**	**409.6**	**102.4**	**25.6**	**83.2**	**12.8**	**32**	**38.4**	**44.8**
Ischadium recurvum	6.4	12.8	0	6.4	0	0	0	0	19.2	0	0
Mytilopsis leucophaeata	57.6	153.6	6.4	460.8	102.4	19.2	0	121.6	38.4	0	0
Amphicteis floridus	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	710.4	134.4	147.2	204.8	416.0	576.0	19.2	96.0	172.8	57.6	140.8
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	**416.0**	**332.8**	**128.0**	**102.4**	**153.6**	**6.4**	**25.6**	**32.0**	**12.8**	**6.4**	**44.8**
Streblospio benedicti	544.0	454.4	108.8	249.6	364.8	454.4	89.6	864.0	326.4	76.8	19.2
Polydora cornuta	19.2	339.2	0	403.2	185.6	115.2	19.2	518.4	531.2	0	12.8
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereididae	0	0	0	0	76.8	160.0	0	25.6	0	0	0
Neanthes succinea	38.4	70.4	6.4	204.8	108.8	83.2	0	224	115.2	0	6.4
Eteone heteropoda	38.4	76.8	6.4	38.4	51.2	57.6	6.4	44.8	25.6	6.4	6.4
Naididae sp.	326.4	249.6	115.2	89.6	185.6	128.0	76.8	364.8	281.6	537.6	179.2
Amphipoda	6.4	0	0	6.4	19.2	0	12.8	0	0	70.4	0
Gammaridea	12.8	0	38.4	0	12.8	0	0	0	0	57.6	6.4

Table 2-10 – (continued)

	Station										
Taxon	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Ameroculodes spp complex	0	0	0	0	0	0	0	0	0	0	0
Leptocheirus plumulosus	153.6	64.0	172.8	6.4	51.2	147.2	262.4	32.0	70.4	716.8	435.2
Gammarus sp.	0	0	0	0	0	0	0	0	0	0	0
Melitidae	0	0	0	0	12.8	0	0	0	0	0	0
Melita nitida	6.4	0	0	0	32.0	19.2	0	0	12.8	83.2	0
Corophiidae	0	51.2	0	44.8	108.8	57.6	0	96.0	38.4	0	0
Apocorophium lacustre	19.2	1081.6	6.4	1241.6	1766.4	1568.0	0	1836.8	876.8	6.4	0
Cyathura polita	**192.0**	**140.8**	**57.6**	**403.2**	**307.2**	**108.8**	**64.0**	**70.4**	**12.8**	**128.0**	**70.4**
Edotia triloba	19.2	6.4	0.0	12.8	6.4	6.4	0	0	0	0	0
Chiridotea almyra	0	0	0	0	0	0	0	0	0	0	0
Cirripedia	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	147.2	0	320.0	6.4	332.8	0	614.4	403.2	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	6.4	25.6	0	32.0	12.8	25.6	0	38.4	0	0	0
Membranipora sp	+	+	+	+	+	+	+	+	+	+	0
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	0	0	0	0	6.4	0	0	12.8	0
Chironomus sp.	0	6.4	0	0	0	0	0	6.4	0	6.4	0
Victorella pavida	0	512.0	0	0	0	0	0	0	0	0	0
Gammaridae	0	0	6.4	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0
Gobiosoma bosc	0	0	0	0	0	0	0	6.4	0	0	0
Mysidacea	0	6.4	0	0	0	0	0	6.4	0	6.4	0
Cassidinidea ovalis	0	0	0	0	0	0	0	0	0	0	0
Argulus sp.	0	0	0	0	0	0	0	0	0	0	0

Note: Presence of *Membranipora* sp. is indicated by +

Table 2-11. Average number of individuals collected per square meter at each station during the HMI Year 27 late summer sampling, September 2008, stations MDE-27 to MDE-51. Depending on salinity, taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

	Station										
Taxon	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Nemata	211.2	0	0	0	6.4	0	0	0	0	0	0
Carinoma tremaphoros	0	0	0	25.6	0	12.8	25.6	0	0	0	19.2
Bivalvia	25.6	0	0	51.2	0	0	6.4	12.8	12.8	160	0
Macoma sp.	19.2	0	0	0	12.8	6.4	0	6.4	0	0	0
Macoma balthica	**0**	**0**	**0**	**0**	**0**	**19.2**	**0**	**6.4**	**6.4**	**0**	**166.4**
Macoma mitchelli	121.6	0	38.4	38.4	6.4	44.8	51.2	12.8	25.6	12.8	57.6
Rangia cuneata	**115.2**	**64**	**192**	**1875.2**	**627.2**	**6.4**	**12.8**	**57.6**	**32.0**	**25.6**	**12.8**
Ischadium recurvum	0	0	0	19.2	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	6.4	678.4	19.2	0	0	0	0	6.4	0
Amphicteis floridus	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	76.8	12.8	6.4	153.6	32.0	57.6	70.4	12.8	25.6	19.2	345.6
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	**288.0**	**96.0**	**0**	**307.2**	**780.8**	**6.4**	**51.2**	**249.6**	**172.8**	**6.4**	**32**
Streblospio benedicti	396.8	166.4	38.4	486.4	422.4	76.8	102.4	44.8	185.6	6.4	38.4
Polydora cornuta	0	12.8	12.8	908.8	102.4	0	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereididae	0	0	0	0	6.4	0	0	0	0	25.6	0
Neanthes succinea	12.8	0	0	102.4	25.6	0	0	6.4	0	19.2	12.8
Eteone heteropoda	19.2	0	12.8	147.2	25.6	0	25.6	0	6.4	12.8	32.0
Naididae sp.	2419.2	147.2	6.4	1254.4	601.6	313.6	275.2	64.0	230.4	0	716.8
Amphipoda	38.4	38.4	0	6.4	25.6	89.6	32.0	12.8	19.2	32.0	38.4
Gammaridea	0	64.0	0	6.4	6.4	0	32.0	19.2	0	0	0

Table 2-11 – (continued)

Taxon	Station MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Ameroculodes spp. complex	0	6.4	0	0	0	6.4	0	0	0	0	0
Leptocheirus plumulosus	448.0	505.6	102.4	147.2	403.2	832.0	595.2	428.8	876.8	281.6	684.8
Gammarus sp.	0	0	0	0	0	0	0	0	0	0	0
Melitidae	0	0	0	6.4	0	0	0	0	6.4	0	6.4
Melita nitida	230.4	6.4	0	19.2	38.4	268.8	57.6	57.6	96.0	0	57.6
Corophiidae	0	0	12.8	12.8	0	6.4	0	0	0	0	0
Apocorophium lacustre	0	12.8	243.2	2214.4	108.8	0	0	0	6.4	12.8	6.4
Cyathura polita	**12.8**	**115.2**	**6.4**	**102.4**	**96.0**	**153.6**	**96**	**179.2**	**76.8**	**0**	**243.2**
Edotia triloba	38.4	0	6.4	70.4	32.0	0	0	0	0	0	0
Chiridotea almyra	0	0	0	134.4	0	0	0	0	0	0	0
Cirripedia	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	0	6.4	0	0	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	0	0	6.4	0	0	0	0	0	0	0
Membranipora sp	0	0	+	+	+	0	+	+	0	+	0
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	51.2	19.2	0	0	0	0	12.8	0	12.8	0	0
Chironomus sp.	6.4	0	6.4	0	0	6.4	0	0	0	0	0
Victorella pavida	0	0	0	0	0	0	0	0	0	0	0
Gammaridae	0	0	0	0	0	0	0	0	0	0	32.0
Copepoda	0	0	0	0	0	0	0	0	0	+	0
Gobiosoma bosc	0	0	0	0	0	0	0	0	0	0	0
Mysidacea	6.4	0	6.4	0	0	6.4	0	0	0	0	0
Cassidinidea ovalis	0	0	0	6.4	0	0	0	0	0	0	0
Argulus sp.	0	0	0	0	0	0	0	6.4	0	0	0

Note: Presence of *Membranipora* sp. is indicated by +

Table 2-12. Average number of individuals collected per square meter at each station during the HMI Year 27 spring sampling, April 2009, stations MDE-1 to MDE-22. Depending on salinity, taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

	Station										
Taxon	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Nemata	0	0	0	0	0	0	0	0	0	0	0
Carinoma tremaphoros	0	0	0	0	6.4	6.4	6.4	0	0	6.4	6.4
Bivalvia	1376.0	134.4	185.6	467.2	793.6	224	793.6	134.4	1414.4	390.4	1843.2
Macoma sp.	0	224.0	115.2	0	83.2	76.8	160.0	96.0	0	268.8	25.6
Macoma balthica	**0**	**0**	**742.4**	**6.4**	**684.8**	**236.8**	**288.0**	**0**	**32.0**	**172.8**	**268.8**
Macoma mitchelli	6.4	0	57.6	12.8	166.4	57.6	64.0	0	32.0	102.4	38.4
Rangia cuneata	**38.4**	**51.2**	**83.2**	**230.4**	**19.2**	**19.2**	**70.4**	**0**	**32.0**	**6.4**	**64.0**
Ischadium recurvum	0	0	32.0	6.4	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	25.6	288.0	83.2	0	12.8	0	12.8	0	0	0
Capitellidae	0	0	0	0	12.8	44.8	0	0	0	0	0
Heteromastus filiformis	211.2	32.0	332.8	57.6	115.2	294.4	102.4	25.6	76.8	140.8	185.6
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	**48070.4**	**10393.6**	**26521.6**	**21734.4**	**11494.4**	**11072.0**	**21849.6**	**19424.0**	**8576.0**	**3942.4**	**6668.8**
Streblospio benedicti	0	0	0	0	6.4	12.8	0	0	12.8	6.4	12.8
Polydora cornuta	0	0	0	0	0	0	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereididae	0	12.8	0	38.4	0	134.4	0	32.0	12.8	0	0
Neanthes succinea	6.4	51.2	121.6	102.4	44.8	153.6	0	89.6	0	0	19.2
Naididae sp.	32.0	70.4	204.8	358.4	236.8	313.6	320.0	134.4	70.4	38.4	230.4
Amphipoda	467.2	115.2	262.4	185.6	89.6	38.4	377.6	89.6	192.0	320	236.8
Gammaridea	0	0	44.8	0	70.4	38.4	134.4	0	0	838.4	102.4
Ameroculodes spp. complex	0	6.4	0	0	6.4	12.8	0	6.4	0	0	6.4
Leptocheirus plumulosus	1632.0	499.2	1107.2	780.8	1420.8	806.4	1286.4	320.0	1043.2	889.6	1670.4

Table 2-12 – (continued)

Taxon	Station										
	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Gammaridae	0	0	0	0	0	0	0	0	12.8	0	0
Gammarus sp	0	0	0	12.8	0	25.6	0	51.2	0	0	0
Melitidae	0	0	32.0	0	0	25.6	6.4	12.8	0	0	0
Melita nitida	6.4	0	38.4	19.2	89.6	102.4	6.4	51.2	83.2	38.4	12.8
Corophiidae	128.0	0	6.4	0	0	6.4	6.4	25.6	0	38.4	0
Apocorophium sp.	0	0	0	0	0	6.4	0	0	0	0	0
Apocorophium lacustre	992.0	262.4	3545.6	6.4	38.4	166.4	44.8	134.4	57.6	32.0	64.0
Cyathura polita	**32.0**	**51.2**	**70.4**	**160.0**	**134.4**	**134.4**	**38.4**	**121.6**	**96.0**	**204.8**	**147.2**
Edotia triloba	0	0	12.8	6.4	19.2	12.8	0	0	0	0	0
Chiridotea almyra	0	0	0	0	0	0	0	0	6.4	0	0
Balanus improvisus	6.4	0	44.8	32.0	0	179.2	0	25.6	0	0	0
Rhithropanopeus harrisii	0	12.8	0	6.4	0	12.8	0	0	0	0	0
Membranipora sp	+	+	+	+	+	+	+	+	0	0	0
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	0	0	0	0	6.4	0	6.4	0	0
Procladius (*Holotanypus*) sp.	0	0	0	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0
Ostracoda	0	0	0	0	0	0	0	0	0	0	0
Mysidacea	0	0	0	0	0	0	0	0	0	6.4	0
Platyhelminthes sp.	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	12.8	70.4	6.4	19.2	12.8	0	0	0	0	0
Eteone heteropoda	0	0	6.4	6.4	6.4	6.4	12.8	0	12.8	0	89.6

Note: Presence of *Membranipora* sp. is indicated by +

Table 2-13. Average number of individuals collected per square meter at each station during the HMI Year 27 spring sampling, April 2009, stations MDE-27 to MDE-51. Depending on salinity, taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

	Station										
Taxon	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Nemata	70.4	0	0	0	0	0	0	0	0	0	0
Carinoma tremaphoros	0	0	0	0	6.4	12.8	0	0	6.4	0	6.4
Bivalvia	384.0	12.8	38.4	403.2	339.2	1612.8	1702.4	12.8	819.2	2137.6	1337.6
Macoma sp.	249.6	38.4	0	153.6	51.2	166.4	160.0	224.0	96.0	0	0
Macoma balthica	**416.0**	**38.4**	**192.0**	**403.2**	**198.4**	**230.4**	**384.0**	**147.2**	**755.2**	**12.8**	**1228.8**
Macoma mitchelli	172.8	6.4	6.4	64.0	25.6	44.8	64.0	6.4	44.8	6.4	12.8
Rangia cuneata	**6.4**	**6.4**	**128.0**	**825.6**	**275.2**	**160.0**	**57.6**	**19.2**	**12.8**	**6.4**	**19.2**
Ischadium recurvum	0	0	0	57.6	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	0	819.2	6.4	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	70.4	19.2	6.4	32.0	19.2	384.0	147.2	38.4	57.6	102.4	339.2
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	**10617.6**	**3104.0**	**35724.8**	**35488**	**14720**	**7251.2**	**14547.2**	**4672**	**29728**	**33299.2**	**9907.2**
Streblospio benedicti	96.0	12.8	0	0	0	25.6	51.2	6.4	0	0	57.6
Polydora cornuta	0	0	0	0	0	0	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereididae	0	0	0	89.6	12.8	0	0	0	0	6.4	0
Neanthes succinea	25.6	0	0	96.0	38.4	6.4	0	185.6	32.0	25.6	19.2
Naididae sp.	2464.0	377.6	12.8	192.0	505.6	140.8	288.0	57.6	128.0	32.0	275.2
Amphipoda	12.8	108.8	0	12.8	51.2	972.8	121.6	428.8	0	217.6	32.0
Gammaridea	121.6	262.4	89.6	332.8	64.0	64.0	108.8	870.4	403.2	0	108.8
Ameroculodes spp. complex	0	0	0	0	12.8	0	0	0	6.4	6.4	0
Leptocheirus plumulosus	2880.0	1171.2	460.8	896.0	1420.8	1209.6	1209.6	1708.8	531.2	537.6	1158.4

Table 2-13 – (continued)

	Station										
Taxon	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Gammaridae	0	0	44.8	0	0	0	0	0	0	0	0
Gammarus sp	0	0	70.4	89.6	12.8	0	0	0	0	0	19.2
Melitidae	6.4	6.4	0	0	6.4	0	0	6.4	0	0	6.4
Melita nitida	262.4	115.2	12.8	0	32.0	12.8	70.4	70.4	6.4	0	44.8
Corophiidae	0	0	83.2	352.0	12.8	0	6.4	6.4	6.4	0	0
Apocorophium sp.	0	0	12.8	0	115.2	0	0	19.2	6.4	0	0
Apocorophium lacustre	115.2	38.4	1017.6	2342.4	518.4	76.8	64.0	96.0	115.2	51.2	25.6
Cyathura polita	**19.2**	**64.0**	**0**	**51.2**	**83.2**	**147.2**	**128.0**	**96.0**	**38.4**	**6.4**	**313.6**
Edotia triloba	12.8	0	0	19.2	44.8	0	0	0	0	0	0
Chiridotea almyra	0	0	0	19.2	0	0	0	6.4	0	0	0
Balanus improvisus	0	0	0	12.8	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	0	6.4	89.6	0	0	0	0	0	0	0
Membranipora sp	0	0	0	+	0	0	0	+	+	0	0
Chironomidae	0	0	0	6.4	0	0	0	0	0	0	0
Coelotanypus sp.	12.8	0	0	0	6.4	0	0	0	0	0	0
Procladius (*Holotanypus*) sp.	0	0	0	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0
Ostracoda	19.2	6.4	0	6.4	0	6.4	0	6.4	0	0	0
Mysidacea	0	0	0	0	0	6.4	0	6.4	6.4	0	0
Platyhelminthes sp.	0	0	0	0	0	6.4	0	0	0	192.0	0
Mya arenaria	0	0	0	6.4	38.4	0	0	0	0	32.0	12.8
Eteone heteropoda	0	0	0	0	0	25.6	57.6	0	6.4	0	134.4

Note: Presence of Copepoda and *Membranipora* sp. is indicated by +

Infaunal Taxa Abundance

Average total infaunal abundance was lower in the fall (September 2008) than in the spring (April 2009) (Figure 2-2), which is primarily a result of a greater number of organisms in the spring due to recruitment. This has occurred in each of the past 11 years (excluding Year 23, which had an unusually large winter die-off of *R. cuneata*). In September 2008, total infaunal abundance ranged from 454.4 to 7,795.2 organisms per square meter (individuals/m^2) and averaged 2507.4 individuals/m^2 (Table 2-8). The highest September 2008 abundance was found at the Nearfield station MDE-34, due primarily to large numbers of Naididae worms, *A. lacustre*, and *R. cuneata*. The lowest infaunal abundance in September 2008 was found at the Reference station MDE-50 (Table 2-8). The average total infaunal abundance was highest at Nearfield stations (2910.93 individuals/m^2) followed by Back River/Hawk Cove stations (2633.6 individuals/m^2), Reference stations (2152.96 individuals/m^2), and South Cell Exterior Monitoring stations (1,369.60 individuals/m^2) in September. No trend of increasing/decreasing abundances associated with distance from HMI could be discerned. These abundances are comparable to historical averages. The 27-year mean (4,820 individuals/m^2) of fall abundance for the Back River stations is much higher than the Reference (1,989 individuals/m^2) and Nearfield (2,221 individuals/m^2) means. Mean abundance in the South Cell stations has a five-year average of 1,077 individuals/m^2.

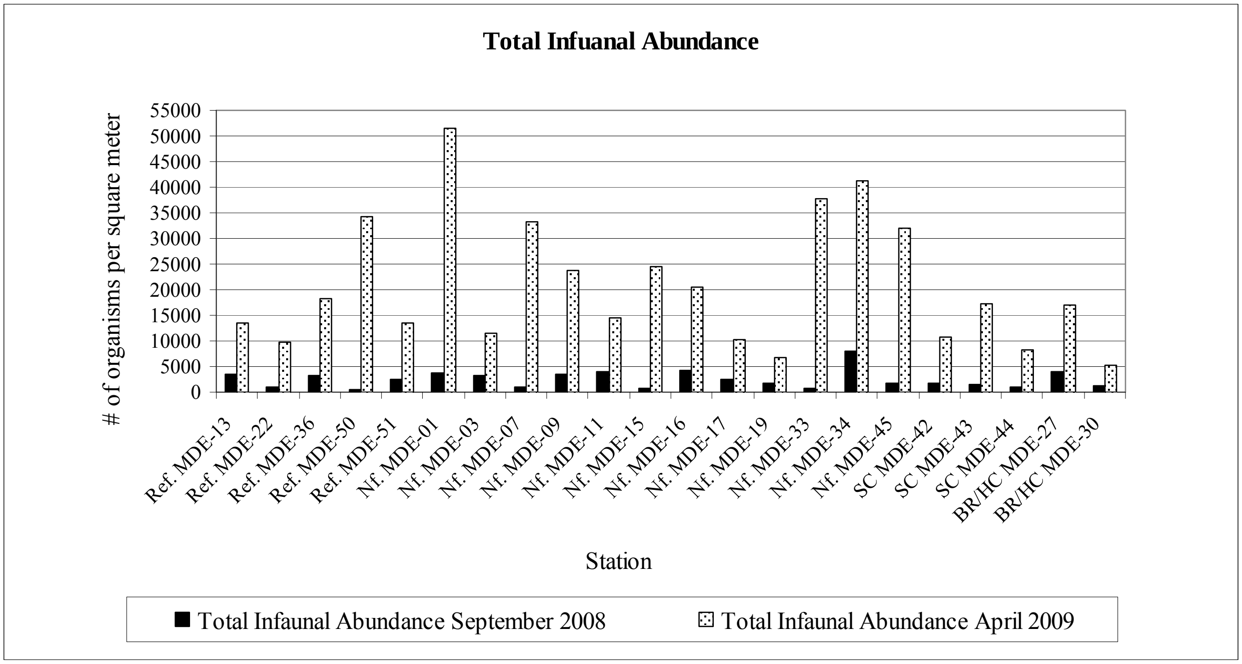

Figure 2-2. Total abundance of infauna taxa collected at each HMI station in Year 27, September 2008 and April 2009 grouped by stations (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

In April 2009, total infaunal abundance ranged from 5,209.60 to 51,616 individuals/m^2 and averaged 20,708.66 individuals/m^2. The station with the highest abundance was the Nearfield station MDE-01, due to very high numbers of the polychaete *M. viridis*. The lowest spring abundance occurred at the Back River/Hawk Cove station MDE-30 (Table 2-9). This was due to depressed abundances of many common species (Table 2-9, 2-12, 2-13). The average total infaunal abundance was lowest at Back River/Hawk Cove stations (11,113.60 individuals/m^2) followed by South Cell Exterior Monitoring stations (12,115.20 individuals/m2), Reference stations (17,902.0 individuals/m2), and highest at Nearfield stations (25,639.47 individuals/m^2). No consistent trend of increasing/decreasing abundances associated with distance from HMI could be discerned. Comparisons of mean spring station type abundances to historical averages were not made. Due to highly variable and often intense spring recruitment, spring benthic data yields variability that does not lend itself to historic analyses and is an unreliable indicator of community health.

Total infaunal abundance and epifaunal abundance are subsets of total abundance. Infaunal abundance excludes certain organisms that have been omitted from the calculation of the B-IBI (see *Methods*). In Year 27, total infaunal abundance was similar to total abundance, accounting for ≥75 percent of all organisms at all stations during both seasons.

Diversity

Species diversity was examined using the Shannon-Wiener Diversity Index (SWDI), which measures diversity on a numerical scale from zero to four. A lower score indicates an unbalanced benthic community dominated by only one or two species whereas a higher score suggests a balanced, diverse benthic community. Pfitzenmeyer et al. (1982) suggested that diversity, as measured by SWDI, would be higher in the summer when recruitment decreased and predation increased as opposed to spring, thus reducing the numbers of the dominant taxa. Correspondingly, diversity has often been lowest at most stations in spring (April or May) due to an influx of juveniles, especially of the dominant species (Duguay et al. 1998, Duguay et al. 1995a, Duguay et al. 1995b, Duguay 1992, Duguay 1990, Pfitzenmeyer and Tenore 1987). Diversity values for Year 27 are presented in Table 2-8 and 2-9. In this monitoring year, average diversity was moderately higher in September 2008 than in April 2009.

SWDI values in Year 27 averaged 2.66 ± 0.28 in September 2008 and 1.1 ± 0.55 in April 2009. The fall average diversity of 2.66 was slightly higher than the 11-year mean fall diversity of 2.32. The lowest diversity value in September 2008 occurred at Back River/Hawk Cove station MDE-27 (2.04, Figure 2-3). This was due to the large percentage of oligochaete worms of the family Naididae, which accounted for 60 percent of total infaunal abundance at this station. The highest September 2008 diversity value (3.11) occurred at Nearfield station MDE-07. The lowest diversity value in April 2009 occurred at Reference station MDE-50 (0.27); this was due to the large percentage of *M. viridis*, which accounted for 74 percent of the total infaunal abundance at this station. The highest April 2009 diversity value occurred at Nearfield station MDE-19 (2.06). Comparisons of mean spring diversity values to historical averages were not made. Due to highly variable and often intense spring recruitment, spring benthic data yields variability that does not lend itself to historic analyses and is an unreliable indicator of community health.

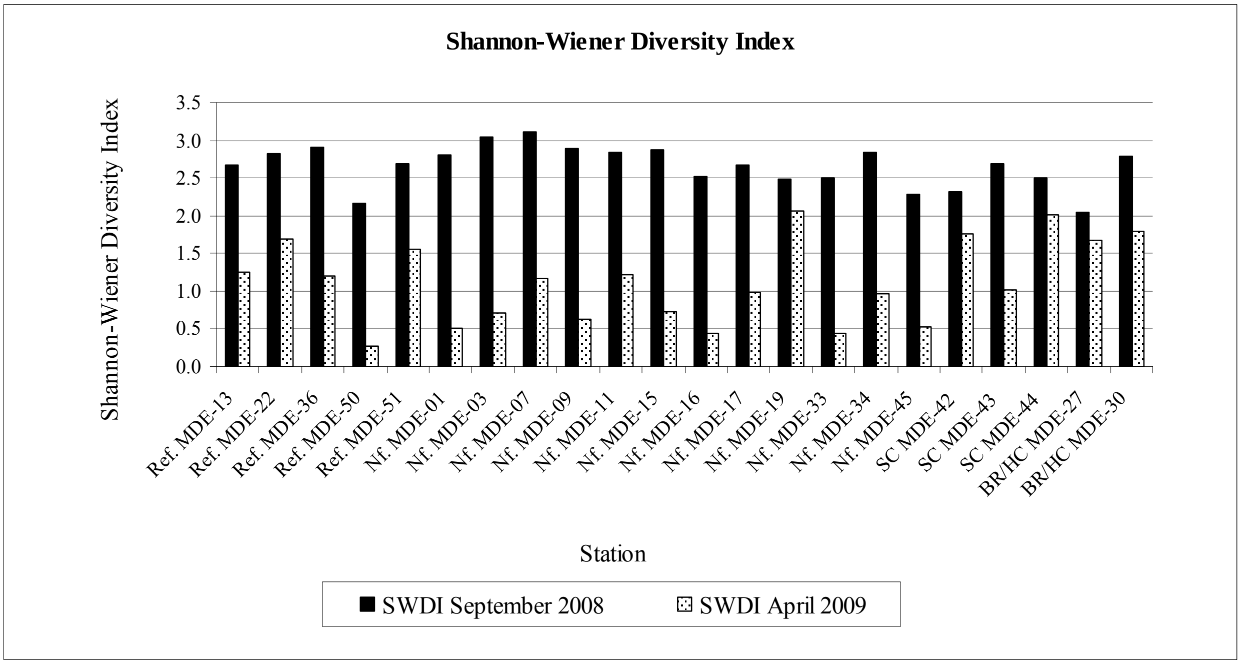

Figure 2-3. Shannon-Wiener Diversity Index (SWDI), HMI Year 27, September 2008 and April 2009 grouped by stations (Ref. = Reference; Nf. = Nearfield; SC = South Cell; BR/HC = Back River Hawk Cove).

On average, Nearfield stations had diversity values similar to Reference stations in September 2008 and April 2009. Comparing station types from the fall only, the lowest average SWDI was 2.42 at the Back River/Hawk Cove stations followed by the South Cell Exterior Monitoring stations at 2.50, and Reference stations at 2.64. The highest average SWDI occurred at the Nearfield stations at 2.74 (Table 2-8). Historically, the 21-year mean SWDI values, ranked from lowest to highest, are associated with the following station types: Back River/Hawk Cove (2.14), Nearfield (2.30), Reference (2.35), and South Cell Exterior Monitoring (2.50, n=5 yrs). No trend of increasing/decreasing diversity associated with distance from HMI could be discerned.

Pollution Sensitive Taxa Abundance (PSTA)

Four taxa found during Year 27 were designated as “pollution-sensitive” according to Alden et al. (2002). These were the polychaete worm *M. viridis,* the bivalves *R. cuneata* and *M. balthica,* and the isopod crustacean *C. polita.* The calculation of the PSTA is a ratio of the relative PSTA abundance to total infaunal abundance.

Small changes in salinity (causing conditions to be either above or below 5.0 ppt) can greatly affect the sensitivity/tolerance designation of several organisms, and correspondingly alter calculated abundances. Because this metric is salinity driven, and salinity varies from year to year, salinity must be controlled for prior to some historical analyses of PSTA fall data. In Year 27, the salinity regime was low mesohaline, similar to Year 26.

In Year 27, pollution sensitive taxa occurred at all station types. In September, PSTA ranged from 2.56 percent at MDE-17 (Nearfield station) to 50.16 percent at MDE-1 (Nearfield station -Table 2-8; Figure 2-4). The average PSTA for all stations in September 2008 was 21.43 percent. Comparing station types, the lowest average PSTA was 16.11 percent at the Back River/Hawk Cove stations followed by the Reference stations at 19.83 percent. The Nearfield and South Cell Exterior Monitoring stations had similar average PSTA percentages (22.70 percent and 22.66 percent respectively). Historically, the 27-year mean fall PSTA values, ranked from lowest to highest, are associated with the following station types: South Cell Exterior Monitoring (31.75 percent, n=4 years), Back River/Hawk Cove (32.09 percent), Nearfield (40.59 percent), and Reference (43.52 percent).

In April 2009, the lowest PSTA was 59.04 percent at MDE-44 (South Cell Exterior Monitoring station) and the highest was 97.09 percent at MDE-50 (Reference station - Table 2-9; Figure 2-4). The average PSTA for all stations in April was 83.20 percent. Back River/Hawk Cove stations had the lowest average PSTA at 63.30 percent, followed by the South Cell Exterior Monitoring stations at 73.10 percent, and the Reference stations at 84.60 percent; the Nearfield stations had the highest average PSTA of 88.40 percent.

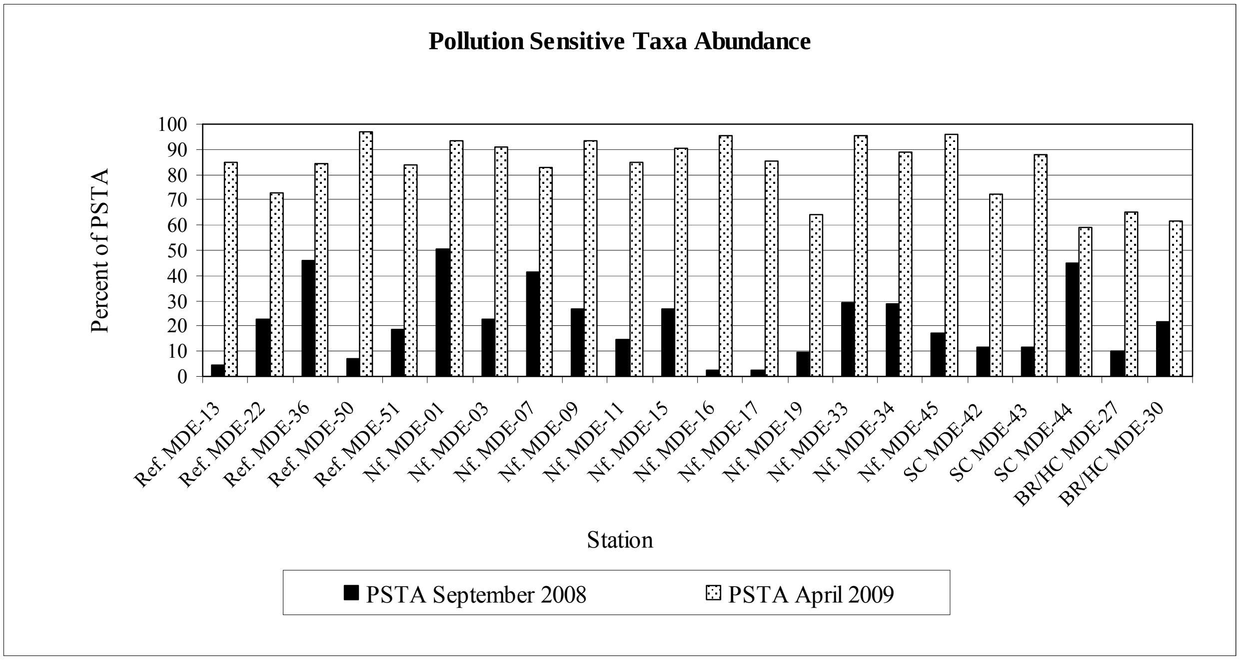

Figure 2-4. Percent abundance comprised of pollution sensitive species (PSTA), HMI Year 27 September 2008 and April 2009 grouped by stations (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

Pollution Indicative Taxa Abundance (PITA)

Five taxa found during the fall sampling of Year 27 benthic monitoring were designated as “pollution-indicative” according to Alden et al. (2002): they were Chironomids of the Genera *Coelotanypus* and *Chironomus*, the polychaete worms *S. benedicti* and *E. heteropoda,* and oligochaete worms of the family Naididae. The calculation of the PITA is a ratio of the relative PITA abundance to total infaunal abundance. Those species which are designated “pollution indicative” are constant throughout all salinity regimes. Therefore salinity does not drive this metric.

In Year 27, pollution indicative taxa occurred at all station types. In September, the PITA ranged from 4.23 percent at MDE-50 (Reference station) to 72.44 percent at MDE-27 (Back River/Hawk Cove station) (Table 2-8; Figure 2-5). The average PITA for all stations in September 2008 was 24.57 percent. Comparing station types, the lowest average PITA was 21.11 percent at the Reference stations, followed by 21.45 percent at the South Cell Exterior Monitoring stations, and 22.65 percent at Nearfield stations. The highest average PITA occurred at the Back River/Hawk Cove stations at 49.42 percent. Historically, the 27-year mean fall PITA values, ranked lowest to highest, are associated with the following station types: Reference (20.83 percent), Nearfield (23.02 percent), Back River/Hawk Cove (35.68 percent), and South Cell Exterior Monitoring (37.02 percent, n = 4 years).

In April 2009, the lowest PITA was 0.03 percent at MDE-33 (Nearfield station) and the highest was 15.12 percent at MDE-27 (Back River/Hawk Cove station -Table 2-9; Figure 2-5). The average PITA for all stations in April was 2.30 percent. Nearfield stations had the lowest average PITA at 0.80 percent, followed by the South Cell Exterior Monitoring stations at 1.60 percent, and the Reference stations at 2.40 percent; the Back River/Hawk Cove stations had the highest average PITA of 11.30 percent.

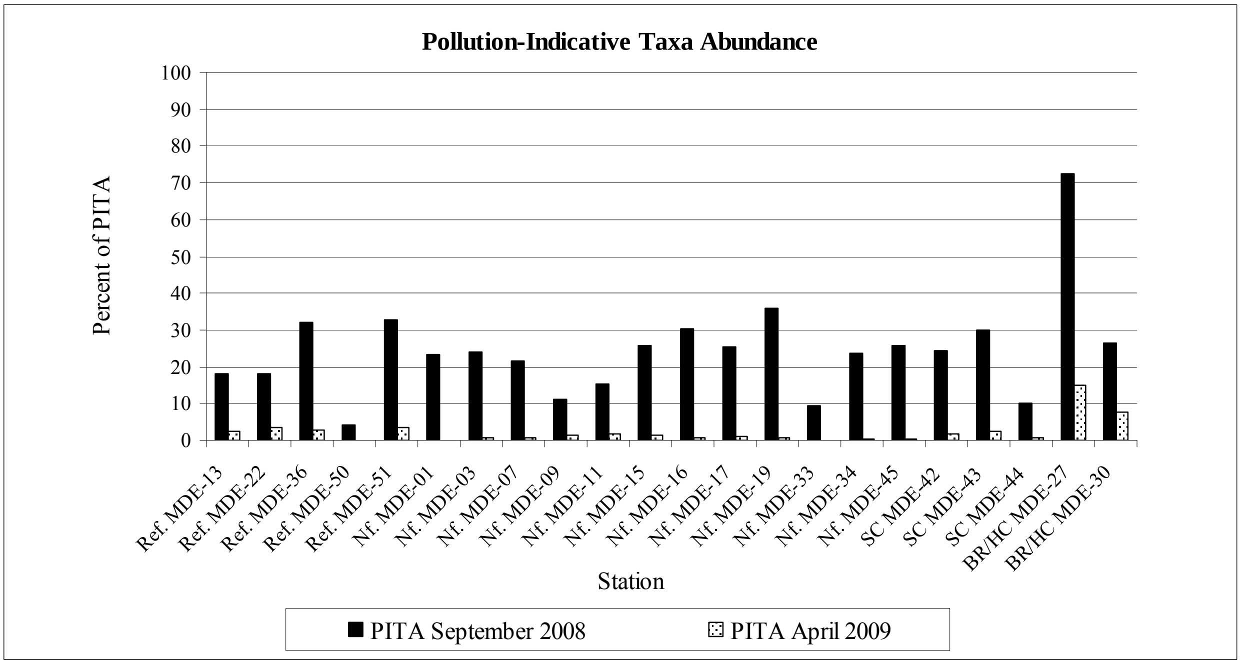

Figure 2-5. Percent abundance comprised of pollution indicative species (PITA), HMI Year 27 September 2008 and April 2009 grouped by stations (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

Benthic Index of Biotic Integrity

The B-IBI was calculated for all stations based on September 2008 data only (see *Methods and Materials*). Four metrics were used to calculate the B-IBI for stations under the low mesohaline classification (5.0 -12 ppt). These metrics were total infaunal abundance, relative abundance of pollution-indicative taxa, pollution-sensitive taxa, and SWDI. The specific scoring criteria for the low mesohaline metrics are presented in Table 2-14. The B-IBI was developed as a benchmark to determine whether any given benthic sample taken from the Bay either approximates (B-IBI score = 5), deviates slightly (B-IBI score = 3), or deviates greatly (B-IBI score = 1) from conditions at the best Reference sites (Weisberg et al., 1997). A B-IBI score greater than or equal to 3.0 represents a benthic community that is not considered stressed by *in situ* environmental conditions. The 22 benthic stations studied during Year 27 were compared to this benchmark.

Table 2-14. Low mesohaline scoring criteria for measures used in calculating the Chesapeake Bay B-IBI in September 2008 (Weisberg et al. 1997).

Measure	Score		
	5	3	1
Total Abundance (individuals per square meter)	≥ 1500-2500	500-1500 **or** > 2500-6000	< 500 **or** ≥ 6000
% Pollution-indicative Taxa	≤ 10%	10-20%	> 20%
% Pollution-sensitive Taxa	≥80%	40-80%	<40%
Shannon-Wiener Diversity Index	≥2.5	1.7-2.5	<1.7

The vast majority of the individual station B-IBI scores for Year 27 increased when compared to Year 26. For the 17 established stations, scores increased at 12 stations, remained the same at 1, and decreased at 4 stations. Twenty-one of the 22 stations met or exceeded the benchmark criteria of 3.0 in Year 27, while only 15 did so in Year 26. In Year 27, Back River/Hawk Cove station MDE-27 (2.50) was the only station that failed to meet the benchmark criteria of 3.0 (Table 2-8, Figure 2-6). Ten stations were below historic averages, one station was equal to its historic average, and six stations (four Nearfield, one South Cell Exterior Monitoring, and one Back River/Hawk Cove) were above.

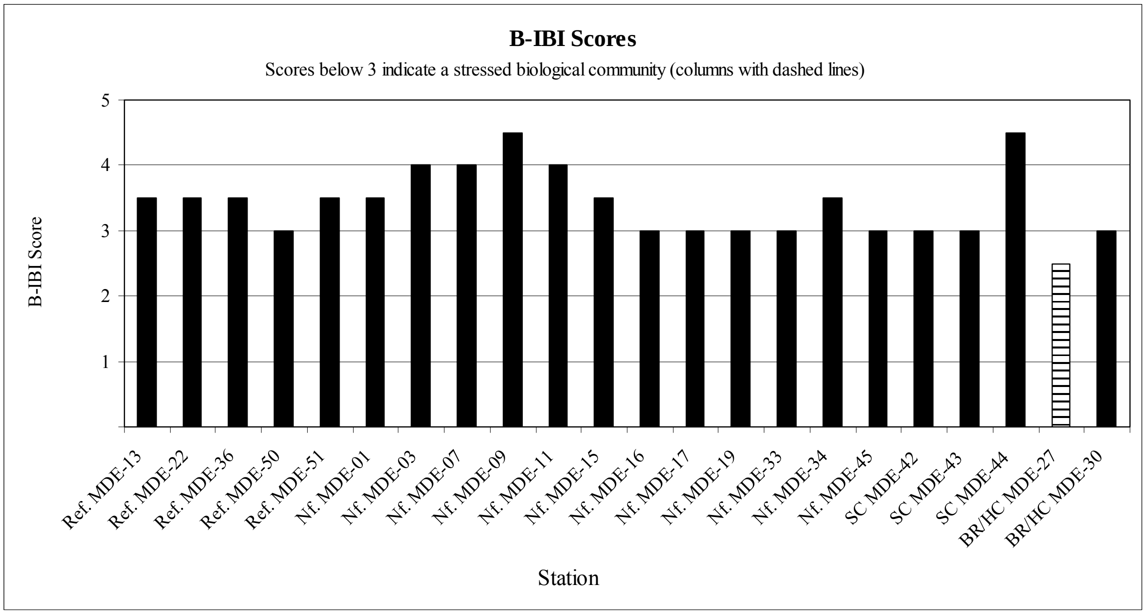

Figure 2-6. B-IBI Scores for all stations in September 2008 grouped by stations (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

The mean B-IBI for Nearfield, Reference, and South Cell Exterior Monitoring stations met or exceeded the benchmark. The mean B-IBI for Back River/Hawk Cove stations failed to meet the benchmark. Average B-IBI scores by station type are shown in Figure 2-7. Compared to Year 26, the mean B-IBI for Reference stations decreased, while the mean B-IBI increased for the other station types. The Year 27 mean B-IBI for Nearfield stations was above the historic average, while all other station types were below the 27-year historic averages (five year average for South Cell Exterior Monitoring Stations, Table 2-8). None of the Year 27 station type means were within 0.5 units of the historic lows.

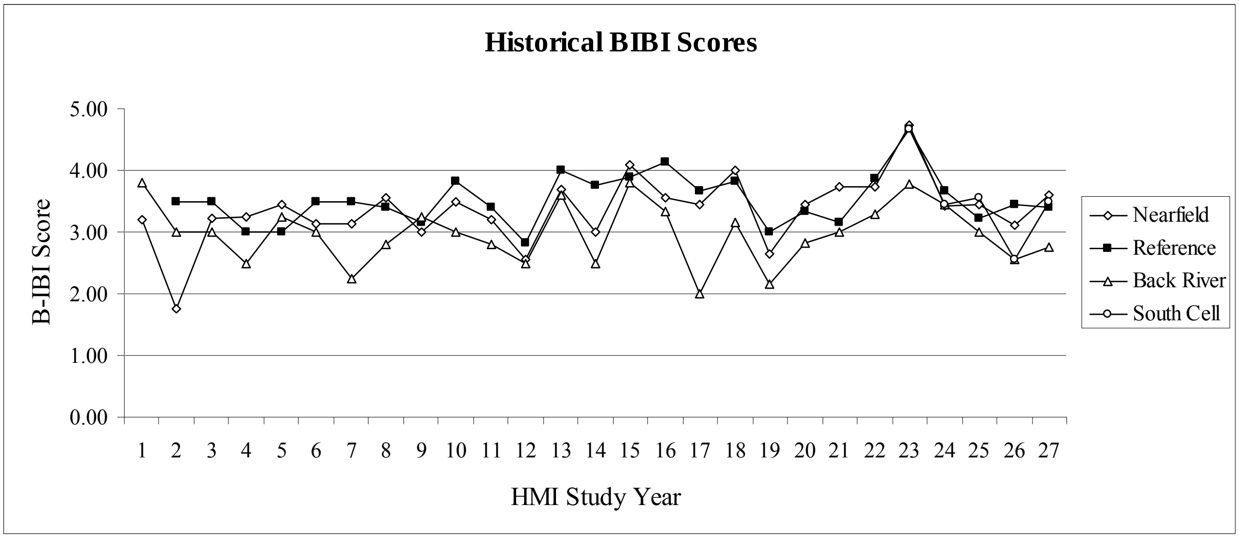

Figure 2-7. Average B-IBI Scores at HMI for Monitoring Years 1-27.

There was no trend of increasing or decreasing B-IBI scores associated with proximity to HMI in Year 27. In some years a slight trend is apparent but there is not consistent association. Back River/Hawk Cove stations have the strongest tendency; they tend to have the lowest B-IBI. Back River/Hawk Cove stations had the lowest mean in Year 27 and have had the lowest average 22 of 27 years.

Clam Length Frequency Distribution

In September 2008, 878 *R. cuneata* were collected. The greatest average abundance of *R. cuneata* occurred at the Nearfield stations (60.08 clams/station), followed by the Reference stations (23 clams/station), the Back River/Hawk Cove stations (13 clams/station), and the South Cell Exterior Monitoring stations (4 clams/station). The greatest abundance of *R. cuneata* during the fall was found in the 11-15 mm size class. In April 2009, 333 *R. cuneata* were collected. The greatest average abundance for this species occurred at the Nearfield stations (19.5 clams/station), followed by the South Cell Exterior Monitoring and Reference (12.3 and 12 clams/station respectively), and the Back River/hawk Cove stations (1.0 clam/station). The dominant size range found during the spring was also in the 21-25 mm size class.

R. cuneata has always been the most abundant bivalve mollusk found in this benthic monitoring project. It is classified as pollution sensitive during higher salinity years ($\geq$5ppt).

The population has historically been very dynamic in terms of overall abundance and distribution by size or station type. The main drivers of *R. cuneata* variability appear to be temperature and salinity. In the Chesapeake Bay, this species exists at the northern extent of its range. Because of this, it is subject to high winter mortality during cold winters (Hopkins, et al., 1973). Additionally, ideal salinity conditions for reproduction and recruitment do not occur regularly. In Maryland, *R. cuneata* rarely if ever reaches its reported maximum age (15-20 years) or size (79 mm). Looking at 11 years of historical HMI frequency distribution data, it is difficult to identify more than four age classes of clams in any one season. This implies very few clams survive longer than five years.

In September 2008, 54 *M. balthica* were collected, with 43 coming from Reference stations, 7 from Nearfield stations, and 4 coming from South Cell Exterior Monitoring stations. The greatest abundance of *M. balthica* during the fall was found in the 9-12 mm size class. In April 2009, 1,006 *M. balthica* were collected with 512 coming from Nearfield stations, 304 from Reference stations, 119 from South Cell Exterior Monitoring stations, and 71 from Back River/Hawk Cove stations. Seven hundred seventy-six were in the 1-4 mm size class and 86 were in the 5-9 mm class, which is indicative of recruitment.

M. balthica has been common and found in low to moderate abundance throughout this benthic monitoring project. It is classified as pollution sensitive during higher salinity years (≥ 5 ppt). The population has historically been somewhat dynamic in terms of overall abundance and size distribution. The main driver of *M. balthica* variability appears to be salinity. In the Chesapeake Bay, this species exists at salinities as low as about 5 ppt (Gosner, 1978), and is generally not found much more than 10-15 miles north of HMI. Looking at 11 years of historical HMI frequency distribution data, the strong freshet in Year 23 appears to have caused high mortality in this species, which is beginning to recover to previous densities. Year 27 recruitment is a sign of recovery.

In September 2008, 103 *M. mitchelli* were collected, with 47 coming from Nearfield stations, 20 from Reference stations, 19 from Back River/Hawk Cove stations, and 17 from South Cell Exterior Monitoring stations. These clams were fairly evenly distributed from 1-15 mm. In April, 155 *M. mitchelli* were collected with 87 coming from Nearfield stations, 28 from Back River/Hawk Cove stations, 22 from Reference stations, and 18 from South Cell exterior Monitoring stations. One hundred-eight were in the 1-8 mm size classes, which is indicative of the spring recruitment time period. Similar to *M. balthica*, *M. mitchelli* populations declined in the spring of Year 22 and remained depressed for several years. *M. mitchelli* is generally not as dominant as *M. balthica*, even during ideal periods. For this reason, a recruitment of the magnitude exhibited in *M. balthica* is unlikely. Year 27 recruitment may be a sign of recovery.

STATISTICAL ANALYSIS

Statistical Background

Cluster analysis is a statistical technique used to interpret multivariate data sets (Johnson, 1998a). This technique is typically employed to identify groups with similar attributes. Comparable multivariate analyses include Principal Components Analysis, Factor Analysis, and Discriminant Analysis (Johnson, 1998). Previous HMI annual reports applied cluster analysis in the form of a hierarchical dendrogram to help identify stations with similar macro-invertebrate assemblages. This year, three new statistical clustering methods were added to explore options to interpret this data. They include Hotelling's pseudo T2 statistic [PST2], Andrews' plots, and three-dimensional Principal Components plots (Johnson, 1998).

The hierarchical dendrogram is the graphical outcome of examining benthic invertebrate similarities among all the HMI stations. This cluster analysis aligns the monitoring stations along the vertical axis. When the analytical equation identifies similarity between two stations, they are linked by a vertical line along the horizontal axis. The results are similar to a branching tree because the varying branch lengths reflect the degrees of similarity among the stations. For HMI Year 27, the horizontal axis variable was the coefficient of determination (R2), a parameter that ranges from 0 to 1.0 and identifies the proportion of the total variability of the data that can be accounted for by the formation of a station group with similar benthic invertebrate assemblages. Initially, at the far left of the horizontal axis, the stations are ungrouped and all data variability is accounted for (R2 = 1.0). As stations are linked into groups by the cluster equations, less and less variability is accounted for because the similarities between the station benthic faunae decline. In order to have confidence in the station groups identified, only groups that formed with an R2 > 60 percent (September 2008) or > 80 percent (April 2009) of the variability accounted for were recognized. Thus any stations that linked to other stations with an R2 < 60 percent (September 2008) or < 80 percent (April 2009) were labeled as single ungrouped outlier stations.

The Hotelling pseudo T2 statistic (PST2) is an algorithm that produces quantitative values by the cluster procedure (SAS, 2008). A new value of the statistic was calculated for each number of hypothesized station groups in the data set. The number of hypothesized station groups ranged from 1 group (all stations are similar enough to be put in one group) to 22 groups (the stations were so dissimilar that each station was in its own separate "group"). To interpret the PST2 values, their relative magnitude is examined. When a PST2 value increases significantly from ***n*** possible station groups to ***n-1*** possible station groups (e.g., from a PST2 value of 12 at ten hypothesized station groups, to a PST2 value of 57 at nine hypothesized station groups), then ***n*** station groups, with the significantly lower PST2 value, is a highly probable number of distinct station groups in the data set.

Three-dimensional Principal Component plots require calculation of Principal Components using the Principal Components Analysis (PCA) procedure (SAS, 2008). The PCA procedures applies mathematical algorithms to a multivariate data set and converts the original correlated variables (the benthic invertebrate species abundances) into a set of new uncorrelated variables called the principal components (Johnson, 1998b). The advantage of identifying the principal components is that most of the variability of the data is accounted for in the first few principal components. Thus we can construct two-dimensional or three-dimensional plots using only the first two or first three principal components, and obtain a valid depiction of station grouping in the two or three-dimensional space.

The Andrews' plot is a sine/cosine wave function of the HMI stations between negative pi and pi (Johnson, 1998c; Andrews, 1972). Stations with similar benthic invertebrate assemblages produce similar wave functions. Hence station groups can fairly easily be identified when all of the station wave functions are plotted. The Andrews' plots were constructed by applying the functional equation to the first five principal components.

In addition to these multivariate statistical procedures, several of the benthic invertebrate metric values (total infaunal abundance, number of infaunal taxa, Shannon-Wiener diversity, PSTA scores, PITA scores, and B-IBI scores) were examined to see how well they correlated to the identified station groups. Good correlations of one or more metric values with identified station groups help to characterize the station groups and outliers, and provide additional support that the station groups identified by the statistical procedures are valid. This examination of metric values to identified station groups was introduced in the HMI Year 26 annual report.

The ultimate objective for identifying station groups with similar benthic invertebrate assemblages was to determine if causative factors like bottom habitat type or water quality strongly correlate with one or more of the identified groups. Habitat and water quality are important determinants of faunal community composition. Thus the use of multivariate procedures to identify station groups could be useful tools for identifying HMI dredging operation impacts on bottom habitat and water quality in areas of close proximity to the island. Cluster analysis in past studies at HMI has clearly indicated a faunal response to bottom type (Pfitzenmeyer, 1985; Duguay et al, 1999). However, in recent years bottom type has been a poor predictor of identified station groups because of the prevalence of silt/clay habitats at most HMI stations. Water quality has also tended to be uncorrelated to identified station groups. More intensive sampling effort would be required if it was believed that identified station groups were the result of habitat or water quality impacts from HMI operations.

Potential impacts to station invertebrate assemblages from HMI operations can also be examined by the Friedman's nonparametric ANOVA test. The Friedman's nonparametric test was utilized again in Year 27 to determine if significant differences in the top ten most abundant invertebrate taxa occurred among the four station types (Nearfield, Back River, South Cell Exterior Monitoring, and Reference) for both the September 2008 and April 2009 sampling data.

Year 27 Statistical Results

The cluster tree figure for September 2008 showed a clear articulation of several HMI station groups (Table 2-8). Not since the Year 21 cluster analyses have station groups been so clearly delineated by the tree figure for September data. However, a weak bottom habitat type to station group correlation for two of the three multi-station groups continued the trend that has occurred in recent years. Fifteen of the twenty-two stations were classified as silt/clay bottom

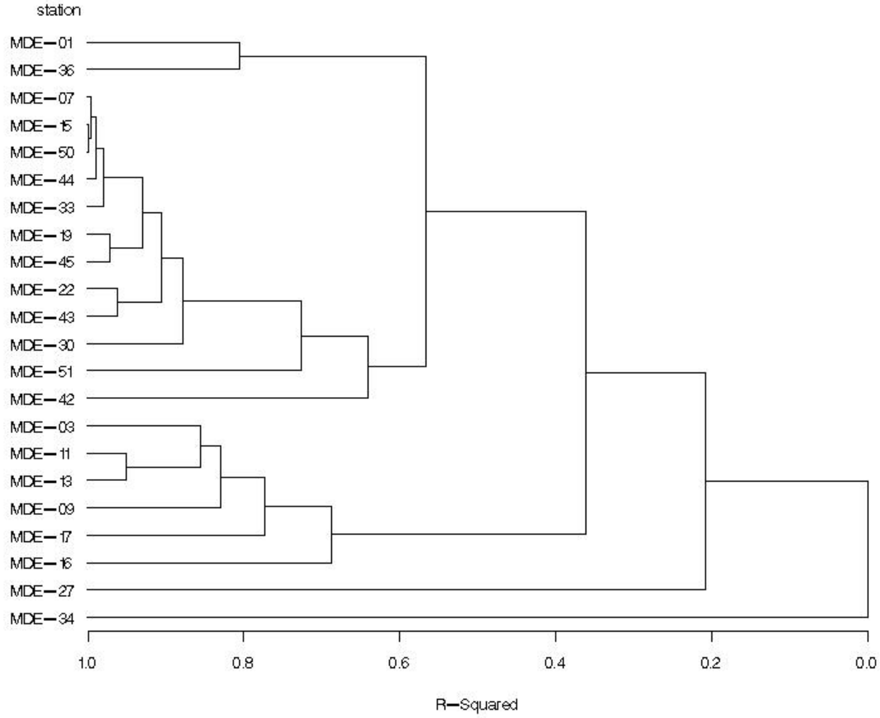

Figure 2-8. September 2008 Cluster Analysis tree.

type in September 2008, and all of the identified station groups were composed of more than one bottom type.

Three multi-station groups and two outlier stations were apparent from examination of the September 2008 tree figure. Clustering of stations was poorly correlated to station type. Group 1, the largest group, consisted of 12 stations: five Nearfield stations (MDE-07, MDE-15, MDE-19, MDE-33, and MDE-45), three Reference stations (MDE-22, MDE-50, and MDE-51), all three South Cell stations (MDE-42, MDE-43, and MDE-44), and Back River station MDE-30. This group exhibited poor spatial proximity, with an average (median) distance between stations of 2,975 meters. Group 1 consisted of eight stations with a silt/clay bottom and four stations with a sand bottom. Group 2 was composed of five Nearfield stations (MDE-03, MDE-09, MDE-11, MDE-16, and MDE-17), and Reference station MDE-13. This group had relatively better spatial proximity, with an average distance of 1,675 meters between stations. Five of the six Group 2 stations had a silt/clay bottom, while one station (MDE-3) had a sand bottom. Group 3 was composed of only two stations, Nearfield station MDE-01 and Reference station MDE-36. These two stations were 4,125 meters apart. MDE-1 had a sand bottom habitat and MDE-36 had a silt/clay bottom. The outlier stations were MDE-27 and MDE-34.

The Hotelling pseudo T2 statistic values provided some evidence supporting the identification of three multi-station groups and two outliers (a total of five distinct “groups”). Comparison of the relative PST2 values indicated that there were from four to eight distinct groups in the September 2008 data. This was the best interpretation that could be made because relatively low values occurred at both four groups and eight groups.

The Andrews' plots for the September 2008 yielded fairly strong support for the three multi-station groups and two outlier stations identified by the cluster tree procedure (Figure 2-9). The plot of the wave function constructed from the first five principal produced good but not perfect coincidence of the stations waves within each group, and good unique wave patterns for the two outlier stations. In the figure, Group 1 stations are the green unbroken waves, Group 2 stations are the blue dashed waves, and the two Group 3 waves are red color-coded. Outlier station MDE-27 is the yellow dashed wave, and outlier MDE-34 is the black dashed wave. The first five principal components accounted for 78.6 percent of the variability of the data, which may explain why there was an imperfect fit of this plot with the identified station groups.

The three-dimensional plot of the first three principal components for the September 2008 invertebrate abundances also provided fairly strong support for the identified station groups (Figure 2-10). Group 1 (pyramids), Group 2 (crosses) and Group 3 (spades) show fairly good within group clumping, and separation from other station groups and outliers. In the figure it is apparent the stations differed primarily along the first principal component axis. Also note in the figure that outlier stations MDE-27 (star) and MDE-34 (cube) are the most isolated in the three-dimensional space (as would be expected) and therefore have the most unique invertebrate assemblages among all the stations.

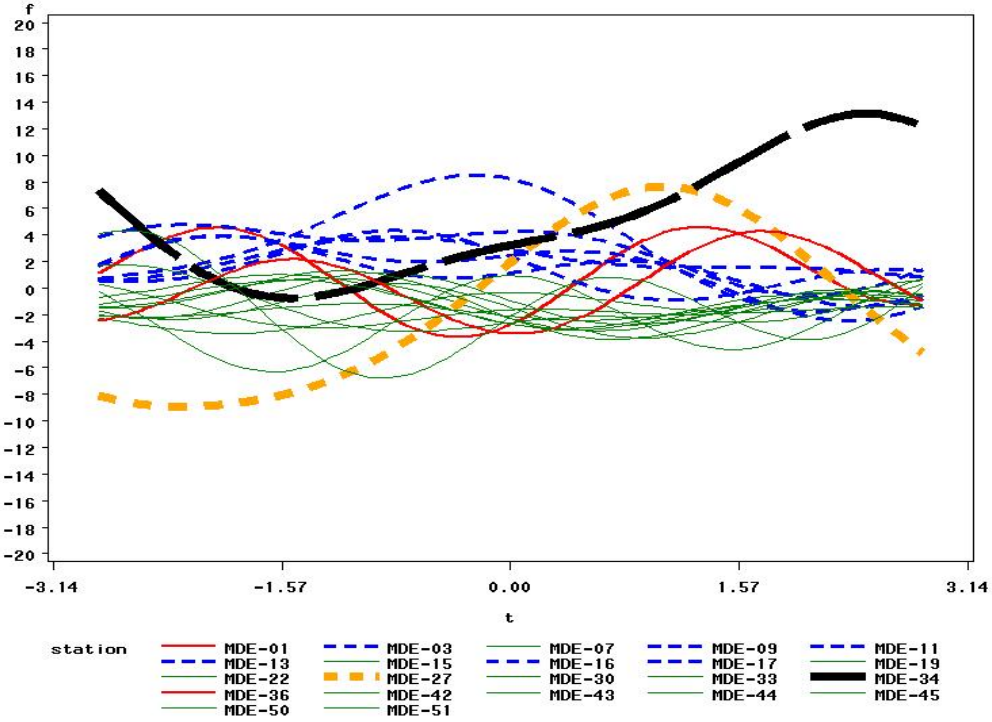

Figure 2-9. Andrews' plot of the September 2008 invertebrate abundance data using the uncorrelated first five principal components in the wave function (accounting for 78.6 percent of the variability of the data). Group 1 stations = continuous green waves; Group 2 stations = dashed blue waves; Group 3 stations = continuous red waves; outlier station MDE-27 = yellow dashed wave; outlier station MDE-34 = black dashed wave.

Examination of the infaunal metric values helped to characterize the identified station groups. Group 1 stations strongly correlated to the total infaunal abundance metric, with all 12 stations having less than the overall mean value. In general, Group 1 stations had lower than average abundance of *Streblospio benedicti* and *Apocorophium lacustre*, but had higher than average abundance of *Leptocheirus plumulosus* for nine of the twelve stations. For the metrics number of infaunal taxa, Shannon Wiener diversity, PSTA percentage, and PITA percentage, the stations of Group 1 tended to split evenly, with half of the stations below the overall average of these metrics and half with greater than the overall average values. For the B-IBI metric, Group 1 stations tended to be at or below the overall average B-IBI (9 of 12 stations). Group 2 stations correlated moderately well to total infaunal abundance, number of infaunal taxa, PSTA percentage and PITA percentage. Group 2 stations had higher than average infaunal abundance (5 of 6 stations), with higher than average (median) abundances of *Heteromastus filiformis*, *Streblospio benedicti*, *Polydora cornuta, Apocorophium lacustre*, and *Balanus improvisus*. Group 2 stations could also be characterized as having higher than average number of infaunal taxa (four of six stations), below average PSTA percentages (four of six stations) and above average PITA scores (four of six stations). Three of the Group 2 stations had extremely low PSTA percentages (PSTA < 5.0). Group 2 stations did not correlate well with either Shannon-

Wiener diversity or with the B-IBI metric. Group 3, with only two stations correlated well with not only total infaunal abundance, but also with Shannon-Wiener diversity, PSTA percentage,

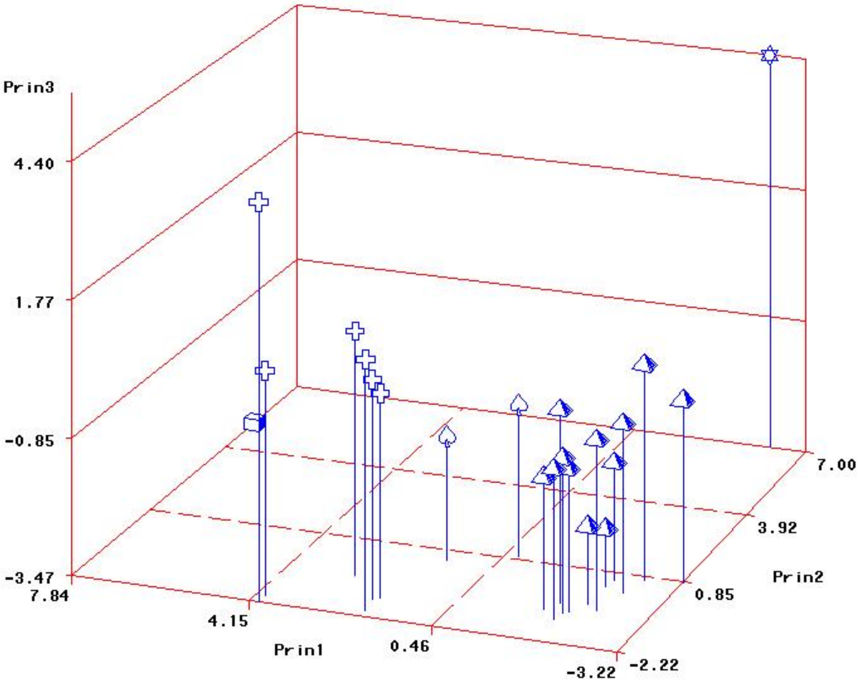

Figure 2-10. Three-dimensional plot of the first three principal components (accounted for 64.3 percent of the variability of the data) for the September 2008 invertebrate abundance data. Group 1 = pyramids; Group 2 = crosses; Group 3 = spades; outlier MDE-27 = star; outlier MDE-34 = cube. Note that Prin1 = principal component 1 axis, Prin2 = principal component 2 axis, and Prin3 = principal component 3 axis.

and with B-IBI scores. Group 3 could be characterized as having higher than average infaunal abundance, with higher than average diversity and percentage of pollution sensitive species, and average B-IBI scores (between the overall mean and median values). The outlier station MDE-27, has historically been identified as an outlier station because of its location in the Back River system. MDE-27 was characterized by higher than average infaunal abundance, average infaunal richness (number of infauna taxa), and lower than average diversity (lowest among all stations), percentage of pollution sensitive species, and B-IBI score, and the highest percentage of pollution indicative species (72 percent). Relative to the other stations, MDE-27 could be characterized as having an impaired infaunal community. In contrast, the other outlier station, MDE-34, had a very healthy infaunal community, with the highest overall infaunal abundance and species richness (number of infaunal taxa), higher than average diversity, PSTA percentage, and B-IBI, and lower than average PITA percentage.

The cluster tree figure for April 2009 was relatively more difficult to interpret (Figure 2-11). Using an R2 = 60 percent as the cutoff for identifying groups of like stations, the cluster tree indicated one large multi-station group (Group 1) and five outlier stations. However, it was apparent that this one large multi-station group was composed of three fairly distinct groups, all forming with an R2 > 80 percent. Thus, using this more stringent criterion as the cutoff point for group formation, resulted in three multi-station groups and seven outlier stations. Comparison of the tree figure with the Andrews' and three-dimensional plots of principal components indicated that the latter interpretation was more valid. As in September 2008, silt/clay bottom predominated, with fourteen of the twenty-two April 2009 stations having this habitat type. One of the multi-station groups (Group 2) did coincide well with bottom habitat type, as all seven stations were dominated by a silt/clay bottom. This was the only station group identified that had only one dominant bottom type for all stations in the group.

Group 1 consisted of six stations: Nearfield stations MDE-3, MDE-9, MDE-16, and MDE-17; Back River station MDE-30; and South Cell station MDE-44. Group 1 stations had relatively poor spatial proximity, with an average (median) distance of 2,550 meters between them. Bottom habitat for Group 1 consisted of two shell, one sand, and three silt/clay stations.

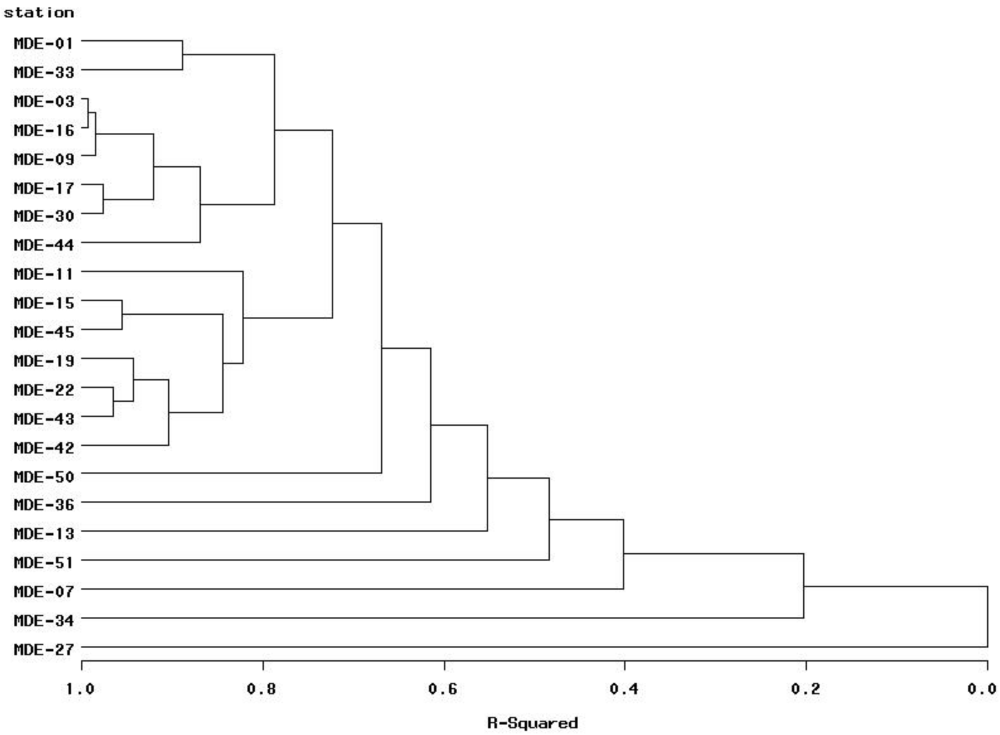

Figure 2-11. April 2009 cluster analysis tree.

Group 2 was composed of seven stations: four Nearfield stations (MDE-11, MDE-15, MDE-19, MDE-45), two South Cell stations (MDE-42 and MDE-43), and Reference station MDE-22. Spatial proximity between Group 2 stations was 1,725 meters. All Group 2 stations had a silt/clay bottom. Group 3 consisted of two Nearfield stations, MDE-1 and MDE-33, and had relatively good spatial proximity. Both stations were located at the north end of HMI, approximately 1,000 meters apart. The seven outlier stations were MDE-50, MDE-36, MDE-13, MDE-51, MDE-07, MDE-34, and MDE-27.

The Hotelling pseudo T2 (PST2) statistic values for April 2009 provided evidence supporting the identification of three multi-station groups and seven outliers (a total of ten distinct "groups"). However, the best conclusion that could be reached from the PST2 statistic was that there were from three to ten total groups. Thus, the PST2 result could not be used to discount the initial interpretation of the tree figure (using the R2 = 60 percent criterion) that there was one large group and five outliers (six total groups).

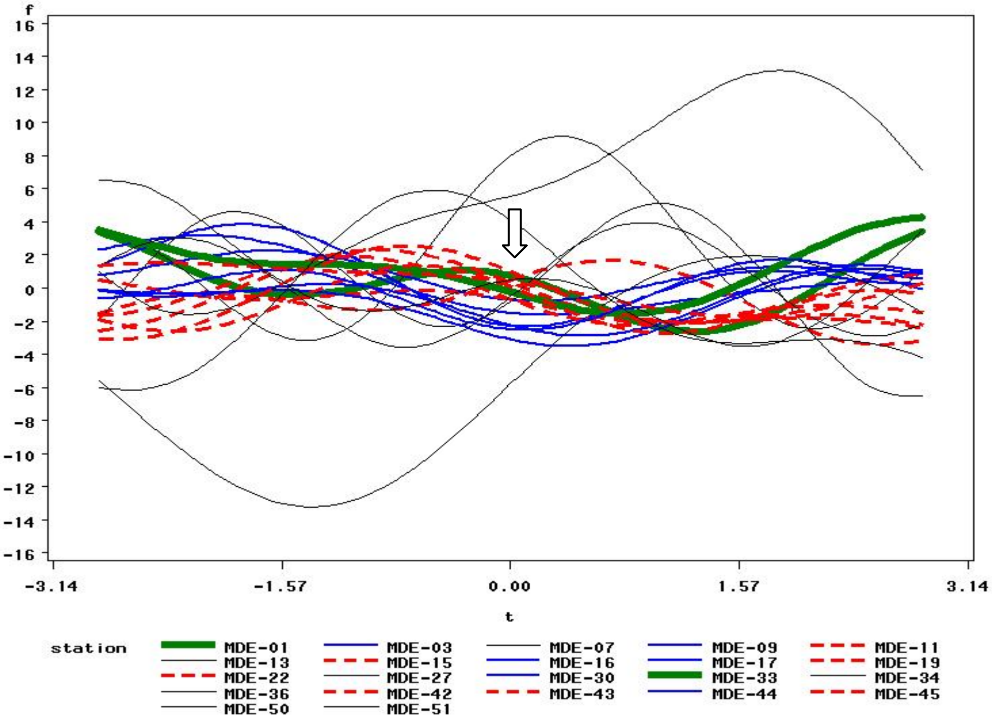

Figure 2-12. Andrews' plot of the April 2009 invertebrate abundance data using the uncorrelated first five principal components in the wave function (accounting for 74 percent of the variability of the data). Color-coded for three multi-station groups and seven outlier stations (using an $R^2 \geq$ 80 percent for identifying groups). Group 1 stations = continuous blue waves; Group 2 stations = dashed red waves; Group 3 stations = continuous green waves; outlier stations MDE-50, MDE-36, MDE-13, MDE-51, MDE-7, MDE-34, and MDE-27 = continuous black waves.

In contrast, the Andrews' plot for the April 2009 data was useful in supporting the three multi-station groups/seven outlier stations interpretation of the tree figure, and discounting the one large multi-station group/five outliers interpretation. Figure 2-12 is the Andrews' plot color-coded for the three multi-station group/seven outlier interpretation, and Figure 2-13 is the plot color-coded for the one large group/five outlier interpretation. In Figure 2-12, Group 1 stations are the blue waves, Group 2 stations are the red dashed waves, and Group 3 stations are the continuous green waves. The outlier stations are the continuous thin black waves. The outlier station waves all show good uniqueness, and the group waves demonstrate good coincidence except for station 11 of Group 2 (marked with arrow). When the figure is color-coded for the one large multi-station group interpretation, there are three station waves in the group (MDE-11, MDE-36, and MDE-50, marked as heavier dashed lines) that have poor coincidence.

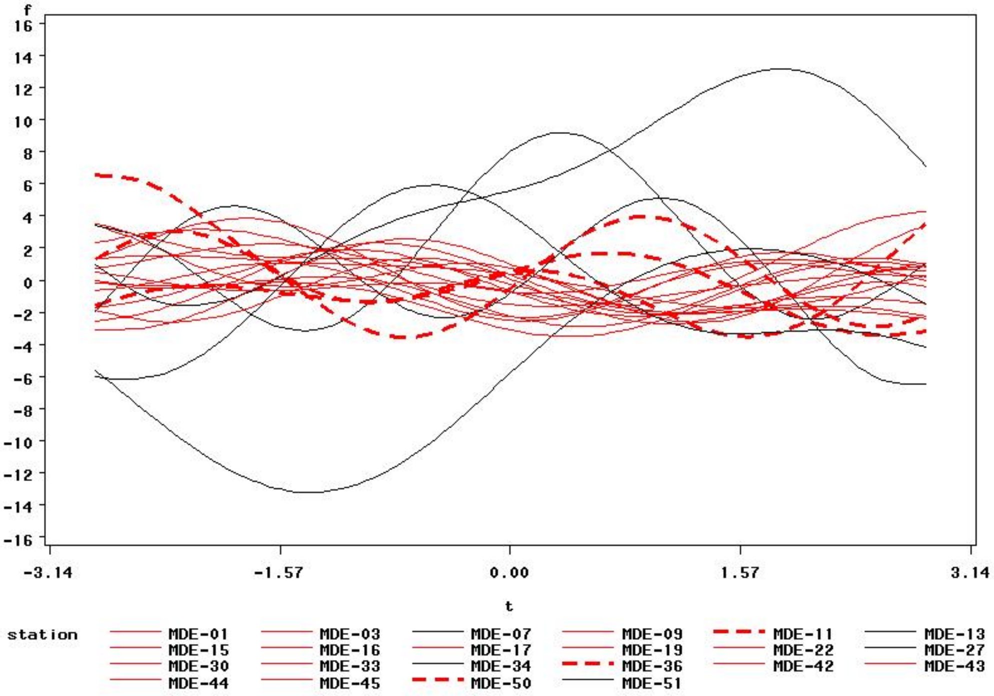

Figure 2-13. Andrews' plot of the April 2009 invertebrate abundance data using the uncorrelated first five principal components in the wave function (accounting for 74 percent of the variability in the data). Color-coded for one large station group and five outlier stations (using an R2 > 60 percent for identifying groups). Group 1 stations = both red continuous waves (good coincidence) and red dashed waves (poor coincidence); outlier stations MDE-13, MDE-51, MDE-7, MDE-34, and MDE-27 = continuous black waves.

The three-dimensional plot of the first three principal components provided additional support for the three multi-station/seven outlier interpretation (Figure 2-14 and Figure 2-15). For the April 2009 invertebrate abundances, most of the variability of the data occurred along the third principal component axis (vertical axis). It was apparent from the figure that the invertebrate assemblage differences among the stations were smaller when compared to the September 2008 group differences. However, the three multi-station groups/seven outlier stations interpretation (Figure 2-14) did a better job of separating out the third principal component variability than did the 1 large multi-station group/five outlier group interpretation (Figure 2-15). Note in the figure, that stations MDE-34 (flag) and MDE-27 (heart), which were outliers in September 2008, remained outliers in April 2009, and again had the most unique invertebrate assemblages (most distant from other stations in the figure).

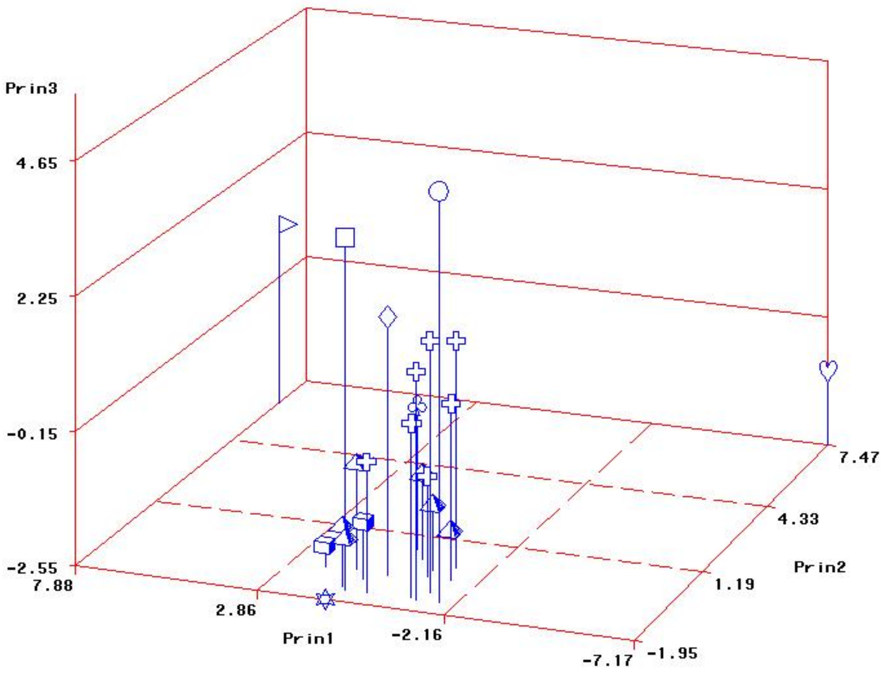

Figure 2-14. Three-dimensional plot of the first three principal components (accounted for 57.6 percent of the variability of the data) for the April 2009 invertebrate abundance data. Coded for three station groups and seven outliers. Group 1 = pyramids; Group 2 = crosses; Group 3 = cubes; outlier MDE-50 = star; outlier MDE-36 = club; outlier MDE-13 = diamond; outlier MDE-51 = balloon; outlier MDE-7 = square; outlier MDE-34 = flag; outlier MDE-27 = heart. Note that Prin1 = principal component 1 axis, Prin2 = principal component 2 axis, and Prin3 = principal component 3 axis.

The infaunal metric values for April 2009 provided some support for the three multi-station groups/seven outlier stations interpretation. Group 1 stations tended to have below average to average infaunal abundance (five of six stations), with lower than average abundances of *Macoma balthica*, *Macoma mitchelli*, and *Heteromastus filiformis*, and generally higher than average abundances of *Neanthes succinea* (four of six stations), *Melita nitida* (five of six stations) and *Cyathura polita* (four of six stations). Group 1 stations also correlated well with the other four metrics, with below average infaunal taxa richness (four of six stations), below average diversity (four of six stations), above average PSTA percentages (four of six stations), and below average PITA percentages (five of six stations). In contrast, Group 2 stations were poorly correlated with the five infaunal metrics, with roughly half the stations scoring below average and half the stations scoring above average. The two Group 3 stations strongly correlated to all five metrics. Group 3 stations were characterized with higher than average infaunal abundance (particularly *Marenzelleria viridis* and *Apocorophium lacustre*), lower than average taxa richness, diversity, and PITA percentages, and above average PSTA percentage. Outlier station MDE-27 was characterized with approximately average infaunal abundance

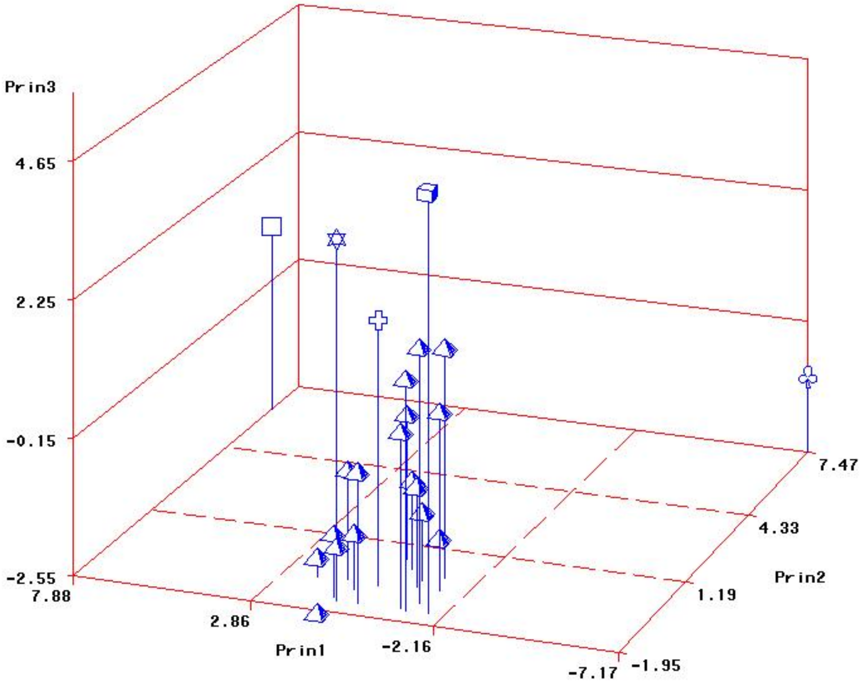

Figure 2-15. Three-dimensional plot of the first three principal components (accounted for 57.6 percent of the variability of the data) for the April 2009 invertebrate abundance data. Coded for one multi-station group and five outliers. Group 1 = pyramids; outlier MDE-13 = cross; outlier MDE-51 = cube; outlier MDE-07 = star; outlier MDE-34 = square; outlier MDE-27 = club. Note that Prin1 = principal component 1 axis, Prin2 = principal component 2 axis, and Prin3 = principal component 3 axis.

(between the mean and median), taxa richness, and PSTA percentage, and higher than average diversity and PITA percentage. Outlier MDE-34 had higher than average infaunal abundance (particularly *Macoma balthica*, *Rangia cuneata*, *Ischadium recurvum*, *Mytilopsis leucophaeata*, and *Apocorophium lacustre*), taxa richness, and PSTA percentage, and less than average diversity and PITA percentage. Outlier MDE-07 was characterized by higher than average infaunal abundance (particularly the bivalves *Macoma balthica*, *Mytilopsis leucophaeata*, and *Ischadium recurvum*; also *Apocorophium lacustre*, and *Hetermastus filiformis*), slightly lower than average PSTA percentage, below PITA percentage, average taxa richness, and average diversity (between mean and median). Outlier MDE-50 was characterized by higher than average infaunal abundance (particularly *Marenzelleria viridis*) and PSTA percentage, average taxa richness, and lower than average diversity and PITA percentage. Outlier MDE-36 had above average taxa richness, diversity, and PITA percentage, and average infaunal abundance and PSTA percentage. Outlier MDE-13 was characterized with lower than average infaunal abundance, and higher than average taxa richness, diversity, PSTA percentage, and PITA percentage. Finally, outlier MDE-51 had lower than average infaunal abundance, average PSTA percentage, and higher than average taxa richness, diversity, and PITA percentage.

Several conclusions can be made from the Year 27 clustering analyses. As in past years, grouping of stations based on infaunal invertebrate assemblages varied greatly between September 2008 and April 2009. This was not unexpected, given the seasonal changes in discharge rates entering Chesapeake Bay from nearby tributaries. The identification of station groups was fairly clear-cut in both seasons, although a higher R2 criterion of 80 percent was required in April 2009 because the variability between stations was lower. This was likely due to the large *Marenzelleria viridis* spring recruitment throughout this region of the Bay. As in past years, station groups did not especially correlate well with station type for most of the station groups identified, however for Group 2 in September 2008 five of the six stations were Nearfield stations, and both stations were Nearfield stations in the small Group 3 of April 2009. Group 2 of September 2008 also correlated well with bottom type as all six stations were dominated by silt/clay bottom. In addition, Group 2 of September 2008 had fairly good spatial proximity, as did Group 2 and Group 3 of April 2009. In Figure 2-15, silt/clay bottom dominated the two Back River stations and most of the stations east/southeast of HMI, however, there were several stations north of the island (MDE-33, MDE-34) and station MDE-50 that maintained a sand bottom. The identification of station groups by the clustering procedure provided evidence that indicated bottom type habitat was affecting the structure of infaunal assemblages, because of the formation of station groups dominated by silt/clay bottom (e.g., Group 2 of April 2009 and Group 2 of September 2008) as well as the formation of small groups at the north end of the island dominated by sand (Group 3 of April 2009). Other groups (Group 1 of September 2008 and Group 1 of April 2009) that formed included the silt/clay Back River station MDE-30 with the silt/clay stations east of the island.

The ultimate objective was to determine if there are any adverse impacts from dredging operations at HMI. Examining the station group correlations with the infaunal metrics, there was no evidence of impairment from HMI. The only station with an impaired infaunal invertebrate assemblage was MDE-27, likely caused by the influence on this station from the high freshwater discharge and sediment loading from Back River. It is likely that sediment discharge from Back River is the main source of the silt/clay sediment that covers most of the HMI stations. However the island acts as a break or barrier to some of this discharge near the north and northeast end of the island, creating a shadow effect that allows these stations to maintain a predominantly sand, or shell habitat.

Finally, one of the strongest conclusions made by the clustering analyses was that stations MDE-27 and MDE-34 were strong outliers with unique infaunal assemblages. MDE-27 had an impaired infaunal assemblage because of the influence of Back River, while MDE-34 had a very healthy infaunal assemblage.

The Friedman's nonparametric ANOVA test results indicated that there were significant differences (despite high variability) in the ten most abundant infaunal taxa between the four station types in September 2008 ($P < 0.099$), but not in April 2009 ($P < 0.89$). In September 2008 the Nearfield stations ranked highest for the top ten most abundant taxa, with a mean of 282 individuals per station, followed by Back River Stations (244 individuals per stations), Reference stations (200 individuals per station), and South Cell stations (123 individuals per station). This indication of significant differences in infaunal invertebrate abundances between station types was supported by the other metrics average values, particularly PSTA percentages, PITA percentages, and B-IBI scores. The station type averages for PSTA ranged from 26.3 percent (Nearfield stations) to 9.4 percent (Reference stations). The station type averages for PITA percentages ranged from 39 percent (Back River stations) to 21.7 percent for Reference stations. B-IBI station type averages ranged from 3.54 for Nearfield stations to 2.75 for Back River stations. Significant Friedman's test results are usually due to distinct Back River and South Cell abundances. Back River stations are impaired relative to the other station types, as indicated by relatively higher PITA percentages and relatively lower PSTA percentages. This has been a consistent pattern since Year 21. In contrast, although South Cell stations abundances for the top ten taxa have consistently been low relative to other station types (since Year 22), no impairment at these stations is indicated because of relatively good B-IBI scores, PSTA and PITA percentages.

Table 2-15. Friedman Analysis of Variance for September 2008's 10 most abundant species among: Back River/Hawk Cove, Nearfield, South Cell Exterior Monitoring, and Reference stations. ANOVA Chi Sqr. (N = 10, df = 3) = 6.272727 p < .09907.

Station Type	Average Rank	Sum of Ranks	Mean	Std. Dev.
Nearfield	3.100000	31.00000	282.3467	193.9951
Reference	2.800000	28.00000	200.4480	118.2432
Back River	2.350000	23.50000	243.8400	395.6192
South Cell	1.750000	17.50000	122.8800	188.1052

In April 2009, Nearfield stations again ranked highest for the top ten most abundant taxa (2,527 individuals per station), followed by South Cell stations (1,839 individuals per station), Reference stations (1,130 individuals per station), and Back River stations (1,037 individuals per station). The non-significant differences in the April 2009 Friedman's ANOVA was mirrored by lack of major differences between station types for Shannon-Weiner diversity, PSTA percentage, and PITA percentage.

Table 2-16. Friedman Analysis of Variance for April 2009's 10 most abundant species among: Back River/Hawk Cove, Nearfield, Reference stations, and South Cell Exterior Monitoring Stations. ANOVA Chi Sqr. (N = 10, df = 3) = .6250000 p < .89069.

Station Type	Average rank	Sum of ranks	Mean	Std. Dev
Nearfield	2.700000	27.00000	2527.476	7070.610
Reference	2.600000	26.00000	1130.453	2825.442
Back River	2.300000	23.00000	1036.587	2114.307
South Cell	2.400000	24.00000	1839.147	5098.316

CONCLUSIONS

In Year 27, the condition of the benthic macroinvertebrate community was examined under fairly typical conditions for this region of the Chesapeake Bay. Bay waters in the vicinity of HMI were low mesohaline in both September 2008 and April 2009. However, a winter to early spring drought resulted in widespread stratification, higher than normal bottom salinities and lower than normal DO values in April.

A marked improvement in the health of the benthic macroinvertebrate community was observed in Year 27. The total number of taxa and taxa richness was higher than observed in the previous sampling year. Average infaunal abundance, diversity, PSTA percentages and PITA percentages varied moderately for all stations around the historical means. Nearfield stations consistently scored high for the macroinvertebrate metrics, indicating that in general, macroinvertebrate communities for these stations were among the healthiest observed in Year 27. Macroinvertebrate community health, as measured by the B-IBI scores, rose in Year 27 after three consecutive years of declining scores (Figure 2-7). Compared to Year 26, B-IBI scores stayed the same at one station, increased at twelve stations, and declined at four stations. B-IBI scores in Year 27 were comparable to historical values. Twenty one of the twenty stations met or exceeded the benchmark criteria of 3.0, and only MDE-27 failed to achieve the benchmark (B-IBI = 2.50). Historically at HMI, B-IBI scores experience regular fluctuation (Figure 2-7), indicating that there is no apparent long-term trend of overall increasing or decreasing benthic invertebrate community health at HMI stations.

Nearfield and South Cell stations had the highest mean B-IBI scores among the four station types (B-IBI = 3.5), and Reference stations had a comparable score of 3.4. In contrast to the relatively healthy benthic macroinvertebrate communities at these sites, the mean B-IBI score for Back River stations (B-IBI = 2.8), indicated that these two sites (MDE-27 and MDE-30) had relatively impaired benthic communities (although MDE-30 did achieve the 3.00 benchmark). The Friedman's nonparametric ANOVA test for the September 2008 data confirmed the B-IBI results by indicating significant differences in infaunal abundance among the four station types, but the result was mainly driven by the significantly lower infaunal abundance at South Cell stations, and not due to infaunal abundance at the two Back River stations. The September 2008 cluster analysis clearly identified Back River station MDE-27 as an outlier station with a very distinct infaunal invertebrate assemblage, supporting the B-IBI results that indicated that this was the only impaired station in Year 27. The B-IBI scores are calculated from a number of metrics, including infaunal abundance, Shannon-Wiener Diversity, PSTA, and PITA score, while the Friedman's nonparametric ANOVA test and the cluster analyses examine differences in faunal abundance only. The comparison of mean B-IBI scores among the station types are a more robust measure of differences between them because they are multi-metric indices, which are fine-tuned to the predominant salinity regime at the time of sampling.

With the exception of station MDE-27 (Back River), no other station in the vicinity of HMI is consistently impaired. Lower B-IBI scores apparently occur as a result of unique conditions inherent to the Back River drainage, which include relatively high freshwater influx and historically elevated nutrient and sediment loads. The additional statistical analyses performed this year confirmed this conclusion.

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APPENDIX 3: ANALYTICAL SERVICES (PROJECT IV)

(September 2008 – August 2009)

Technical Report

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OBJECTIVES

The goals of the project for Hart-Miller Island (HMI) Exterior Monitoring Year 27 (September 2008-August 2009) were to continue to measure and evaluate the current levels of contaminants in the sediment in the vicinity of HMI and to relate these, as far as possible, to historical data. Continued comparison and correlation of this data with historical HMI data, will indicate the extent of contamination and any trend in concentrations at this location.

The objective of this study was to provide sensitive, high-quality information on the concentrations of present day trace metals in surface sediments surrounding HMI during the 27th year of exterior monitoring, and to document any seasonal changes. Specific objectives were:

1. In the fall of 2008 and spring of 2009 collect clams and associated sediment for analyses of trace metals. Sediment and clams were analyzed for total mercury (T-Hg), methylmercury (MeHg), silver (Ag), selenium (Se), arsenic (As), Cadmium (Cd) and lead (Pb).

2. To determine the concentrations of target trace elements in surface sediments around HMI at a larger number of stations collected by the Maryland Geological Survey (MGS) in September 2008 as part of the annual sediment survey. Metal analysis focuses on those metals not measured by MGS, specifically total mercury (T-Hg), methylmercury (MeHg), silver (Ag), selenium (Se) and arsenic (As).

The results of the quality assurance/quality control (QA/QC) procedures and the description of the analytical and field protocols are contained in the *Year 27 Data Report*. Overall, the QA/QC results were acceptable for a study of this nature. No evidence of bias or lack of precision or accuracy was indicated by the QA/QC results. Comparisons of duplicate analyses and comparison of measured values to certified values for the analyzed Standard Reference Materials are also discussed in the *Year 27 Data Report*. Again, the QA/QC objectives were met in this regard.

METHODS AND MATERIALS

Sampling Procedures

Samples were collected using a Ponar grab sampler, from stations designated by the revised sampling plan, developed by the Maryland Department of the Environment (MDE). Again, two sets of samples were collected. A large spatial survey was conducted by MGS (Objective 2) in September 2008 and samples provided to Chesapeake Biological Laboratory (CBL) for analysis. In September 2008 and April 2009 a subset of stations was visited by MDE and CBL personnel to collect clams and sediment for trace metal analysis, the latter being required to make bioaccumulation calculations (Objective 1). Sediment for trace metal analyses were collected using plastic spatulas and glass spatulas respectively, integrating the top several centimeters and avoiding the sides of the sampler to minimize the possibility of contamination. Sediments for metals were placed in plastic sampling cups and were kept cooled in an ice chest or refrigerator until they could be processed in the laboratory.

Sediment was sieved for clams; the whole clams were placed in plastic bags with surface water and held on ice. The clams were frozen to allow easy shucking the next day. For metals analysis, clams were removed whole from their shells with a Teflon-coated spatula. The spatula was acid rinsed between each site to avoid cross contamination between sites. The clam bodies from each site were homogenized in a plastic blender with a stainless steel blade. Unused samples were returned to their respective bags and stored in the freezer until further analysis.

Analytical Procedures for Metals

Methods used for metals analysis are similar to those described in detail in Dalal et al. (1999). For metals, a subsample of each trace metal sample (sediments) was used for dry weight determination. Weighed samples were placed in a VWR Scientific Forced Air Oven at 60^0C overnight. Upon drying, samples were then reweighed and a dry/wet ratio was calculated and applied to the concentrations determined on wet samples.

Sediment and clam tissue were treated the same with regard to analysis. A sub-sample of sediment (5 g wet weight) was placed in acid-cleaned flasks for further digestion (Keith 1991). Ten mL of 1:1 HNO_3 was added and the slurry was mixed and covered with a watch glass. The sample was heated to 95^0C and allowed to reflux for 15 minutes without boiling. The samples were cooled, 5 mL of concentrated HNO_3 was added, and then they were allowed to reflux for another 30 minutes. This step was repeated to ensure complete oxidation. The watch glasses were removed and the resulting solution was allowed to evaporate to 5 mL without boiling. When evaporation was complete and the samples cooled, 2 mL of 30% H_2O_2 was added. The flasks were then covered and returned to the hot plate for warming. The samples were heated until effervescence subsided. Thirty percent H_2O_2 was repeatedly added in 1 mL aliquots with warming until the effervescence was minimal. No more than a total of 10 mL of H_2O_2 was added to each sample. Lastly, 5 mL of concentrated HCl and 10 mL of deionized water were added and the samples refluxed for 15 minutes. The samples were then cooled and filtered through Whatman No. 41 filter paper by suction filtration and diluted to 50 mL with deionized water. Sediment homogenates were then analyzed using a Hewlett Packard model 4500 Inductively Coupled Plasma Mass Spectrometer for the metals and metalloids. These techniques follow USEPA Method 3050b.

Samples for the analysis of mercury (1-3 g wet weight) were digested in a solution of 70% sulfuric/30% nitric acid in Teflon vials, heating overnight in an oven at 60^0C (Mason and Lawrence, 1999). The digestate was then diluted to 10 mL with distilled-deionized water. Prior to analysis, the samples were further oxidized for 30 minutes with 2 mL of bromine monochloride solution. The excess oxidant was neutralized with 10% hydroxylamine solution and the concentration of mercury in an aliquot of the solution was determined by tin chloride reduction cold vapor atomic fluorescence (CVAFS) detection after gold amalgamation in accordance with protocols outlined in USEPA Method 1631 (Mason et al. 1993).

Samples for methylmercury were distilled after adding a 50% sulfuric acid solution and a 20% potassium chloride solution (Horvat et al. 1993, Bloom 1989). The distillate was reacted with a sodium tetraethylborate solution to convert the nonvolatile MeHg to gaseous MeHg. The volatile adduct was purged from solution and recollected on a graphitic carbon column at room temperature. The MeHg was then thermally desorbed from the column and analyzed by cryogenic gas chromatography with CVAFS. Detection limits for Hg and MeHg were based on three standard deviations of the blank measurement.

RESULTS AND DISCUSSION

Metals in Sediment

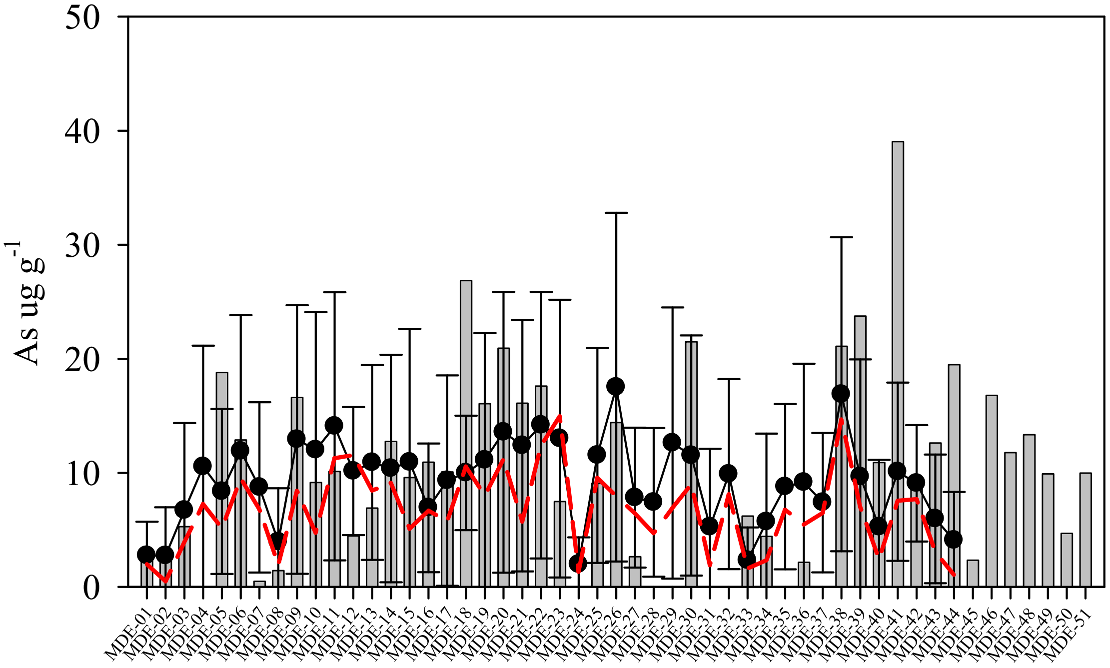
Concentrations of As in the sediment collected around HMI in Year 27 (fall 2008) are toward the higher side of concentrations seen in previous years (Figure 3-1). The concentrations of As are close to the running mean (calculated for the period 1998 to 2007) at the majority of the sampling locations. Sediment concentrations of As exceeded the historical mean by greater than 5 ug g^{-1} at a few locations. However, these stations are spatially diverse. For example, station MDE-41 is located at the entrance to Baltimore Harbor, Station MDE-18 is located near the South Cell outflow, and station MDE-30 is located on the north side of the island. There is no apparent pattern or reason for these higher than previously observed concentration of As in sediment.

The concentration of Se in the sediments collected in the fall of 2008 are generally higher than in sediments collected in previous years but the concentrations lie within the standard deviation of the historic average. Concentrations of Se in sediment from the reference site (MDE-36) remained typical of previous years. The difference in concentration between samples collected in the fall of 2008 and previous years is small, on average less than 1 ug g^{-1}, but because of the generally low concentrations of Se in the sediment around the HMI complex the increase observed in 2008 represents a large percentage change.

Concentrations of Ag in the sediment collected in the fall of 2008 were lower than the median and average concentrations collected around HMI in previous years (Figure 3-2). Annual fluctuations in the concentration of Ag in sediment are common but occur on a system wide basis and appear unrelated to HMI operation.

Concentrations of T-Hg in sediment were largely typical of previous years falling within the standard deviation of measurements made between 1998 and 2007 (Figure 3-2). Concentrations of T-Hg in sediments from the main stem of the Chesapeake Bay range from 0.2 to 250 ng g^{-1} dry weight, which is comparable to sediment concentrations present around the HMI complex (Heyes et al. 2006). Concentrations of T-Hg at three stations, MDE-14, MDE-34 and MDE-44 were much higher than in past years. The sites are located on the south and east sides of the island. Nearby sites do not have T-Hg concentrations elevated above the range observed in past years. There is no obvious explanation for the elevated concentrations at these three sites.

Concentrations of MeHg in sediment collected in the fall of 2008 ranged from 0.01 to 1.4 ng g^{-1} dry weight (Figure 3-3). These concentrations are comparable to the rest of the Chesapeake Bay (Heyes et al. 2006). The percent of mercury that occurred as MeHg was generally less than 1%. One exception was station MDE-50, where the percent of T-Hg that was MeHg was 3.5%. This elevated number is driven by the very low T-Hg concentration in sediment at the site, and not a high MeHg concentration. Note, this was the first sampling of sites MDE-45 through 51, thus there is no historical data to create running averages or medians. Sites MDE-45 through 51 were added to the sampling design in 2008 to increase spatial sample density on the southeast side of the island, which is primarily the HMI zone of influence.



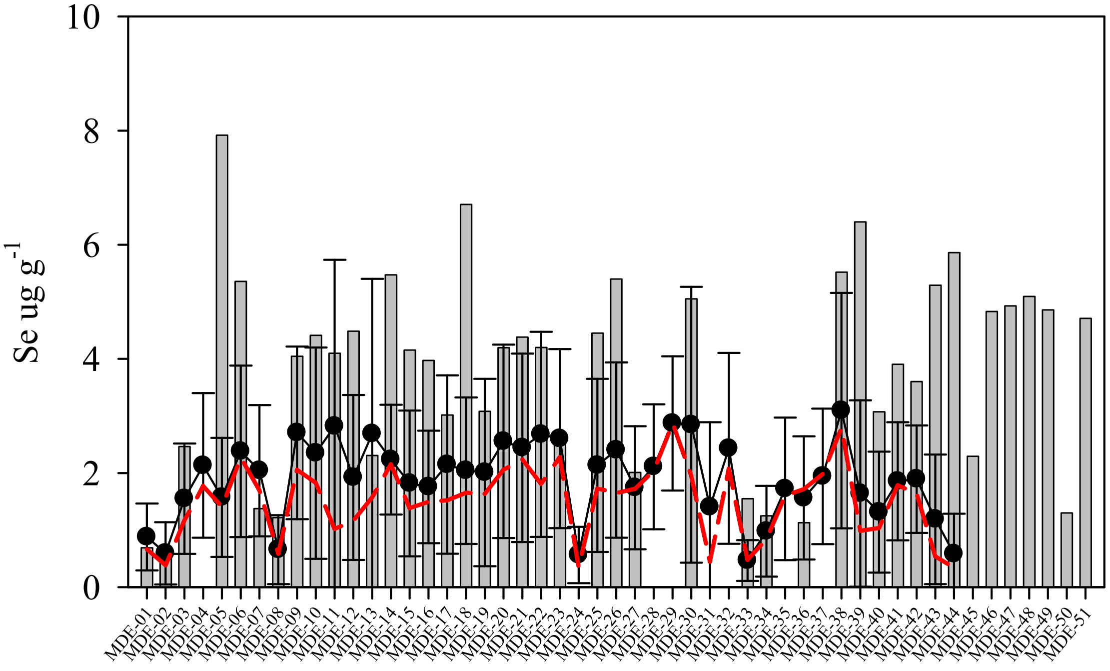


Figure 3-1. As and Se in sediment, expressed as dry weight concentration, collected by MGS in the fall of 2008 (bars) and the 1998-2007 mean (circles) with standard deviation (error bars) and the 1998-2007 median (dashed line).

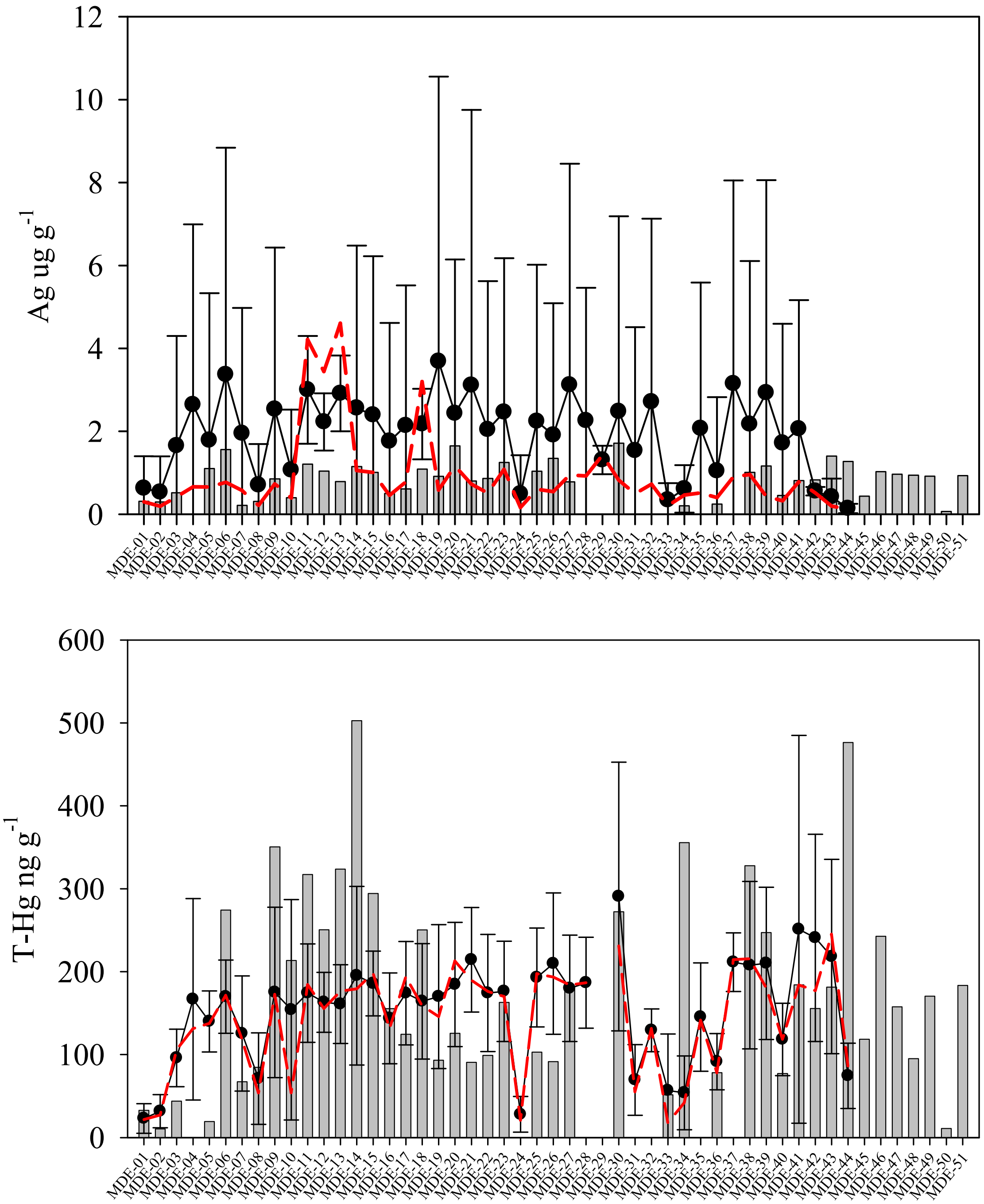


Figure 3-2. Ag and T-Hg concentrations in sediment, expressed as dry weight concentration, collected by MGS in the fall of 2008 (bars) and the 1998-2007 mean (circles) with standard deviation (error bars) and the 1998-2007 median (dashed line).

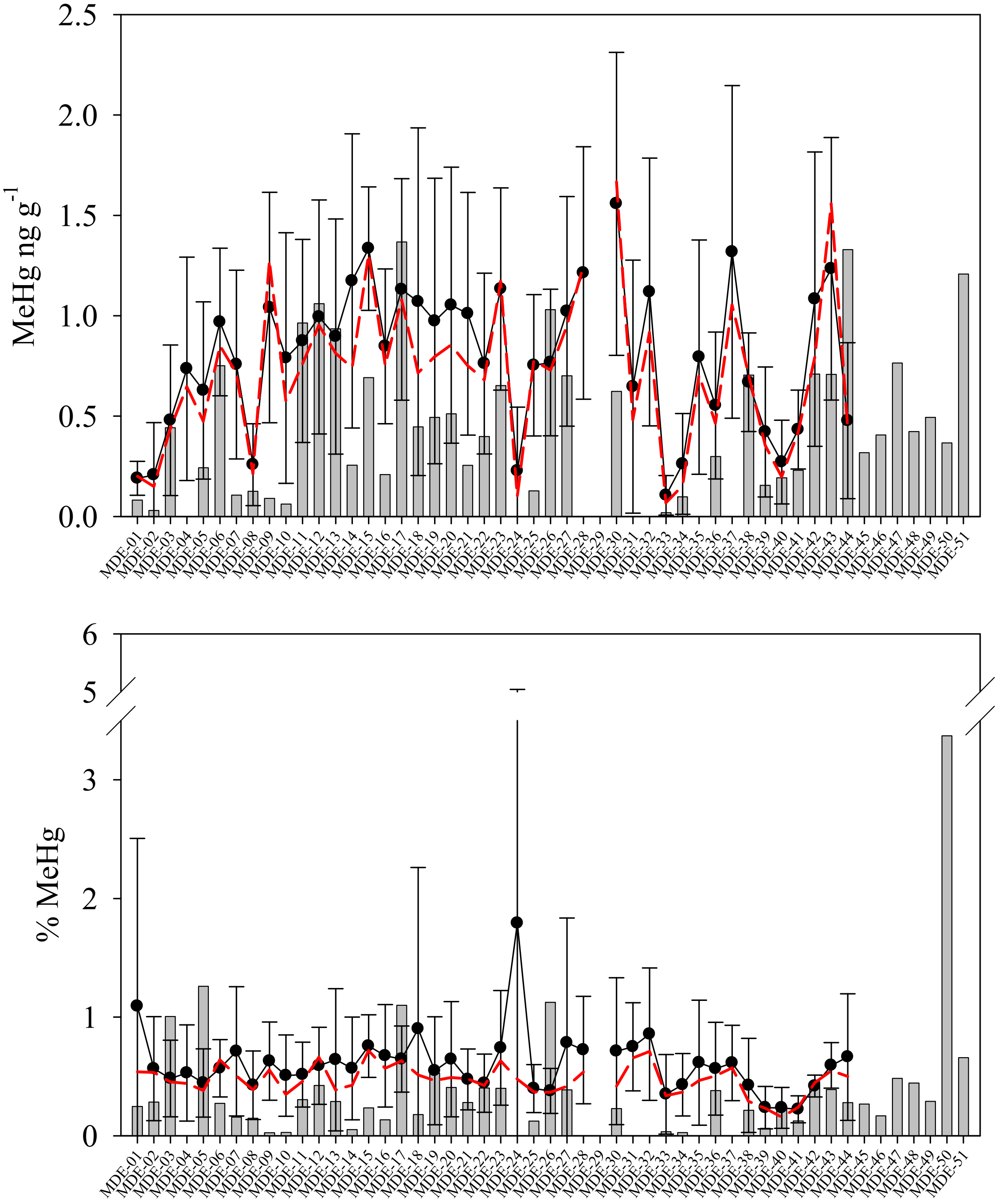


Figure 3-3. MeHg, expressed as dry weight concentrations, and percent of T-Hg as MeHg in sediment collected by MGS in the fall of 2008 (bars), and the 1998-2007 mean (circles), with standard deviation (error bars), and the 1998-2007 median (dashed line).

Metals in Clams

The clam *Rangia cuneata* was collected from 12 sites in the fall (September) of 2008 and 13 sites in spring (April) of 2009. Not all the benthic sites can be examined annually because of the cost, thus sites are selected from the 22 MDE sites to provide broad coverage while maintaining some between-year overlap of sites. In the fall of 2008 the sites monitored were MDE-01, 11, 15, 16, 17, 27, 34, 36, 43, 45, 50, 51. Concentrations of metals and metalloids in clams collected in the fall of 2008 were similar to, or lower than, the historic running averages and medians observed at each of the selected sites (Figure 3-4 and Figure 3-5). Five new sampling sites were added to the sampling design in 2008 to increase the spatial sample density around the southeast side of the island. Two of these sites were sampled for clams in the fall of 2008. Site MDE-45, located adjacent to the island on the south side, and MDE-50, thought to be a reference site, had high concentrations of As and Se in the clams collected from these sites compared to other HMI sites. Site MDE-45 also had high concentrations of T-Hg in clams. There is no historical information available to explain these high concentrations. The fact that concentrations of As and Se in sediments collected from MDE-45 and 50 were found to be normal makes interpreting and explaining the high concentrations in clam tissue even more difficult.

Sites sampled in April 2009 were MDE-01, 07, 13, 15, 17, 27, 30, 33, 34, 36, 43, 45, and 51. In April 2009, concentrations of Cd, Pb, T-Hg and MeHg in clams were close to their historical levels (Figure 3-6 and Figure 3-7). However, the concentration of As in clams was on average 4 times higher than historical levels, and the concentration of Se was 2 times higher. In past years elevated concentrations of Ag have been observed in clams collected in the spring as opposed to the fall. This trend was not see in the fall 2008 to spring 2009 period. In fact Ag was much lower in April 2009 compared to historic values. As was the case for Ag in past years, the elevated As and Se concentrations were also seen at the reference site (MDE-36) which suggests a Bay wide issue and not related to operations at the HMI facility.

As discussed above, a seemingly anomalous concentration of T-Hg was observed in clams collected from station MDE-45 in the fall of 2008. Clams were again collected from this site in the spring of 2009. Concentrations of T-Hg in clams collected from MDE-45 in the spring of 2009 were much lower than the concentration measured in the fall of 2008. The concentrations of T-Hg in clams from MDE-45 collected in the fall of 2009 appear to have been anomalous. It is recommended that the site should be sampled again in 2010.

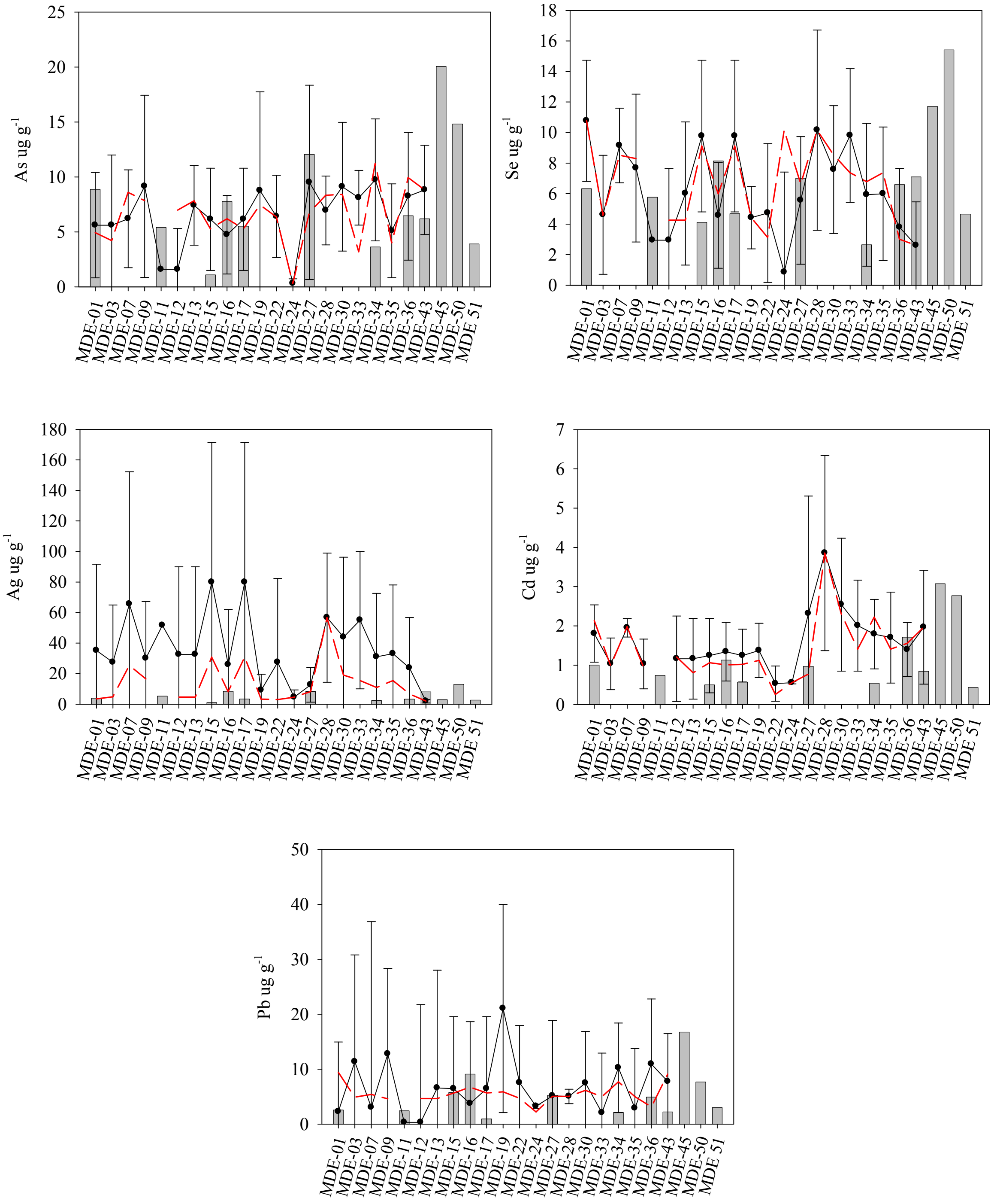


Figure 3-4. Concentrations of Pb, Cd, As, Se, Ag in clams collected in September 2008. Concentrations (bars) are dry weight based and the 1998-2007 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2007 median (dashed line).

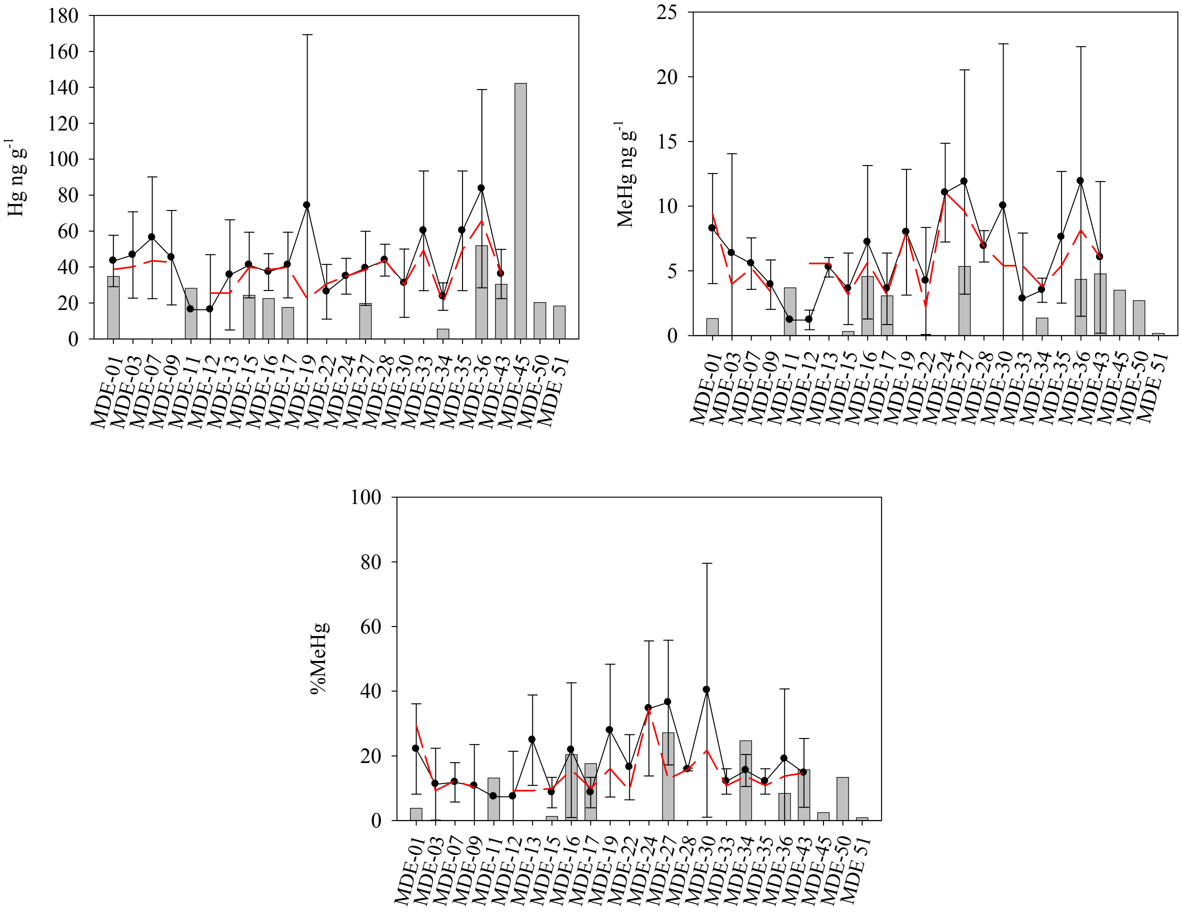


Figure 3-5. Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent of Hg that is MeHg in clams, collected in September 2008 (bars) and the 1998-2007 mean (circles) with standard deviation (error bars) and the 1998-2007 median (dashed line).

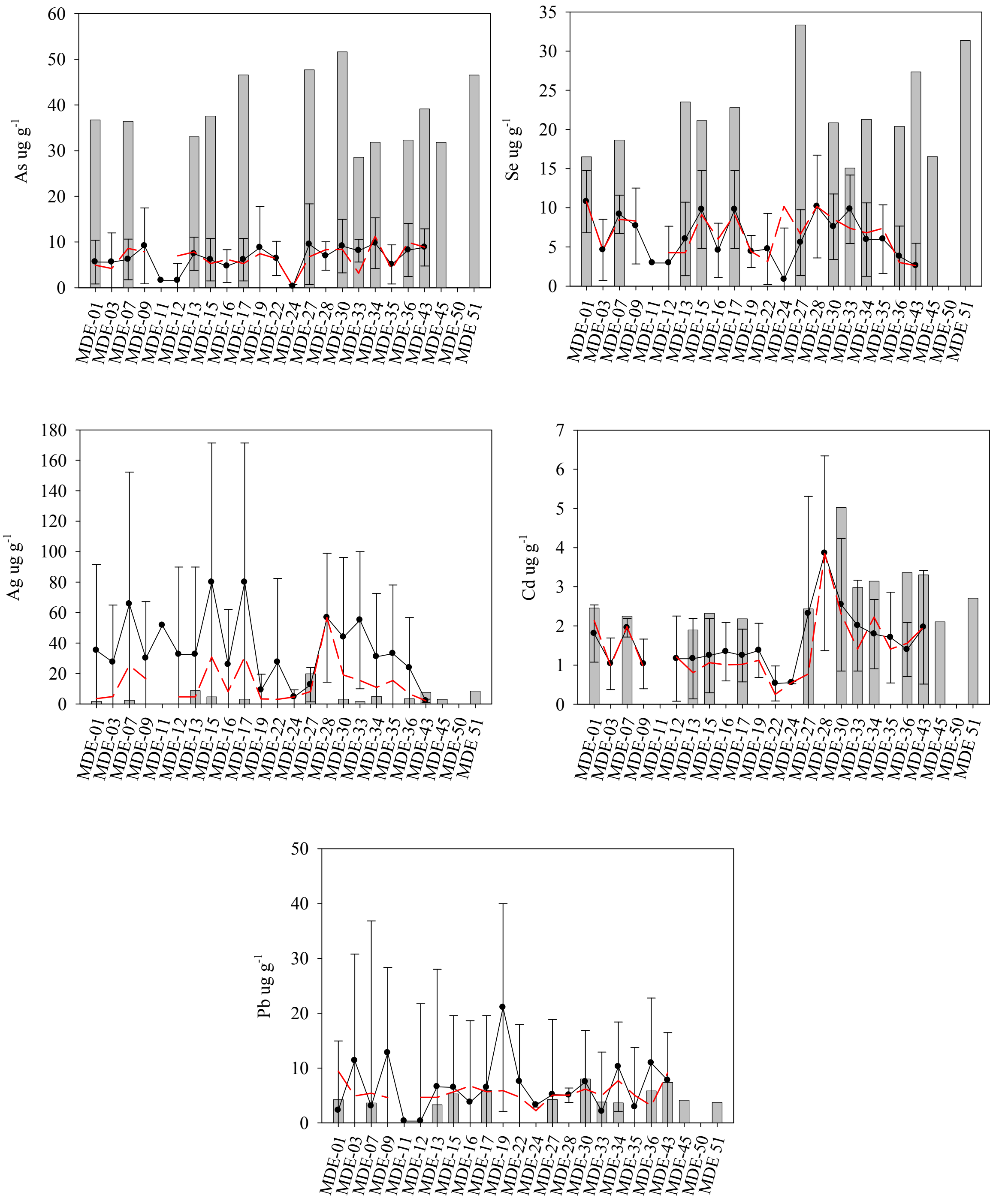


Figure 3-6. Concentrations of Pb, Cd, As, Se, Ag in clams collected in April 2009. Concentrations (bars) are dry weight based, and the 1998-2007 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2007 median (dashed line).

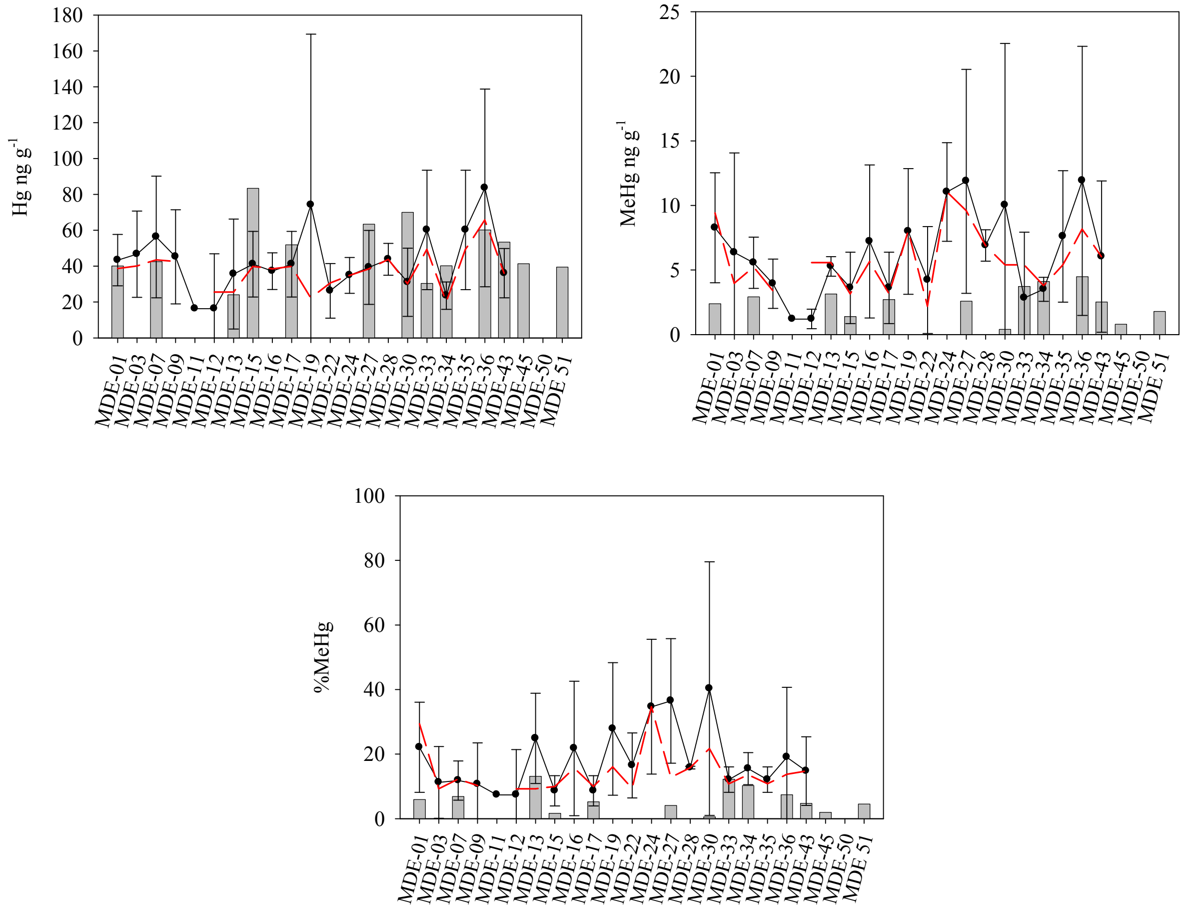


Figure 3-7. Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent of Hg that is MeHg in clams, collected in April 2009 (bars) and the 1998-2007 mean (circles) with standard deviation (error bars) and the 1998-2007 median (dashed line).

Bioaccumulation Factors

The bioaccumulation factors (BAFs) for clams were calculated for Cd, Pb, As, Ag, Se, T-Hg and MeHg (Figure 3-8) using the metal and metalloid concentration data from the sediment (Table 3-1) concurrently collected with the clams in both September 2008 and April 2009. In both September 2008 and April 2009, the BAFs for Pb (not shown) were less than 1 for all sites sampled, indicating no bioaccumulation of Pb by the clams. BAFs of less than 1 for Pb have been observed for the duration of the study.

In September 2008, little bioaccumulation of As, Cd and T-Hg by clams (BAFs typically less than 10, Figure 3-8) was observed, and moderate bioaccumulation of Se, Ag and MeHg by clams (BAFs on the order of 10). In April 2009, moderate bioaccumulation of As, Ag, Se, Cd and MeHg by clams (BAFs on the order of 10) was observed. No bioaccumulation of T-Hg by clams was observed. In general, the largest BAFs occurred at sites MDE-01 and 07 but these elevated numbers where driven by low concentrations of metals and metalloids in sediment and not by high concentrations in clams (Table 3-1 and Table 3-2).

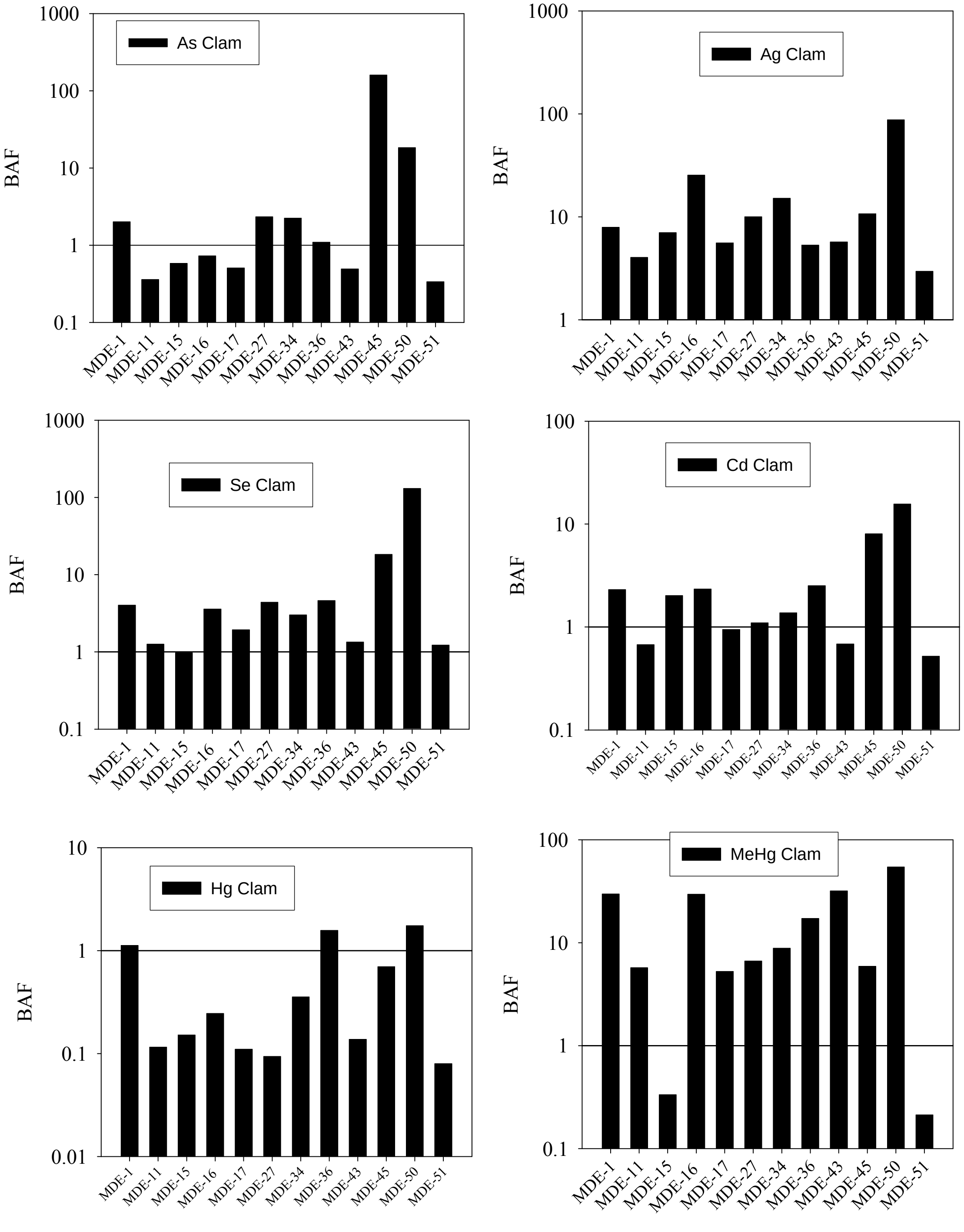


Figure 3-8. Bioaccumulation factors for the metals As, Ag, Se, Cd, T-Hg and MeHg September 2008.

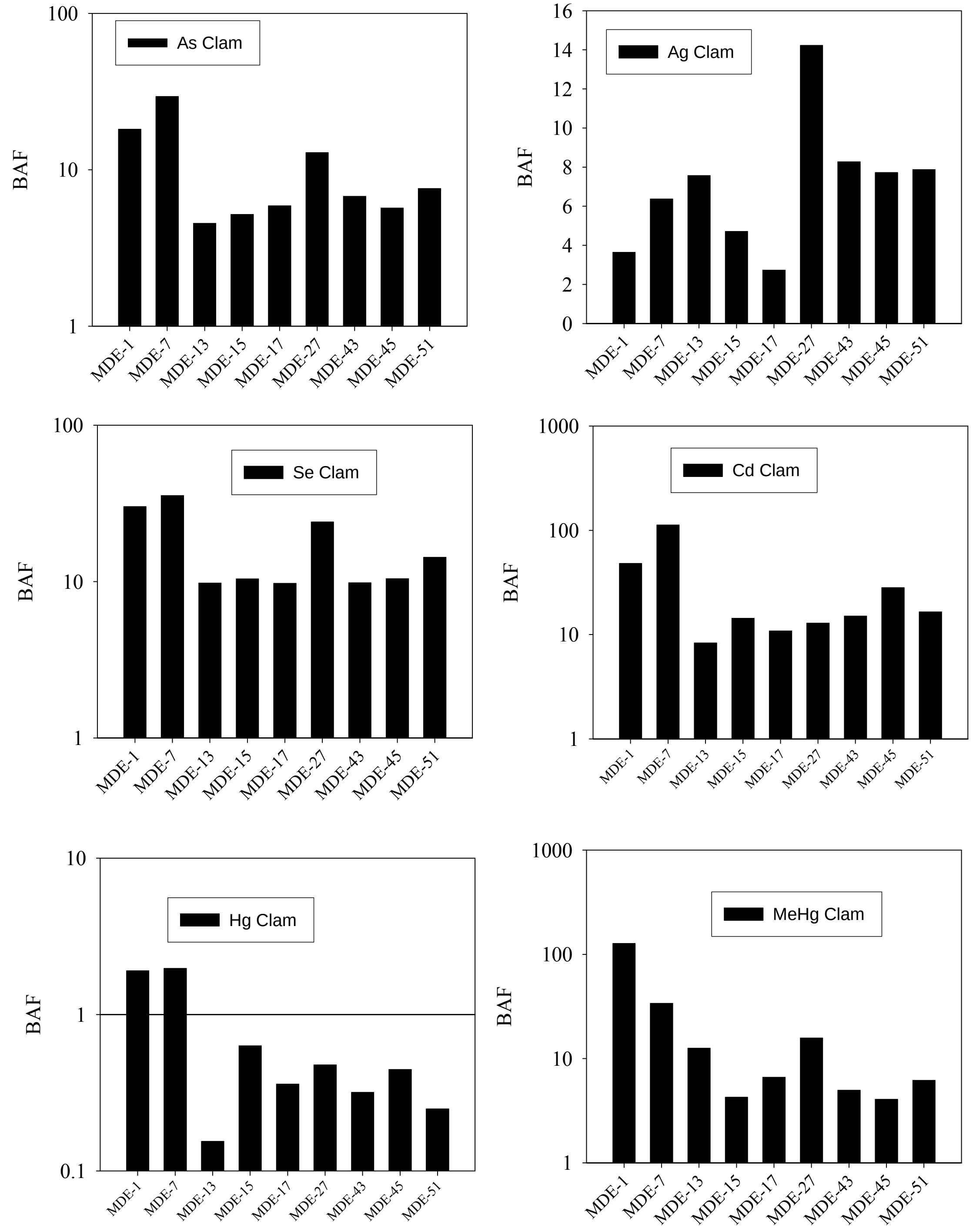


Figure 3-9. Bioaccumulation factors for the metals As, Ag, Se, Cd, T-Hg and MeHg April 2009.

Table 3-1. Trace metal concentrations in sediment (dry weight) collected in September 2008 with clams. These sediment samples are different than the sediment samples described earlier which were collected by MGS.

Fall 2008 sediments collected with clams

	As	Se	Ag	Cd	Pb	T-Hg	MeHg
	ug/g	ug/g	ug/g	ug/g	ug/g	ng/g	ng/g
MDE-1	4.41	1.57	0.49	0.43	37.42	30.91	0.04
MDE-11	15.05	4.57	1.31	1.10	71.33	243.12	0.65
MDE-15	3.55	0.81	0.37	0.31	14.73	160.48	0.92
MDE-16	10.68	2.27	0.33	0.48	30.98	91.50	0.15
MDE-17	10.91	2.42	0.61	0.60	45.21	158.32	0.58
MDE-22	11.41	3.36	1.00	0.93	72.12	199.94	0.83
MDE-27	5.15	1.59	0.82	0.88	56.57	210.29	0.80
MDE-34	1.62	0.88	0.16	0.39	17.54	15.42	0.15
MDE-36	5.91	1.43	0.61	0.68	48.56	33.01	0.25
MDE-43	12.61	5.29	1.40	1.23	69.75	220.34	0.15
MDE-44	10.32	2.33	0.54	0.55	42.02	211.32	0.26
MDE-45	0.13	0.64	0.27	0.38	24.06	203.97	0.59
MDE-50	0.81	0.12	0.15	0.18	12.92	11.59	0.05
MDE-51	11.59	3.79	0.90	0.83	58.47	228.30	0.77

Table 3-2. Trace metal concentrations in sediment (dry weight) collected in April 2009 with clams. These sediment samples are different than the sediment samples described earlier which were collected by MGS.

Spring 2009 sediments collected with clams

	As	Se	Ag	Cd	Pb	T-Hg	MeHg
	ug/g	ug/g	ug/g	ug/g	ug/g	ng/g	ng/g
MDE-1	2.03	0.55	0.46	0.05	9.07	21.06	0.02
MDE-7	1.24	0.53	0.38	0.02	5.89	21.55	0.09
MDE-13	7.27	2.40	1.16	0.23	34.20	155.59	0.25
MDE-15	7.26	2.03	0.98	0.16	31.97	132.28	0.33
MDE-17	7.93	2.33	1.13	0.20	37.67	144.66	0.41
MDE-27	3.71	1.38	1.39	0.19	32.05	133.07	0.16
MDE-43	5.79	2.78	0.92	0.22	38.52	167.64	0.51
MDE-45	5.58	1.59	0.40	0.07	19.06	92.89	0.20
MDE-51	6.14	2.19	1.08	0.16	30.01	158.14	0.29

Investigating Potential Metal Toxicity

For some metals, toxicological affects criteria have been established by the National Oceanic and Atmospheric Administration (NOAA). As a frame of reference for the overall condition of the sediment around HMI, the Probable Effects Levels (PEL) for the metals analyzed by CBL was plotted along with the concentrations of metals and metalloids in sediments collected by MGS (Figure 3-10 and Figure 3-11). For the metals As, Ag and T-Hg, sediment concentrations are below the PEL. No PEL has been established for the metalloid Se as the data used to create screening criteria for Se in sediment is very limited.

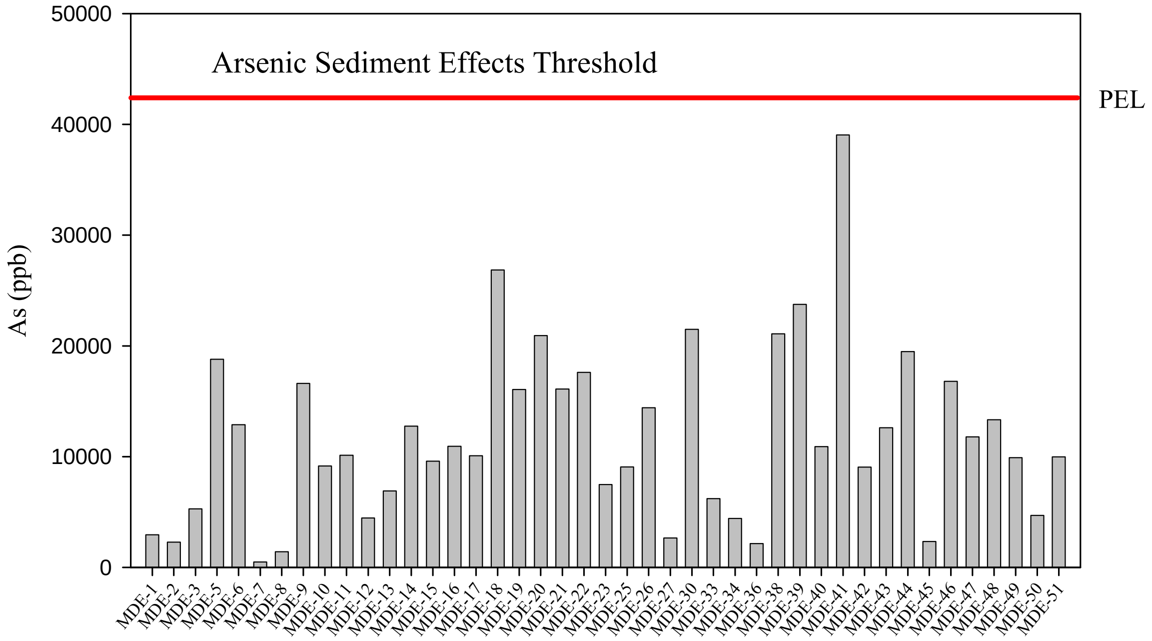


Figure 3-10. Arsenic (As) concentrations in sediment along with the Probable Effects Level (PEL) identified by NOAA for marine sediment.

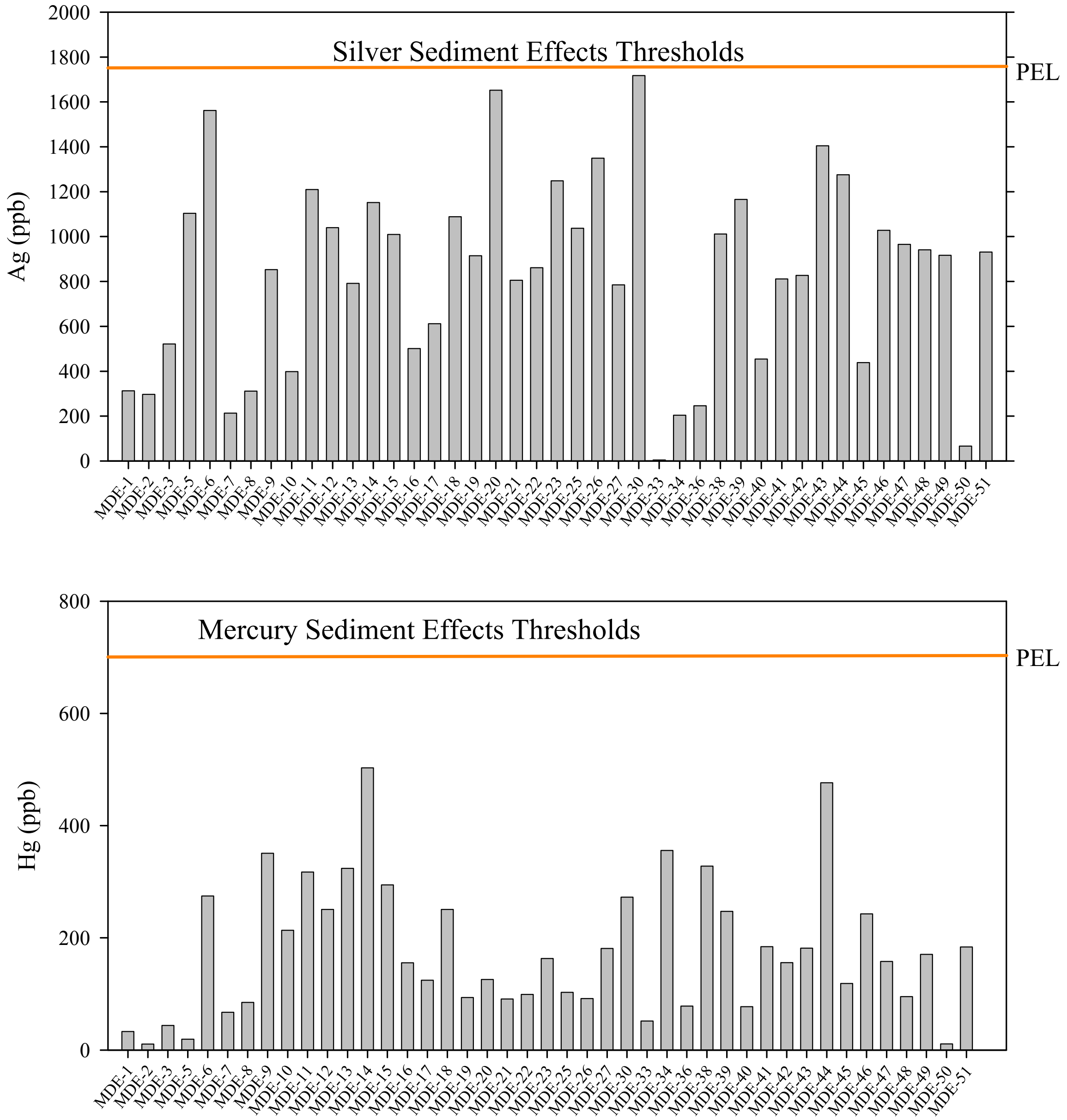


Figure 3-11. Total mercury (T-Hg) and Silver (Ag) concentrations in sediment along with Probable Effects Level (PEL) as identified by NOAA for marine sediment.

Section summary

Sediment concentrations of As, Se, Ag, T-Hg and MeHg remain similar to past years. Concentrations of As and Se in clams collected in April 2009 were higher than concentrations observed in clams from previous years (1998-2007) but concentrations in clams collected at the reference site also had high concentrations of As and Se. Therefore it is suggested that a regional influence is responsible for the elevated concentrations of As and Se in clams and the source is other than the HMI facility.

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