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

Year 34 Exterior Monitoring Technical Report

(September 2016-August 2017)

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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., groundwater 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.
Effects Range Low (ERL)	Concentration below which effects are rarely observed or predicted among sensitive life stages and (or) species of biota for Sediment Effect Concentrations used to evaluate sediment concentrations of trace elements and sediment concentrations of trace elements and synthetic organic compounds.

Effects Range Median (ERM)	Concentration above which effects are frequently or always observed among most species of biota for Sediment Effect Concentrations used to evaluate sediment concentrations of trace elements and synthetic organic compounds.
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 in*material*	Sediments consisting of particles less than or equal to 0.062 mm 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.
Least-Squares fit	A method to choose the "best" line fit through a cluster of data points. It is possible to fit many different lines through a set of data points. A line that results in the smallest value of the sum of the squares of the differences between observed and expected values is considered the best fit.
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.
Outlier	An observation that is outside of the expected range of values.
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 34

(September 2016– August 2017)

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INTRODUCTION

The HMI DMCF (Hart-Miller Island Dredged Material Containment Facility) was designed to receive dredged material from navigation channel maintenance and improvement activities in the Baltimore Harbor and its approaches. Construction of HMI, which entailed building a diked area connecting the remnants of Hart and Miller Island, began in 1981 and was completed in 1983. The facility, encompassing approximately 1,100 acres, is divided by a 4,300 foot interior cross-dike resulting in a North and South Cell. In the early years, material was mainly placed in the South Cell, which was completed on October 12, 1990 after which efforts were initiated to convert it into an upland-wetland wildlife refuge. Placement of dredged material was then diverted to the North Cell and continued until December 31, 2009 at which time all inflow of dredged material ceased.

Because the North Cell is now no longer receiving dredged material while design plans are being finalized, dewatering and crust management will be minimal. The goal is to shape the area creating upland habitat around the northwest side with a gradual slope to the southeast producing a pond ranging in depth from one and a half to six feet in depth with occasional mudflats similar to, but not to the extent of, the South Cell. The current scheduled plan is to use the existing water collected from precipitation events in the cell to form the pond, which allows for minimal discharge during crust management. During this truncated phase of crust management, dredged material could potentially be exposed to air resulting in sulfides becoming oxidized creating acidic conditions during rainfall events. Acidic conditions can mobilize metals, which is cause for concern if discharged to the exterior environment through the spillways. Discharge will continue to be monitored to comply with the permit requirements, and water is not discharged if it does not comply with permit limits. Post closure exterior monitoring will continue to occur to see if any possible concerns do arise during this period.

The first sampling cruises for monitoring Year 28 took place in September 2009, while HMI was still receiving dredged material. The April 2010 sampling cruises marked the first sampling after closure. Thus, only the April 2010 monitoring results can be considered post-closure baseline data. Year 34 marks the sixth consecutive year of post-closure monitoring. It is important that monitoring continued for at least 5 years post-closure during this crucial period of dewatering and crust management, and habitat development of the North Cell to establish a robust post-closure data set. These years of data can then be compared to the thirty years of data collected during dredged material placement. This comparison of pre- and post-closure data will allow the scientists to determine differences, if any, in the exterior environment, and whether the differences were a result of HMI operations. The information learned can be applied to future dredged material containment facilities.

Throughout this Year 34 Exterior Monitoring Technical report, the companion *Year 34 Data Report* is referenced. This report contains the detailed information in regards to sampling locations, field description of samples which includes and is not limited to the number of specimens collected and the detailed results of findings.

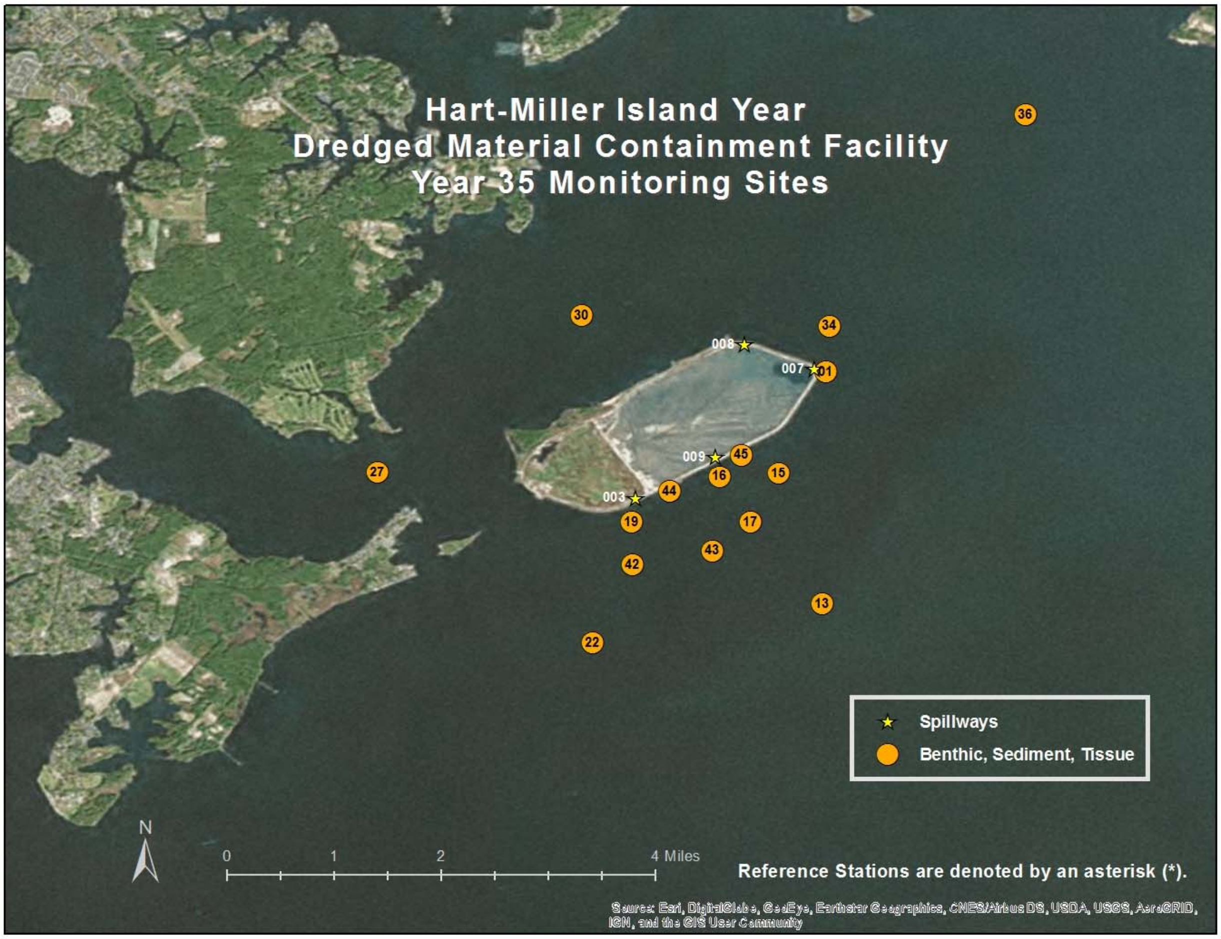
Year 34 represents the fifth consecutive year of post-closure monitoring, and unlike previous years with the exception of Year 32 and Year 33, no spring samples were taken. Now, monitoring continues but with a reduced sampling grid (15 sampling sites), which will be conducted every other year, only in the fall. The final bi-annual sampling is scheduled to be collected in fall of 2018. The biannual data will be reviewed with the HMI Citizens Oversight Committee. Maryland Geological Survey (MGS) will continue to evaluate ground water data collected by MES. Ground water data will be collected on a biannual basis, following the Exterior Monitoring schedule. This monitoring schedule is also adaptive depending on future findings, which includes taking into account the occurrence of any unusual events. In 2019, the frequency of monitoring will be reevaluated based on the findings in Project II, Project III, and Project IV. Close cooperation with Maryland Department of Transportation Maryland Port Administration (MDOT MPA) and Maryland Environmental Science (MES) will continue to be important in this endeavor.

HMI EXTERIOR MONITORING DESIGN

The HMI DMCF Exterior Monitoring Program is modeled after the Sediment Quality Triad developed in the mid-1980s (Long and Chapman, 1985). This approach consists of three separate components: sediment chemistry, sediment toxicity, and benthic community composition. The sediment chemistry project (Project II) assesses contamination by evaluating metal concentrations in exterior sediments. Project III, benthic community studies, monitors animal communities living in sediments surrounding HMI. As a surrogate for toxicity, Project IV looks at benthic tissue concentrations of both metals and organics in the brackish-water clam *Rangia cuneata*. Whereas sediment contamination thresholds, benthic toxicity benchmarks, and benthic macroinvertebrate indices alone may not conclusively identify pollution impacts, combining them into a triad approach provides a body of evidence for pollution determinations. Summary Table 1-1 illustrates the triad concept.

Summary Table 1-1: Differential Triad Responses

Scenario	Sediment Contamination (Project II)	Toxicity (Project IV)	Benthic Community Impacts (Project III)	Possible Conclusions
1	+	+	+	Strong evidence for pollution
2	–	–	–	Strong evidence that there is no pollution
3	+	–	–	Sediment pollutants are elevated but not affecting biota
4	–	+	–	Pollutant levels increasing through food chain
5	–	–	+	Benthic community impacts not a result of pollution
6	+	+	–	Pollutants are stressing the system
7	–	+	+	Pollutants increasing through the food chain and altering the benthic community
8	+	–	+	Pollutants are available at chronic, non-lethal levels



Summary Figure 1-1: Shows the sampling design and parameters which were monitored in Year 34. MGS analyzed sediment for physical and chemical properties from 15 sites, MDE samples the benthic organisms at 15 sites, and CBL collected the brackish water clam Rangea cuneata from 15 sites in the fall for tissue and sediment analysis of metals and metalloids.

HMI PROJECT SUMMARIES

PROJECT II: Sedimentary Environment and Groundwater Monitoring

The Coastal and Environmental Geology Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Containment Facility (HMI DMCF) from the initial planning stages of construction of the facility to the present. The facility stopped receiving dredged material in December of 2009. As part of the 34th year exterior monitoring program, MGS collected bottom sediment samples from 15 sites on September 26, 2016. Due to the reduced discharge from the facility, ongoing post-closure monitoring consists of the collection of sediment from a focused set of 15 stations, which is a subset of the original 43 stations sampled previously. Current ongoing post-closure monitoring is conducted on a biennial basis, with sediments samples collected in September 2014, September 2016, and a remaining sampling event anticipated to occur in September 2018. 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).

The grain size distribution of the Year 34 sediment samples do not show any clear divergence in sedimentation patterns when compared to previous years. The clay to mud ratios illustrate that the depositional environment was similar during the last seven monitoring years. 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 34.

Sediment metal data was analyzed by taking into account grain size included variability and references the data to a regional norm. Elemental analyses of the data indicate that the sediment elemental concentrations are similar to the previous year, which includes the high Cr value measured at a sampling site in the Baltimore Harbor Zone Influence. At most sampling sites, concentrations of Cr, Cu, Pb and Zn in the sediment exceed the Effects Range Low (ERL) values; and at most sampling sites, concentrations of Ni exceed the Effects Range Medium (ERM) values. 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 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 are significantly enriched in some samples compared to the baseline behavior.

Presented in Appendix 1A, the groundwater monitoring report is a summary of the HMI well data collected from six wells on December 10, 2015, June 22, 2016, and January 25, 2017. These wells are part of 34 wells installed around the facility dike between 2001 and February 2002 for a groundwater study (US, 2003). 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.

Maryland Environmental Service (MES) analyzed the water samples for the following parameters: pH, temperature, conductivity, dissolved oxygen (DO), oxidation-reduction potential (ORP), salinity, alkalinity, chloride (Cl^-), sulfate (SO_4^{2-}), total Kjeldahl nitrogen (TKN), total nitrogen (TN), nitrates/nitrites (NO_3^-/NO_2^-), P, aluminum (Al), arsenic (As), Cd, calcium (Ca), Cr, Cu, Fe, Pb, magnesium (Mg), Mn, potassium (K), silver (Ag), sodium (Na), and Zn. The groundwater sampling and analyses are done as part of the on-going Hart Miller Island (HMI) external monitoring effort and as a continuation of the groundwater studies completed in 2003 (URS, 2003), and 2005 (Hill, 2005). As part of the monitoring effort, the Maryland Geological Survey (MGS) evaluated the results of the MES analyses of the water samples.

During Year 34, the facility released discharge from both the North and South Cells in order to manage pond levels. To mitigate low pH conditions, a liming plan was developed and implemented in 2015 for the North Cell. MES began to lime and discharge from Spillway 007 in March 2015, from Spillway 008 in April 2015 and from Spillway 009 in January 2016(Amanda Peñafiel, pers. comm. 10/21/2015). In prior years, water within the North Cell pond generally had a low pH. However during this monitoring year, achievement of neutral pH pond waters made permissible discharge from Spillways 007, 008, and 009 in the North Cell.

Groundwater in all of the wells is generally anoxic or hypoxic with dissolved oxygen (DO) levels less than 2.0 mg/L. Groundwater over much of HMI is consistent with that of a transitional to reducing environment (e.g. ORP 200 to -200 millivolts) with circum-neutral pH (e.g. alkalinity 100-400 mg/L as $CaCO_3$ and pH often above 6), despite the occasional localized presence of acidic and/or oxidizing conditions which may form within the shallow ponds and/or dried crusts. Groundwater over much of HMI is similar in composition to mesohaline Bay water, and generally ranges within 4 to 8 part per thousand salinity. Groundwater at Well 12A remains an exception to this generalization and is near fresh with respect to salinity. Dissolved chloride content generally tracks salinity spatially and ranged from approximately 10 mg/L (Well 12A) to approximately 5,500 mg/L (Well 2A) during this last monitoring period.

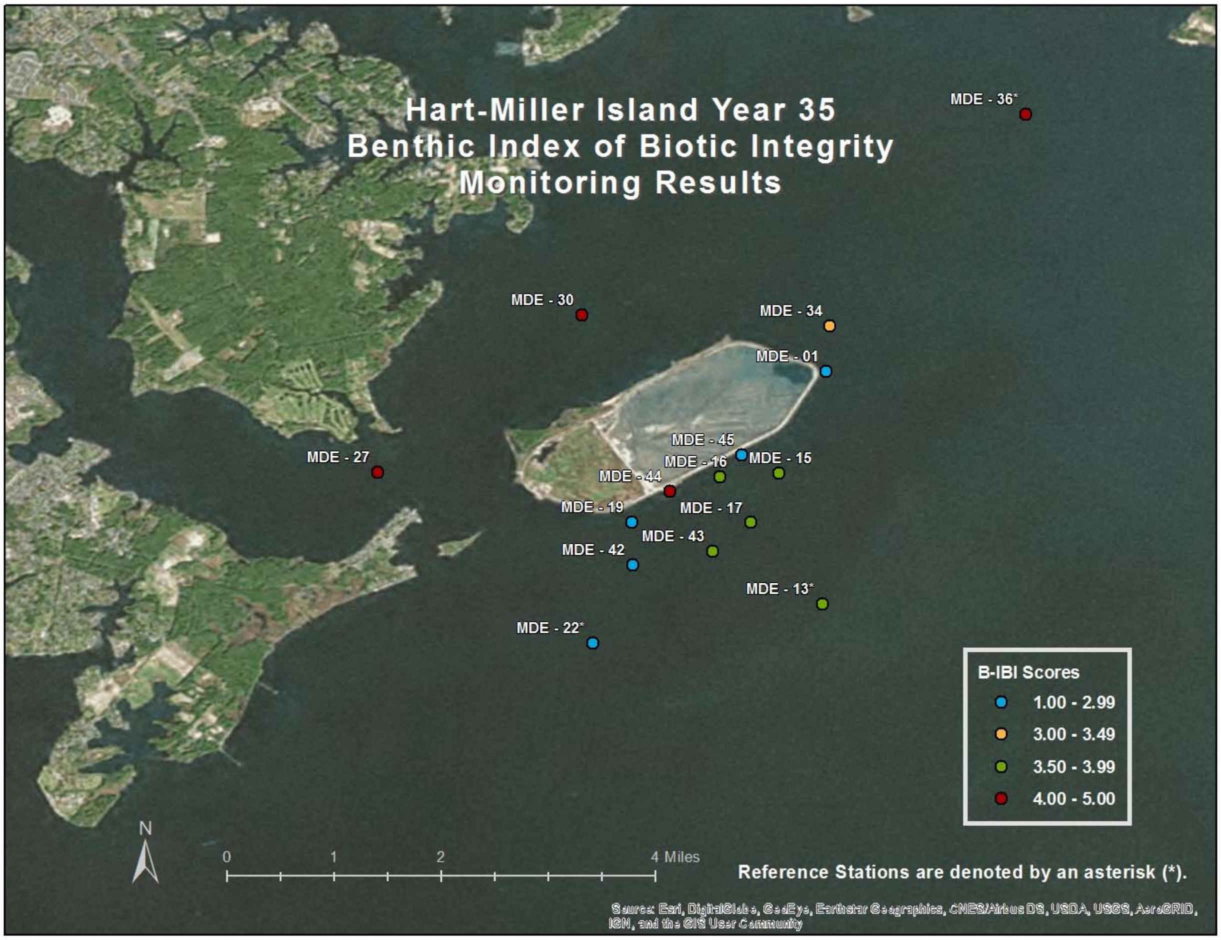
Chloride concentrations are highest in groundwater at Well 2A, by approximately two to three times the concentrations encountered in the other two wells of the North Cell. Alkalinity and pH are often highest in North Cell well 6A. The ground waters of the North Cell usually have higher alkalinity, slightly higher chloride and total nitrogen than the ground waters of the South Cell. The concentrations of several metals, such as As, Mg and Zn, are all higher in the ground waters of the North Cell than of the South Cell, whereas the concentration Mn is lower. In general, greater variability has been observed in the concentrations of several chemical species, first after the closure to new dredge in 2009, and more so since 2012. The groundwater from the North Cell Well 2A continues to exhibit behavior typical of anoxic or hypoxic groundwater that has minimal exposure to oxidized sediment. Generally the behavior of measured parameters in each of the North Cell wells is different reflecting a number of factors.

The ground waters of the South Cell wells have been in contact with oxidized sulfide mineral bearing sediments, thus have higher levels of excess sulfate (Figure 1A-7). Chloride concentrations are relatively high in Wells 8A and 10A. However, rain and a fresh water lens appear to be a major source of groundwater accessed via Well 12A, the waters of which appear to be entirely fresh water. Total nitrogen (ammonium) and alkalinity are slightly lower, while some metals (Mn) are higher in the ground waters of the South Cell than they are in the ground water in the North Cell. On average, metal concentrations in both the North and South Cell wells have been stable during this monitoring year. Cu and Pb remain below the detection limit in both Cells, and Zn remains intermittently detected. Fe concentrations declined over the last three events in the South Cell Wells 10A and 12A but remained dynamic in groundwater from the remaining wells. Mn concentrations in all Wells have been generally stable. Fe and Mn are the only metals with concentrations that exceed the MCL in both cells.

PROJECT III: Benthic Community Studies

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI-DMCF) was studied for the thirty-fourth year under Project III of the HMI Exterior Monitoring Program during the 35th year of operations at the site. 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, and conductivity were measured *in situ*. Fifteen stations (7 Nearfield, 3 Reference, 2 Back River/Hawk Cove, and 3 South Cell Exterior Monitoring stations) were sampled on September 26, 2016. Due to scaling back of monitoring efforts during the post closure era at HMI, benthic sampling was not done in 2015 (HMI Year 34) or in the spring of 2016.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI), a multi-metric index of biotic condition that evaluates summer populations of benthic macro-invertebrates, was calculated for all stations. Metrics applicable to the low mesohaline classification (5 - 12 ppt) were used. The B-IBI's and derivative metrics (Total Infaunal Abundance, Pollution Indicative Taxa Abundance, Pollution Sensitive Taxa Abundance, and Shannon-Weiner Diversity Index) were compared to historical data and were analyzed both spatially and statistically.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Summary Figure 1-2: Year 33 B-IBI Monitoring Results

The health of the benthic macroinvertebrate community around HMI in Year 34 was similar to historical averages. In Year 34, ten of the fifteen stations met the benchmark criteria of 3.00. Nine stations were above their historic averages and six stations were below the historic averages for B-IBI. In addition to six stations being below the historic average three stations set new historic lows; and one station set a new historic high. Year 34 B-IBI's are starting to trend upward after five consecutive years where B-IBI's had been trending downward. While Nearfield stations showed improvement from the past five years they were the only station type that failed to meet the benchmark of 3.0. Improved B-IBI's can be attributed to fluctuations in the invertebrate community. They included above average abundance of the pollution sensitive bivalve *M. balthica* and the isopod *C. polita* at many stations. This general trend tended to increase the B-IBIs. One fluctuation was largely responsible for depressing B-IBI's at other stations. This was the exceptionally high average abundance of the pollution indicative oligochaete worms in the family Naididae at three of the five failing stations. These abundances adversely impacted all four metrics used to compute the B-IBI. They depressed the Total Infaunal Abundance metric scores (by having too many organisms per square meter), increased the Pollution Indicative Taxa metric (because they are pollution indicative), depressed the relative Pollution Sensitive Taxa Abundance metric (by dilution), and depressed the Shannon Weiner Diversity Index metric.

The cluster analysis indicated that the benthic communities measured in September 2016 were highly similar in the area to the east of HMI and their similarity was correlated with relative healthy, unstressed hydrologic and sediment conditions, as identified by the B-IBI analyses. In addition the cluster analysis indicated that the identified outlier stations (located north or HMI) were all similar in that they had stressed benthic communities. However, the Friedman's test comparison between Nearfield, Reference, South Cell and Back River stations was not significant, indicating that no localized adverse impacts from HMI operational discharges could be identified.

PROJECT IV: Analytical Services

As part of HMI annual exterior sediment survey, the University of Maryland for Environmental Science Chesapeake Biological Laboratory (UMCES CBL) measured and evaluated the levels of select trace elements in the sediment in the vicinity of HMI. Specific objectives for Year 34 were to collect clams and associated sediment in the fall of 2016 for analyses of trace elements. Fifteen sites were selected from the larger pool of Maryland Department of the Environment (MDE) biota stations for this work. Sediment and clams were collected at the same time. Both sediment and clams were analyzed for Hg, MeHg, Ag, Se and As, and clams were also analyzed for Pb and Cd to support MGS sediment studies.

Additionally, the clam *Rangia Cuneata* was collected from 15 stations in the fall (September) of 2016. In general, concentrations of As, Se, Ag and Cd in these clams are less than the sites running mean concentration determined from the measurements made in previous years.

PROJECT 1 SUMMARY AND RECOMMENDATIONS

Project I recaps the findings and future recommendations of Project II, Project III, and Project IV. As part of the 34th year exterior monitoring program, MGS collected bottom sediment samples from 15 sites on September 26, 2016. Due to the reduced discharge from the facility, ongoing post-closure monitoring consists of the collection of sediment from a focused set of 15 stations, which is a subset of an original 43 stations sampled previously. Current ongoing post-closure monitoring is conducted on a biennial basis, with sediments samples collected in September 2014, September 2016, and a remaining sampling event anticipated to occur in September 2018. The grain size distribution of the Year 34 sediment samples do not show any clear divergence in sedimentation patterns when compared to previous years. The clay to mud ratios illustrate that the depositional environment was similar during the last seven monitoring years. 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 34.

This year's monitoring documents slight increases over the previous year in enrichment of Cu, Fe, Mn, Ni, Pb, and Zn around the HMI facility; however, concentrations of Cd and Cr remained about the same compared to Year 33 sampling. For Year 34, enrichment of Ni, Pb and Zn continued to be above background levels in regard to sigma levels. These persistent enrichment levels indicate a need for continued monitoring, particularly since the facility has experienced water quality issues which have been exacerbated by unusual weather events contributing a significant volume of fresh, oxygenated water to the facility. During the monitoring Year 34, MES documented better water quality (*i.e.*, more neutral pH, lower levels of metals) at North Cell spillways 007, 008, and 009, and South Cell Spillway 003, and water was permitted to be discharged from each as depicted on Figures 1-4 and 1-5. (Amanda Peñafiel, pers. Comm. 8/21/2017). Monitoring should continue in order to document the effect that operations have on the exterior environment and to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of crust formation and water management processes inside the facility. Close cooperation with MES is important in this endeavor.

The health of the benthic macroinvertebrate community around HMI in Year 34 was similar to historical averages. In Year 34, ten of the fifteen stations met the benchmark criteria of 3.00. Nine stations were above their historic averages and six stations were below the historic averages for B-IBI. In addition to six stations being below the historic average three stations set new historic lows; and one station set a new historic high. Year 34 B-IBI's are starting to trend upward after five consecutive years where B-IBI's had been trending downward. While Nearfield stations showed improvement from the past five years they were the only station type that failed to meet the benchmark of 3.0. Improved B-IBI's can be attributed to fluctuations in the invertebrate community. They included above average abundance of the pollution sensitive bivalve *M. balthica* and the isopod *C. polita* at many stations. This general trend tended to increase the B-IBIs. One fluctuation was largely responsible for depressing B-IBI's at other stations. This was the exceptionally high average abundance of the pollution indicative oligochaete worms in the family Naididae at three of the five failing stations. These abundances adversely impacted all four metrics used to compute the B-IBI. They depressed the Total

Infaunal Abundance metric scores (by having too many organisms per square meter), increased the Pollution Indicative Taxa metric (because they are pollution indicative), depressed the relative Pollution Sensitive Taxa Abundance metric (by dilution), and depressed the Shannon Weiner Diversity Index metric. Naididae are generally considered indicators of organic enrichment.

Since the first benthic survey studies of the Hart-Miller Island area in 1981, several taxa have been consistently dominant. Year 34 was no exception. Seven of the ten most dominant taxa in Year 34 have been consistently dominant through the years. Those are: the amphipod *L. plumulosus,* the polychaete worms *N. succinea* and *S. benedicti,* the isopod *C. polita,* oligochaete worms of the family Naididae, and the bivalves, *R. cuneata* and *M. balthica*. Falling out of the most dominant taxa was the polycheate worm *M. viridis*, and the amphipods *A. lacustre* and *M. nitida.* The average abundance of each taxon (individuals per square meter) found at each station during the cruise are provided in Table 2-10 through Table 2-11.

There were several unique observations in the benthic community made in Year 34. The bivalve mollusk, *Mulinia lateralis* was found in low numbers at nine of the fifteen stations. This is the first time it has been found since Year 20. Historically this clam was mostly found in Harbor Stations, which have not been monitored since Year 20. It is designated pollution indicative in low mesohaline conditions but has no designation under other salinity ranges. Oligochaete worms in the family Naididae were found at exceptionally high densities in some stations (MDE-34, MDE-44, and MDE-45). These worms are associated with organic enrichment and pollution indicative in all salinity regimes. Future monitoring plans: MDE proposed and MPA accepted the continuation of benthic monitoring at a reduced level at fifteen sites, during the fall, every other year, in even numbered years, through 2018.

For analytical services, in past years, sediments of a few sites were observed to be enriched in more than one trace element to a degree well above the sites historic mean concentration calculated from period leading up to current years' analysis. In 2016 only one site was enriched above the standard deviation of the previous years running mean. That was MDE 44, and only for Ag. Concentrations of Se in sediment appear to be trending downward, as concentrations in 2016 appear similar to 2012 through 2014. Concentrations of Ag and As in sediment remain unchanged over the last few years, with As fluctuating more widely. T-Hg concentrations in sediment had been trending upward but this no longer seems to be the case. MeHg concentrations appear to be trending downward in recent years but given the observed temporal variability in other elements it remains to be seen if this is a long lived trend.

The relationships between As, Se and Ag concentrations in sediment suggest either that they either had a similar origin or they had a similar diagenetic behavior once deposited in the sediments around HMI for most of the study period. The continued lack of a correlation between Ag and As at sites located NE ofHMI suggest a different mechanism of delivery or retention for these elements in this area compared to sites elsewhere around the complex. The weakening relationship between Ag and Se from 2011 to 2016 may indicate a divergence of the respective metal sources at some sites or in the diagenetic behavior is changing. The behavior of T-Hg in HMI sediments is different from the other trace elements. T-Hg is seldom correlated with other trace elements, and is more dependent on organic matter and clay content of sediment than the other elements. This might imply a different source such as broad scale atmospheric deposition as being the main driver of Hg distribution but this does not explain the spikes in T-Hg concentration seen in some years at some sites. In general, concentrations of As, Se, Ag and Cd in these clams are less than the sites running mean concentration determined from the measurements made in previous years. Finally, sediment concentrations of trace elements tend to rise and fall over a period of years. A prolonged deviation however would suggest changes in source or a change in diagenetic behavior. MeHg concentrations have been trending downward but this may also be part of a longer term cycle.

Concentrations of trace elements in clams were similar to or below concentrations observed in previous years. Bioaccumulation of trace elements by clams was typical in 2016 compared to previous years however Pb at MDE 44 was anomalously high and should be examined closely in 2018.

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APPENDIX 1: SEDIMENTARY ENVIRONMENT (PROJECT II)

(September 2016 - August 2017)

Technical Report

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EXECUTIVE SUMMARY

The Coastal and Environmental Geology Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Containment Facility (HMI DMCF) from the initial planning stages of construction of the facility to the present. The facility stopped receiving dredged material in December of 2009. The information presented in this report represents the 34th year of the continuous monitoring of the sedimentary environment in the vicinity of the HMI Facility. As part of the 34th year exterior monitoring program, MGS collected bottom sediment samples from 15 sites on September 26, 2016. Due to the reduced discharge from the facility, ongoing post-closure monitoring consists of the collection of sediment from a focused set of 15 stations, which is a subset of an original 43 stations sampled previously. Current ongoing post-closure monitoring is conducted on a biennial basis, with sediments samples collected in September 2014, September 2016, and a remaining sampling event anticipated to occur in September 2018. 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).

The grain size distribution of the Year 34 sediment samples do not show any clear divergence in sedimentation patterns when compared to previous years. The clay to mud ratios illustrate that the depositional environment was similar during the last seven monitoring years. 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 34.

Elemental analyses data indicate that the sediment elemental concentrations are similar to the previous years, which are based on summary statistics. The elemental data show that:

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

ERL and ERM are proposed criteria put forward by the National Oceanic and Atmospheric Administration (NOAA) (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 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 are significantly enriched in some samples compared to the baseline behavior.

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), and in regard to the number of samples, Pb>Zn>Ni. Within the HMI Zone of Influence (both distal and proximal), the sediments containing multiple metals (primarily Ni, Pb or Zn) exceeding ERLs or ERMs, and sigma levels greater than 2 include sites MDE-13, -19, -27, -34, -44, and -45. 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 three local sources - HMI, Baltimore Harbor and Back River. The two sampling sites in Back River showed no enrichment for Zn.

Prior to Year 28 monitoring, most of the samples with potential benthic effects due to high concentrations of Ni were in the Back River and Baltimore Harbor Zones of Influence. Between Monitoring Years 28 and 30, sigma levels of Ni steadily increased in the HMI Zone. In Year 31, sigma levels of Ni were within normal ranges in the HMI Zone. Many sites in the HMI Zone showed significant enrichment of Ni in Years 32 and 33. This year, in terms of absolute concentration, Ni exceeds ERMs at all sites, except for MDE-1, at which Ni exceeds the ERL only.

This year’s monitoring documents slight increases over the previous year in enrichment of Cu, Fe, Mn, Ni, Pb, and Zn around the HMI facility; however, concentrations of Cd and Cr remained about the same compared to Year 33 sampling. For Year 34, enrichment of Ni, Pb and Zn continued to be above background levels in regard to sigma levels. These persistent enrichment levels indicate a need for continued monitoring, particularly since the facility has experienced water quality issues which have been exacerbated by unusual weather events contributing a significant volume of fresh, oxygenated water to the facility. During the monitoring Year 34, MES documented better water quality (*i.e.*, more neutral pH, lower levels of metals) North Cell spillways 007, 008, and 009, and South Cell spillway 003, and water was permitted to be discharged from each as depicted on Figures 1-4 and 1-5. (Amanda Peñafiel, pers. Comm. 8/21/2017). Monitoring should continue in order to document the effect that operations have on the exterior environment and to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of crust formation and water management processes inside the facility. Close cooperation with 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 located in the 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's 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, 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 maintenance 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. All effluent discharged from HMI facility must meet water quality permit limits for metal concentrations.

Previous Work

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

1. Pre-construction (Summer 1981 and earlier)
2. Construction (Fall 1981 - Winter 1983)
3. Post-construction
    a. Pre-discharge (April 1984 - Fall 1986)
    b. Post-discharge (Fall 1986 - present).
4. Closing of South Cell to new dredged material (October 1990)
5. Closing of North Cell to new dredged material (December 2009).

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.,* 1990). Zn levels rose from the regional average enrichment factor of 3.2 to 5.5. Enrichment factors are normalized concentrations, referenced to a standard material. 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; 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 predicted the dispersion of discharge from the facility, coupled with discharge records from the spillways. The discharge records showed 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 (Figure 1-1) 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 (Figure 1-1). 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.

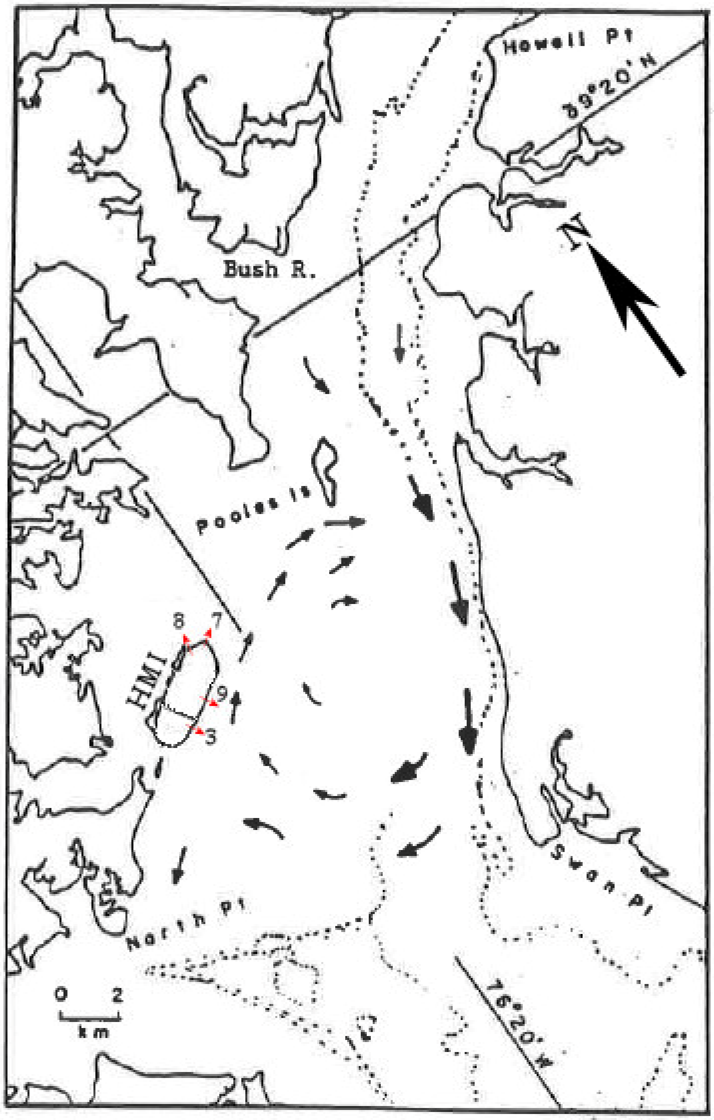
3. Releases from Spillway 008 are spread more evenly to the north, east, and west. However, dispersion is not as great as from Spillways 007 and 009 because of the lower shearing and straining motions away from the influence of the gyre.

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 affect the rate of dilution of 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 MES. The behavior of this model supports the hypothesis of metal contamination during low flow conditions. Sediments discharged from the facility are one of the sources 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, higher than expected levels of Zn and Pb have persisted in the vicinity of the facility. Figure 1-2, in addition to showing the sampling sites

Figure 1- 1: Schematic surface gyre circulation in the upper Chesapeake Bay and relation to HMI DMCF (modified from Wang, 1993). Red arrows indicate approximate location of the HMI DMCF spillways; numbers 3, 7, 8 and 9 identify spillways 003, 007, 008 and 009, respectively.



for Year 34, shows zones which indicate influence of sources of material to the exterior sedimentary environment based on elevated metal levels from previous years' studies. 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 shows 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 1996 sediment characterization of Baltimore Harbor and Back River (Baker *et al.,* 1997). 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 34 years of monitoring that this occurred. Surprisingly, the record rainfall from back-to-back storms in Year 30 monitoring (*i.e*., Hurricane Irene, and Tropical Storm Lee) and Year 31 (Hurricane Sandy) did not result in the any incursion of Baltimore Harbor material (Maryland Department of the Environment (MDE), 2013).

HMI stopped accepting dredged material after December 31, 2009 and facility operations shifted to dewatering and long-term crust management in the North Cell 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 the post-closure operation phase. In anticipation of these changes, a modified sediment sampling scheme was implemented during the 27th monitoring year, to provide better coverage in targeted areas south and east of the facility (Rowe and Hill, 2008). The modified sampling scheme continued through the 32nd monitoring year; however, in the 33rd year, monitoring was reduced to 15 stations with a biennial sampling scheme in the fall. This year represents the sixth year of the post-closure monitoring phase and covers only the reduced number of stations for this fall sampling (Cruise 69). Figure 1-2 shows the sampling locations for Years 27-32 and Years 33-34 for sample collection comparison.

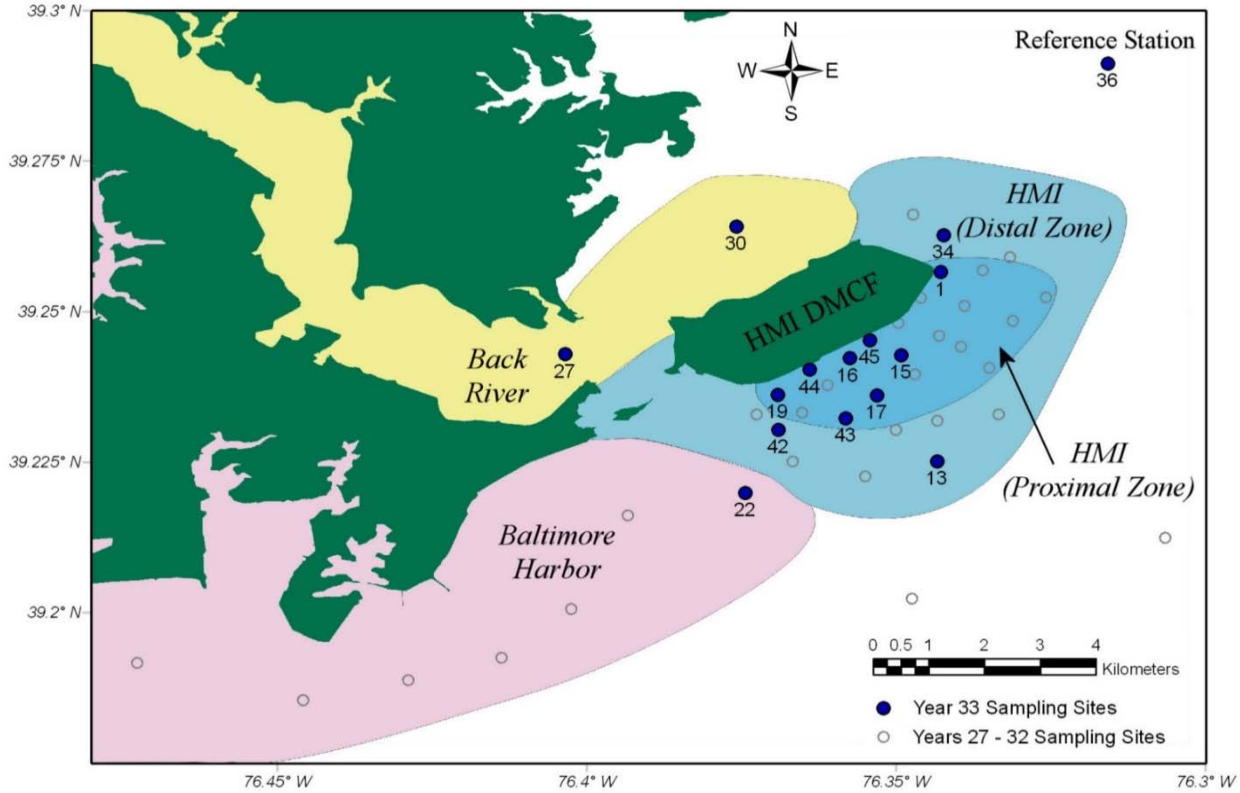


Figure 1- 2: Sampling locations for Year 33 and 34 (solid blue circles) and Years 27 through 32 (open gray circles). Color areas show zones of influence found in previous studies. Stations 38 – 41 (not numbered) were added in Year 18 to measure the influence of Baltimore Harbor. Starting in Year 27, four stations in the Back River zone were dropped and additional stations were added in the proximal zone 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 the Year 34 cruise (69) are summarized below. Information covering the period from April 1, 2015 to April 30, 2017 was provided by Amanda Peñafiel and Lien Vu of MES.

The facility stopped accepting new dredged material at the end of 2009, after which operations in the North Cell focused on dewatering activities and long-term crust management in preparation for environmental restoration efforts. Precipitation accounts for almost all of the water input in the North and South Cells. The South Cell also receives water that flows into the holding pond used for controlling the interior waterfowl pond and spray irrigation.

Figure 1-3 compares the monthly rainfall for HMI and Baltimore Washington International Airport (BWI) for the period between November 2015 and November 2016. The trend in monthly total precipitation recorded at HMI generally tracked that of BWI.

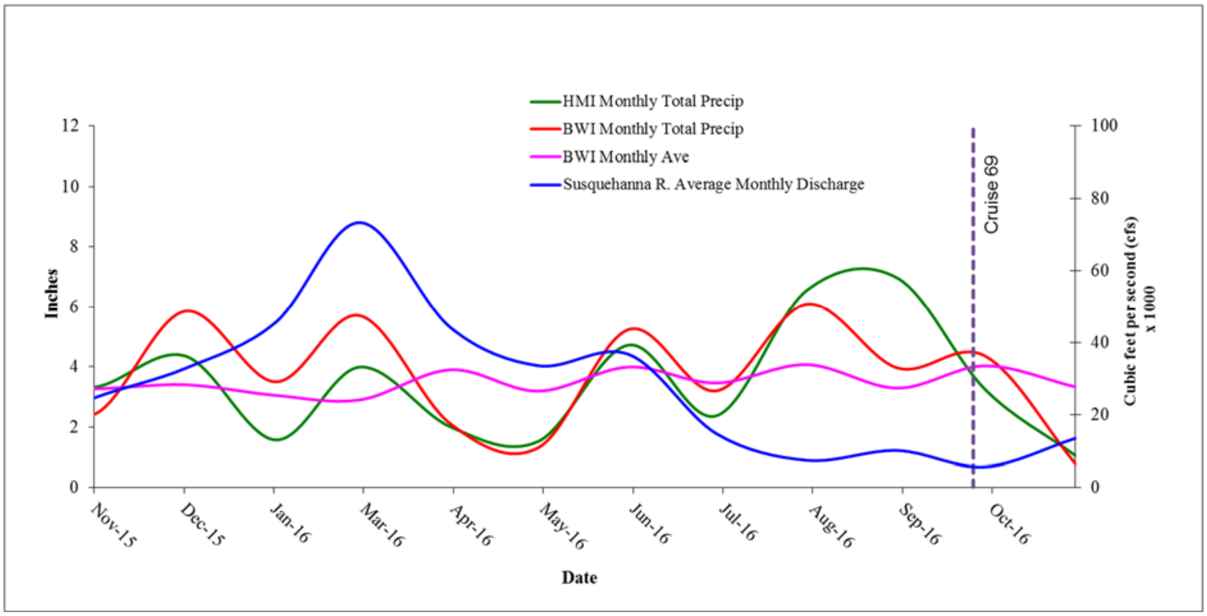


Figure 1- 3: Comparison of monthly precipitation data collected at HMI Facility and at the National Weather Service (NWS) Station at BWI (NOAA, 2017) with the average monthly discharge of the Susquehanna River. BWI monthly averages were based on monthly precipitation data from 1981 to 2010. Susquehanna River data were obtained from the USGS website (USGS, 2017).

Also shown in Figure 1-3 is the average monthly discharge for the Susquehanna River at the Conowingo Dam. As noted earlier, flow from the Susquehanna River influences the dispersion of material around HMI. During this monitoring year, the River flow was largely seasonal, with lower flow during the winter and spring (dry) and higher flow during the summer and fall (wet). For this monitoring period, the October-March average, which represents the high flow or wet season, was 39,162 cubic feet per second (cfs), and the April-September average, representing the dry or low flow season, was 18,086 cfs. While the high flow average is similar to the rate used in the hydrodynamic model (40,878 cfs), the low flow average is much higher than the 9,376 cfs used in the model to predict the dispersion of discharge from the facility (Wang, 1993).

A new discharge permit with reduced monitoring requirements became effective in April 2014 (Amanda Peñafiel, pers. Comm. 10/20/2015). These requirements included quarterly monitoring of the South Cell, monthly monitoring of Spillways 007 and 008, and daily monitoring of Spillway 009 (Amanda Peñafiel, pers. Comm. 10/20/2015). Discharge from Spillways 007 and 008 continued from Year 33 through Year 34, and discharge from Spillway

009 begun during monitoring Year 34. Discharge from the North Cell Spillways lasted several months (Figure 1-4). All periods of discharge for Spillways 007, 008, and 009 were low flow (i.e. generally < 2.0 mgd).

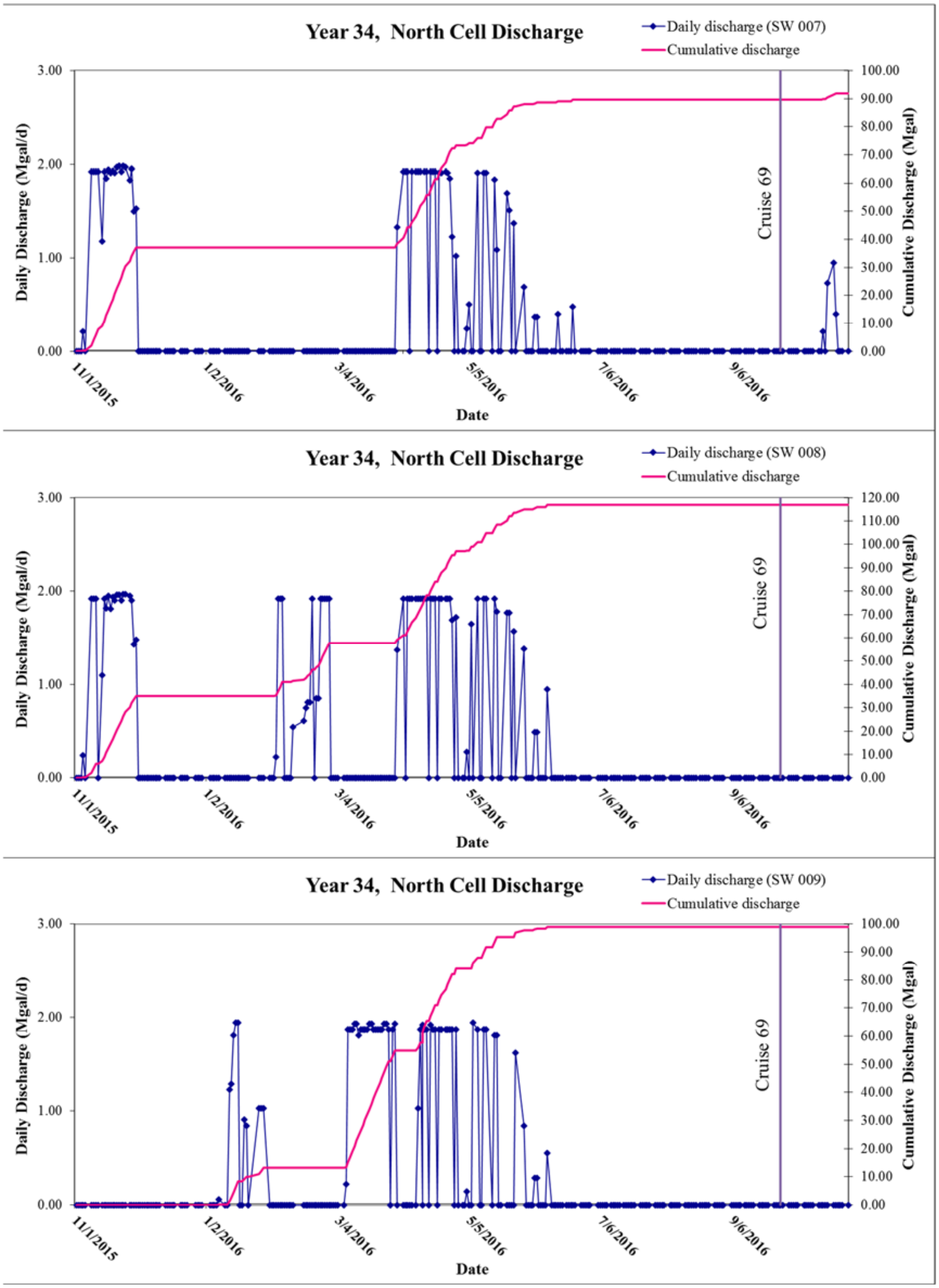


Figure 1- 4: Daily and cumulative discharge from North Cell Spillways 007, 008, and 009 for the late spring to early fall time frame where discharge was released from the Spillways. This year was the first time in several years that discharge was released from Spillway 009.

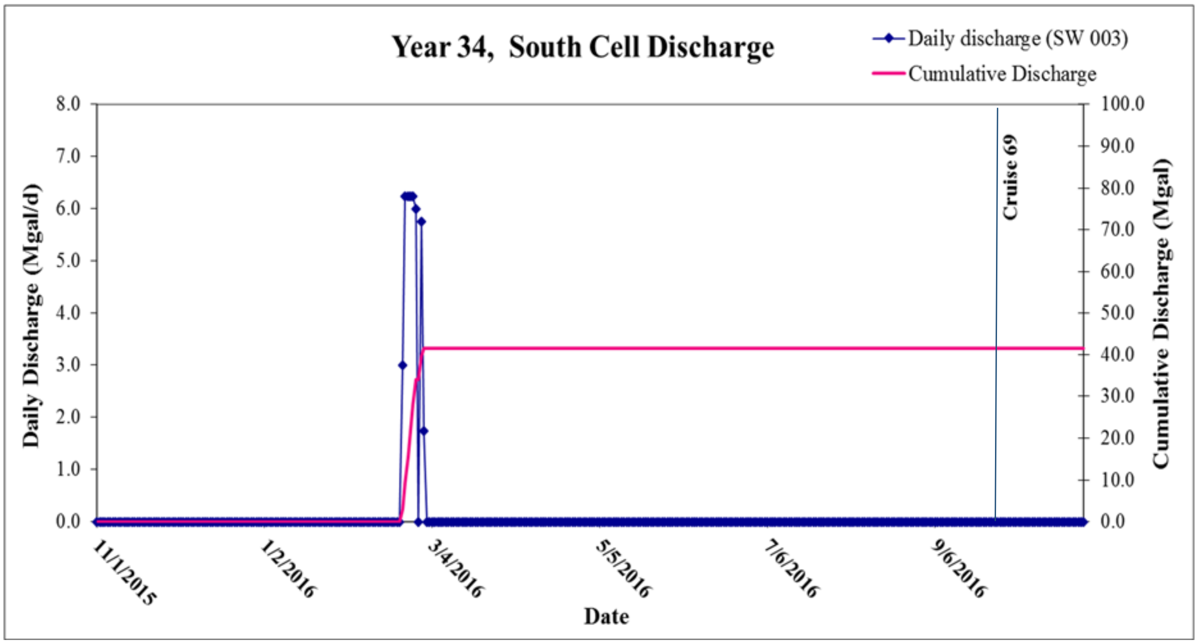


Figure 1- 5: Daily and cumulative discharge from the South Cell for the 13 month period covered in this report. The discharge from the South Cell is from SW003, which is the only discharge point for the cell. The discharge from SW003 was done to maintain the pond level. The exterior sediment sampling event (i.e. sampling cruise) is marked by the vertical line.

There was one period of discharge from the South Cell, occurring over 8 days in late February 2016, with daily discharge ranging from approximately 2 to 6 Mgal/d (Figure 1-5). This discharge was done to reduce the pond level following high rainfall events. The discharge was within the discharge permit criteria. Year 34 sampling took place approximately 7 months after this discharge. During the monitoring period, total cumulative discharge from the South Cell into the Bay was 41.4 million gallons.

OBJECTIVES

As with previous monitoring years, the main objectives of the Year 34 monitoring 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 on September 26, 2016 (Cruise 69) aboard the *R/V Kerhin.* This cruise was the second to have a reduced number of sample sites (15) and no samples were collected in the following spring, making the sampling identical to Year 33.

Sampling sites (Figure 1-2) 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 (i.e. the ability to return to a location at which a navigation fix has previously been obtained) is between 5-10 meters (16-33 feet). Where replicates were collected, the captain repositioned the vessel between samples to counteract drifting off the station during sample retrieval. The captain recorded station coordinates and water depth at each site. Target and actual coordinates (latitude and longitude - North American Datum of 1983, or NAD83) of Year 34 sample locations are reported in the companion *Year 34 Data Report*.

Using a dip-galvanized Petersen sampler (maximum depth of penetration = 38 centimeters or 15 inches), crew members collected undisturbed samples, or grabs, of surficial sediments at 15 sites. As shown by Figure 1-2, these 15 stations are a fraction of the 43 stations that were sampled in the former monitoring cruise sampling scheme.

At 12 stations, a single grab sample was collected, described lithologically, and a representative sample taken of the grab. Triplicate grab samples were collected at the remaining three stations (MDE-1, MDE-30, and MDE-44) and, likewise, described and subsampled. Triplicate samples are identified by ‘a’, ‘b’, or ‘c’ after the station number. MGS analyzed each sample for grain size composition, a suite of trace metals, and total nitrogen, carbon and sulfur. Field descriptions of samples are included as appendices in the *Year 34 Data Report.*

Using plastic scoops cleaned with deionized water, the crew took sediment sub-samples from below the flocculent (floc) 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 grain size sub-samples were each placed in an 18-ounce Whirl-Pak^{TM} bag and the trace chemistry sub-samples were each placed in a 4-ounce Whirl-Pak™ bag, and all samples were refrigerated. The samples were maintained at 4° Celsius (C) until they could be processed in the laboratory.

Laboratory Procedures

Textural Analyses

In the laboratory, sediment samples were analyzed for water content and grain size composition (sand-silt-clay content). Water content was calculated as the percentage of the water weight in grams (g) to the total weight of the wet sediment:

$$W_c = \frac{W_w}{W_t} \times 100 \qquad \textbf{Equation (1)}$$

Where: W_c = water content (%)
W_w = weight of water (g)
W_t = weight of wet sediment (g)

Water weight was determined by weighing approximately 25 g of the wet sample, drying the sediment at 65°C, and reweighing it. The difference between total wet weight (W_t) and dry weight equals water weight (W_w). 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 micron (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).

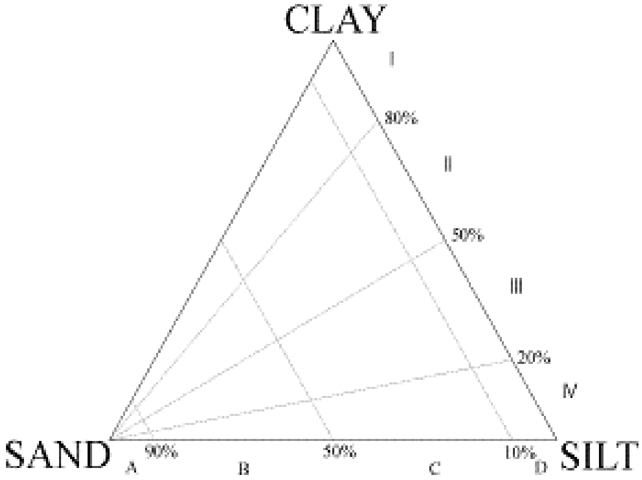


Figure 1- 6: Pejrup's Diagram (1988) classification of sediment type.

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 to 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 to mud ratio between 0.50 and 0.80.

The primary advantage of Pejrup's classification system over other schemes is that the clay to 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 to 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 to mud ratios, not Pejrup's classes themselves.

Elemental Analysis

The sediment samples were analyzed for elements by *Activation Laboratories Inc.* (ActLabs). The quality assurance and quality control of ActLabs 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 ActLabs for analyses using both Instrumental Neutron Activation Analysis (INAA) and a four acid “near total” digestion technique followed by analysis on an Inductively Coupled Argon Plasma Spectrophotometer

(ICAP). In addition to the standards and blanks used by ActLabs, National Institute for Standards and Technology (NIST) and Canadian Research Council (CRC) Standard Reference Materials (SRMs) were inserted as blind samples for analyses. NIST and CRC SRM blind samples represented one in every eight samples.

Results of the analyses of the SRMs reported by ActLabs are presented in the *Year 34 Data Report.* Both the accuracy and precision of the Actlabs analyses are in good agreement with the SRMs.

Carbon-Sulfur-Nitrogen Analysis

Sediments were analyzed by MGS for total carbon, 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 gases 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, sulfanilamide was used. Blanks (tin capsules containing only vanadium pentoxide) were run at the beginning of the analyses and after 10 to 12 unknowns (samples) and standards. Replicates of every eighth sample were also run. As a secondary standard, one of several NIST SRMs was run after every 10 to 12 sediment samples. The recovery of the SRMs was in good agreement with the NIST certified values and MGS's results, as they were well within the two standard deviations of replicate analyses. Results of the SRMs are presented in the *Year 34 Data Report*.

RESULTS AND DISCUSSION

Sediment Distribution

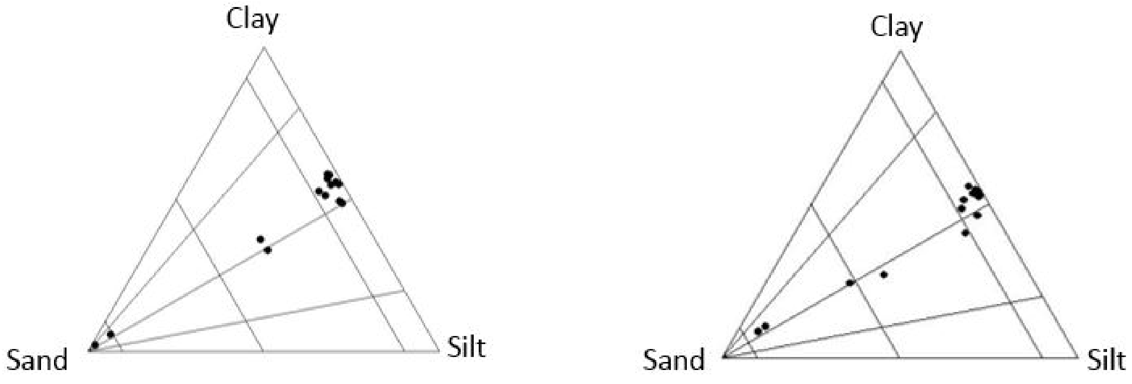
The monitoring effort around HMI is based on the identification of long-term trends in sediment distribution and on the detection of changes in those trends. The sampling scheme, revised in Year 17 and expanded in Year 18, established a new baseline against which any future changes in the sedimentary 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. For this report, the current Year 34 results are discussed with respect to the preceding Year 33 results, and where appropriate, with references to earlier monitoring year results.

All sampling sites visited during Year 34 yielded results that can be compared to the same stations measured in Year 33. The grain size composition (proportions of sand, silt, and clay) of the 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 Year 33 and Year 34 sediment samples.

Variable	Sept 2014 Year 33, Cruise 68	Sept 2016 Year 34, Cruise 69
% Sand		
Mean	19.36	20.23
Median	3.55	4.96
Minimum	1.21	0.81
Maximum	96.70	85.50
Range	95.49	84.69
Count	15	15
Clay:Mud		
Mean	0.56	0.53
Median	0.56	0.54
Minimum	0.49	0.46
Maximum	0.63	0.59
Range	0.14	0.13
Count	15	15

The ternary diagrams show very similar distributions of sediment type compared to the previous year. The samples range widely in composition, from very sandy (>95% sand) to very muddy (<1% sand). Muddy sediments predominate; 11 of the 15 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 or 50%). For both samplings (Cruises 68 and 69), most points lie above the 50% line (clay-silt boundary), indicating that the fine (muddy) fraction of the sediments contains more clay than silt. Samples from Year 34 are slightly siltier and less sandy than samples from Year 33.



(a) September 2014 (Cruise 68)

(b) September 2016 (Cruise 69)

Figure 1- 7: Pejrup's diagrams showing the grain size composition of sediment samples collected in Years 33 and 34: (a) September 2014 grain size results and (b) September 2016 grain size results. Grain size compositions were adjusted to exclude any gravel component.

Based on the summary statistics (Table 1-1), average grain size composition, reported as % sand and as clay:mud ratios, varied little over the two sampling periods. When comparing the stations from each year, sand content and clay:mud ratios are nearly identical.

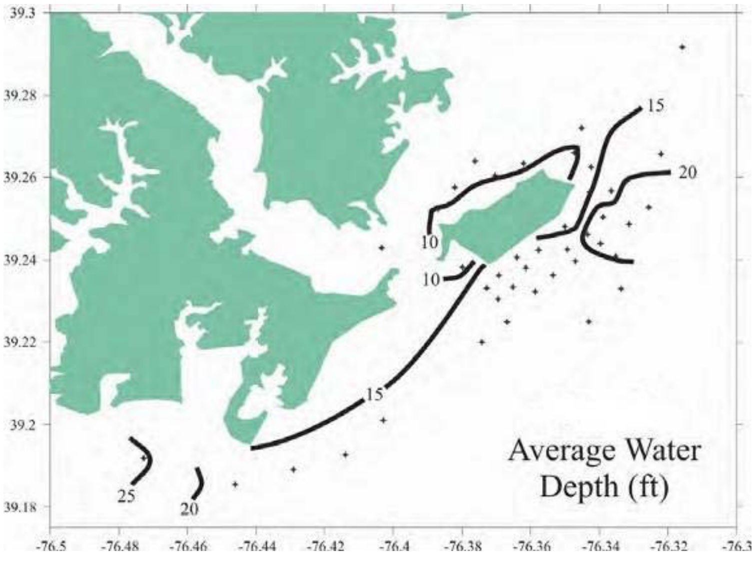


Figure 1- 8: Average water depths around HMI and vicinity, utilizing bathymetric data prior to Year 33 in order to have a larger sample size with more data. Contour interval = 5 ft.

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, two contour levels are shown, representing 10%, 50% sand, and coinciding with the parallel lines in Pejrup's diagram (Figure 1-6). In previous years were there has been more than 90% at any site, this would also have been shown. 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. In Figure 1-10, three contour levels represent 50%, 55%, and 60% clay:mud ratio, as a percentage.

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 Islands, 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 area (*e.g.,* MDE-30) contain less than 10% sand. The sand distribution map for Year 34, shown in Figure 1-9, is similar in appearance to the sand distribution map from the previous September (Cruise 68) (Sylvia *et al.,* 2015). Sand contents continue to be highest near the perimeter of HMI in shallow water depths. The contour lines marked in Figure 1-9 for Year 34 are very similar to the contour lines from the previous year for that area. 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.

Compared to the distribution of sand, the distribution of clay to mud ratios has tended to be more variable over time. The fine (mud) fraction of the sediments around HMI is generally richer in clay than in silt. That is, the clay to 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 to mud ratio < 0.50) of the fine fractions are evident at the mouth of Baltimore Harbor, which continued to be clay-rich (Figure 1-10). The areas of higher silt seen along the south perimeter of HMI are likely related to high turbulence associated with the dike wall, preventing the settling of the finer clay size sediment. These patterns are most likely due to the combined effects of storms and seasonal changes. In previous monitoring years (prior to Year 32, when biannual sampling took place), the April samplings occurred during a period of higher turbulence due to weather, whereas the September samplings took place after a comparatively quiet, low flow summer during which more clay size sediment accumulated on the bottom.

Based on the overall similarities between the fine fraction results from the past five years, one may conclude that the depositional environment in the vicinity of HMI has not changed significantly over this period. The depositional environment continues to be very stable despite major storm events over the last several years.

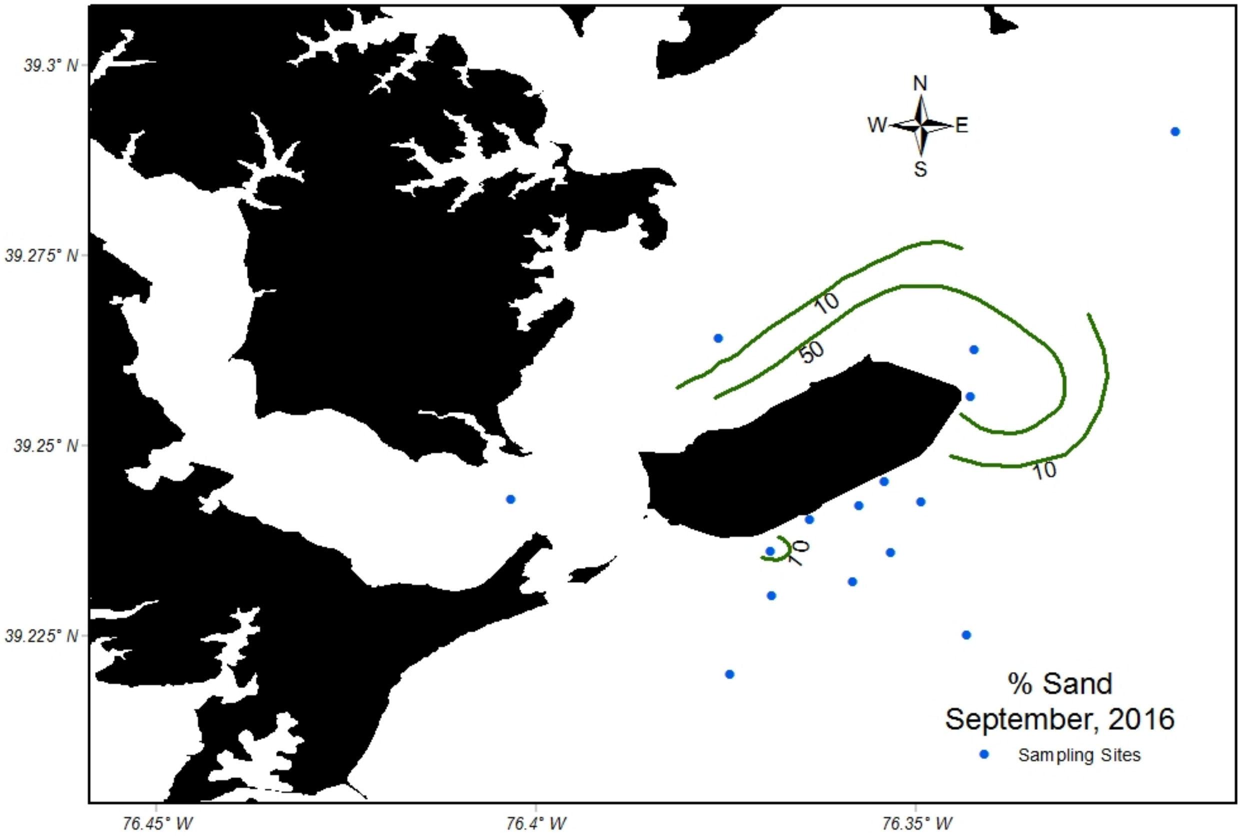


Figure 1- 9: Sand distribution for Monitoring Year 34 which included one sampling cruise: September 2016 (Cruise 69). Contour intervals are 10% and 50% sand.

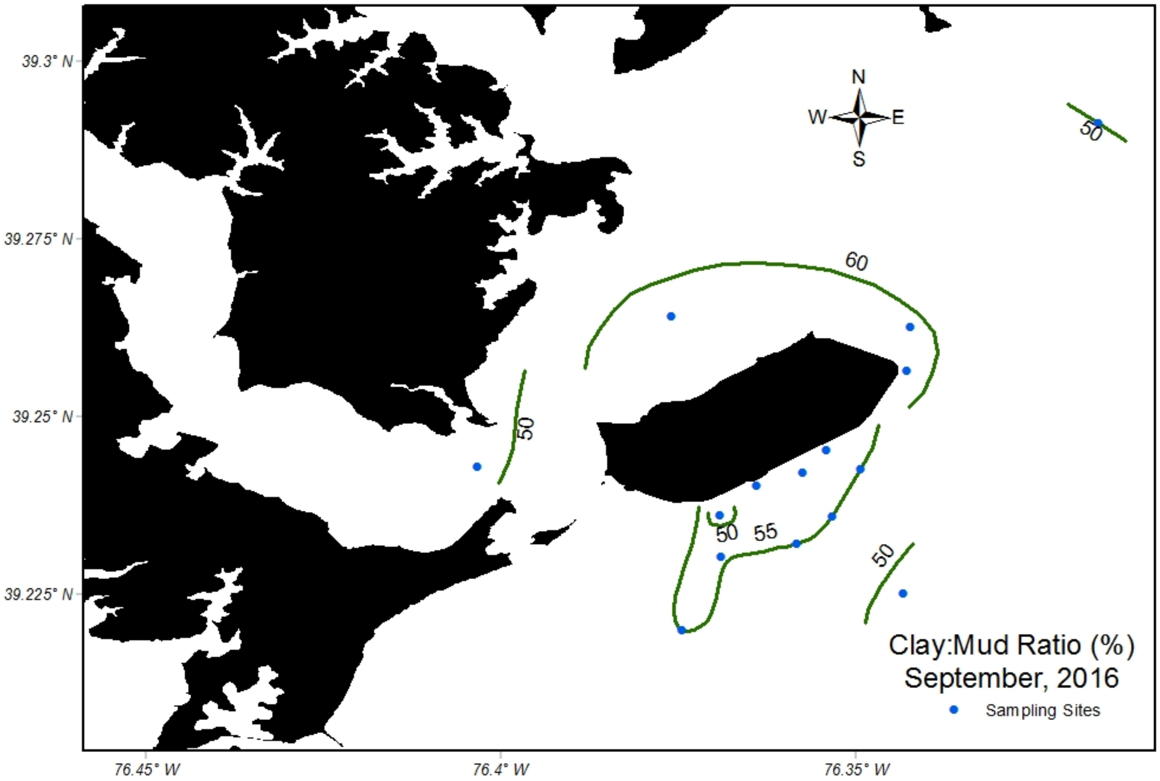


Figure 1- 10: Clay:mud ratios for September 2016 (Cruise 69). Contour intervals are 50% and 55% (clay:mud ratio expressed as %).

Elemental Analyses

Interpretive Technique for Metals

Previous monitoring years have focused on eight 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 normalizes the data to a regional norm. The method involves correlating 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 metal levels. Normalization of grain size induced variability of metal concentrations was accomplished by fitting the data to the following equation:

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

Where: X = the metal 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, Pb, and Zn, indicating that the concentrations of these metals are directly related to the grain size of the sediment. The correlations for Mn and Cu are weaker, though still strong. In addition to being part of the lattice and adsorbed structure of the mineral grains, Mn occurs as oxy-hydroxide chemical precipitate coatings. These coatings cover exposed surfaces, that is, they cover individual particles as well as particle aggregates. Consequently, the correlation between Mn and the disaggregated sediment size fraction is weaker than for metals, 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 metals. 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 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					Equation (2)		
	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
a	0.32	25.27	12.3	0.553	668	15.3	6.81	44.4
b	0.14	91.92	18.7	1.17	218	0	4.1	0
c	1.373	160.8	70.8	7.57	4158	136	77	472
R^2	0.12	0.733	0.61	0.91	0.36	0.88	0.88	0.77

The strong correlation between the metals and the physical size fractions makes it possible to predict metal levels at a given site if the grain size composition is known. 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.

Equation 3 was used to examine the variation from the norm around HMI. In this equation, the differences between the measured and predicted levels of Zn are normalized to the 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 ±2 standard deviations (σ) are within normal background variability for the region. Samples with a value of $\pm 3\sigma$ 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 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.).

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

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

General Results

The summary statistics for the concentrations of the elements analyzed are given in Table 1-3. Generally, the statistics are very similar to the previous four years.

With regard to Effects Range Low (ERL) and Effects Range Median (ERM) values list in Table 1-3, the following statistics, which are very similar to the previous three years' findings, 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. At most sampling sites, concentrations of Ni exceed the ERM values; and the concentration of Zn exceed the ERM value at one site.

Table 1- 3: Summary statistics for elements analyzed for Year 34. All concentrations are in mg/kg (ppm) unless otherwise noted. '*N*' is the total number of values reported above detection limits and represents the number of values used in calculating the average.

	Cd	**Cr**	**Cu**	**Fe (%)**	**Mn**	**Ni**	**Pb**	**Zn**
Ave	0.9	88	42	3.95	2762	78	56	293
Std	0.3	32	17	1.44	1600	31	23	123
Min	0.5	22	10	1.03	748	19	15	71
Max	1.9	121	78	5.12	5770	161	106	614
N	17	21	21	21	21	20	21	21
ERL	1.3	81	34	n/a	n/a	21	47	150
#>ERL	1	16	16			2	16	16
ERM	9.5	370	270	n/a	n/a	52	218	410
#>ERM	0	0	0			17	0	1

ERL and ERM are screening criteria put forward by the National Oceanic and Atmospheric Administration (NOAA) (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 differences. 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 and Ni, compared to the baseline behavior.

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 1-11 shows the variation of the data from the predicted baseline behavior for each of the elements measured for the last two cruises (Cruise 68 and Cruise 69). 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 (indicated by grey lines in Figure 1-11) are considered to be within the natural variability of the baseline values. Comparing the elemental data associated with the 15 sample sites, 4 samples came back within the range expected for normal baseline behavior (i.e., between +/- 2 sigma) in this area. Five of the 15 samples (MDE-13, -19, -27, -30, and -34) contain Pb significantly exceeding the baseline levels (*i.e.,* >3 sigma levels, indicated by red line) there is one sample (MDE-34) where Mn and Ni levels significantly exceed the baseline, and one sample (MDE-19) where Ni levels significantly exceed the baseline. Historically, most of the samples with elevated Pb and Zn sigma levels are in the Baltimore Harbor and Back River Zones of Influence.

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].

Sediments from a handful of sites met these conditions. Samples for the September 2016 cruise from sites within the Back River Zone contained multiple metals exceeding ERLs or ERMs and sigma levels greater than 2 include both Back River Zone sites, MDE-27 and -30. Within the HMI Zone of influence (both distal and proximal), the sediments containing multiple metals exceeding ERLs or ERMs and sigma levels greater than 2 include sites MDE-13, -19, -27, -30, -34, and -45.

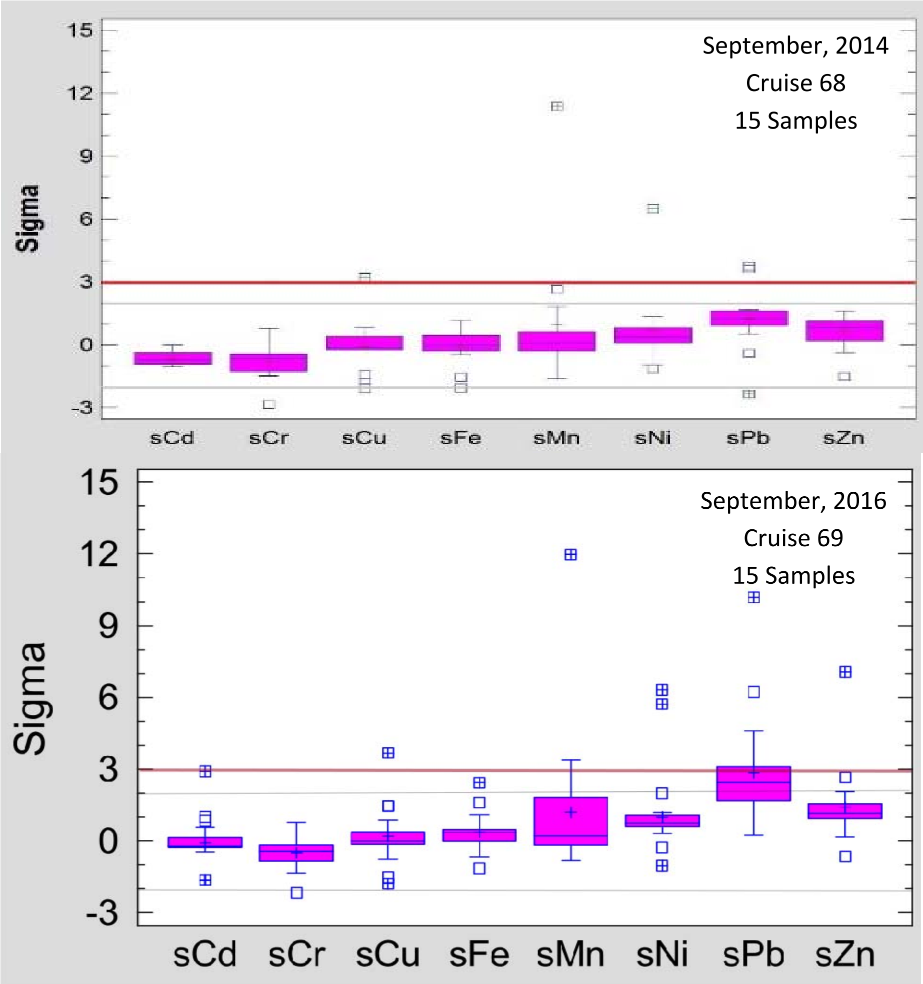


Figure 1-11: Box and whisker diagrams showing the ranges of the sigma levels for Years 32, 33 and 34. The box encloses the middle 50% of the sigma level values for each metal (interquartile range, or IQR); the median is indicated by the horizontal blue line within each box; the mean is indicated by the black '+' . The vertical lines, or whiskers, bracket the +/- 1.5 IQR. Inside outliers (between 1.5 and 3 IQR) and outside outliers (>3 IQR) are plotted as individual points (shown as open blue squares and blue squares with '+', respectively).

Metal Distributions and Trends

Beginning in Year 8, increased metal sigma 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 earlier HMI 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 dredge disposal 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 (Figure 1-1). 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.

Figures 1-12, 1-13, and 1-14 show the distribution of significant sigma levels for Ni, Pb and Zn, respectively, for Year 34 monitoring in the study area adjacent to HMI. Sigma levels are the multiple of the standard deviation of the baseline data set. Data that fall 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 may be significant. Samples having >3 sigma are considered significantly elevated above background. As shown in Figure 1-2, there are three primary areas of interest that will be referred to as: Back River, Baltimore Harbor, and HMI Zones of Influence.

Back River – The influence of the Back River is assessed via monitoring sites MDE-27 and -30. During the Year 34 sampling, sediments collected from these sites contained elevated levels of Pb (6.2 and 3.4 sigma levels, respectively). This is consistent with historical patterns of elevation and distribution. Ni and Zn concentrations were less than 3 sigma for Year 34, consistent with the previous five years of monitoring.

Baltimore Harbor – The influence of the Baltimore Harbor is assessed via monitoring site MDE-22. Historically, elevated levels of Pb and Zn have been observed to extend into the area southwest of HMI. However, no elevated levels of Pb or Zn originating from the Baltimore Harbor were detected in the sediment from this station in Year 34. In spite of the major storms affecting the area in the past, the distribution of Pb and Zn levels originating from the Baltimore Harbor has remained separated from the HMI Zone of Influence adjacent to the island.

HMI – The influence of discharge from HMI itself is assessed via all other monitoring sites, except for the reference (MDE-36). Historically, elevated levels of Ni, Pb and Zn are seen at isolated sites southeast of HMI; however, beginning in Year 33, the sampling network has been focused upon the area immediately south of the facility, and not including each of the mentioned sites.

In Year 34, the count of samples with concentrations of any metal present above the ERL/ERL was slightly higher than it was in Year 33 (e.g. 16 samples above the ERL for Cu in Year 34 vs. 15 samples above the ERL for Cu in Year 33, etc. [Table 1-3]). Additionally, a single ERL exceedance for Cd happened in Year 34 (distinct from none for this metal in Year 33), and during Year 34, Ni was present above the ERL at station MDE-1 (distinct from the previous Year 33 in which Ni was below the ERL at this location.) Relative to the sigma levels, sediments collected from locations MDE-13, -19, -34, and -45 contained concentrations of at least one metal with a greater sigma level than was measured during Year 33 (e.g. Sigma Cu, Ni, Pb and Ni all rose from less than 3 to greater than 3 in the sediments collected from station MDE-19 during Year 34). Station MDE-19 is adjacent to Spillway 003. Lastly, the prevalence of elevated sigma Pb levels increased in Year 34 with respect to Year 33; from 2 stations previously to 6 stations most recently. Spatially, the distribution of sigma levels of Ni, Pb, and Zn observed in Year 34 is similar to that observed in Year 33, with the following adjustments; an additional local high in Ni, Pb and Zn was present in sediments at station MDE-19, and an additional local high in Pb was present in sediments at station MDE-34. In recent years, the source of the enrichment of Ni, Pb and Zn is attributed to the effluent discharged from the South Cell (Spillway 003, station MDE-19), but because there have been discharges from the North Cell (Spillway 007 and 008, station MDE-34), enrichment may also be linked to that effluent. The patterns observed in Year 34 are consistent with this explanation.

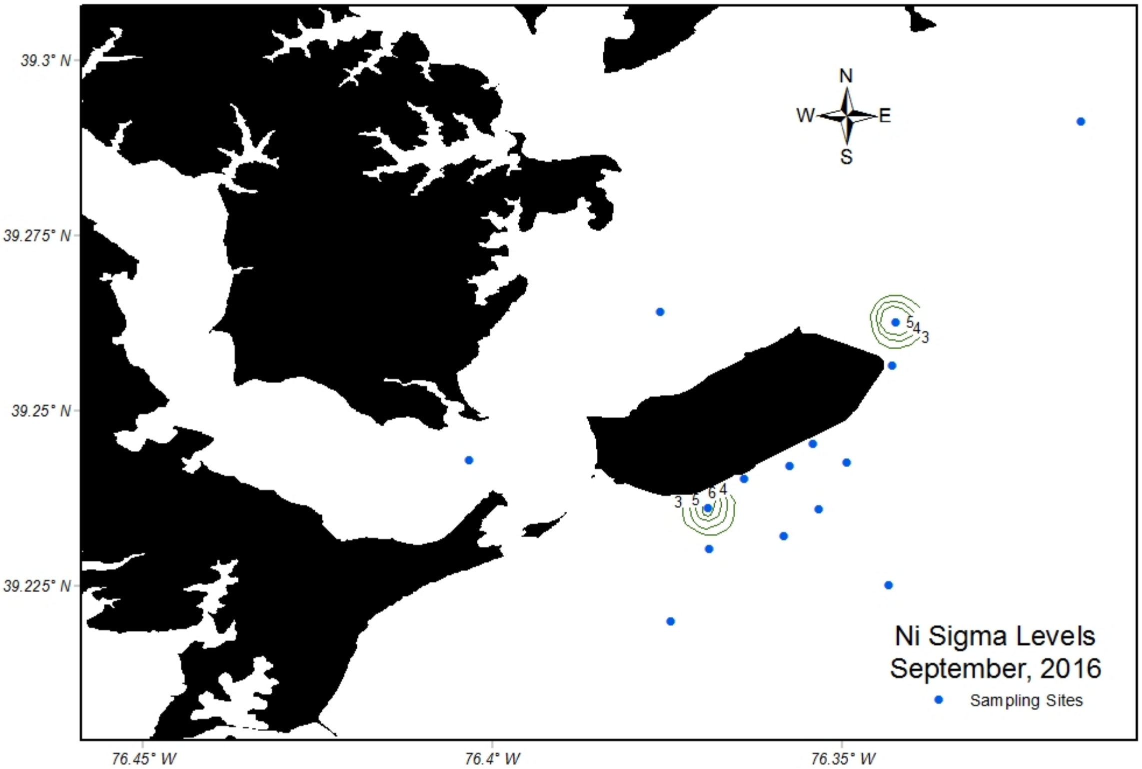


Figure 1- 11: Distribution of Ni sigma levels in the study area for the September 2016 sampling cruise. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (contour intervals less than 3 not shown), >3 = significantly enriched.

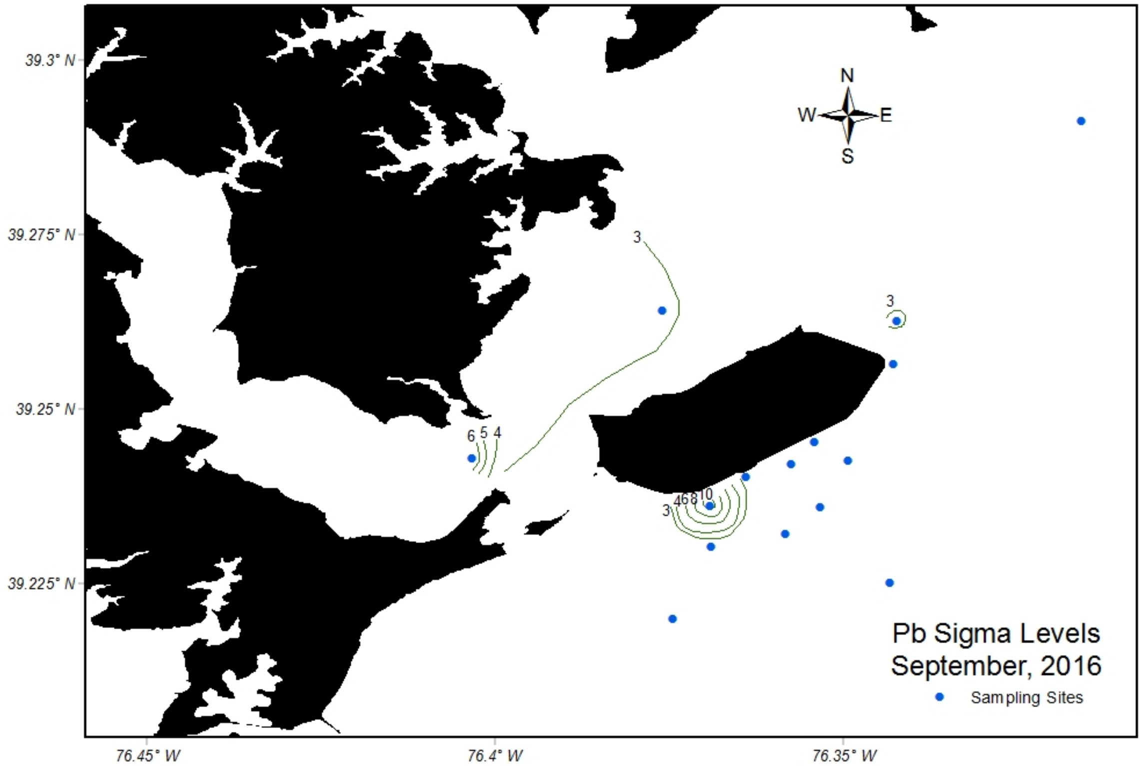


Figure 1- 12: Distribution of Pb in the study area for the September 2016 sampling cruise. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (contour intervals less than 3 not shown), >3 = significantly enriched.

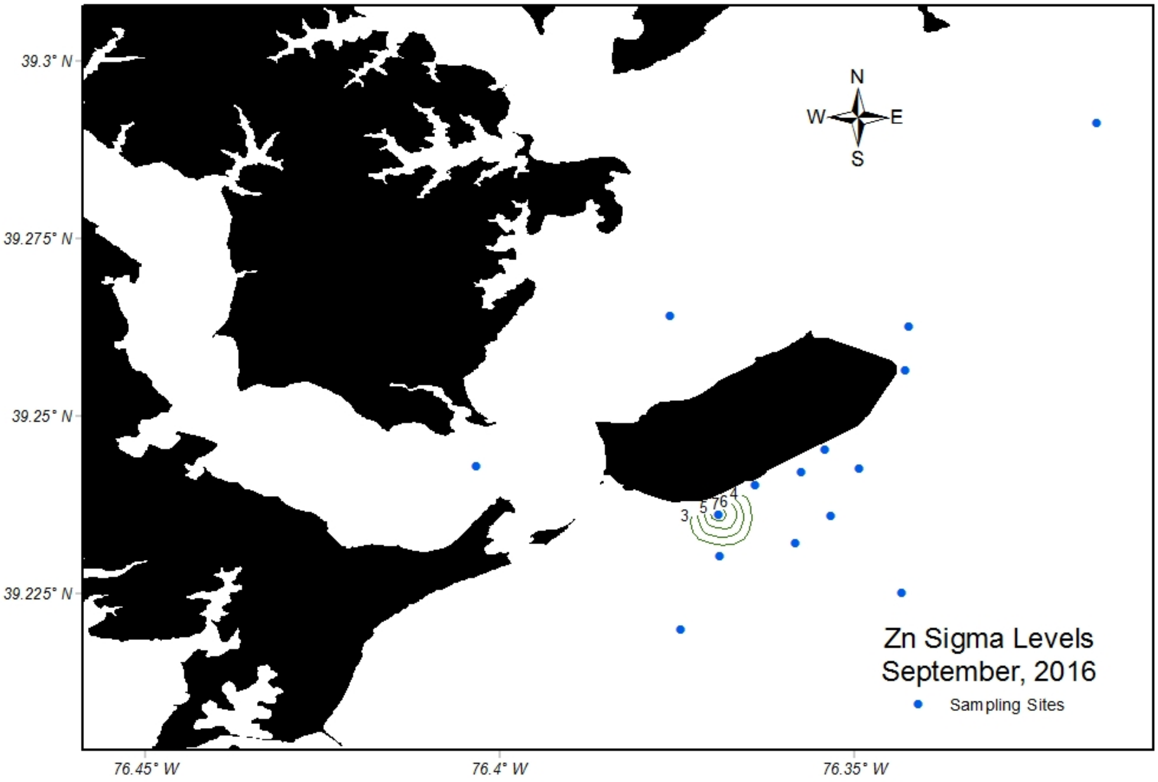


Figure 1- 13: Distribution of Zn in the study area for the September 2016 sampling cruise. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (contour intervals less than 3 not shown), >3 = significantly enriched.

To illustrate the long-term trends of the data, the highest levels of Zn enrichment (shown a slightly different way, as the % excess Zn within Equation 3) from the HMI zone of influence for all monitoring sampling events (cruises) are plotted in Figure 1-14. The data from this monitoring year, shown as the solid point, show a pronounced increase relative to the preceding year, and less pronounced increase relative to Years 32 and 31. The overall trend has been one of increase since Year 29 (2011). Additional evaluation relative to the ERL/ERM and benthic studies follows.

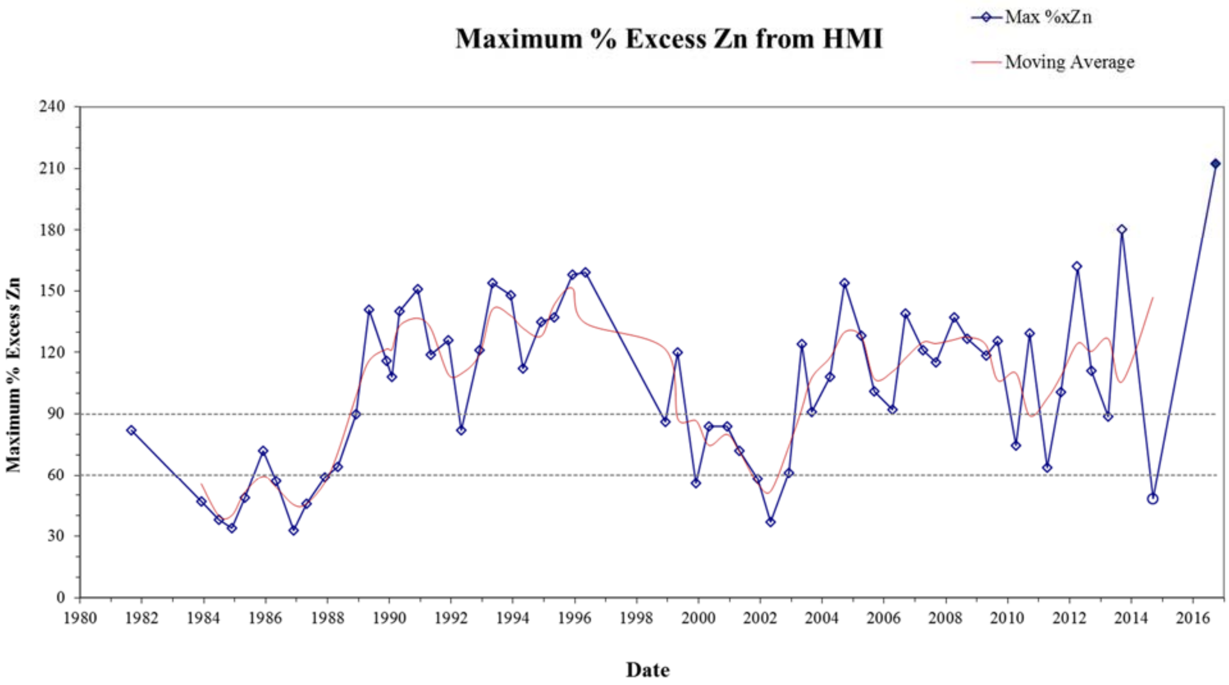


Figure 1- 14: Record of the maximum % excess Zn for all of the cruises for which MGS analyzed the sediments. The filled point is the maximum from this year's study (Cruise 69). Horizontal lines at 60% and 90% excess zinc correspond to 2 and 3 standard deviations from prediction (i.e. 2 and 3 sigma.

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].

Sediments from some of the sites met these conditions. Samples for the September 2016 cruise from sites within the Back River Zone contained metals exceeding ERLs or ERMs *and* sigma levels greater than 2 at both Back River Zone sites, MDE-27 and -30. Within the HMI Zone of influence (both distal and proximal), the sediments containing multiple metals exceeding ERLs or ERMs *and* sigma levels greater than 2 include sites; MDE-13, -19, -34, -42, -44 and -45. Lastly, within the Baltimore Harbor Zone of Influence, site MDE-22 contained metals concentrations which satisfied both of these conditions (Figure 1-15). The overlap of sigma enrichment plus concentrations above the ERL/ERM is seen most commonly and strongly for Pb, followed by Zn, and to a lesser extent Ni (i.e. Pb>Zn>Ni.

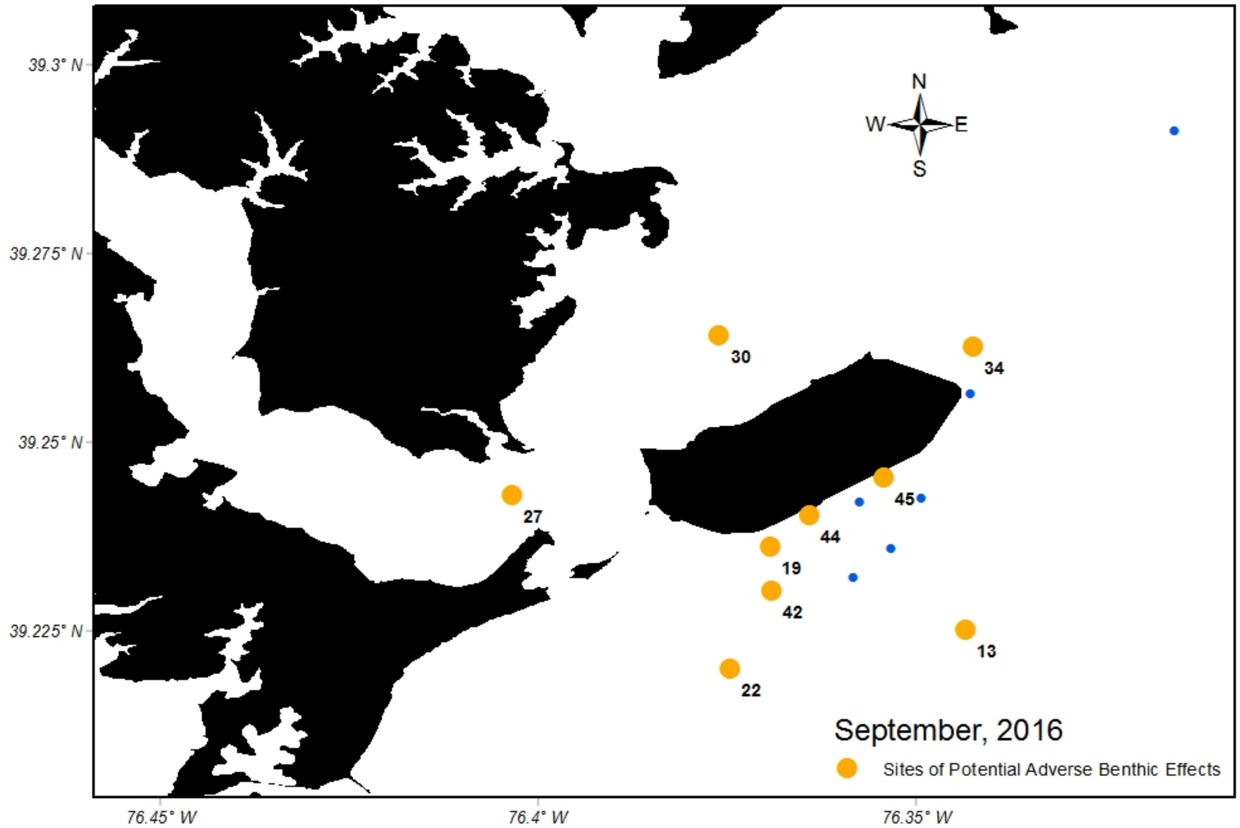


Figure 1- 15: Distribution of sites of potential adverse benthic effects for September 2016 (Cruise 69). At the sampling sites shown in orange, sediments contained both multiple metals (primarily Ni, Pb or Zn) exceeding ERLs or ERMs and sigma levels greater than 2.

CONCLUSIONS AND RECOMMENDATIONS

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 34. The depositional environment continues to be stable.

Elemental analyses data indicate that the sediment chemistry is similar to the previous year.

Based on summary statistics, the elemental data show that:

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

ERL and ERM are screening criteria put forward by NOAA (Buchman, 2008) to gauge the potential for deleterious biological effects. Sediments with concentrations below the ERL are considered ambient 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 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 thus normalized, Ni, Pb, and Zn are significantly enriched in some samples compared to the baseline.

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 three local sources - HMI, Baltimore Harbor and Back River. In Years 31 and 32, sediments were slightly enriched (above 3 sigma levels) with Zn at one to two stations in the HMI zone of influence. In Year 33, no enrichment in Zn in the HMI zone of influence was detected. This year (Year 34), sediments enriched in Zn (above 3 sigma levels) were again encountered in the HMI zone of influence, at a single station (MDE #19). In regards to Pb, in Years 31 and 32, sediments enriched with this metal were encountered at three and six stations, respectively, in the HMI zone of influence. In Year 33, no enrichment in Pb in the HMI zone of influence was detected. This year, sediments enriched in Pb were again encountered in the HMI of influence, at two stations (MDE -19 and MDE-34).

This year's monitoring documents a continued enrichment of Ni, Pb and Zn around the HMI facility. These persistent enrichment levels indicate a need for continued monitoring, particularly since the facility has experienced water quality issues which have been exacerbated by unusual weather events contributing a significant volume of fresh, oxygenated water to the facility. During the monitoring Year 34, MES documented better water quality (*i.e.*, more neutral pH, lower levels of metals) North Cell spillways 007, 008, and 009, and South Cell spillway 003, and water was permitted to be discharged from each as depicted on Figures 1-4 and 1-5. (Amanda Peñafiel, pers. Comm. 8/21/2017). Although the frequency and extent of exterior monitoring of the sediment has decreased since Year 31, it is important that monitoring and sediment sampling occur at the new, current level (*i.e.*, the 15-sample sampling grid). Exterior sediment monitoring should continue in order to document the effect that future operations have on the exterior environment, particularly in the case of the continuation of discharge from the North Cell and assessment of the effectiveness of any amelioration protocol implemented by MES to counteract the effects of crust and water management inside the facility. Close cooperation with MES remains important in this endeavor.

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APPENDIX 1A: HMI Groundwater Monitoring Wells 2015-2017 (PROJECT II)

INTRODUCTION

Groundwater samples from six wells were collected on December 10, 2015, June 22, 2016, and January 25, 2017. Maryland Environmental Service (MES) analyzed the water samples for the following parameters: pH, temperature, conductivity, dissolved oxygen (DO), oxidation-reduction potential (ORP), salinity, alkalinity, chloride (Cl^-), sulfate (SO_4^{2-}), total Kjeldahl nitrogen (TKN), total nitrogen (TN), nitrates/nitrites (NO_3^-/NO_2^-), P, aluminum (Al), arsenic (As), Cd, calcium (Ca), Cr, Cu, Fe, Pb, magnesium (Mg), Mn, potassium (K), silver (Ag), sodium (Na), and Zn. The groundwater sampling and analyses are done as part of the on-going Hart Miller Island (HMI) external monitoring effort and as a continuation of the groundwater studies completed in 2003 (URS, 2003), and 2005 (Hill, 2005). As part of the monitoring effort, the Maryland Geological Survey (MGS) evaluated the results of the MES analyses of the water samples.

The monitoring wells are equally divided between the North and South Cells as seen in Figure 1A-1: North Cell wells 2A, 4A & 6A; South Cell wells 8A, 10A & 12A. These wells are part of 34 wells that were installed around the facility dike between 2001 and February 2002 for a groundwater study (URS, 2003). The purpose of that 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 six wells (*i.e.,* 'A' wells) were installed to depths to monitor the shallow saturated groundwater zone; terminal depths of the wells range from -4 ft to -16.6 ft North America Vertical Datum of 1988 (NAVD88) (Table 1A-1).

Table 1A- 1: Elevation and depth of well data for the HMI Wells sampled for groundwater monitoring (URS, 2003). Elevation is 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	13.6	25	-11.4

The South Cell, which was closed to new dredged material in 1990, has been converted to upland and wetland areas. Activities within the South Cell are specific to the management of these different habitats. The North Cell was closed to dredged material in December of 2009. Since then, activities within the North Cell consisted primarily of crust management as part of habitat development. In the last few years, several significant storms, the most recent being Hurricane Sandy (October 29-30, 2012), contributed an enormous volume of water to the facility, resulting in water quality issues (MES, 2012). This year, the facility released discharge from both the North and South Cells in order to manage pond levels. To mitigate low pH conditions, a liming plan was developed and implemented in 2015. MES began to lime and discharge from Spillway 007 in March 2015 and from Spillway 008 in April 2015 (Amanda Peñafiel, pers. comm. 10/21/2015). In prior years, water within the North Cell pond generally had a low pH. However during this monitoring year, achievement of new neutral pH pond waters made permissible discharge from spillways 007, 008, and 009 (North Cell) and the spillway 003 (South Cell). A more detailed summary of the facility operations for the Year 34 monitoring period is presented in the Technical Report for Sedimentary Environment.

Presented in this groundwater monitoring report is a summary of the well data collected from the quarterly and then biannual sampling conducted during the 34th monitoring year. Discussion of data includes comparison with previous data collected since June 2006 when MES adopted new protocols for sampling groundwater monitoring wells (MES, 2010). Data analyses are based on the interpretive methods detailed in the HMI Well Monitoring report (Hill, 2005).

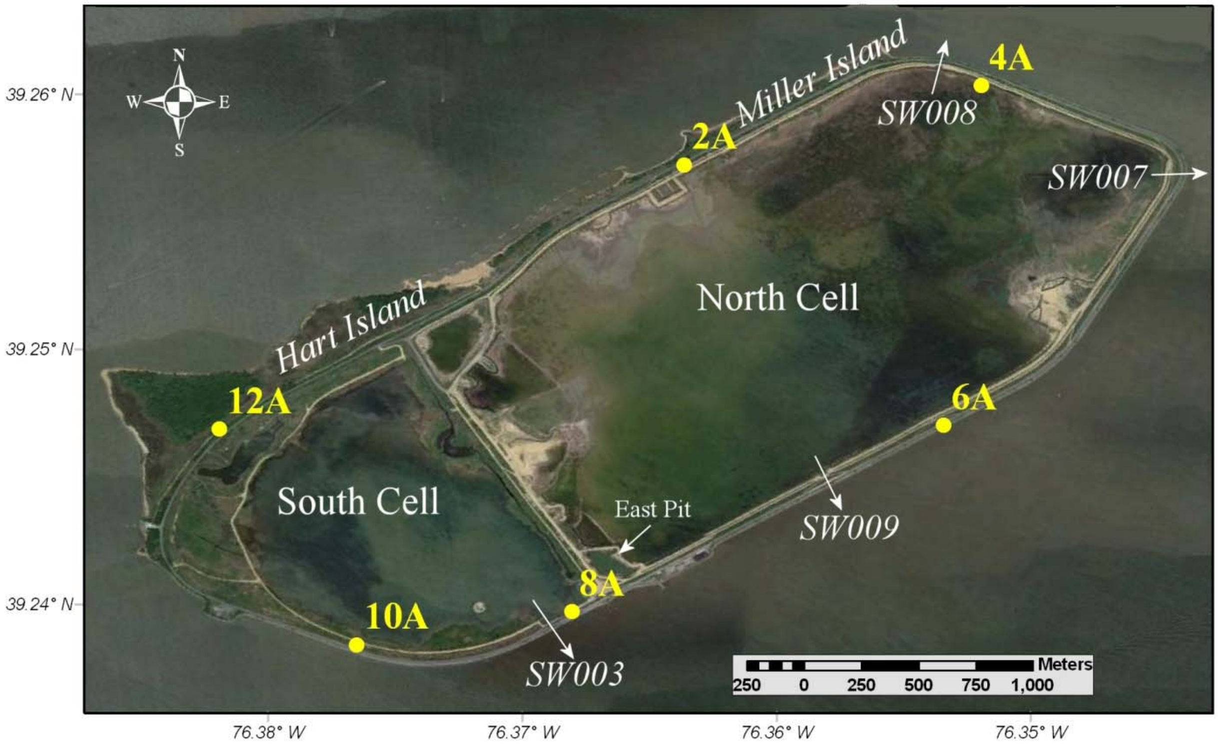

Figure 1A- 1: Aerial photograph of the HMI DMCF, taken on May 5, 2013, showing the locations of the groundwater monitoring wells (yellow dots) and the spillways (*SW; white arrows*). Aerial photography from Google Earth (2014).

SUMMARY OF WELL DATA

Trend plots of select field parameters and metal concentrations measured in ground water samples collected since 2006 are presented in Figures 1A-3 through 1A-6. The vertical lines in the plots correspond to several major events affecting operations and water quality within the facility.

Groundwater in all of the wells is generally anoxic or hypoxic with dissolved oxygen (DO) levels less than 2.0 mg/L. There have, however, been influxes of oxygenated water observed; in December 2013 (Wells 2A and 4A), in March 2014 (Wells 4A, 8A, 10A and 12A), in June 2016 (Well 6A), and most recently in January 2017 (Wells 2A, 4A, 6A, and 12A), as shown on Figures A1-2 and A1-3.

Groundwater over much of HMI is consistent with that of a transitional to reducing environment (e.g. ORP 200 to -200 millivolts) with circum-neutral pH (e.g. alkalinity 100-400 mg/L as $CaCO_3$ and pH often above 6), despite the occasional localized presence of acidic and/or oxidizing conditions which may form within the shallow ponds and/or dried crusts.

Groundwater over much of the island is similar in composition to mesohaline Bay water, and generally ranges within 4 to 8 part per thousand salinity. Groundwater at Well 12A remains an exception to this generalization and is near fresh with respect to salinity. Dissolved chloride content generally tracks salinity spatially and ranged from approximately 10 mg/L (Well 12A) to approximately 5,500 mg/L (Well 2A) during this last monitoring period.

North Cell Wells 2A, 4A and 6A

The ground waters accessed via the North Cell wells were for several years most often in contact with reducing, anoxic pond water (e.g. sediments were maintained subaqueous), which served to limit the oxidization of sulfide minerals in the dredged material, and at other times, North Cell ground waters have been in contact with drying sediments undergoing active crust formation.

Chloride concentrations are highest in groundwater at Well 2A, by approximately two to three times the concentrations encountered in the other two wells of the North Cell. Alkalinity and pH are often highest in North Cell well 6A. The ground waters of the North Cell usually have higher alkalinity, slightly higher chloride and total nitrogen than the ground waters of the South Cell. Historically, ORP and DO have been quite low in groundwater of the North Cell, but are observed to spike sporadically after 2012 in what we interpret to be rainfall infiltration and freshening events. The concentrations of several metals, such as As, Mg and Zn, are all higher in the ground waters of the North Cell than of the South Cell, whereas the concentration Mn is lower. In general, greater variability has been observed in the concentrations of several chemical species, first after the closure to new dredge in 2009, and more so since 2012.

Prior to December 2009, alkalinity in Well 6A had been consistently higher compared to other wells. After December 2009, alkalinity dropped and leveled off but continued to be higher than the other two wells in the North Cell and the wells in the South Cell (Figures 1A-3 and 1A-5). The higher concentrations suggest that the alkalinity in groundwater here is greater than the demand from neutralizing acidity and/or may be buffered somewhat, particularly during and after liming. This is supported by the pH values for Well 6A, which generally have been higher than the other wells (both North and South Cell wells). Also, the behavioral trend of alkalinity in Well 6A matches those of total nitrogen and arsenic. In June 2012, pH increased to the highest levels in all wells except Well 2A. After June 2012, pH in all wells, both North Cell and South Cell, fluctuated seasonally, reaching high in March and low in September.

The groundwater from the North Cell Well 2A continues to exhibit behavior typical of anoxic or hypoxic groundwater that has minimal exposure to oxidized sediment. It may be that Well 2A is the least affected by operations in the North Cell compared to Wells 4A and 6A due to its location and depth. Generally the behavior of measured parameters in each of the North Cell wells is different reflecting a number of factors. The recharge area for the monitoring wells is the North Cell, the surface conditions of which have been constantly changing due to crust management and dewatering operations and the influx of fresh, oxygenated rainwater. Another factor is the heterogeneous material contained in the dike wall and the North Cell substrate, both of which affect transport rates and chemistry of the groundwater.

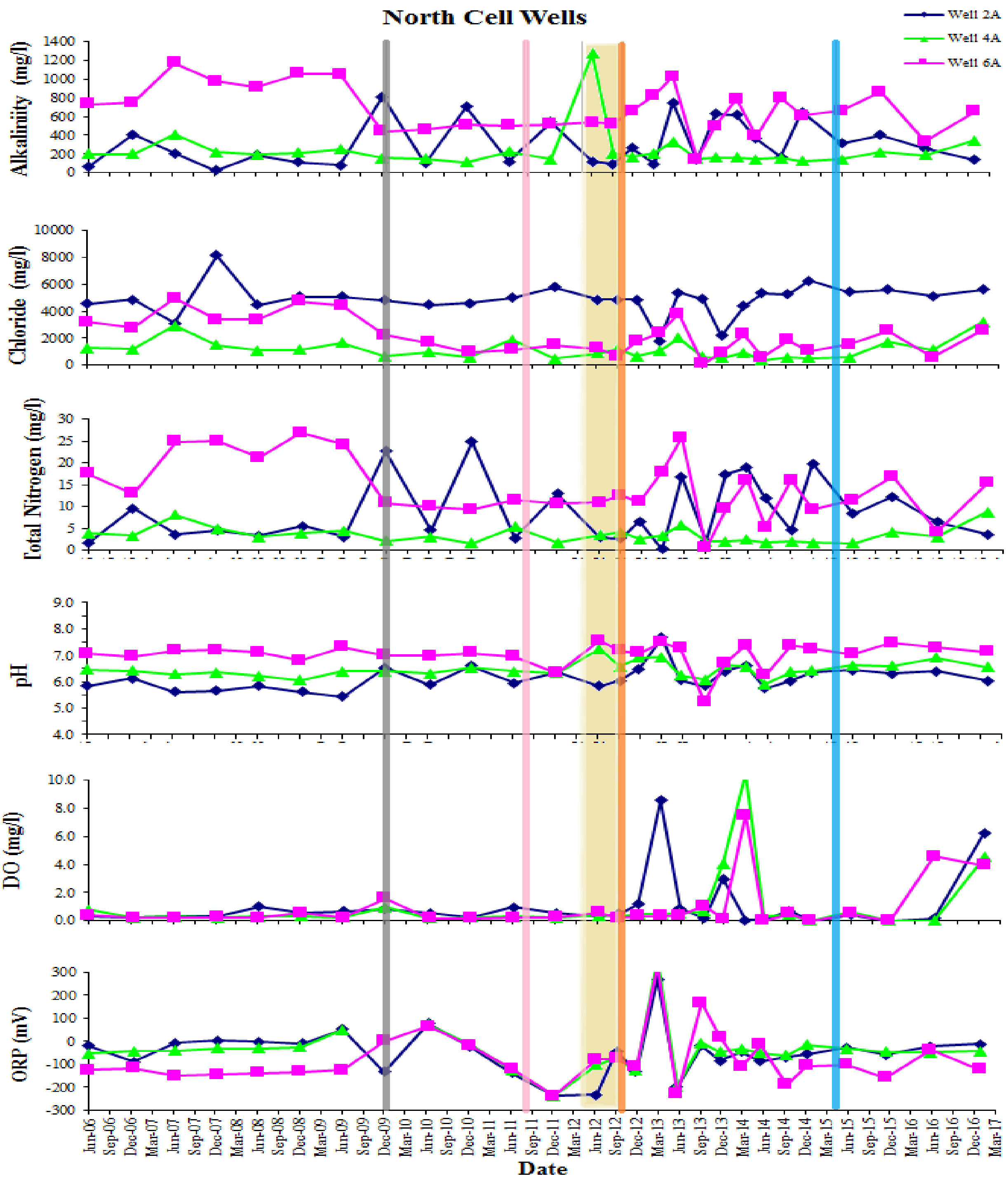

Figure 1A- 2: Trend plots for field parameters measured in groundwater samples collected since 2006 from North Cell wells. The vertical lines in the plots mark several notable events having an impact on the Facility: 1) Dec-09 (gray line) when North Cell was closed to dredge material; 2) Aug-Sept-11 (pink) Hurricane Irene and TS Lee; 3) Apr-12 to Oct-12 (yellow shading) marking the period when liming took place in North Cell; 4) Hurricane Sandy (orange line) occurred at the end of the liming period (end of Oct. 2012); 5) Jun-15 (blue line) liming began and continued during every discharge event.

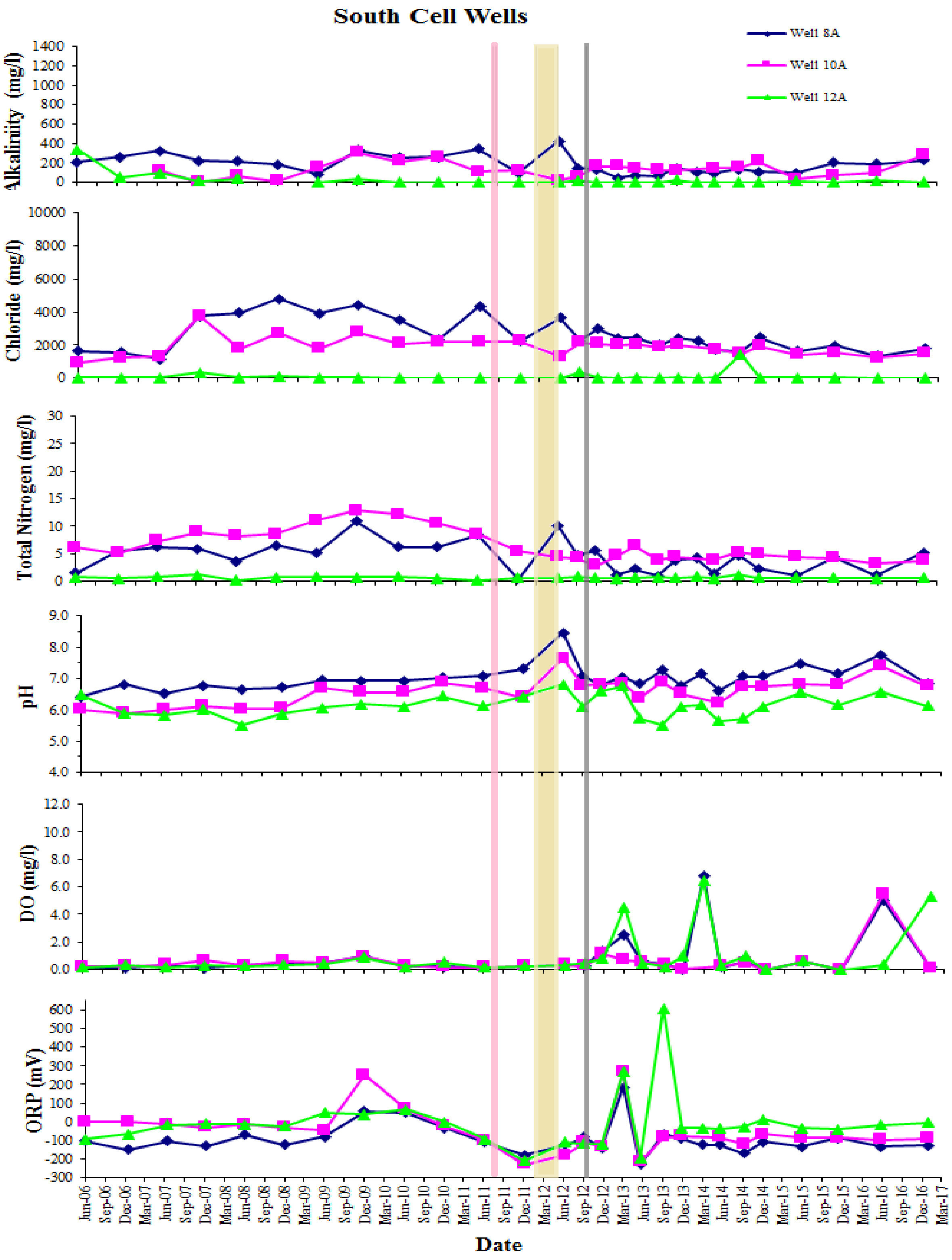

Figure 1A- 3: Trend plots for field parameters measured in groundwater samples collected since 2006 from South Cell wells. The vertical lines in the plots mark several notable events having an impact on the Facility: 1) Aug-Sept-11 (pink) Hurricane Irene and TS Lee; 2) Feb-12 to Jun-12 (yellow shading) marking the period when liming took place in South Cell; 3) Oct-12 (gray) Hurricane Sandy.

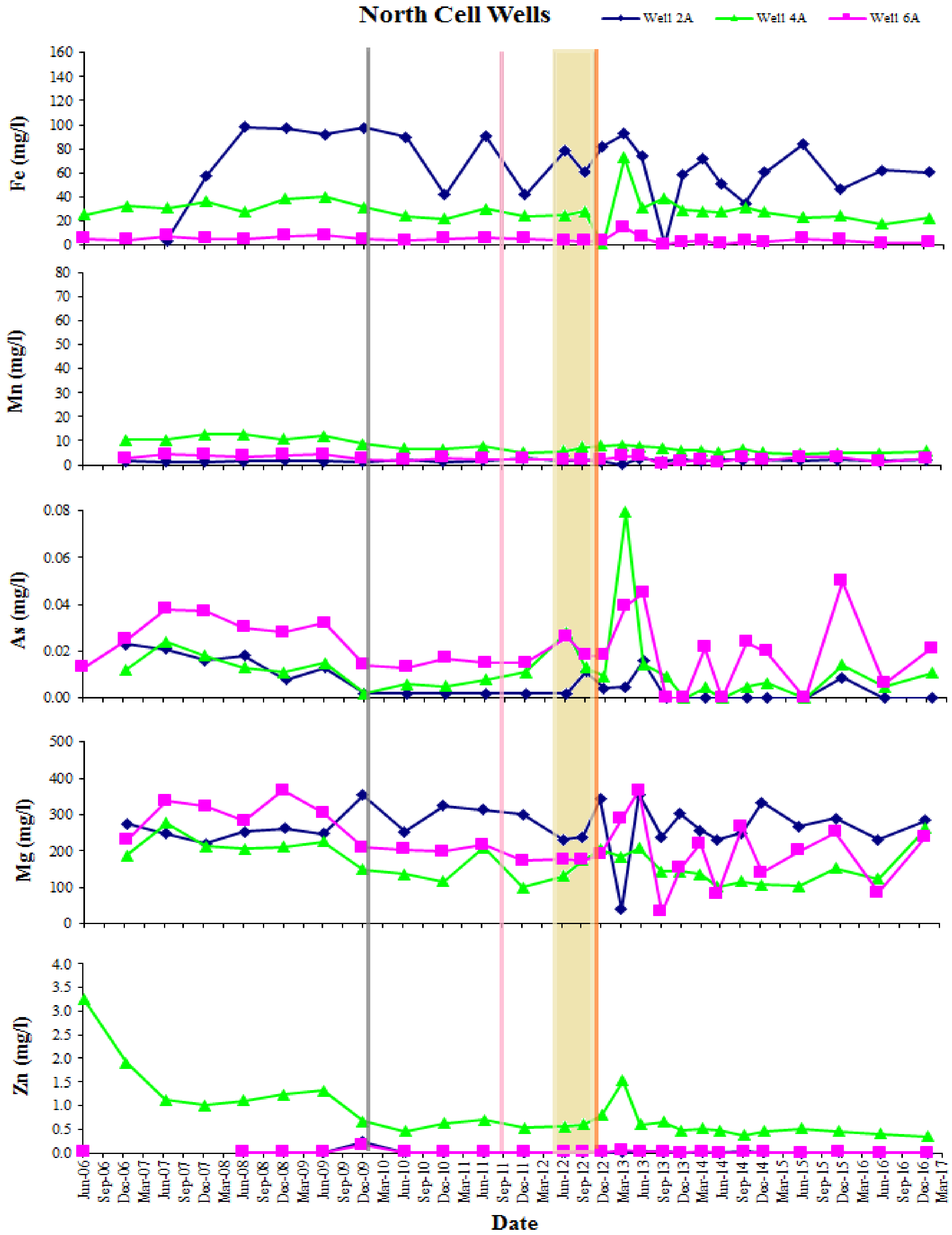

Figure 1A- 4: Trend plots for select metals measured in groundwater samples collected since 2006 from North Cell wells. The vertical lines in the plots mark several notable events having an impact on the Facility (refer to caption for Figure 1A-2 for explanation).

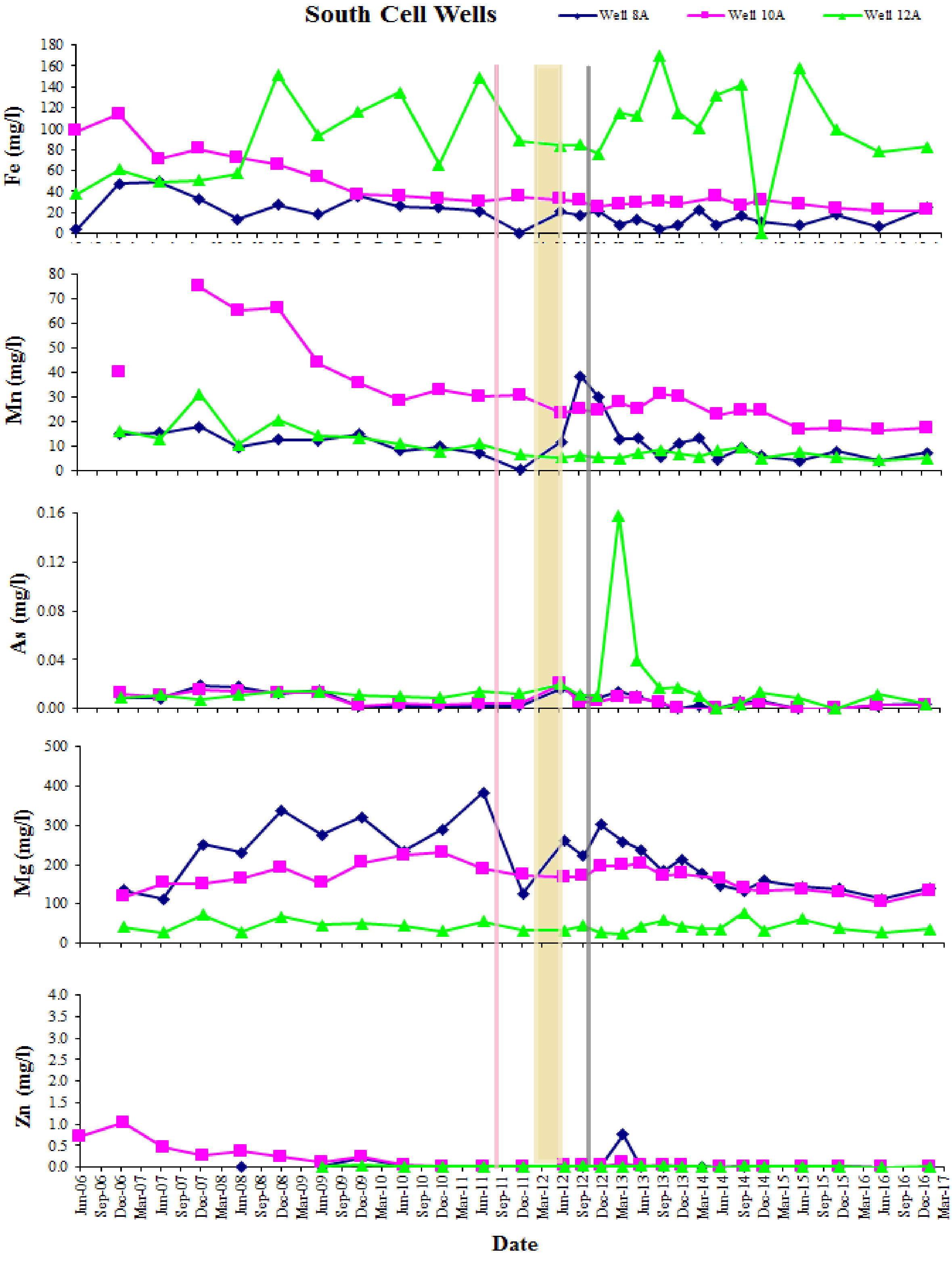

Figure 1A- 5: Trend plots for select metals measured in groundwater samples collected since 2006 from South Cell wells. The vertical lines in the plots mark several notable events having an impact on the Facility (refer to caption for Figure 1A-3 for explanation).

South Cell Wells 8A, 10A & 12A

The ground waters of the South Cell wells have been in contact with oxidized sulfide mineral bearing sediments, thus have higher levels of excess sulfate (Figure 1A-7). Chloride concentrations are relatively high in Wells 8A and 10A. However, rain and a fresh water lens appear to be a major source of groundwater accessed via Well 12A, the waters of which appear to be entirely fresh water. The lowest level of chloride present in groundwater at this well was observed in June, 2016 (Cl^- at 3.0 mg/L). Well 12A is located in a stand of mixed hardwood and conifer trees on a portion of the dike underlain by a remnant of Hart Island.

Total nitrogen (ammonium) and alkalinity are slightly lower, while some metals (Mn) are higher in the ground waters of the South Cell than they are in the ground water in the North Cell. Since the sediments in the South Cell had been exposed to the atmosphere, one time or another, much of the sulfide in the sediments has been oxidized, accounting for the higher excess sulfate in the groundwater. Until June 2012, water chemistry in the South Cell wells tended to be more stable, showing less fluctuation, compared to the North Cell wells. Starting in June 2012, South Cell wells also began to exhibit fluctuations in some field parameters and metal concentrations, although not to the same degree as seen in the North Cell wells (Figures 1A-3 and 1A-5). As with the North Cell wells, the fluctuations in chemistry seen in the South Cell wells after June 2012 are attributable as delayed responses to operations activities in the cell (e.g., liming to adjust pond pH) and extreme weather events.

Ratios

Figure 1A-6 shows the chloride (Cl^-) concentrations from the December 10, 2015, June 22, 2016, and January 25, 2017 samplings as a function of the amount of excess sulfate. This analysis is useful for inferring the actions of bacterial sulfate reduction and/or sulfide mineral oxidation. Briefly, excess sulfate is the dissolved sulfate either removed from the water as a result of bacterial sulfate reduction (– excess sulfate) or added to the water as the result of sulfide mineral oxidation in the sediment solids (+ excess sulfate). The predicted sulfate levels are calculated from the chloride concentration based on a conservative mixing between rainwater and seawater. For Year 34 Cl^- concentration is plotted on a logarithmic scale, rather than a linear scale. Based on the depletion in dissolved sulfate in comparison to predicted concentrations, groundwater near North Cell Well 2A is inferred to be a locus of active bacterial sulfate reduction. Conversely, groundwater accessed through the remaining wells is inferred to be receiving additional sulfate generated by oxidation of sulfide minerals in the sediments and released to the ground water. Lastly, as mentioned previously, ground waters accessed via Well 12A are near fresh in composition and have several orders of magnitude lower Cl^- concentration.

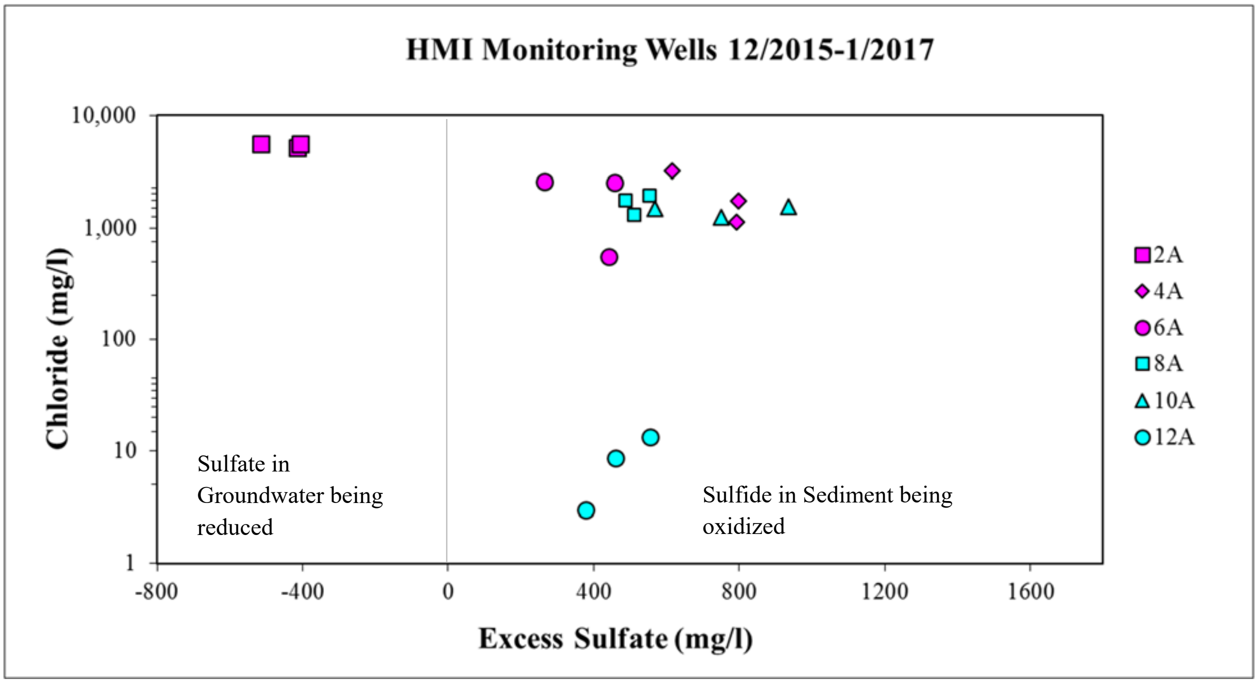

Figure 1A- 6: Groundwater chloride concentrations as a function of excess sulfate (the difference of the measured sulfate concentrations minus the predicted concentrations). Monitoring wells are grouped by general location; North Cell (pink) or South Cell (light blue).

Figure 1A-7 shows ratios of K^+/Cl^- and Ca^{2+}/Cl^- as a function of the amount of excess sulfate. This analysis is useful for inferring the dissolution of $CaCO_3$ (shell and/or limestone) and the potential for ion-exchange reactions occurring in response to a decline in pH. Dissolving $CaCO_3$ consumes acidity, and changes in H^+ ion activity can result in metals being either sorbed or displaced from mineral surfaces. For reference, the mass ratio of both K^+/Cl^- and Ca^{2+}/Cl^- are approximately equal to 0.02 in seawater. Since acidity is not thought to being generated in the vicinity of Well 2A, there is minimal mineral dissolution (specifically calcium carbonate) or ion exchange occurring in groundwater here, and the composition of groundwater near this well is close to that of seawater, with respect to the mass ratio of Ca^{2+}/Cl^- (e.g. 0.02 at this location). In ground water in the majority of the remaining wells (Wells 4A, 6A, 8A and 10A), we infer that acidity generation is ongoing, and that hydrogen ion from acid becomes preferentially bound on ion exchange sites in the sediment releasing other previously adsorbed cations (*e.g.* K^+, Ca^{2+}). K^+/Cl^- increases slightly in these four wells relative to Well 2A. Ca^{2+}/Cl^- increases approximately 5-fold (from 0.02 to 0.10), which we infer to indicate the addition of Ca^{2+} from active liming and/or relict shell dissolution. Groundwater in the vicinity of 12A is compositionally distinct from the others, having a much lower than seawater Cl^- concentration (and much higher resultant K^+/Cl^- and Ca^{2+}/Cl^- ratios).

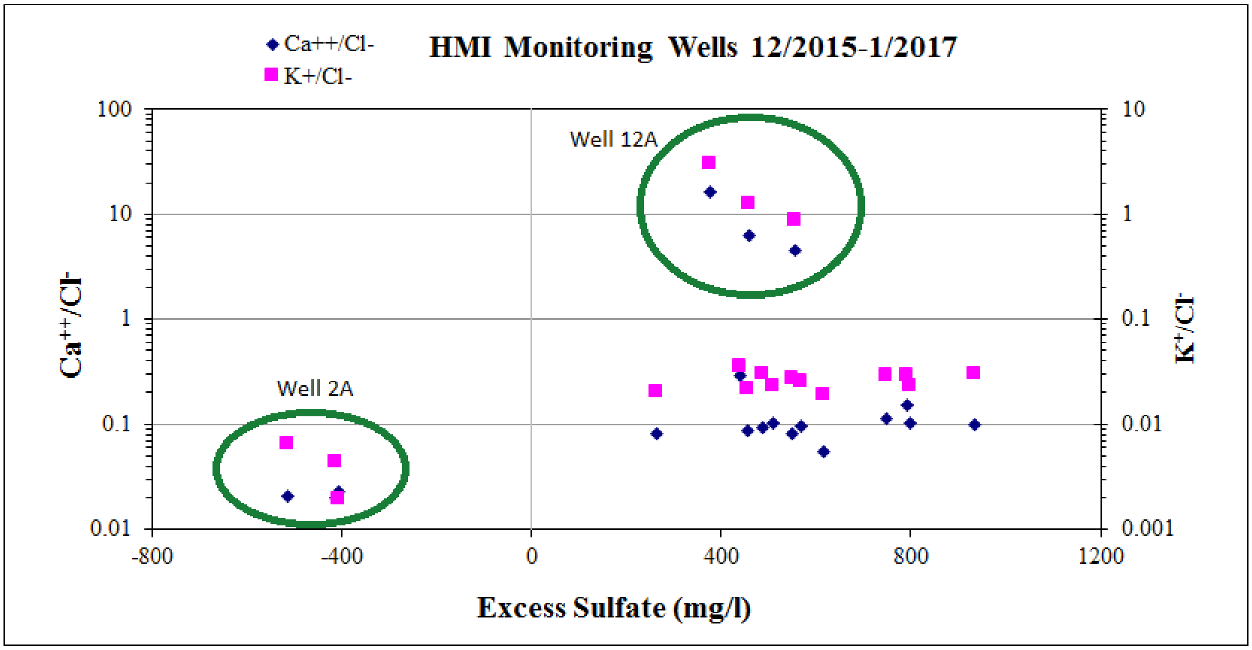

Figure 1A- 7: The ratios of K^+/Cl^- and Ca^{++}/Cl^- as a function of excess sulfate. For reference, the mass ratio for both of these cations in seawater is ~0.02. Note that scale of the y-axes are logarithmic to accommodate the relatively large ratios calculated for Well 12A; the mass ratios were high due the extremely low chloride concentrations.

Trace Metal Data

Table 1A-2 is a summary of the trace metal data for the groundwater sampled during this monitoring period (three sampling events), listing the number of samples, the number below detection, the mean, maximum and minimum concentration and the EPA Maximum Concentration Level (MCL) in drinking water (U.S. EPA, 2002). On average, metal concentrations in both the North and South Cell wells have been stable during this monitoring year. Cu and Pb remain below the detection limit in both Cells, and Zn remains intermittently detected. Fe concentrations declined over the last three events in the South Cell Wells 10A and 12A but remained dynamic in groundwater from the remaining wells. Mn concentrations in all Wells have been generally stable. Fe and Mn are the only metals with concentrations that exceed the MCL in both Cells. These two metals are not considered a primary health risk but affect the taste and aesthetic quality of the water (i.e. a secondary standard). These metals precipitate from solution in oxic conditions, so as the ground water mixes with Bay water further down the flow path, these metals will precipitate out as metal oxyhydroxides. The metal-rich precipitate will cement the sands and make the dike more impermeable with time.

Table 1A- 2: Monitoring wells trace metal analyses for December 2015 through January 2017 (three sampling events). Values in mg/L, unless otherwise indicated. Detection limits (*dl)* for Fe and Mn were not reported (highlighted in yellow).

North Cell Groundwater							
	n	*n>dl*	*dl*	*Mean*	*Min*	*Max*	*MCL*
Al	12	0	0.05	<dl	<dl	<dl	0.05 - 0.2*
As	12	4	0.01	0.013	<dl	0.050	0.01
Cd	12	0	0.001	<dl	<dl	<dl	0.005
Cr (total)	12	0	0.005	<dl	<dl	<dl	0.1
Cu	12	1	0.005	0.001	<dl	0.005	1.3
Fe	12			30.1	1.7	82.3	0.3*
Pb	12	0	0.02	0.000	<dl	0.003	0
Mn	12			3.12	1.32	5.60	0.05*
Zn	12	5	0.005	0.137	<dl	0.457	5*
Ag	12	0	0.001	<dl	<dl	<dl	0.1*
South Cell Groundwater							
	n	*n>dl*	*dl*	*Mean*	*Min*	*Max*	*MCL*
Al	12	0	0.05	<dl	<dl	<dl	0.05 - 0.2*
As	12	1	0.01	0.003	<dl	0.012	0.01
Cd	12	0	0.002	<dl	<dl	<dl	0.005
Cr (total)	12	0	0.005	<dl	<dl	<dl	0.1
Cu	12	0	0.005	<dl	<dl	<dl	1.3
Fe	12			41.8	6.6	98.8	0.3*
Pb	12	0	0.02	<dl	<dl	<dl	0
Mn	12			9.59	4.05	17.60	0.05*
Zn	12	4	0.005	0.005	<dl	0.017	5*
Ag	12	0	0.001	0.000	<dl	<dl	0.01*

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

CONCEPTUAL MODEL: PROCESSES OPERATING IN HMI GROUNDWATER

Figure 1A-8 shows a hypothetical cross section of HMI at the South Cell. Hydrogeologically, there are four areas to consider:

1. *The surface sediments of the interior of the cell.* Here ***if*** the sediment is kept inundated, the sediment and the associated pore fluids would remain anoxic and would have the characteristics similar to in-place Bay sediments. This is largely the situation in the North Cell, especially after the influx of rainwater from the major storms. However, in

the South Cell circumstance, a large area is often sub-areal with rain water being the primary source of water to the system. The moisture contained within 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 saturated sediment is exposed to atmospheric oxygen, oxic processes commence. One of the most significant reactions is the oxidation of the naturally occurring sulfide minerals (primarily iron mono-sulfides and pyrite) that produces sulfuric acid. The acidified waters have sulfate concentrations in excess of that which would be encountered if only conservative mixing of seawater and Bay water were responsible for the sulfate load. The oxidation of the sulfide minerals, and resultant acidity generation, can increase the dissolved concentrations of Fe and Mn, and the generated acidity can react with the sediment to release other metals, acid soluble nutrients, and trace organic compounds. This acidified water either joins surface water runoff or infiltrates into the sediment in the dike forming the groundwater flow through the dike. This surface water is monitored and its pH controlled by MES.

2. *Dredged sediment in the diked area.* 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 acidity is neutralized by calcium carbonate; acidity and metals are bound by ion exchange processes; the reduction in acidity causes precipitation of insoluble metal compounds (combined with anions such as phosphate and carbonate), and; reduction occurs which consumes oxygen and groundwater environment becomes more reducing. The flow of water through the dike is relatively fast compared to the rate of bacterial sulfate reduction since the concentrations of sulfate remain high (this is shown as the positive Excess Sulfate in the Figures 1A-6 and 1A-7). If strongly reducing conditions existed, dissolved sulfate concentrations would decrease, sulfide gas would be generated, and the sulfide gas would either escape the system or reform mono-sulfide minerals.

3. *Movement through the dike walls.* The dike walls are made of clean sands and thus are relatively inert; however, they can act as a mechanical filter. As a filter, the dike retains the fine sediment placed in the diked area, and removes the precipitates that form as the water reacts in the contained sediment. Eventually as with any filter, the filter (*i.e.* the dike walls) can become plugged as material is trapped along the flow lines. This is the area where the sampling wells are located. The groundwater sampled at this point reflects 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 Bay water. The Bay water is oxic 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.

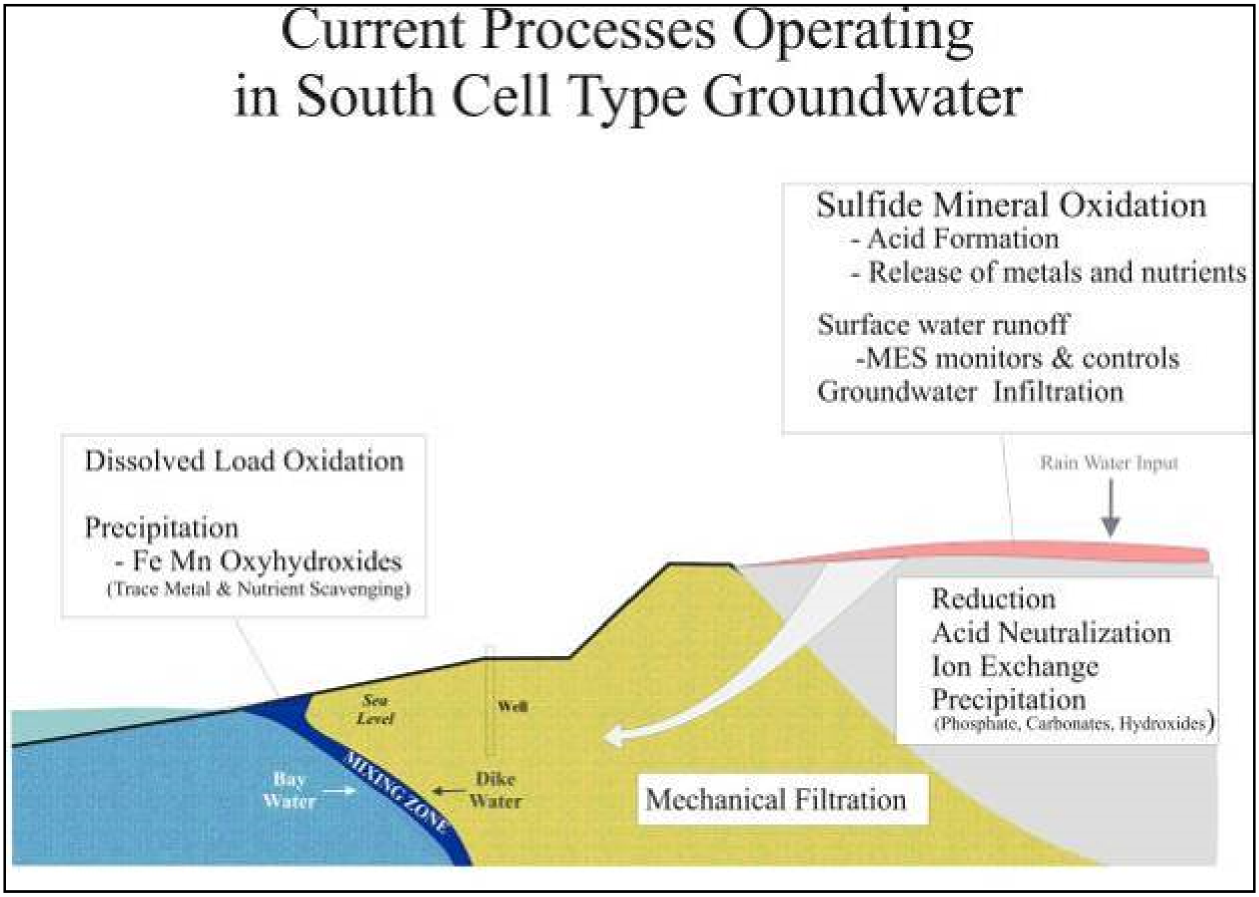

Figure 1A- 8: Schematic presentation of the processes which produce the groundwater similar to those found in the South Cell wells.

As a means of further exploring the processes outlined above, the groundwater data from December 10, 2015, June 22, 2016, and January 25, 2017 was input into the USGS software PHREEQCi, which can be used to calculate whether a secondary mineral may be forming from groundwater (Parkhurst and Appelo, 1999). Briefly, the complete available groundwater chemistry (inclusive of pH, ORP, temperature and all dissolved species) is input into the PHREEQCi software. The model then calculates which solid phases would be precipitating (or dissolving) based on chemical equilibria. A mineral with a saturation index greater than 1 is predicted to be precipitating from the groundwater solution. The PHREEQCi model makes predictions based on thermodynamics, and so some user discretion is advised in interpreting the results, in order to identify minerals which may be favored but forming too slowly to be meaningfully observed on project timescales. Secondary minerals such as iron oxyhydroxides, carbonates and phosphates form relatively quickly and it would be appropriate to use the model to screen for the presence of these phases.

Iron oxyhydroxides, including amorphous $Fe(OH_3)$ and goethite ($FeOOH$) were predicted to be supersaturated (precipitating) in the groundwater environments represented by all six wells at each of the three time points. This is consistent with a conceptual model wherein iron oxyhydroxides are expected to form with movement through the dike wall. Carbonate minerals, including siderite ($FeCO_3$), dolomite ($MgCO_3$) and rhodocrosite ($MnCO_3$) were predicted to intermittently supersaturated in Well 2A (2015, 2016), Well 6A (2015, 2017), Well 8A (2015, 2016) and Well 10A (2016). Calcium carbonate ($CaCO_3$) was not predicted to be supersaturated by this model, but was however predicted to be near equilibrium (still dissolving) with respect to ground water at Well 6A, at each of the three time points. This is consistent with a conceptual model where Well 6A receives the weathering products of active liming in the North Cell. Lastly, a single phosphate mineral (vivianite, [$Fe_3(PO_4):8H_2O$]) was predicted to be supersaturated with respect to groundwater at Well 10A during the 2016 sampling event. This is consistent with a conceptual model wherein phosphates are expected to form within the sediments of the diked area.

Table 1A- 3: An example PHREEQCi Output for Well 6A for January 2017. Saturation indices above 1.0 indicate a mineral is predicted to precipitate.

Phase	Saturation Index	Formula
Aragonite	0.23	$CaCO_3$
Calcite	0.38	$CaCO_3$
Dolomite	1.05	$CaMg(CO_3)_2$
$Fe(OH)_3$(a)	-0.13	$Fe(OH)_3$
Goethite	5.43	FeOOH
Hematite	12.82	Fe_2O_3
Rhodochrosite	0.84	$MnCO_3$
Siderite	0.52	$FeCO_3$
Vivianite	-2.43	$Fe_3(PO_4)_2:8H_2O$

As noted earlier, the groundwater monitoring wells are located in the sandy matrix of the dike walls which may act as a mechanical filter for the groundwater. Groundwater in these wells is generally anoxic, however, influxes of oxygenated water have been observed; in December 2013 (Wells 2A and 4A), in March 2014 (Wells 4A, 8A, 10A and 12A), in June 2016 (Well 6A), and most recently in January 2017 (Wells 2A, 4A, 6A, and 12A). The behavior of measured parameters in each well within the two cells is different reflecting a number of factors including: 1) the heterogeneous material contained in the dike; 2) source material that effected transport rates and chemistry of the groundwater, and 3) location of the well with respect to specific operation activities such as liming and surface water ponding.

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APPENDIX II: BENTHIC COMMUNITY STUDIES (PROJECT III)

(September 2016 – August 2017)

Technical Report

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September 2017

EXECUTIVE SUMMARY

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI-DMCF) was studied for the thirty-fourth year under Project III of the HMI Exterior Monitoring Program during the 34th year of operations at the site. 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, and conductivity were measured *in situ.* Fifteen stations (7 Nearfield, 3 Reference, 2 Back River/Hawk Cove, and 3 South Cell Exterior Monitoring stations) were sampled on September 26, 2016. Due to scaling back of monitoring efforts during the post closure era at HMI, benthic sampling was not done in 2015 or in the spring of 2016.

The salinity regime was in its historical average range. The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI), a multi-metric index of biotic condition that evaluates summer populations of benthic macro-invertebrates, was calculated for all stations. Metrics applicable to the low mesohaline classification (5 - 12 ppt) were used. The B-IBI's and derivative metrics (Total Infaunal Abundance, Pollution Indicative Taxa Abundance, Pollution Sensitive Taxa Abundance, and Shannon-Weiner Diversity Index) were compared to historical data and were analyzed both spatially and statistically.

The health of the benthic macroinvertebrate community around HMI in Year 34 was similar to historical averages. In Year 34, ten of the fifteen stations met the benchmark criteria of 3.00. Nine stations were above their historic averages and six stations were below the historic averages for B-IBI. In addition to six stations being below the historic average three stations set new historic lows; and one station set a new historic high. Year 34 B-IBI's are starting to trend upward after five consecutive years where B-IBI's had been trending downward. While Nearfield stations showed improvement from the past five years they were the only station type that failed to meet the benchmark of 3.0.

Improved B-IBI's can be attributed to fluctuations in the invertebrate community. They included above average abundance of the pollution sensitive bivalve *M. balthica* and the isopod *C. polita* at many stations. This general trend tended to increase the B-IBIs. One fluctuation was largely responsible for depressing B-IBI's at other stations. This was the exceptionally high average abundance of the pollution indicative oligochaete worms in the family Naididae at three of the five failing stations. These abundances adversely impacted all four metrics used to compute the B-IBI. They depressed the Total Infaunal Abundance metric scores (by having too many organisms per square meter), increased the Pollution Indicative Taxa metric (because they are pollution indicative), depressed the relative Pollution Sensitive Taxa Abundance metric (by dilution), and depressed the Shannon Weiner Diversity Index metric. Naididae are generally considered indicators of organic enrichment.

The cluster analysis indicated that the benthic communities measured in September 2016 were highly similar in the area to the east of HMI and their similarity was correlated with relative healthy, unstressed hydrologic and sediment conditions, as identified by the B-IBI analyses. In addition the cluster analysis indicated that the identified outlier stations (located north or HMI) were all similar in that they had stressed benthic communities. However, the Friedman's test comparison between Nearfield, Reference, South Cell and Back River stations was not significant, indicating that no localized adverse impacts from HMI operational discharges could be identified.

INTRODUCTION

Annual dredging of the shipping channels leading to the Port of Baltimore is necessary to maintain safe navigation. An average 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. HMI is split into two cells, the North and South Cell. Over the years, a series of four spillways, Spillways 007,008 and 009 in the North Cell, and Spillway 003 in the South Cell, periodically discharged excess water released from on-site dredged material disposal operations.

An exterior monitoring program was developed to assess potential environmental impacts associated with HMI operations in support of the environmental permitting process for dredged material containment. Various agencies have worked together since the inception of this program to assess the 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. Since Year 17, the Maryland Department of the Environment (MDE) has been responsible for all aspects of benthic community monitoring.

Midway through Year 28, on December 31, 2009, HMI stopped accepting dredged material. The fall of Year 28 represented the final monitoring data collected while HMI received dredged material. Post closure exterior benthic monitoring will be terminated after the final benthic samples are taken fall 2018 (Year 37). HMI Years 34 (2015) and 36 (2017) were not scheduled to be sampled for benthics.

Year 34 represents the sixth year of post closure data. During HMI Years 35 and 33 samples were only collected during the fall and at a reduced (15) number of stations. The stations not sampled during these years were: Nearfield Stations MDE-03, MDE-07, MDE-09, MDE-11, and MDE-33, and Reference Stations MDE-50, and MDE-51.

The goals of the Year 34 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 stations near 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 areas near all functioning spillways, particularly 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 34. Field sampling cruises were conducted on board the Maryland Department of Natural Resources vessel "*R/V Kerhin*". Fifteen fixed benthic stations were monitored during a fall cruise (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 34 benthic community monitoring, and predominant sediment type at each station for September.

Station #	Latitude	Longitude	Sediment Type	Maryland 7-Digit Station Designation
Nearfield Stations				
MDE-01	39º 15.3948	-76º 20.5680	Sand	XIF5505
MDE-15	39º 14.5686	-76º 20.9526	Silt/clay	XIF4609
MDE-16	39º 14.5368	-76º 21.4494	Silt/clay	XIF4615
MDE-17	39º 14.1690	-76º 21.1860	Shell	XIF4285
MDE-19	39º 14.1732	-76º 22.1508	Silt/clay	XIF4221
MDE-34	39º 15.7650	-76º 20.5392	Silt/clay	XIF5805
MDE-45	39º 14.7198	-76º 21.2538	Silt/clay	N/A
Reference Stations				
MDE-13	39º 13.5102	-76º 20.6028	Silt/clay	XIG3506
MDE-22	39º 13.1934	-76º 22.4658	Silt/clay	XIF3224
MDE-36	39º 17.4768	-76º 18.9480	Silt/clay	XIG7589
Back River/Hawk Cove Stations				
MDE-27	39º 14.5770	-76º 24.2112	Silt/clay	XIF4642
MDE-30	39º 15.8502	-76º 22.5528	Silt/clay	XIF5925
South Cell Exterior Monitoring Stations				
MDE-42	39º 13.8232	-76º 22.1432	Silt/clay	XIF3879
MDE-43	39º 13.9385	-76º 21.4916	Silt/clay	XIF3985
MDE-44	39º 14.4229	-76º 21.8376	Silt/clay	XIF4482

Figure 2-1: Year 34 benthic sampling stations for the HMI exterior monitoring program.

The fifteen stations sampled in Year 34 have been continuously sampled since at least Year 27. Over the years, the list of stations sampled has changed several times. Occasionally old stations were deleted and new stations were added to suit monitoring needs[1]. 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 for sediment analysis.

Temperature, depth, salinity, pH, conductivity, and dissolved oxygen (DO) were measured *in situ* using a Yellow Springs Instruments (YSI) 6600 V2 multi-parameter water quality meter in September 2016. 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 not measured in 2016.

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.

All organisms were identified to the lowest practical taxon (usually to species) using a stereo dissecting microscope. The number of specimens for each taxon collected in each replicate (raw data) is presented in the *Year 34 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.

Six major measures of benthic community condition were examined, including: Total Infaunal Abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance

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[1] 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"

of pollution-sensitive infaunal taxa, the Shannon-Wiener diversity index, taxa richness, and total abundance of all taxa (excluding Bryozoa and Copepoda). Four of these measures (total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa, and the Shannon-Wiener diversity index) were used to calculate the B-IBI for September 2016. 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). In addition to the above metrics, the numerically dominant taxa 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 34 Data Report*. Total infaunal abundance was calculated as the average abundance of infaunal organisms per square meter (#/m^2). These two different measures of 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 15 stations, a single-linkage cluster analysis was performed on a Euclidean distance matrix comprised of station infaunal abundance values for all 15 stations. This analysis was performed for September 2016 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 September 2016. The statistical analyses were performed using SAS, Version 9.4 and SPSS, Version 11.5.

RESULTS AND DISCUSSION

Water Quality

Minimal variations between surface and bottom values for salinity, temperature, DO, conductivity, and pH values during the 2016 cruise (Table 2-5) indicated that water column stratification was not prevalent.

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 34, bottom water temperatures showed little variation. The mean bottom water temperature ranged from 21.52°C – 22.61°C and averaged 22.02°C ± 0.33°C (Table 2-3). This mean was 1.90ºC lower than the 29-year fall average of 23.97ºC.

The mean bottom DO concentration exceeded the water quality standard (5.0 ppm) to protect aquatic life (Maryland Code of Regulations COMAR) during Year 34. The bottom DO ranged between 6.84 – 8.20 ppm and had a mean of 7.26 ppm ± 0.38 ppm (Table 2-3). This mean was 0.15 ppm lower than the 19-year fall average of 7.41 ppm.

In the early fall, 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 30-year mean fall bottom salinity is 6.40 ppt, ± 2.81 ppt. Low Mesohaline conditions (5-12 ppt) were found during the fall 2016 sampling season.

In Year 34 salinity values varied slightly (Table 2-5 mean=10.58 ppt ± 0.96 ppt, range = 9.09 ppt – 12.02 ppt) and the mean fall salinity was 4.18 ppt higher than the historical average. 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.

Table 2-2: Year 34 physical parameters measured in situ at all HMI stations on September 28, 2016.

MDE Station	Time	Tide	Water Depth (m)	Wave Height (m)	Wind Direction	Wind Speed (knots)		Air Temp. (ºC)	Cloud Cover (%)	Weather		Observed Bottom Sediment (%)				
						Min.	Max			Past 24 hrs.	Today	silt/clay	sand	shell	gravel	detritus
MDE-01	12.:01	Flood	2.74	0.3	NE	5	10	20.0	40	0	5	0	85	15	0	0
MDE-13	10:42	Flood	1.31	0.3	NE	5	10	19.4	40	0	5	90	0	10	0	0
MDE-15	11:45	Flood	4.53	0.3	NE	5	10	19.4	40	0	5	90	0	10	0	0
MDE-16	11:20	Flood	3.55	0.3	NE	5	10	19.4	40	0	5	90	0	10	0	0
MDE-17	11:05	Flood	3.09	0.3	NE	5	10	19.4	40	0	5	65	0	35	0	0
MDE-19	9:58	Flood	3.89	0.3	NE	5	10	18.9	40	0	5	65	0	35	0	0
MDE-22	9:01	Flood	2.03	0.3	NE	5	10	18.3	40	0	5	90	0	10	0	0
MDE-27	12:52	Flood	3.22	0.3	NE	5	10	20.0	40	0	5	75	0	15	0	10
MDE-30	12:29	Flood	1.93	0.3	NE	5	10	20.0	40	0	5	60	0	40	0	0
MDE-34	12:13	Flood	2.58	0.3	NE	5	10	19.4	40	0	5	90	0	10	0	0
MDE-36	13:22	Flood	2.56	0.3	NE	5	10	20.0	40	0	5	70	0	30	0	0
MDE-42	9:29	Flood	2.83	0.3	NE	5	10	18.3	40	0	5	95	0	5	0	0
MDE-43	10:27	Flood	3.11	0.3	NE	5	10	18.9	40	0	5	90	0	10	0	0
MDE-44	10:13	Flood	3.80	0.3	NE	5	10	18.9	40	0	5	90	0	5	0	5

Note: The Weather code 0 stands for “Clear”. The Weather code 5 stands for “Light Rain”.

Table 2-3: Year 34 water quality parameters measured in situ at all HMI stations on September 28, 2016.

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	0.5	9.57	21.63	7.60	7.03	N/A	16,310
		Bottom	2.74	9.64	21.66	7.67	7.04		16,400
MDE-15	XIF4609	Surface	0.5	10.64	21.99	7.07	7.04	N/A	17,990
		Bottom	4.53	10.64	22.00	7.09	7.04		17,980
MDE-16	XIF4615	Surface	0.5	10.28	21.90	7.10	6.99	N/A	17,410
		Bottom	3.55	10.26	21.89	7.33	7.02		17,380
MDE-17	XIF4285	Surface	0.5	10.94	22.14	6.84	7.00	N/A	18,460
		Bottom	3.09	10.91	22.13	7.04	7.02		18,380
MDE-19	XIF4221	Surface	0.5	10.85	22.17	6.90	7.07	N/A	18,320
		Bottom	3.89	11.45	22.61	6.84	7.03		19,250
MDE-34	XIF5805	Surface	0.5	9.72	21.73	7.67	7.08	N/A	16,590
		Bottom	2.58	9.72	21.74	7.70	7.09		16,550
MDE-45	N/A	Surface	0.5	9.46	21.69	7.22	7.02	N/A	16,140
		Bottom	1.48	10.33	22.07	7.07	6.99		17,450
Reference Stations									
MDE-13	XIG3506	Surface	0.5	11.91	22.24	7.03	7.15	N/A	19,960
		Bottom	1.31	11.93	22.24	7.07	7.15		19,980
MDE-22	XIF3224	Surface	0.5	11.08	22.10	7.36	7.21	N/A	18,700
		Bottom	2.03	12.02	22.32	7.16	7.2		18,770
MDE-36	XIG7589	Surface	0.5	9.06	21.51	7.71	6.99	N/A	15,480
		Bottom	2.56	9.09	21.52	7.72	7.00		15,520
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.5	9.35	21.62	6.83	7.22	N/A	15,950
		Bottom	3.22	9.66	21.72	6.97	7.13		16,500
MDE-30	XIF5925	Surface	0.5	9.26	21.59	8.19	7.30	N/A	15,820
		Bottom	1.93	9.26	21.58	8.20	7.31		15,810
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.5	10.54	21.96	7.18	7.15	N/A	17,800
		Bottom	2.83	11.39	22.42	6.98	7.11		19,050
MDE-43	XIF3985	Surface	0.5	11.20	22.13	7.01	7.11	N/A	18,830
		Bottom	3.11	11.49	22.23	7.04	7.11		19,350
MDE-44	XIF4482	Surface	0.5	10.66	22.01	6.89	7.01	N/A	18,010
		Bottom	3.80	10.91	22.13	7.08	7.04		18,490

BENTHIC MACROINVERTEBRATE COMMUNITY

Taxa Richness and Dominance

A total of 30 invertebrate taxa were found in Year 34. This is lower than the 13-year fall average of 31.18 taxa. This decrease may be due in part to the reduced number (15 vs. 22, or 31.8% fewer) of stations sampled in the year compared to historic averages. 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). Ten taxa of Arthropoda were found in Year 34. The most common types of arthropods were the amphipods (including *Leptocheirus plumulosus*) and the isopods (including *Cyathura polita*). Eight taxa of annelid worms in the Class Polychaeta were found. Six species of bivalve mollusks were found. Overall, infaunal bivalve average abundance was higher in Year 34 than previous years (Table 2-6).

Table 2-4: Average and total abundance (individuals per square meter) of each taxon found at HMI during the September 2016 sampling; by substrate and station type. Taxa in bold are pollution sensitive and taxa highlighted in gray are pollution indicative for the low mesohaline conditions found in Year 34.

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	310.61	4659.20	354.95	38.40	6.40	377.60	119.47	444.80	256.00
Carinoma tremophoros	41.39	620.80	44.80	38.40	0.00	29.26	61.87	3.20	74.67
Bivalvia	0.85	12.80	0.98	0.00	0.00	0.00	0.00	3.20	2.13
Macoma sp.	30.72	460.80	32.98	19.20	12.80	15.54	89.60	0.00	27.73
Macoma balthica	**194.56**	**2918.40**	**214.15**	**134.40**	**0.00**	**253.26**	**121.60**	**16.00**	**249.60**
Macoma mitchelli	36.69	550.40	39.88	32.00	0.00	35.66	40.53	32.00	38.40
Rangia cuneata	**37.97**	**569.60**	**38.89**	**64.00**	**0.00**	**36.57**	**64.00**	**28.80**	**21.33**
Ischadium recurvum	2.56	38.40	0.49	0.00	32.00	5.49	0.00	0.00	0.00
Mytilopsis leucophaeata	239.36	3590.40	220.55	32.00	691.20	485.49	57.60	3.20	4.27
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	91.73	1376.00	92.55	160.00	12.80	74.97	162.13	60.80	81.07
Spionidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marenzelleria viridis	26.03	390.40	30.03	0.00	0.00	21.94	34.13	44.80	14.93
Streblospio benedicti	139.52	2092.80	139.82	96.00	179.20	137.14	106.67	323.20	55.47
Polydora cornuta	17.49	262.40	9.85	0.00	134.40	37.49	0.00	0.00	0.00
Boccardiella ligerica	1.71	25.60	0.98	0.00	12.80	3.66	0.00	0.00	0.00
Nereidae	0.85	12.80	0.98	0.00	0.00	0.91	0.00	3.20	0.00
Neanthes succinea	162.56	2438.40	144.25	38.40	524.80	302.63	98.13	12.80	0.00

Table 2-4 – (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	31.15	467.20	32.98	6.40	32.00	35.66	32.00	44.80	10.67
Naididae sp.	1567.15	23507.20	1770.34	403.20	89.60	2235.43	375.47	457.60	1939.20
Amphipoda	1.28	19.20	1.48	0.00	0.00	0.00	0.00	3.20	4.27
Gammaridea	0.85	12.80	0.98	0.00	0.00	0.91	0.00	3.20	0.00
Ameroculodes spp complex	8.53	128.00	9.85	0.00	0.00	4.57	21.33	0.00	10.67
Leptocheirus plumulosus	111.36	1670.40	124.55	51.20	0.00	53.03	25.60	403.20	138.67
Gammarus sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Melitadae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Melita nitida	20.48	307.20	16.74	0.00	89.60	26.51	2.13	44.80	8.53
Corophiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apocorophium lacustre	2.13	32.00	2.46	0.00	0.00	2.74	2.13	0.00	2.13
Cyathura polita	**244.48**	**3667.20**	**266.34**	**204.80**	**0.00**	**191.09**	**298.67**	**281.60**	**290.13**
Edotea triloba	1.28	19.20	1.48	0.00	0.00	0.00	6.40	0.00	0.00
Chiridotea almyra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ciripedia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Balanus improvisus	22.61	339.20	2.95	0.00	300.80	42.97	12.80	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	23.04	345.60	13.29	6.40	166.40	46.63	6.40	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 2-4 – (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.	9.39	140.80	10.83	0.00	0.00	3.66	2.13	41.60	8.53
Anthozoa	5.12	76.80	0.98	0.00	64.00	10.06	2.13	0.00	0.00
Mulinia lateralis	8.96	134.40	9.35	12.80	0.00	4.57	12.80	3.20	19.20
Glycinde solitaria	**0.43**	**6.40**	**0.49**	**0.00**	**0.00**	**0.00**	**2.13**	**0.00**	**0.00**
Gobiosoma bosci	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Platyhelminthes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nudibranchia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mysidacea	2.56	38.40	2.95	0.00	0.00	1.83	0.00	3.20	6.40
Copepoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrozoa	1.28	19.20	0.98	0.00	6.40	1.83	2.13	0.00	0.00

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

Of the 30 taxa found in Year 34, seventeen are considered truly infaunal, nine are considered epifaunal, and the remaining four are considered too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 34 were the amphipod *L. plumulosus*, the polychaete worms *H. filiformis*, *N. succinea*, and *S. benedicti*, the bivalve *M. balthica*, worms from the family Naididae, and the isopod *C. polita*. The most common epifaunal species was the bivalve *M. leucopheata*. While the invasive, epifaunal Zebra Mussel has been weakly established in the upper Chesapeake Bay in the past two years, it was not found in any of the 15 stations sampled around HMI.

Nearfield station MDE-34 had the highest number of taxa (20 taxa, Table 2-8). The stations with the fewest number of taxa (14 taxa) were Nearfield station MDE-16 and Back River/Hawk Cove station MDE-30 (Table 2-8). Overall, average taxa richness was highest at Reference stations but did not vary greatly between station types (average taxa richness: Reference=18.7 taxa, South Cell Exterior Monitoring =17.3 taxa, Nearfield=17.0 taxa, Back River/Hawk Cove =15.0 taxa). It is important to note that there are 7 Nearfield stations, 3 Reference stations, 3 South Cell Exterior Monitoring stations and 2 Back River/Hawk Cove stations. So, historic higher taxa abundances at Nearfield stations may have simply been an artifact of sample size. In Year 34, the historic correlation of increasing taxa richness with more stations per station type was somewhat reversed. There was a small increase in richness at stations located farther from HMI (exception: Back River/Hawk Cove).

Table 2-5: Summary of metrics for each HMI benthic station surveyed during the Year 34 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 (%)	Tolerance Score	% Carnivore/ Omnivore	Tanypodinae: Chironomidae	B-IBI
Nearfield Stations											
MDE-01	985.60	2,348.80	17	7	1.96	0.00	30.52	N/A	N/A	N/A	2.00
MDE-15	1,075.20	1,107.20	16	12	2.90	41.07	42.26	N/A	N/A	N/A	3.50
MDE-16	1,785.60	1,798.40	14	11	2.44	41.58	44.80	N/A	N/A	N/A	3.50
MDE-17	1,241.60	1,299.20	16	12	2.93	32.47	41.75	N/A	N/A	N/A	3.50
MDE-19	1,440.00	1,452.80	17	14	2.63	48.00	30.22	N/A	N/A	N/A	3.50
MDE-34	11,552.00	14,528.00	20	13	1.24	1.22	82.83	N/A	N/A	N/A	1.00
MDE-45	6,131.20	6,176.00	16	11	1.26	17.95	78.91	N/A	N/A	N/A	1.50
MEAN	**3458.70**	**4101.50**	**16.57**	**11.43**	**2.19**	**26.04**	**50.19**	**N/A**	**N/A**	**N/A**	**2.64**
Reference Stations											
MDE-13	1,299.20	1,510.40	19	15	3.12	42.86	17.24	N/A	N/A	N/A	4.00
MDE-22	1,638.40	1,696.00	19	14	3.06	42.58	32.81	N/A	N/A	N/A	4.00
MDE-36	1,433.60	1,715.20	18	12	2.75	21.43	57.59	N/A	N/A	N/A	3.00
MEAN	**1,457.10**	**1,640.50**	**18.66**	**13.66**	**2.98**	**35.62**	**35.88**	**N/A**	**N/A**	**N/A**	**3.67**
Back River/Hawk Cove Stations											
MDE-27	2,380.80	2,406.40	16	11	2.69	27.42	53.76	N/A	N/A	N/A	4.00
MDE-30	1,062.40	1,228.80	14	11	2.10	8.43	43.37	N/A	N/A	N/A	2.50
MEAN	**1,721.60**	**1,817.60**	**15**	**11**	**2.40**	**17.92**	**48.57**	**N/A**	**N/A**	**N/A**	**3.25**
South Cell Exterior Monitoring Stations											
MDE-42	1,484.80	1,536.00	18	13	2.90	44.40	25.00	N/A	N/A	N/A	3.50
MDE-43	1,568.00	1,664.00	18	13	2.65	33.06	47.35	N/A	N/A	N/A	4.00
MDE-44	5,792.00	5,824.00	16	12	1.10	9.50	86.08	N/A	N/A	N/A	2.00
MEAN	**2,948.30**	**3,008.00**	**17.33**	**12.66**	**2.22**	**28.99**	**52.81**	**N/A**	**N/A**	**N/A**	**3.17**

Since the first benthic survey studies of the Hart-Miller Island area in 1981, several taxa have been consistently dominant. Year 34 was no exception. Seven of the ten most dominant taxa in Year 34 have been consistently dominant through the years. Those are: the amphipod *L. plumulosus,* the polychaete worms *N. succinea* and *S. benedicti,* the isopod *C. polita,* oligochaete worms of the family Naididae, and the bivalves, *R. cuneata* and *M. balthica*. Falling out of the most dominant taxa was the polycheate worm *M. viridis*, and the amphipods *A. lacustre* and *M. nitida.* The average abundance of each taxon (individuals per square meter) found at each station during the cruise are provided in Table 2-10 through Table-11.

There were several unique observations in the benthic community made in Year 34. The bivalve mollusk, *Mulinia lateralis* was found in low numbers at nine of the fifteen stations. This is the first time it has been found since Year 20. Historically this clam was mostly found in Harbor Stations, which have not been monitored since Year 20. It is designated pollution indicative in low mesohaline conditions but has no designation under other salinity ranges. Oligochaete worms in the family Naididae were found at exceptionally high densities in some stations MDE-34, MDE-44, and MDE-45). These worms are associated with organic enrichment and pollution indicative in all salinity regimes. Historically the highest abundances measured for these taxa have been at the high detritus, Back River-Hawk Cove Station, MDE-27. The observed density of Naididae at these three stations in Year 34 was the highest ever observed for any station, except for Year 22 and Year 19 at MDE-27. Naididae had the highest average abundance for all taxa in Year 34.

Table 2-6: Average number of individuals collected per square meter at each station during HMI Year 34, stations MDE-1 to MDE-22. Taxa in bold are pollution sensitive and taxa highlighted in gray are pollution indicative for the low mesohaline conditions found in Year 34.

Station							
Taxon	MDE-01	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Nemata	6.4	0	89.6	352	38.4	1158.4	6.4
Carinoma tremaphoros	0	102.4	32	44.8	38.4	32	76.8
Bivalvia	0	0	0	0	0	0	0
Macoma sp.	12.8	153.6	19.2	0	19.2	0	38.4
Macoma balthica	**0**	**128**	**179.2**	**320**	**134.4**	**364.8**	**224**
Macoma mitchelli	0	51.2	38.4	64	32	19.2	44.8
Rangia cuneata	**0**	**57.6**	**38.4**	**25.6**	**64**	**12.8**	**25.6**
Ischadium recurvum	32	0	0	0	0	0	0
Mytilopsis leucophaeata	691.2	12.8	0	0	32	0	0
Amphicteis floridus	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0
Heteromastus filiformis	12.8	230.4	51.2	64	160	76.8	198.4
Spionidae	0	0	0	0	0	0	0
Marenzelleria viridis	**0**	**12.8**	**32**	**32**	**0**	**19.2**	**64**
Streblospio benedicti	179.2	38.4	76.8	25.6	96	6.4	83.2
Polydora cornuta	134.4	0	0	0	0	0	0
Boccardiella ligerica	12.8	0	0	0	0	0	0
Nereidae	0	0	0	0	0	6.4	0
Neanthes succinea	524.8	108.8	0	0	38.4	6.4	6.4
Eteone heteropoda	32	6.4	0	12.8	6.4	12.8	25.6
Naididae sp.	89.6	166.4	358.4	755.2	403.2	403.2	396.8
Amphipoda	0	0	0	0	0	0	0
Gammaridea	0	0	0	0	0	6.4	0

Table 2-6: Average number of individuals collected per square meter at each station during HMI Year 34, stations MDE-1 to MDE-22. Taxa in bold are pollution sensitive and taxa highlighted in gray are pollution indicative for the low mesohaline conditions found in Year 34.

	Station						
Taxon	MDE-01	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Nemata	6.4	0	89.6	352	38.4	1158.4	6.4
Carinoma tremaphoros	0	102.4	32	44.8	38.4	32	76.8
Bivalvia	0	0	0	0	0	0	0
Macoma sp.	12.8	153.6	19.2	0	19.2	0	38.4
Macoma balthica	**0**	**128**	**179.2**	**320**	**134.4**	**364.8**	**224**
Macoma mitchelli	0	51.2	38.4	64	32	19.2	44.8
Rangia cuneata	**0**	**57.6**	**38.4**	**25.6**	**64**	**12.8**	**25.6**
Ischadium recurvum	32	0	0	0	0	0	0
Mytilopsis leucophaeata	691.2	12.8	0	0	32	0	0
Amphicteis floridus	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0
Heteromastus filiformis	12.8	230.4	51.2	64	160	76.8	198.4
Spionidae	0	0	0	0	0	0	0
Marenzelleria viridis	**0**	**12.8**	**32**	**32**	**0**	**19.2**	**64**
Streblospio benedicti	179.2	38.4	76.8	25.6	96	6.4	83.2
Polydora cornuta	134.4	0	0	0	0	0	0
Boccardiella ligerica	12.8	0	0	0	0	0	0
Nereidae	0	0	0	0	0	6.4	0
Neanthes succinea	524.8	108.8	0	0	38.4	6.4	6.4
Eteone heteropoda	32	6.4	0	12.8	6.4	12.8	25.6
Naididae sp.	89.6	166.4	358.4	755.2	403.2	403.2	396.8
Amphipoda	0	0	0	0	0	0	0
Gammaridea	0	0	0	0	0	6.4	0

– (continued)

Station

Taxon	MDE-01	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Ameroculodes spp complex	0	19.2	25.6	0	0	6.4	12.8
Leptocheirus plumulosus	0	6.4	38.4	76.8	51.2	166.4	70.4
Gammarus sp.	0	0	0	0	0	0	0
Melitadae	0	0	0	0	0	0	0
Melita nitida	89.6	0	0	0	0	0	6.4
Corophiidae	0	0	0	0	0	0	0
Apocorophium lacustre	0	0	0	0	0	0	0
Cyathura polita	**0**	**352**	**192**	**364.8**	**204.8**	**294.4**	**384**
Edotea triloba	0	0	0	0	0	0	6.4
Chiridotea almyra	0	0	0	0	0	0	0
Ciripedia	0	0	0	0	0	0	0
Balanus improvisus	300.8	38.4	0	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0
Rhithropanopeus harrisii	166.4	0	6.4	0	6.4	0	0
Membranipora sp	+	+	+	0	+	0	+
Chironomidae	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	6.4	6.4	0	6.4	6.4
Anthozoa	64	6.4	0	6.4	0	0	0
Mulinia lateralis	0	12.8	12.8	0	12.8	6.4	25.6
Glycinde solitaria	**0**	**6.4**	**0**	**0**	**0**	**0**	**0**
Gobiosoma bosci	0	0	0	0	0	0	0
Platyhelminthes	0	0	0	0	0	0	0
Nudibranchia	0	0	0	0	0	0	0
Mysidacea	0	0	0	0	0	6.4	0
Copepoda	0	0	0	0	0	0	0
Hydrozoa	6.4	0	0	0	0	0	0

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

Table 2-7: Average number of individuals collected per square meter at each station during the HMI Year 34, stations MDE-27 to MDE-51. Taxa in bold are pollution sensitive and taxa highlighted in gray are pollution indicative for the low mesohaline conditions found in Year 34.

Station								
Taxon	MDE-27	MDE-30	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45
Nemata	192	697.6	25.6	352	307.2	51.2	409.6	972.8
Carinoma tremaphoros	0	6.4	6.4	6.4	102.4	64	57.6	51.2
Bivalvia	6.4	0	0	0	0	0	6.4	0
Macoma sp.	0	0	44.8	76.8	6.4	76.8	0	12.8
Macoma balthica	**12.8**	**19.2**	**12.8**	**12.8**	**256**	**224**	**268.8**	**761.6**
Macoma mitchelli	57.6	6.4	19.2	25.6	44.8	51.2	19.2	76.8
Rangia cuneata	**51.2**	**6.4**	**89.6**	**108.8**	**19.2**	**32**	**12.8**	**25.6**
Ischadium recurvum	0	0	6.4	0	0	0	0	0
Mytilopsis leucophaeata	6.4	0	2675.2	160	6.4	6.4	0	0
Amphicteis floridus	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0
Heteromastus filiformis	89.6	32	128	57.6	83.2	89.6	70.4	32
Spionidae	0	0	0	0	0	0	0	0
Marenzelleria viridis	**57.6**	**32**	**19.2**	**25.6**	**19.2**	**6.4**	**19.2**	**51.2**
Streblospio benedicti	524.8	121.6	499.2	198.4	19.2	32	115.2	76.8
Polydora cornuta	0	0	128	0	0	0	0	0
Boccardiella ligerica	0	0	12.8	0	0	0	0	0
Nereidae	6.4	0	0	0	0	0	0	0
Neanthes succinea	25.6	0	1548.8	179.2	0	0	0	0
Eteone heteropoda	89.6	0	179.2	64	6.4	6.4	19.2	6.4
Naididae sp.	659.2	256	8889.6	563.2	320	659.2	4838.4	4748.8
Amphipoda	0	6.4	0	0	6.4	6.4	0	0
Gammaridea	0	6.4	0	0	0	0	0	0

Table 2-7: Average number of individuals collected per square meter at each station during the HMI Year 34, stations MDE-27 to MDE-51. Taxa in bold are pollution sensitive and taxa highlighted in gray are pollution indicative for the low mesohaline conditions found in Year 34.

	Station							
Taxon	MDE-27	MDE-30	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45
Nemata	192	697.6	25.6	352	307.2	51.2	409.6	972.8
Carinoma tremaphoros	0	6.4	6.4	6.4	102.4	64	57.6	51.2
Bivalvia	6.4	0	0	0	0	0	6.4	0
Macoma sp.	0	0	44.8	76.8	6.4	76.8	0	12.8
Macoma balthica	**12.8**	**19.2**	**12.8**	**12.8**	**256**	**224**	**268.8**	**761.6**
Macoma mitchelli	57.6	6.4	19.2	25.6	44.8	51.2	19.2	76.8
Rangia cuneata	**51.2**	**6.4**	**89.6**	**108.8**	**19.2**	**32**	**12.8**	**25.6**
Ischadium recurvum	0	0	6.4	0	0	0	0	0
Mytilopsis leucophaeata	6.4	0	2675.2	160	6.4	6.4	0	0
Amphicteis floridus	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0
Heteromastus filiformis	89.6	32	128	57.6	83.2	89.6	70.4	32
Spionidae	0	0	0	0	0	0	0	0
Marenzelleria viridis	**57.6**	**32**	**19.2**	**25.6**	**19.2**	**6.4**	**19.2**	**51.2**
Streblospio benedicti	524.8	121.6	499.2	198.4	19.2	32	115.2	76.8
Polydora cornuta	0	0	128	0	0	0	0	0
Boccardiella ligerica	0	0	12.8	0	0	0	0	0
Nereidae	6.4	0	0	0	0	0	0	0
Neanthes succinea	25.6	0	1548.8	179.2	0	0	0	0
Eteone heteropoda	89.6	0	179.2	64	6.4	6.4	19.2	6.4
Naididae sp.	659.2	256	8889.6	563.2	320	659.2	4838.4	4748.8
Amphipoda	0	6.4	0	0	6.4	6.4	0	0
Gammaridea	0	6.4	0	0	0	0	0	0

– (continued)

	Station							
Taxon	MDE-27	MDE-30	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45
Ameroculodes spp complex	0	0	0	32	25.6	6.4	0	0
Leptocheirus plumulosus	275.2	531.2	0	0	204.8	96	115.2	38.4
Gammarus sp.	0	0	0	0	0	0	0	0
Melitadae	0	0	0	0	0	0	0	0
Melita nitida	0	89.6	83.2	0	12.8	0	12.8	12.8
Corophiidae	0	0	0	0	0	0	0	0
Apocorophium lacustre	0	0	19.2	6.4	0	6.4	0	0
Cyathura polita	**531.2**	**32**	**19.2**	**160**	**364.8**	**256**	**249.6**	**262.4**
Edotea triloba	0	0	0	12.8	0	0	0	0
Chiridotea almyra	0	0	0	0	0	0	0	0
Ciripedia	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	0	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	0	147.2	19.2	0	0	0	0
Membranipora sp	+	0	+	0	0	+	0	0
Chironomidae	0	0	0	0	0	0	0	0
Coelotanypus sp.	6.4	76.8	0	0	12.8	6.4	6.4	6.4
Anthozoa	0	0	0	0	0	0	0	0
Mulinia lateralis	0	6.4	0	0	12.8	38.4	6.4	0
Glycinde solitaria	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gobiosoma bosci	0	0	0	0	0	0	0	0
Platyhelminthes	0	0	0	0	0	0	0	0
Nudibranchia	0	0	0	0	0	0	0	0
Mysidacea	6.4	0	0	0	12.8	0	6.4	6.4
Copepoda	0	0	0	0	0	0	0	0
Hydrozoa	0	0	0	6.4	0	0	0	6.4

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

Infaunal Taxa Abundance

In Year 34, total infaunal abundance at the various stations ranged from 985.60 to 11,552.00 organisms per square meter (individuals/m^2) and averaged 2,724.69 individuals/m^2 Table 0-(Table 2-8). The highest abundance was found at the Nearfield station MDE-34, due primarily to large numbers of oligochaete worms of the family Naididae and the polycheate worm *N. succinea*. The lowest infaunal abundance was found at the Nearfield station MDE-01 (Table 2-8). MDE-01 has unique habitat because it has the highest percentage of oyster shell of all stations. The substrate supports a community that is different from other HMI stations. The white fingered mud crab, *R. harrisii*, barnacles, bryozoans, and the attached bivalves *I. recurvum* and *M. leucophaeta* are all more typical at MDE-01 and relatively uncommon or non-existent elsewhere. The presence of shell makes collecting consistent sample volumes difficult. This station historically has some of the most volatile average abundances implying that sampling error may account for some of the low abundance. This station is also very close to the HMI exterior dike and the closest to Spillway 007.

The average total infaunal abundance was highest at Nearfield stations (3,459.00 individuals/m^2), followed by South Cell Exterior Monitoring stations (2,948.27 individuals/m^2), Back River/Hawk Cove stations (1,721.60 individuals/m^2), and Reference stations (1,457.07 individuals/m^2). This represents an above average total abundance (from good to fair abundance of organisms) for Nearfield and South Cell Exterior Monitoring stations and a shift into good abundances at Back River/Hawk Cove stations. There was a small drop in mean abundances at Reference stations from the good range toward fair abundance.

The 34-year mean (4,617.07 individuals/m^2) of fall abundance for the Back River stations is much higher than the Nearfield (2,235.07 individuals/ m^2), and Reference (1,972.80 individuals/m^2) means. It is also higher than the twelve-year average for South Cell Exterior Monitoring stations (1,719.27 individuals/m^2). For the prevailing salinity regime, the ideal range for the Total Abundance metric is between 1,500 and 2,500 individuals/m^2.

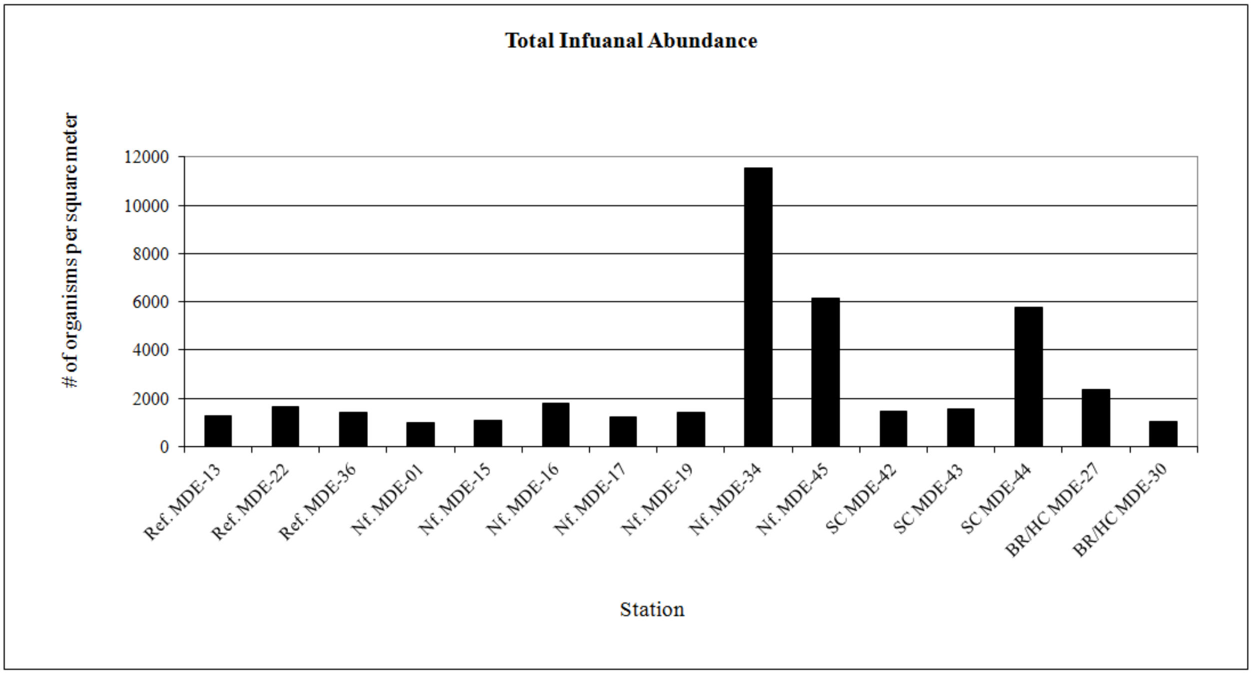

Figure 2-2: Total abundance of infaunal taxa collected at each HMI station in Year 34, September 2016 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

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 34, total infaunal abundance was similar to total abundance, typically accounting for ≥85 percent of all organisms at all stations, except MDE-01 (43%) and MDE-34 (80%). This ratio is historically typical for this project.

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. Diversity values for Year 34 are presented in Table 2-8 and 2-9.

SWDI values in Year 34 averaged 2.38± 0.69 in September 2016. The fall average diversity was higher than the 18-year mean fall SWDI of 2.26. The lowest SWDI value occurred at South Cell Exterior Monitoring station MDE-44 (1.10, Figure 2-3). This was due to the large percentage of oligochaete worms of the family Naididae, which accounted for 84 percent of total infaunal abundance at this station. The highest diversity value (3.12) occurred at Reference station MDE-13.

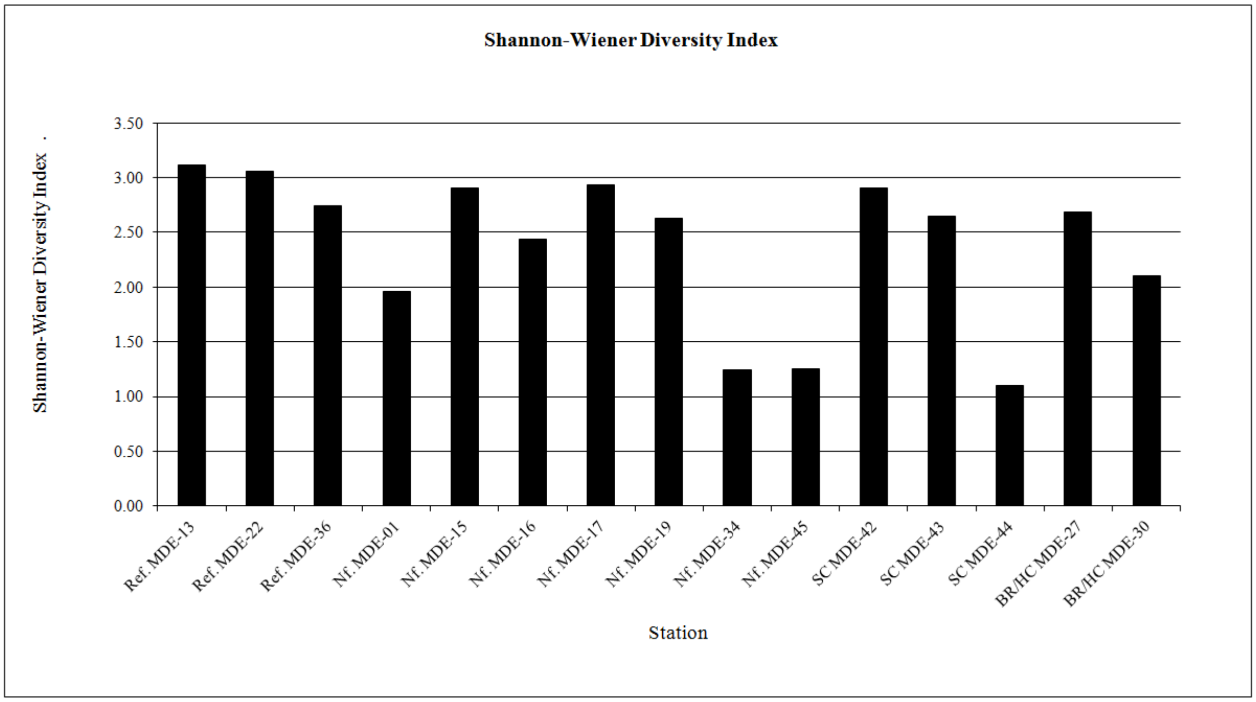

Figure 2-3: Shannon-Wiener Diversity Index (SWDI), HMI Year 34, September 2016 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell; BR/HC = Back River Hawk Cove).

On average, Nearfield, South Cell Exterior Monitoring, and Back River/Hawk Cove stations had diversity values below Reference stations. Comparing station types, the lowest average SWDI was 2.19 at the Nearfield stations followed by the South Cell Exterior Monitoring stations at 2.22, and Back River/Hawk Cove stations at 2.39. The highest average SWDI occurred at the Reference stations at 2.97 (Table 2-8). Historically, the 28-year mean SWDI values, ranked from lowest to highest, are associated with the following station types: Back River/Hawk Cove (2.10), Nearfield (2.30), South Cell Exterior Monitoring (2.39, n=12 yrs), and Reference (2.40). This represents a worse than average condition for Nearfield and South Cell Exterior Monitoring stations, and improvements in diversity at Back River/Hawk Cove and Reference stations.

Pollution Sensitive Taxa Abundance (PSTA)

Five taxa found during Year 34 were designated as "pollution-sensitive" according to Alden et al. (2002). These were the polychaete worms *M. viridis* and *G. solitaria*, 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, in part, salinity driven, and salinity varies from year to year, salinity must be accounted for prior to some historical analyses of PSTA fall data. In Year 34, the fall salinity regime was low mesohaline.

Pollution sensitive taxa occurred at all station types. PSTA ranged from 0.00 percent at MDE-01 (Nearfield station) to 48.00 percent at MDE-19 (Nearfield station – Table 2-8; Figure 2-4). The average PSTA for all stations was 27.46 percent. Comparing station types, the lowest average PSTA was 17.93 percent at the Back River/Hawk Cove stations, followed by the Nearfield stations at 26.04 percent, followed by the South Cell Exterior Monitoring stations at 28.99 percent. The highest average PSTA was 35.62 percent at Reference stations. Historically, the 34-year mean fall PSTA values, ranked from lowest to highest, are associated with the following station types: South Cell Exterior Monitoring (24.34 percent, n=11 years), Back River/Hawk Cove (28.28 percent), Nearfield (36.05 percent), and Reference (39.83 percent).

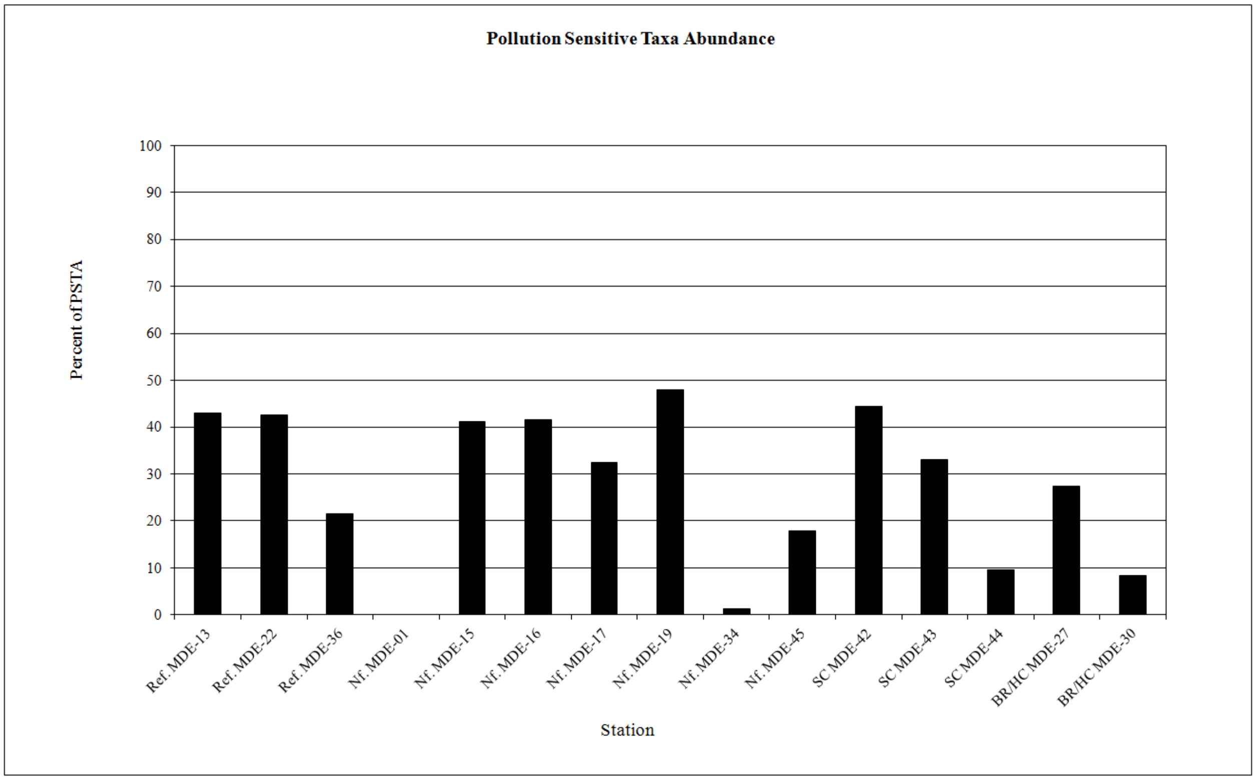

Figure 2-4: Percent abundance comprised of pollution sensitive species (PSTA), HMI Year 34 September 2016 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

Pollution Indicative Taxa Abundance (PITA)

Five taxa found during the Year 34 benthic monitoring were designated as "pollution-indicative" according to Alden et al. (2002): the Chironomid *Coelotanypus* sp., the polychaete worms *S. benedicti* and *E. heteropoda,* oligochaete worms of the family Naididae, and the bivalve *M. lateralis*. The calculation of the PITA is a ratio of the relative PITA abundance to total infaunal abundance.

Pollution indicative taxa occurred at all station types. The PITA ranged from 17.24 percent at MDE-13 (Reference station) to 86.08 percent at MDE-44 (South Cell Exterior Monitoring station) (Table 2-8; Figure 2-5). The average PITA for all stations was 47.37 percent. Comparing station types, the lowest average PITA was 35.88 percent at the Reference stations, followed by 48.57 percent at the Back River/Hawk Cove stations, and 50.19 percent at Nearfield stations. The highest average PITA occurred at the South Cell Exterior Monitoring stations at 52.81 percent. Historically, the 34-year mean fall PITA values, ranked lowest to highest, are associated with the following station types: Reference (23.59 percent), Nearfield (27.10 percent), South Cell Exterior Monitoring (39.73 percent, n = 12 years), and Back River/Hawk Cove (39.75 percent).

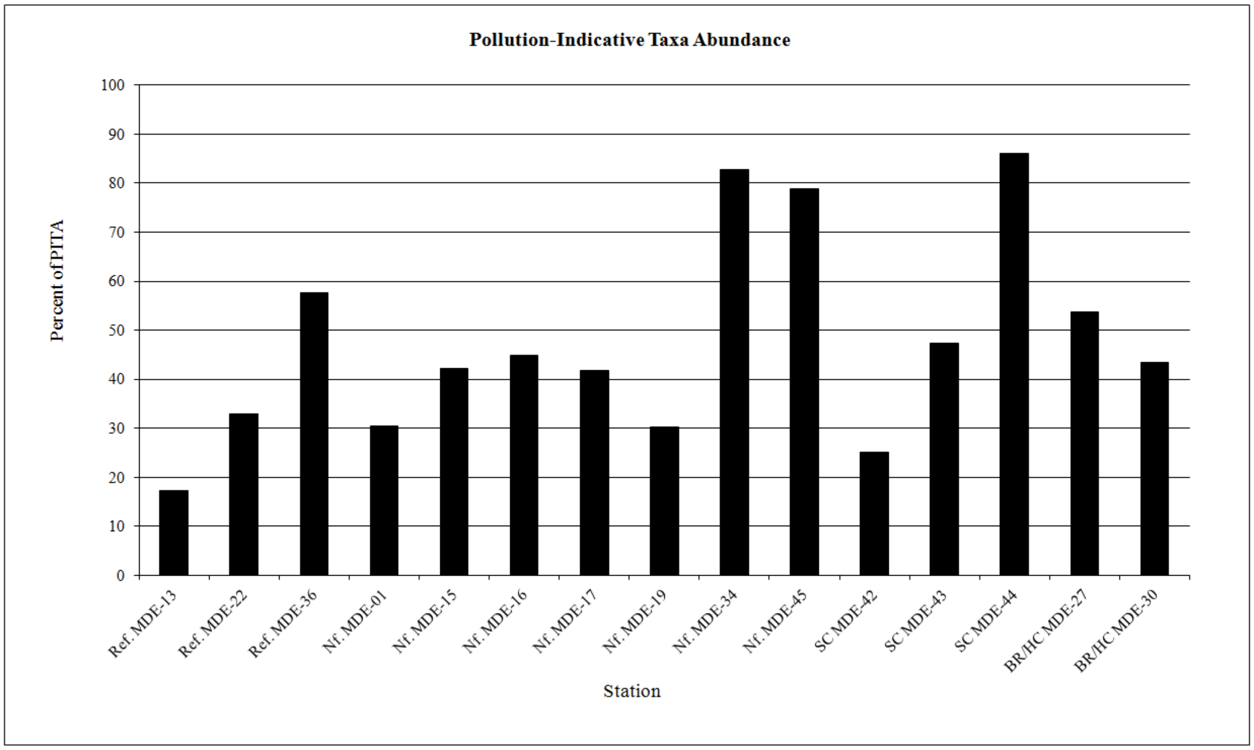

Figure 2-5: Percent abundance comprised of pollution indicative species (PITA), HMI Year 34 September 2016 grouped by station type (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

Benthic Index of Biotic Integrity

The B-IBI was calculated for all stations (see *Methods and Materials*). Four metrics were used to calculate the B-IBI for stations under the low mesohaline classification (5 - 12 ppt). These metrics were total infaunal abundance, relative abundance of pollution-indicative taxa, relative abundance of pollution-sensitive taxa, and Shannon-Wiener diversity index. 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 15 benthic stations studied during Year 34 were compared to this benchmark.

Table 2-8: Low mesohaline scoring criteria for measures used in calculating the Chesapeake Bay B-IBI in September 2016 (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	≥25%	5-25%	<5%
Shannon-Wiener Diversity Index	≥ 2.5	1.7-2.5	< 1.7

Compared to Year 33, individual station B-IBI Scores increased at 9 stations, remained the same at 2, and decreased at 4 stations. Ten of the fifteen stations met or exceeded the benchmark criteria of 3.0 in Year 34. In Year 34, the following stations failed to meet the benchmark criteria of 3.0 (Table 2-8, Figure 2-6): Back River/Hawk Cove station MDE-30 (2.50), Nearfield Stations MDE-01 (2.00), MDE-34 (1.00), and MDE-45 (1.50), and South Cell Exterior Monitoring station MDE-44 (2.00). Nine stations were above their historic averages and six stations were below the historic averages for B-IBI. In addition to six stations being below their historic average three set a new historic low (Nearfield stations MDE-34 and MDE-45, and South Cell Exterior Monitoring station MDE-44). One station set a new historic high (Back River/Hawk Cove station MDE-27).

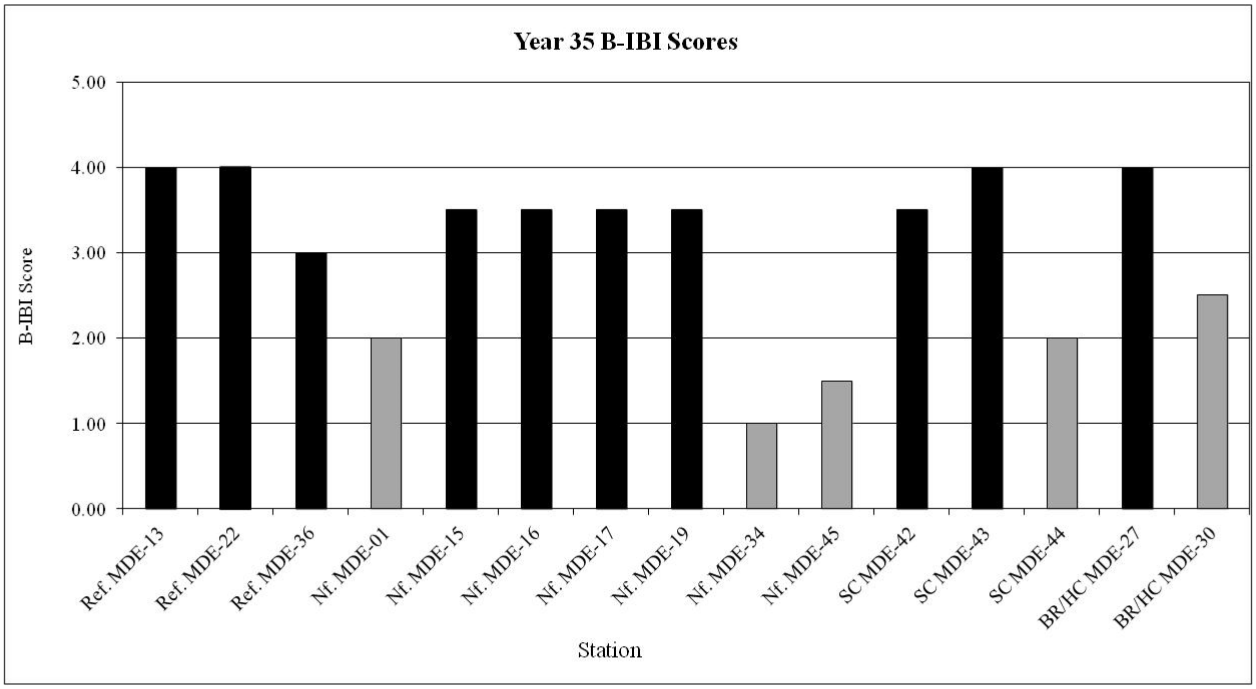

Figure 2-6: B-IBI Scores for all stations in September 2016 grouped by station type (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

The mean B-IBI for Nearfield stations failed to meet the benchmark of 3.0. Average B-IBI scores by station type are shown in Figure 2-7. Compared to Year 33, the mean B-IBI increased for Nearfield, Reference, and Back River/Hawk Cove stations, while South Cell Exterior Monitoring stations remained the same. The Year 34 mean B-IBI's for Nearfield and South Cell Exterior Monitoring station types were below their historic averages (twelve year average for South Cell Exterior Monitoring Stations, Table 2-8).

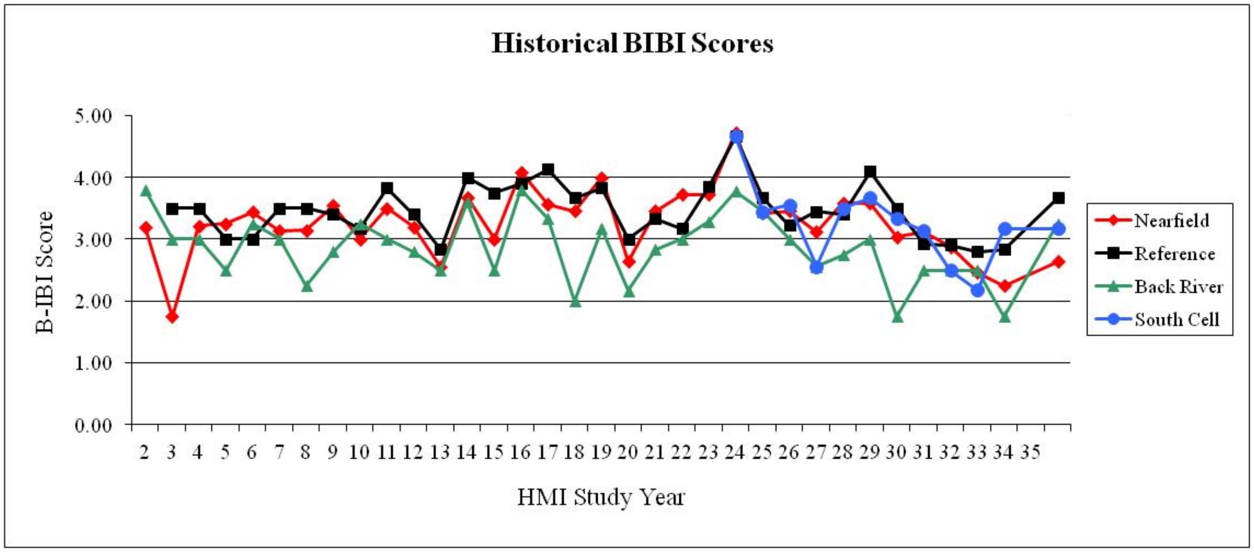

Figure 2-7: Average B-IBI Scores by station type at HMI for Monitoring Years 1-35.

There was a trend of deceasing B-IBI scores associated with closeness to HMI in Year 34. Compared to other station types, Nearfield stations had the lowest mean IBI's in Year 34. Nearfield stations were also the only station type to have an average B-IBI score that failed to meet the benchmark score of 3.0. Back River/Hawk Cove stations have had the lowest average in 27 of the 34 years; however, in Year 34 they had the second highest average B-IBI Score.

In Year 33 low B-IBI's were attributable to several variations in the invertebrate community. Dropping and historically low B-IBI's had been observed for the previous five years throughout the HMI Region. In Year 34 this trend was not seen and B-IBI scores increased across all station types.

Total infaunal abundances have been and are exceptionally high at stations that fail to meet the benchmark score of 3.0. This metric is graded highest when abundances are in a certain range (1,500-2,500 organisms/m2). When abundances are either too low or too high the metric value falls. Over the last four years, abundances are approximately three times higher than ideal at failing stations. These high abundances depressed the total infaunal abundance metric and adversely affect the other metrics as well (because the increased abundances are largely due to sharp increases in pollution indicative oligochaete worms in the family Naididae).

The Pollution Sensitive Taxa Abundance (PSTA) metric has been low over the last six years as well. PSTA taxa were found in higher abundances during Year 34 than in the previous five years, but were still not high enough to get an ideal score. This is due to both dilution of sensitive taxa by the overall high total infaunal abundances, and a decrease in some sensitive taxa. The high abundances for taxa which are not sensitive result in the sensitive taxa percentage dropping even if the numbers of sensitive organisms are unchanged. Combined with the dilution of sensitive taxa by high overall abundances, the numbers of the polycheate worm, *M. viridis* (a sensitive taxon) decreased to about a tenth their historic mean during Year 34.

The Pollution Indicative Taxa Abundance (PITA) metric has been low over the last five years as well. Unlike for PSTA, many of the organisms that contributed to the elevated Total Infaunal abundances are also pollution indicative, so there has been little or no dilution effect on PITA. Increased numbers of the polychaete worm, *S. benedicti* (a pollution indicative taxon) have been a major driver for the drop in this metric and the other three metrics. Increased abundances of oligochaete worms in the family Naididae (pollution indicative taxa) have had an even larger negative effect.

The Shannon-Weiner Diversity Index (SWDI) scores had also been very low over the past five years. This is caused when the diversity of infaunal species is overwhelmed by the dominance of one or two species unbalancing the benthic community. In Year 34 SWDI scores increased at ten of the fifteen stations helping to improve overall B-IBI scores. The five stations that failed to meet the benchmark of 3.0 all had low SWDI scores caused by increases of oligochaete worms in the family Naididae.

Based on B-IBI's, Year 34 reversed a five-year general trend of declining health. Year 33 was among the poorest years since HMI monitoring was begun. While Nearfield stations had shown a four or five year declining trend in B-IBI and are now starting to improve., four of the five stations that still failed to meet the benchmark of 3.0 are located nearest to outflow structures. While B-IBI's at most stations showed improvements, the mean B-IBI's at Nearfield stations MDE-34, MDE-45, and South Cell Exterior Monitoring station MDE-44 (all stations near outflow structures) set new historic lows.

Clam Length Frequency Distribution

In September 2016, 89 *R. cuneata* were collected. The greatest average abundance of *R. cuneata* occurred at the Nearfield stations (40.00 clams/station), followed by the Reference stations (30.00 clams/station), the South Cell Exterior Monitoring stations (10.00 clams/station), and the Back River/Hawk Cove stations (9.00 clams/station). The greatest abundance of *R. cuneata* was found in the 26-30 mm size class.

Historically, *R. cuneata* tends to be the most abundant bivalve mollusk found in this benthic monitoring project. It is classified as pollution sensitive during mesohaline 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. The reduction in *Rangia* abundance from Year 30 (78.7 clams/station) to Year 31 (3.5 clams/station) (95.6 %) was greater than the typical winter die-off which usually ranges between 5 and 68%. In Years 32 and 33 we recorded the beginning of a recovery of the population (an increase to 10.6 clams/station and 31.1 clams/station, respectively). Another large scale winter die-off occurred in Year 34, where 5.9 clams/station were found (ranging from small to large size classes). In Maryland, *R. cuneata* rarely if ever reaches its reported maximum age (15-20 years) or size (79 mm). Looking at 18 years of frequency distribution data around HMI, it is difficult to identify more than four age classes of clams at any time. This implies very few clams survive longer than five years.

In Year 34, 447 *M. balthica* were collected with 268 coming from Nearfield stations, 117 from South Cell Exterior Monitoring stations, 57 from Reference stations, and 5 from Back River/Hawk Cove stations. The greatest abundance of *M. balthica* was found in the 11-12 mm size class.

M. balthica has been commonly observed in low to moderate abundances throughout this benthic monitoring project. It is classified as pollution sensitive during mesohaline years ($\geq$ 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. Nineteen years of monitoring data indicates that strong freshets are responsible for causing wide population fluctuations. After high mortality occurred during a strong freshet in Year 23 the population gradually recovered to previous densities only after the upper bay become more salty during Year 29. Another freshet-induced mortality was documented in 2011(Year 30) as MDE confirmed a major die-off in the northern part of the bay, in late June, as a result of low salinity. Following that event, no *M. balthica* were found in the fall of Year 31. In Years 32 and 33, we recorded the beginning of a recovery of this population, although it is still low in abundance. In Year 34, we are seeing numbers indicative of a full recovery to historical numbers found over the course of this project, mainly due to salinity being in the mesohaline range for a prolonged period of time.

In Year 34, 83 *M. mitchelli* were collected, with 39 coming from Nearfield stations, 19 from Reference stations, 18 from South Cell Exterior Monitoring stations, and 7 from Back River/Hawk Cove stations. The greatest abundance of *M. mitchelli* was found in the 11-12 mm size class. Similar to *M. balthica*, *M. mitchelli* populations declined in the spring of Year 22 and remained depressed for several years. Based on 18 years of historical HMI frequency distribution data, a strong freshet in Year 23 caused high mortality in this species; however, by Year 29 it appeared to have recovered to previous densities. The freshet of spring 2011 induced another mass mortality and the population has recovered. Population density of *M. mitchelli* is naturally lower than *M. balthica* in the HMI Region.

MULTIVARIATE AND FRIEDMAN'S ANALYSES

Multivariate Analysis

Multivariate cluster analysis was applied to Year 34 station invertebrate abundances to examine the patterns of variability among the HMI stations. Multivariate methods are used to make sense of large, complex data sets where several variables (for HMI, the invertebrate taxa abundances) are measured at each sampling location (the 15 HMI stations). In general, the purpose of multivariate methods is to simplify the complex data and identify patterns (Johnson, 1998a). Specifically, the cluster procedure was applied to the HMI data to identify groups of stations with similar benthic invertebrate assemblages.

The multivariate clustering procedure has been conducted twenty-nine times since Year 12. The cluster tree figure is used to identify station groups with invertebrate communities of varying similarities. Although there has been recurring pairings of stations in identified groups from year to year, the over-riding pattern is high variability of station groupings between years. A more consistent year to year pattern had been the identification of outlier stations, stations with invertebrate communities that do not group well with any other stations. Three stations have consistently been identified as outliers: MDE-27 (eighteen times since Year 19), MDE-01 (twelve times since Year 19) and MDE-34 (eight times since Year 19).

The cluster dendrogram for September 2016 showed a clear articulation of several HMI station clusters (Figure 2-8). R^2, the coefficient of determination, was used to evaluate the strength of station clusters. R^2 is the percentage of variation in the benthic assemblages that is "explained" by the cluster model. Four station clusters were apparent at $R^2 > 0.90$, indicating high similarity in their benthic invertebrate assemblages. Stations MDE-16 and MDE-43 were connected into a group at $R^2 = 0.97$ and were joined to stations MDE-15 and MDE-42 at an $R^2 = 0.96$. These four stations were identified as Cluster Group 1. Cluster Group 2, consisting of two stations (MDE-19 and MDE-44), was fully formed at an $R^2 = 0.94$. Cluster Group 3 consisted of the pair of stations MDE-13 and MDE-17, which connected at an $R^2 = 0.93$. In addition to the strong within-group linkage for each of these three groups, they also demonstrated moderately high between-group linkage, as Cluster Group 1 and Cluster Group 2 linked at R2 = 0.90 and all three station groups were linked at $R^2 = 0.86$. The cluster dendrogram indicated that stations MDE-01, MDE-30 and MDE-34 were strong outliers with weak linkage to the other stations ($R^2 \leq 0.50$), indicating that the benthic invertebrate assemblage at these stations were unique and dissimilar from the benthic communities at the other stations. The remaining four stations, MDE-22, MDE-45, MDE-27 and MDE-36, were identified as weak outliers or intermediate stations because their R^2 values were less than 0.85 but greater than a R^2 of 0.60. Their benthic invertebrate communities have some similarities to communities of the identified station cluster groups and also have variant components to their benthic communities that prevent these stations from being characterized as either belonging to a cluster group or being identified as strong outlier stations.

The September 2016 cluster dendrogram results viewed in context with the B-IBI results presented earlier (see section "Benthic Index of Biotic Integrity"), indicate that stations of Cluster Group 1 (MDE-15, MDE-16, MDE-42 and MDE-43) and Cluster Group 3 (MDE-13 and MDE-17) had unstressed benthic invertebrate assemblages (all stations with B-IBI $\geq$ 3.50). The strong outlier stations MDE-01, MDE-30 and MDE-34 were identified by the B-IBI as having stressed benthic invertebrate assemblages. The repeated identification of stations MDE-01, MDE-30 and MDE-34 as having different benthic invertebrate assemblages distinct from stations to the east of HMI (Cluster Group 1, 2 and 3 stations) indicates that the hydrologic and sediment dynamics that affect these communities on the west and north side of HMI are unique and detached from conditions occurring at the benthic communities of stations on the east side of HMI. Likewise, the repeated indication by the B-IBI in recent years that stations MDE-01 and MDE-34 have stressed benthic communities indicates that the unique hydrologic and sediment dynamics occurring there are having regular adverse biological impacts.

As in previous years, the relationship between identified cluster groups and station type (Nearfield, Reference, Back River and South Cell) was poor. Likewise, bottom type correlated poorly with identified cluster groups because of the prevalence of silt/clay bottom in the HMI area.

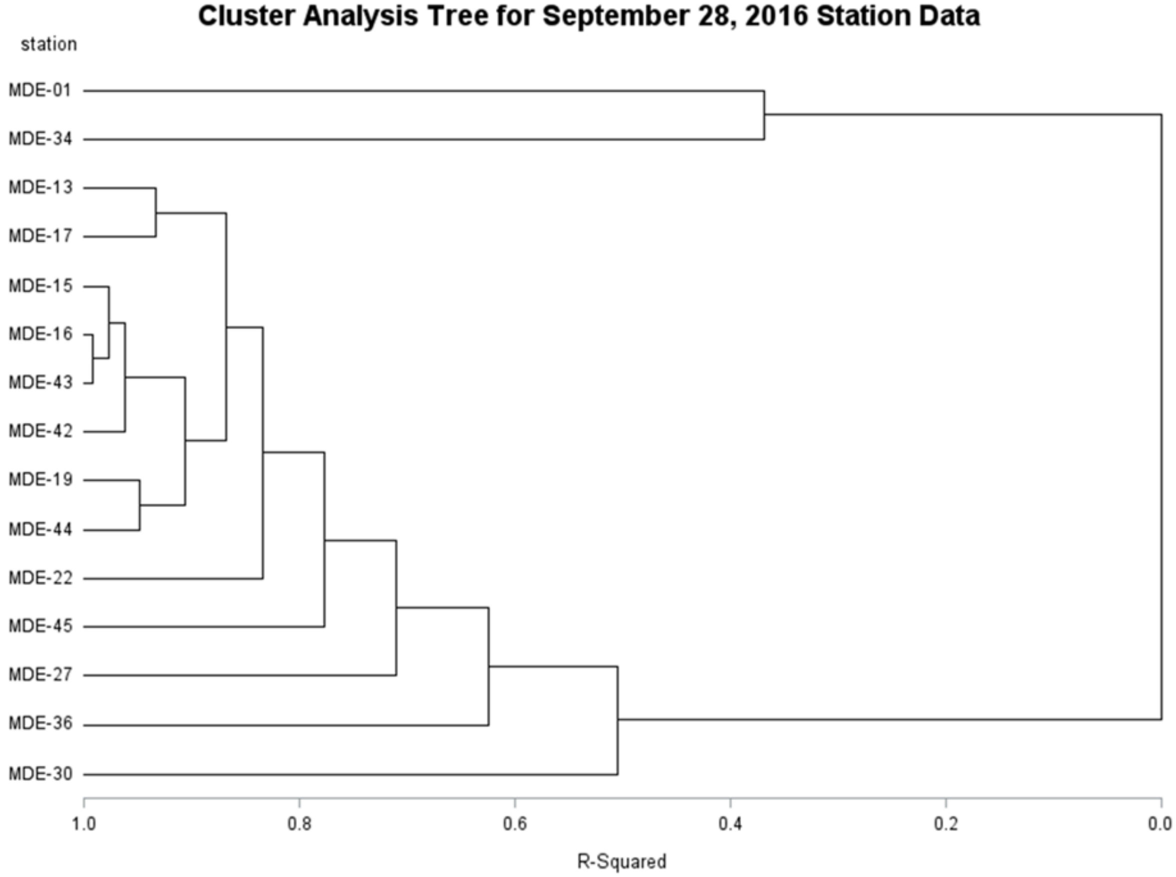

Figure 2-8: September 2016 Cluster Analysis tree.

Average distance between stations in Cluster Group 1 (4,647 ft) and between pairs of stations in Cluster Group 2 (2,117 ft), and Cluster Group 3 (4,855 ft) were less than the overall average distance between all stations (11,481 ft), indicating that spatial proximity was an influencing factor in group formation. Spatial proximity was also an important factor influencing the benthic community similarities among the three cluster groups (average distance between all stations of Cluster Group 1, 2, and 3 = 4,486 ft).

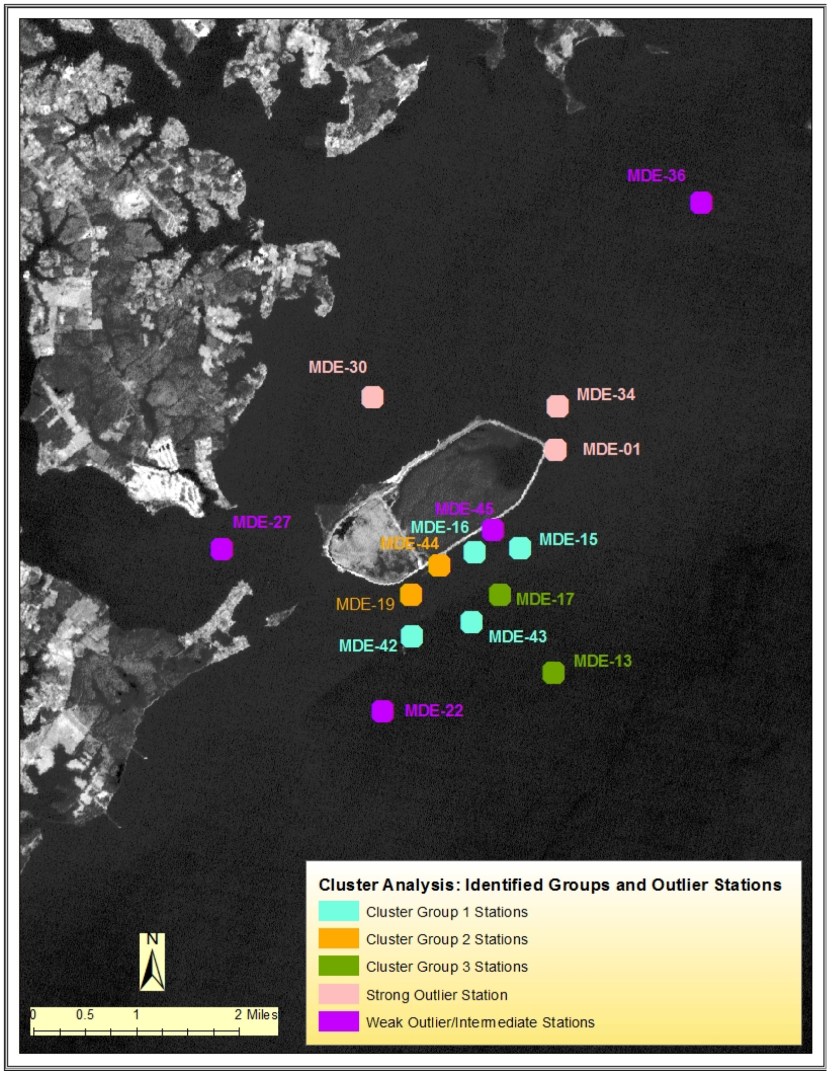

Figure 2-9: Identified Cluster Groups, Strong Outlier and Weak Outliers/Intermediate Areas for September 2016

Color-coding of identified cluster groups 1 - 3, the strong outlier stations MDE-01, MDE-30 and MDE-34, and the four weak outlier/intermediate stations MDE-22, MDE-27, MDE-36 and MDE-45 (neither strong grouping characteristics nor strong outlier characteristics) are shown in Figure 2-9.

Friedman's Analysis

As in past years, Friedman's nonparametric ANOVA test was applied to Year 34 benthic macroinvertebrate data. The Friedman's nonparametric test determines if significant differences in the top ten most abundant invertebrate taxa occur between station types. For Year 34 the Friedman's test was run on the conventional four station groups – Reference, Nearfield, South Cell Exterior Monitoring, and Back River.

Friedman test results (Tables 2-16 and 2-17) indicated no significant differences in the ten most abundant infaunal taxa between the four station types in September 2016 (P = 0.564). Significant Friedman results occur infrequently (only 8 times since Year 19), usually because of high station to station variability of taxa abundances, both among and within station groups. In addition, the relative close proximity of the Nearfield, South Cell and Reference stations on the east side of the island contributes to preventing significant differences between the station types because these stations tend to be influenced by similar hydrologic conditions.

Table 2-9: Friedman Analysis of Variance for September 2016's 10 most abundant species among: Back River/Hawk Cove, Nearfield, South Cell Exterior Monitoring, and Reference stations. ANOVA Chi-Square. (N = 10, df = 3) = 2.04, p = 0.564.

Station Type	Average Rank	Mean	Std. Dev.
Nearfield	3.00	414	657
Reference	2.40	153	129
Back River	2.30	299	583
South Cell	2.30	198	198

CONCLUSIONS

In Year 34, the benthic macroinvertebrate community was examined in the fall only and at a reduced number of stations compared to previous years. The salinity regime remained in its historical average range. As usual, little stratification of water quality was evident during the sampling cruise. Dissolved oxygen at all stations exceeded the state standard of 5.0 ppm deemed necessary to support healthy aquatic communities. Dissolved oxygen, pH, and turbidity were near historic means in Year 34. Temperature was slightly lower than the historical mean. Salinity was slightly higher than the historical mean. None of the differences from the mean were statistically significant. The B-IBI was calculated for all stations using four metrics applicable to the low mesohaline classification (5 - 12 ppt). The B-IBI's and derivative metrics were compared to historical data and analyzed both spacially and statistically.

The health of the benthic macroinvertebrate community around HMI generally improved after five consecutive years of decline. Only Nearfield Monitoring stations are trending worse than historical averages. Ten of the 15 stations met the benchmark B-IBI criteria of 3.00. Nine stations were above their historic averages and six stations were below the historic averages for B-IBI. Three stations set new historic lows and one station set a new historic high.

The mean B-IBI for Nearfield stations failed to meet the benchmark of 3.0. The mean B-IBI increased for Nearfield, Reference, and Back River/Hawk Cove stations, while South Cell Exterior Monitoring stations remained the same. The Year 34 mean B-IBI's for Nearfield and South Cell Exterior Monitoring station types were below their historic averages. There was a trend of deceasing B-IBI scores associated with closeness to HMI in Year 34 as Nearfield stations had the lowest mean IBI's in Year 34. Reference and Back River/Hawk Cove stations showed the greatest improvement and Reference stations had the highest mean B-IBI.

Total infaunal abundances were exceptionally high (due to sharp increases in pollution indicative oligochaete worms in the family Naididae) at a few stations. These high abundances depressed all of the four metrics that are used to calculate the B-IBI throughout the region. They depressed the Total Infaunal Abundance metric scores (by having too many organisms per square meter), increased the Pollution Indicative Taxa metric (because Naididae are pollution indicative), depressed the relative Pollution Sensitive Taxa Abundance metric (by dilution), and depressed the Shannon Weiner Diversity Index metric by dominating the community. Naididae are generally considered indicators of organic enrichment.

The multivariate cluster analysis identified three station groups that had strongly similar unstressed benthic invertebrate assemblages ($R^2 \geq 0.91$). Cluster Group 1 (MDE-15, MDE-16, MDE-42 and MDE-43), Cluster Group 2 (MDE-19 and MDE-44) and Cluster Group 3 (MDE-13 and MDE-17) were composed of stations all located on the east side of the island. In contrast, the identified outlier stations indicated adverse impacts to the benthic community north and west of HMI.

The Friedman's nonparametric ANOVA test indicated no significant differences between the four station types. Hence, Friedman's results did not pinpoint any localized adverse impacts to the surrounding benthic community from HMI operational discharges.

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APPENDIX III: ANALYTICAL SERVICES (PROJECT IV)

(September 2016 – August 2017)

Technical Report

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June 2017

OBJECTIVES

The 2016 (Year 34) project goals were to continue to measure and evaluate the levels of select trace elements in the sediment in the vicinity of Hart Miller Island (HMI) facility and to relate these, as far as possible, to historical data. Continued comparison and correlation of annual data with the historical HMI data, will indicate the extent of any contamination, biological exposure and if any trend in concentrations are developing at locations around the island.

Specific objectives for Year 34 were to collect clams and associated sediment in the fall of 2016 for analyses of trace elements. Fifteen sites were selected from the larger pool of Maryland Department of the Environment (MDE) biota stations for this work. Sediment and clams were collected at the same time. Both sediment and clams were analyzed for mercury, methyl-mercury, silver, selenium, and arsenic (Hg, MeHg, Ag, Se and As), and clams were also analyzed for lead and cadmium Pb and Cd to support MGS sediment studies.

METHODS AND MATERIALS

Sampling Procedures

In September 2016, 15 stations were visited by MDE and CBL personnel to collect clams and sediment for trace element analysis. The simultaneous collection is required to make the best bioaccumulation calculations. Sediment was collected using a ponar and the sediment subsampled using spatulas thereby integrating the top several centimeters of sediment for the sample while avoiding the sides of the sampler to minimize the possibility of contamination. Sediments for metals were placed in plastic sampling cups and kept cool until they could be processed in the laboratory.

Sediment was sieved in the field for clams; the whole clams were placed in plastic bags with surface water and held on ice. The clams were depurated and then frozen to allow easy shucking the next day. Clams for trace metal analysis were removed whole from their shells with a Teflon-coated spatula and the spatula was acid rinsed between each site's samples, to avoid cross contamination. The clam bodies from each site were homogenized in a plastic blender with a stainless steel blade for trace element analysis.

Procedures for Trace Element Analyses

For trace element analysis other than T-Hg and MeHg, EPA Method 3052 is generally followed. The Milestone EOTHO-EZ uses quartz reaction vessels placed inside Teflon cups, which are pressure sealed during digestion. For digestion, 1-2 grams of sediment is placed in the vessel with 9 ml of concentrated ultra pure Nitric Acid (HNO_3) and 2 ml of concentrated ultrapure Hydrochloric Acid (HCl). The vessel is covered with a loose fitting quartz cap, and placed in the Teflon cup. 5 ml of 30% Hydrogen Peroxide (H_2O_2) is added to the Teflon cup and the cup sealed. The sample is heated to 180°C and allowed to reflux for 15 minutes. The samples are then cooled and filtered through Whatman No. 41 filter paper by suction filtration and diluted to 100 ml with deionized water. Clams are digested in a similar fashion. These extracts are analyzed for Ag, As, Se, Pb and Cd using a Hewlett-Packard 4500 Inductively Coupled Plasma-Mass Spectrometer (ICP-MS).

Samples for the determination of T-Hg (1-3 g wet weight) were placed in Teflon vials along with a solution of 70% sulfuric/30% nitric acid. The Teflon vials are placed in an oven and heated overnight at 60°C (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 T-Hg 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).

For the determination of MeHg, clams and sediments were first extracted by sub-boiling distillation (Horvat et al. 1993). Clam or sediment tissue was weighed into Teflon vessels along with 1 ml of 50% sulfuric acid solution, 1 ml of a 20% potassium chloride solution and 18 ml of ultra pure water. The vessels were heated to approximately 90°C and volatiles and water distilled under a nitrogen stream for three hours. The distillate was reacted with a sodium tetraethylborate solution to convert the nonvolatile MeHg to gaseous MeHg (Bloom 1989). 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 gas chromatography with CVAFS detection. Detection limits for T-Hg and MeHg are based on three standard deviations of the blank measurement.

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°C overnight. Upon drying, samples were then reweighed and a dry/wet ratio was calculated.

RESULTS AND DISCUSSION

Trace Elements in Sediment, September 2016

Concentrations of As in the sediment collected around HMI in Year 34 (fall 2016) are generally below the running mean and median calculated from historic values (Figure 3-1). Only sediment from the site MDE 45, had a concentration equal to this running mean.

Concentrations of Se in sediment were at or below the historical running mean and median for all sites except site MDE 34, where the concentration in 2016 (0.96 ug g^{-1}) was above the mean (0.81 ug g^{-1}). On average site MDE 34 has low sediment Se concentrations when compared to other sites, and the observed concentration in 2016 falls within the normal variation that has been observed. No sites had Se concentrations outside the standard deviation around the mean (Figure 3-1).

Concentrations of Ag in the sediment collected from sites MDE-1 through MDE-41 in 2016 were lower than the median and average concentrations of previous years (Figure 3-2). In 2016, only site MDE 44 had sediment concentrations of Ag (0.83 ug g^{-1}) above mean of previous collections (0.41 ug g^{-1}). The 2016 concentration at this site is on the high end of what has been observed, and outside the standard deviation calculated from previous observations. This condition, lower than average Ag concentrations in sediment at sites MDE 1 through MDE 41, has been observed for the past 7 years. Sites with shorter histories (sites numbered MDE 42 to MDE 45) do not show this trend. As reported in the past, elevated Ag concentrations in 2000 and 2001 continue to bias the mean sediment concentration data and thus the median concentration (red line Figure 3-2) better reflects the general condition. Annual fluctuations in the concentration of Ag in sediment are system wide and appear unrelated to HMI operation.

Concentrations of mercury (T-Hg) in sediment were generally near the running mean calculated from previous years concentrations, with the exceptions being site MDE 19, 34 and 44. No sites were observed to have sediment concentrations elevated above the standard deviation calculated from concentrations of previous years. Concentrations of T-Hg are correlated with organic matter content measured as Loss on Ignition (r^2 = 0.51).

Concentrations of MeHg in sediment collected in the fall of 2016 were generally lower than previous years collections (Figure 3-3). However, sites MDE 17, 34 and 42 had concentrations above the running means. Only site, MDE 34 (0.70 ng g^{-1}), had concentrations above the standard deviation of pervious years concentrations (mean of 0.21 ng g^{-1}) However, MeHg concentrations at MDE 34 are generally lower than most other sites and even the elevated concentration is still lower than what occurs at most other sites. The percent of mercury that occurred as MeHg was less than 1% at all sites. At site MDE 17, the % MeHg was outside the normal range, as indicated by the standard deviation of previous years. The high percentage of MeHg at the site MDE 17 is driven by the higher than normal Me-Hg concentration.

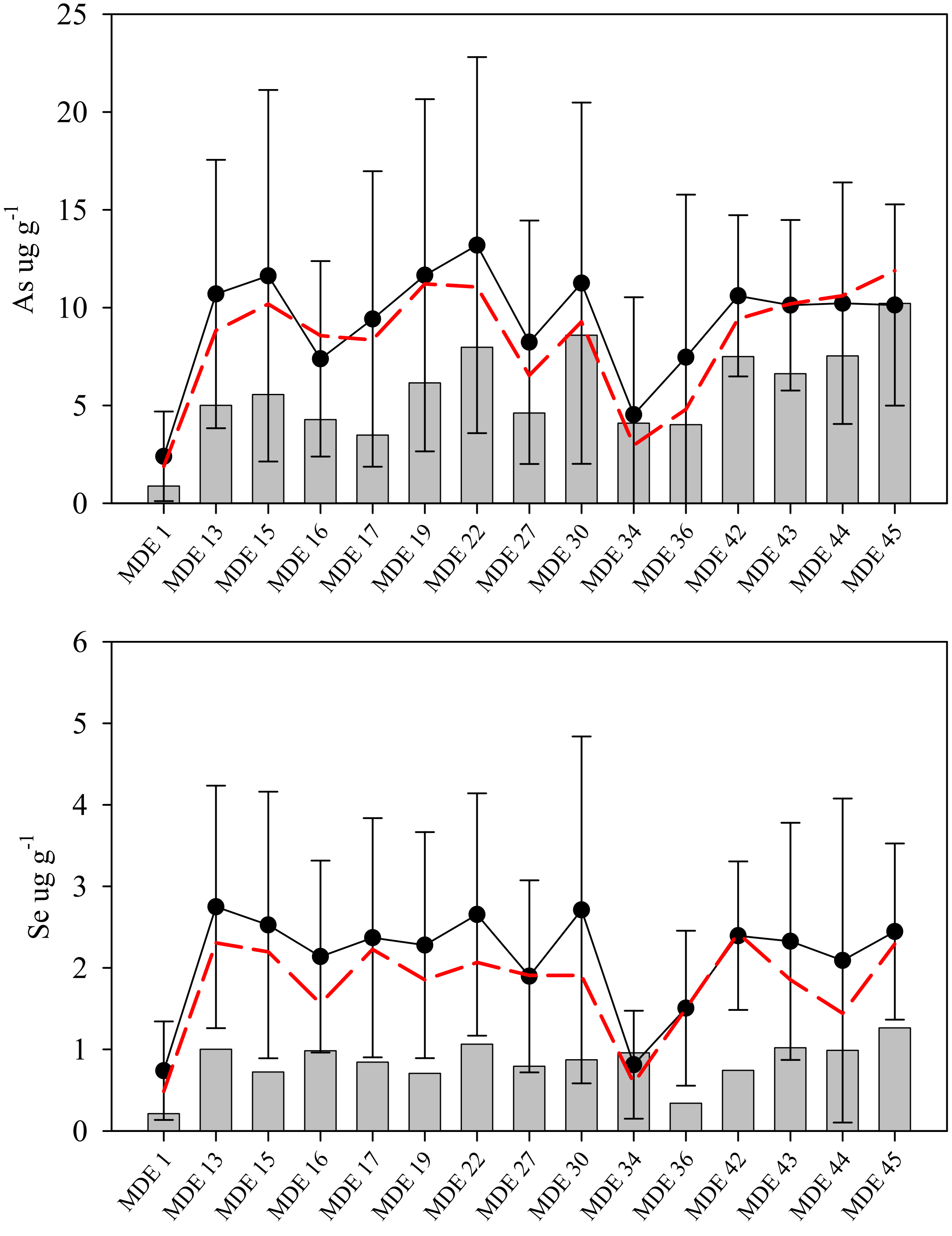


Figure 3- 1: As and Se in sediment, expressed as dry weight concentration, collected by CBL in the fall of 2016 (bars) and the 1998-2014 mean (circles) with standard deviation (error bars) and the 1998-2014 median (dashed line).

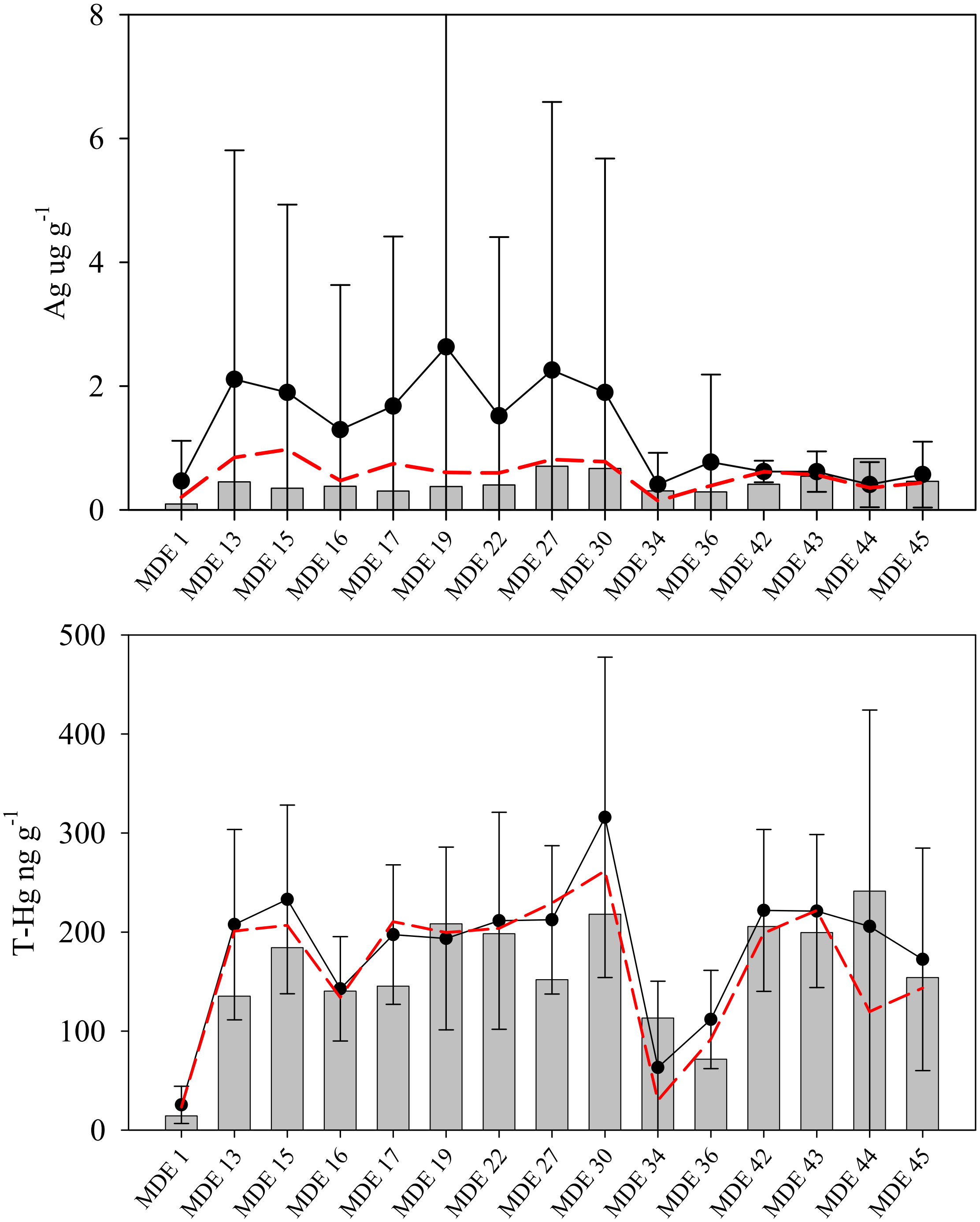


Figure 3- 2: Ag and T-Hg concentrations in sediment, expressed as dry weight concentration, collected by CBL in the fall of 2016 (bars) and the 1998-2014 mean (circles) with standard deviation (error bars) and the 1998-2014 median (dashed line).

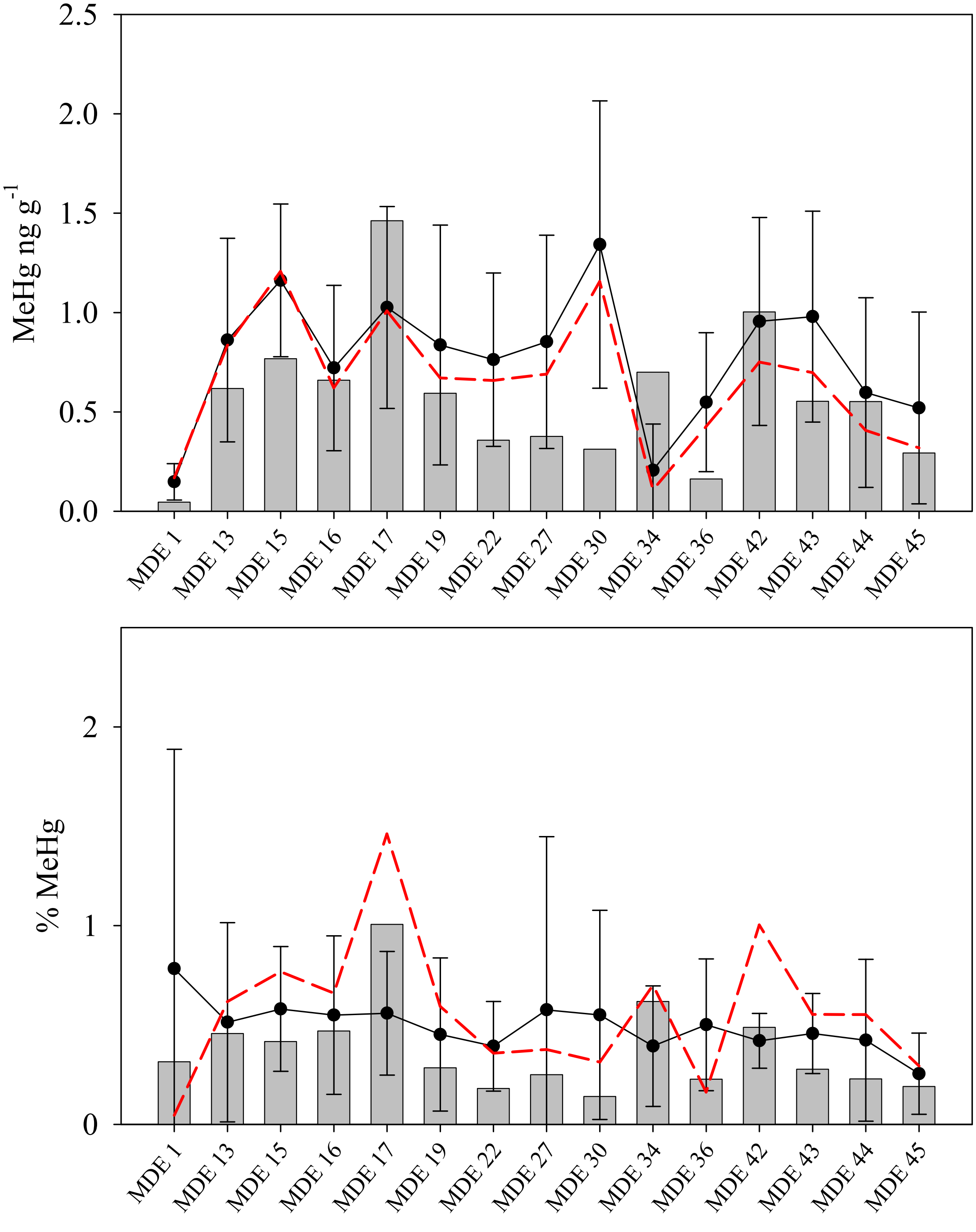


Figure 3- 3: MeHg, expressed as dry weight concentrations, and percent of T-Hg as MeHg in sediment collected by CBL in the fall of 2016 (bars), and the 1998-2014

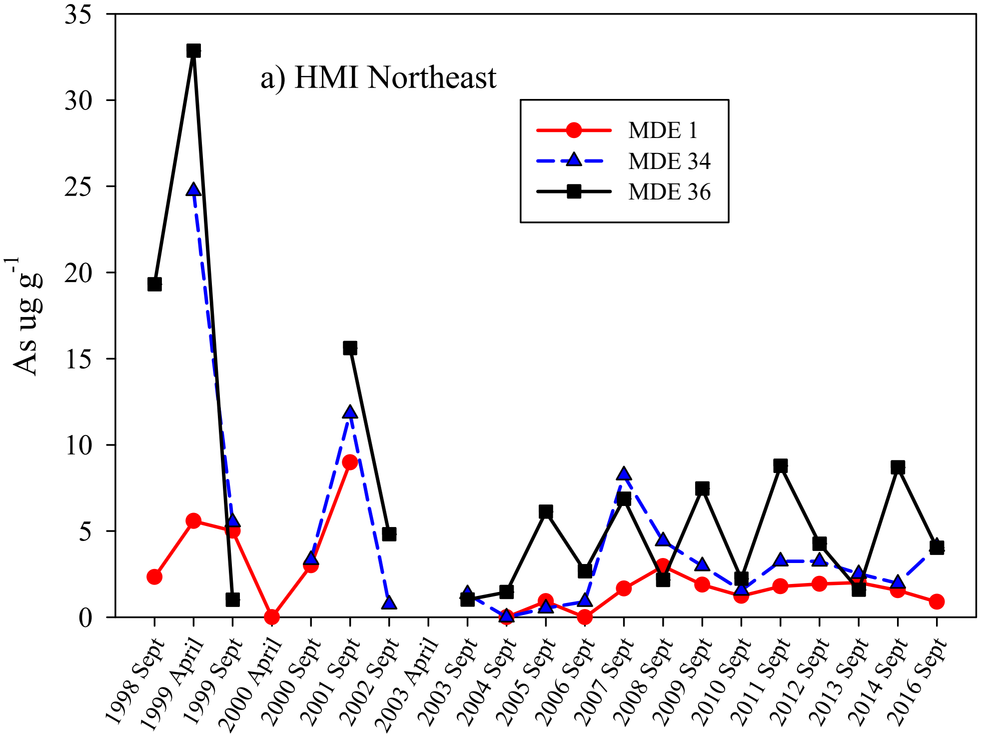
mean (circles), with standard deviation (error bars), and the 1998-2014 median (dashed line).

Relationships between trace elements (As, Se, Ag, Hg) in sediment among sites and years

If the sources of the trace elements to the sediment around HMI are similar, correlations between some element concentrations would be expected in both time and space. Having a basic understanding of such trends allows anomalous stations and years to be identified especially if multiple elements can be used to confirm the existence of an anomaly. Stations located near the Back River and Baltimore Harbor need be treated with care because the potential for contaminants to migrate from sources within these water bodies to the vicinity around the HMI complex is great. In this section, temporal tends of elements across the individual sites and the relationships between elements among sites is discussed along with the influence of site characteristics on element concentrations. To examine the temporal trends at individual sites, the sites have been broken into 5 regions based on proximity to one another and to reduce the number of figures.

Arsenic in Sediment 1998-2016

The temporal plots of As in sediment from each site are presented in Figures 3-4 to 3-6. Prior to 2001, concentrations of As were higher and more variable than the following years. From 2002 to 2006 concentrations were much lower, typically less than 10 ug g^{-1}. However, since 2006 concentrations of As in sediment have trended slightly upward. This upward trend continued until 2014 although year to year variability is high. Concentrations of As in the sediment off the Northeast side of the island are lower than the references station (MDE 36) were as concentrations of As at all other stations tend to be higher. In general concentrations of As in sediment at each site tend to oscillate around the mean concentration. The oscillations are most evident at MDE 36. Such oscillation at the reference site means one should expect significant annual variability in the As concentration data from all sites.



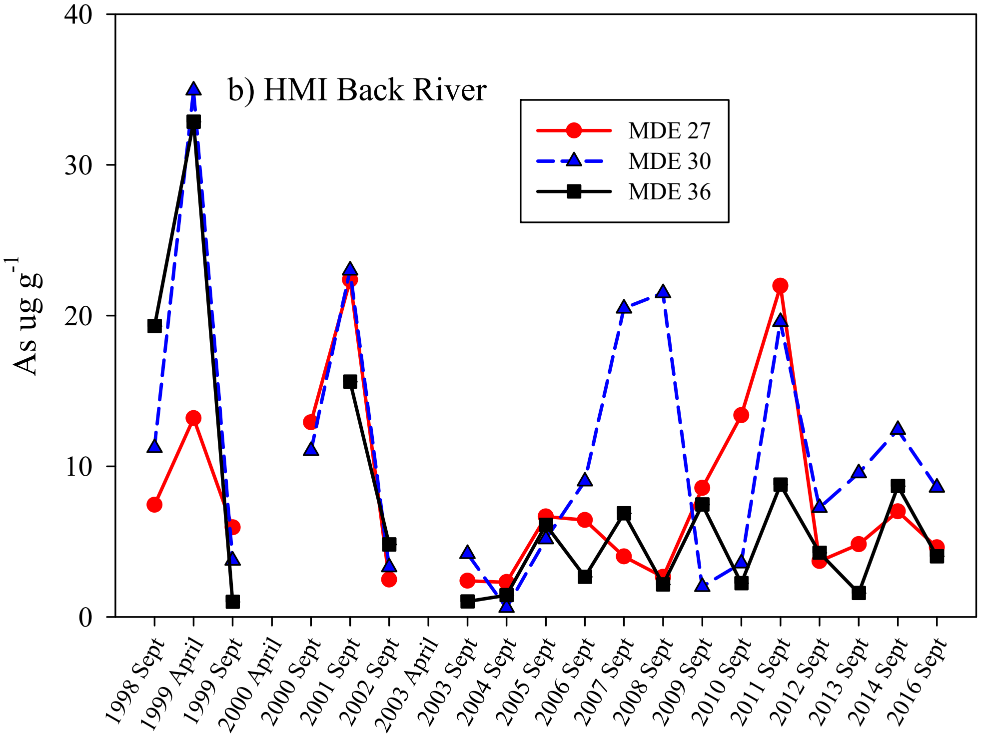
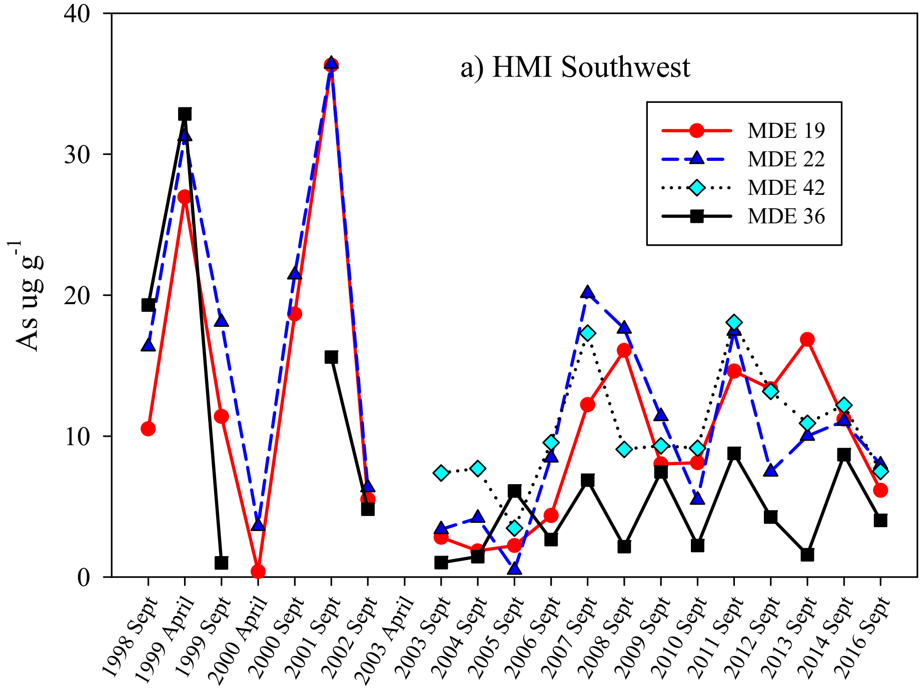


Figure 3-4: Arsenic (As) concentrations in sediment from the a) northeast side of the island and b) Back River influenced side of the island from 1998 to 2016. MDE station 36 is shown for reference.


a) HMI Southwest
MDE 19
MDE 22
MDE 42
MDE 36
As ug g^{-1}
0
10
20
30
40
1998 Sept
1999 April
1999 Sept
2000 April
2000 Sept
2001 Sept
2002 Sept
2003 April
2003 Sept
2004 Sept
2005 Sept
2006 Sept
2007 Sept
2008 Sept
2009 Sept
2010 Sept
2011 Sept
2012 Sept
2013 Sept
2014 Sept
2016 Sept

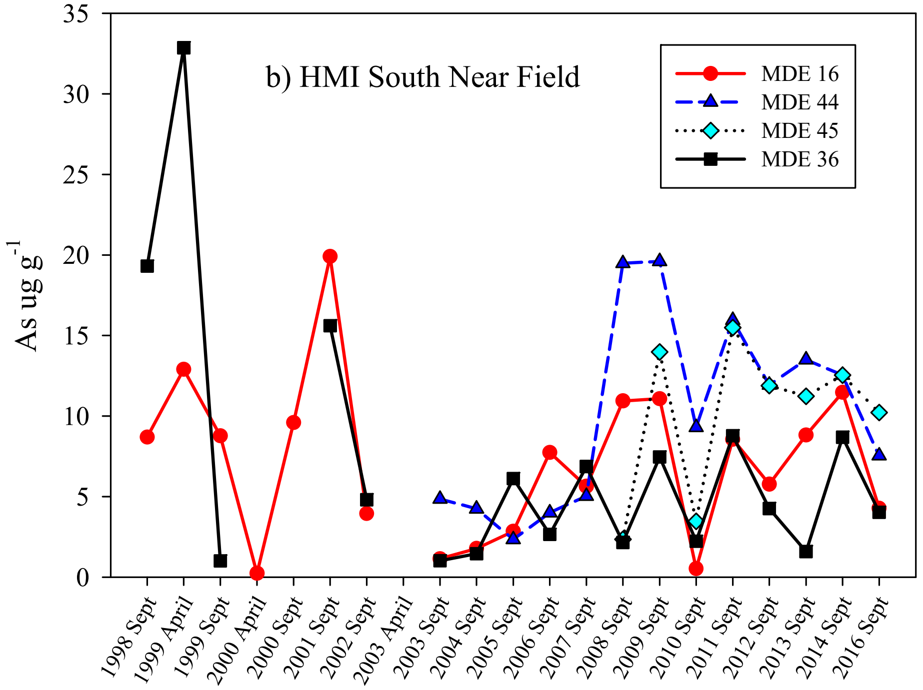

b) HMI South Near Field
MDE 16
MDE 44
MDE 45
MDE 36
As ug g^{-1}
0
5
10
15
20
25
30
35
1998 Sept
1999 April
1999 Sept
2000 April
2000 Sept
2001 Sept
2002 Sept
2003 April
2003 Sept
2004 Sept
2005 Sept
2006 Sept
2007 Sept
2008 Sept
2009 Sept
2010 Sept
2011 Sept
2012 Sept
2013 Sept
2014 Sept
2016 Sept

Figure 3- 5: Arsenic (As) concentrations in sediment from a) Southwest side of the island and b) close to the south side of the island (near field) from 1998 to 2016. MDE station 36 is shown for reference.

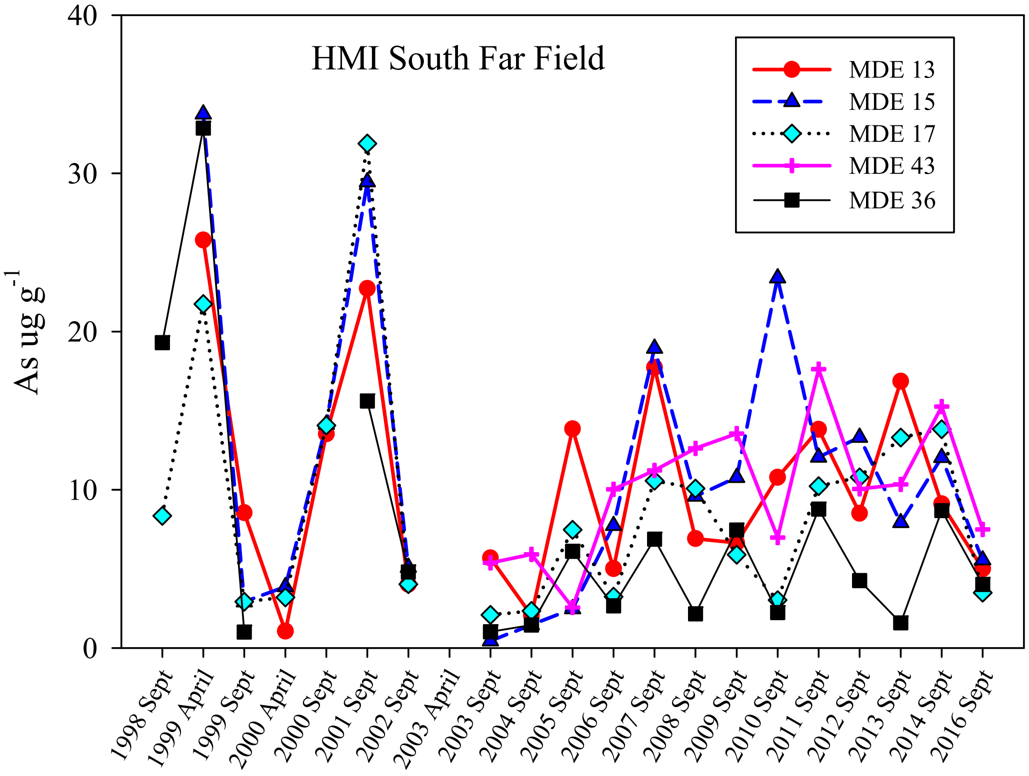
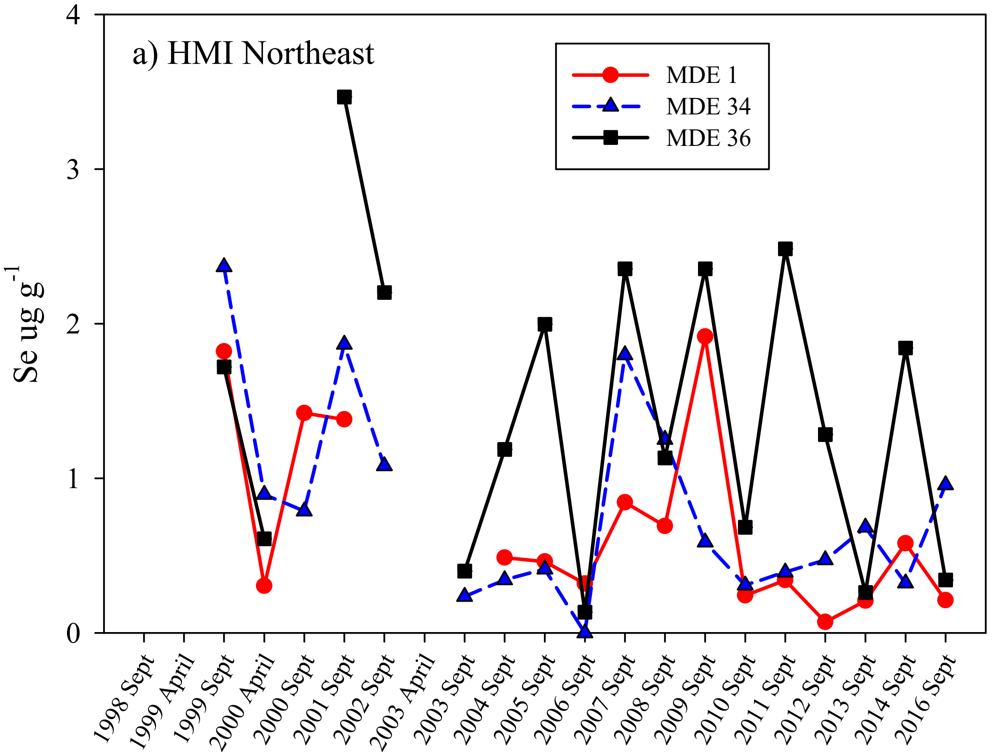


Figure 3-6: Arsenic (As) concentrations in sediment from South Side of the island Far Field stations 1998 to 2016. Station MDE 36 is shown for reference.

Selenium in Sediment 1998 to 2016

Concentrations of Se in sediment behave similarly to As (Figures 3-7, 3-8, 3-9). Se concentrations range from undetectable to 8 ug g^{-1}. There appears to be four periods during which concentrations where similar; 1) a period of elevated Se concentrations that extended from the onset of measurements up to 2002, 2) a period of lower concentrations from 2002 to 2006, and then 3) a return to a period of elevated Se concentrations from 2006 to 2011. Starting in 2012, a fourth period has taken shape with lower Se concentrations again having developed, as concentrations at the same site have remained low and similar from 2012 to 2016. Se concentrations at the North East stations are similar to the reference site MDE 36 (Figure 3-7a). Concentrations at the other sites tend to be higher than MDE 36 but there is a temporal synchronicity between all the sites as the Se concentrations at all the sites tend to increase and decrease together which suggests a regional influence on top of the controls specific to each site.


a) HMI Northeast
MDE 1
MDE 34
MDE 36
Se ug g^{-1}
0
1
2
3
4
1998 Sept
1999 April
1999 Sept
2000 April
2000 Sept
2001 Sept
2002 Sept
2003 April
2003 Sept
2004 Sept
2005 Sept
2006 Sept
2007 Sept
2008 Sept
2009 Sept
2010 Sept
2011 Sept
2012 Sept
2013 Sept
2014 Sept
2016 Sept

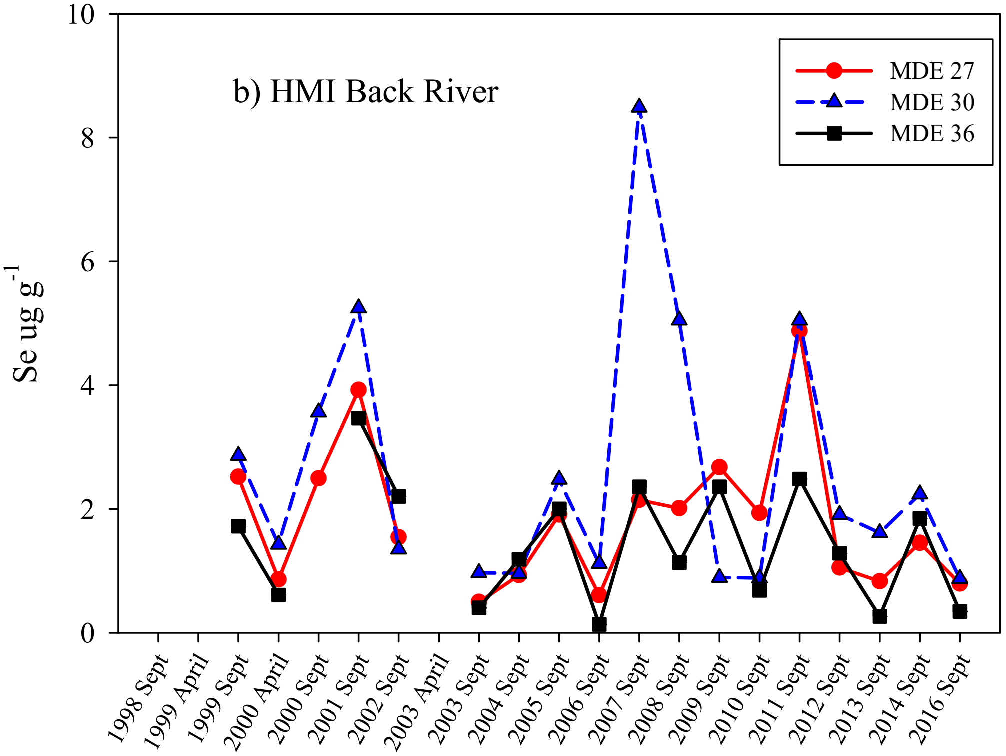

b) HMI Back River
MDE 27
MDE 30
MDE 36
Se ug g^{-1}
0
2
4
6
8
10
1998 Sept
1999 April
1999 Sept
2000 April
2000 Sept
2001 Sept
2002 Sept
2003 April
2003 Sept
2004 Sept
2005 Sept
2006 Sept
2007 Sept
2008 Sept
2009 Sept
2010 Sept
2011 Sept
2012 Sept
2013 Sept
2014 Sept
2016 Sept

Figure 3-7: Se concentrations in sediment from the a) northeast side of the island and b) Back River influenced side of the island from 1998 to 2016. MDE station 36 is shown for reference.

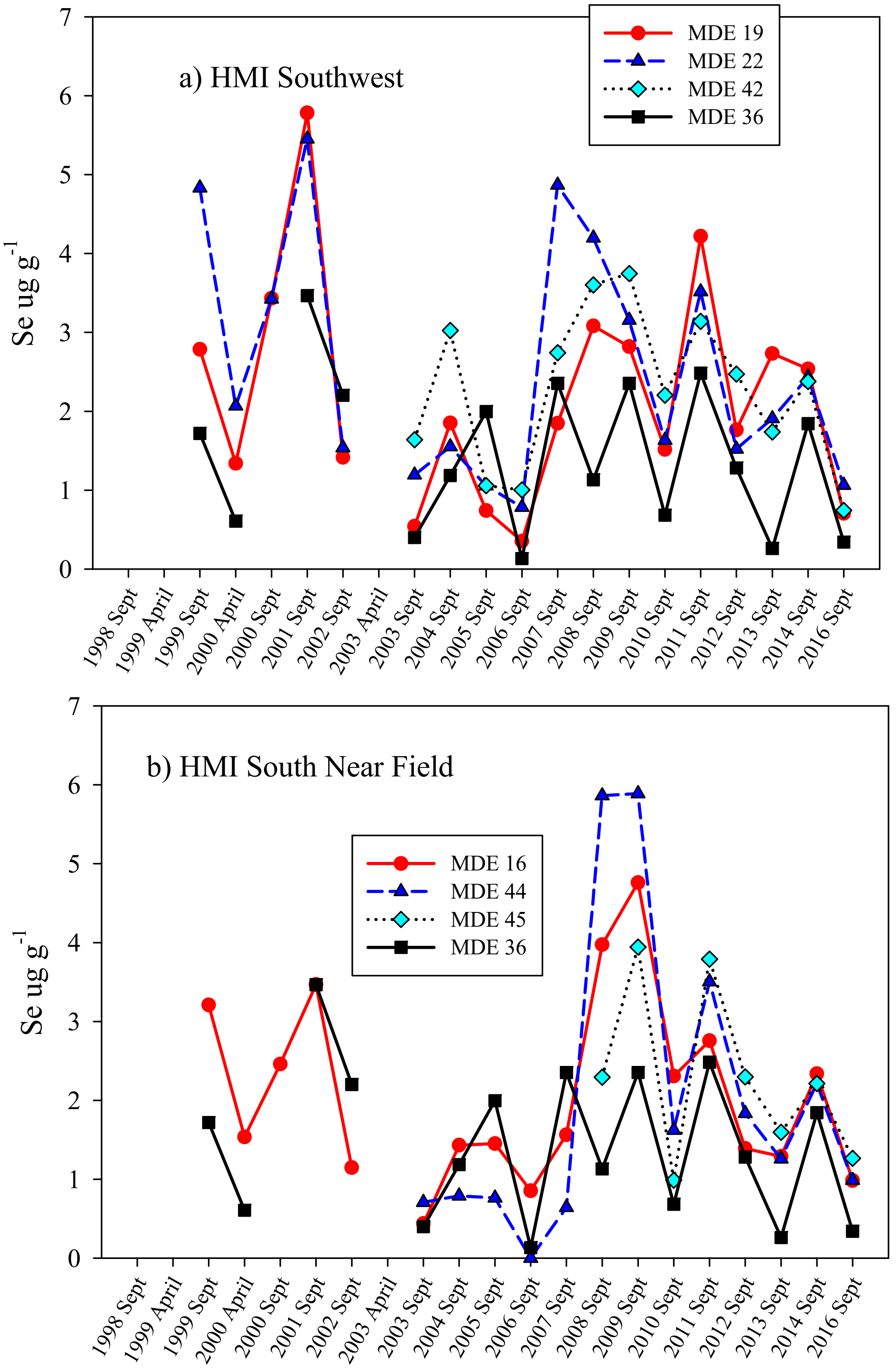


Figure 3- 8: Selenium (Se) concentrations in sediment from a) Southwest side of the island and b) close to the south side of the island (near field) from 1998 to 2016. MDE station 36 is shown for reference.

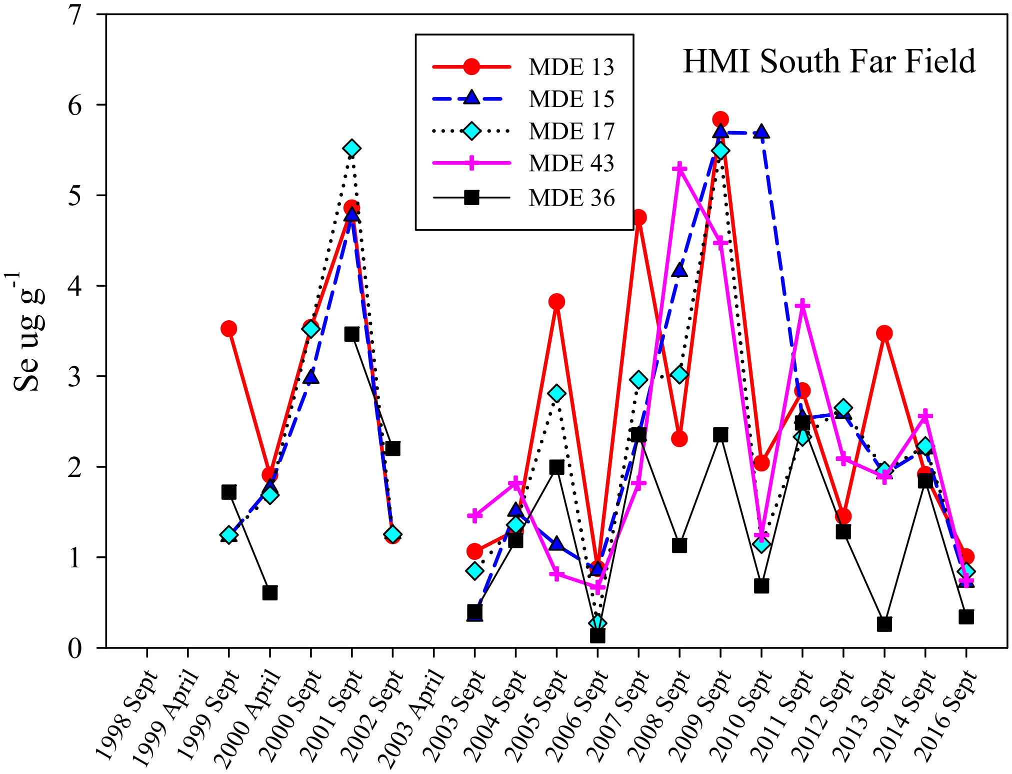
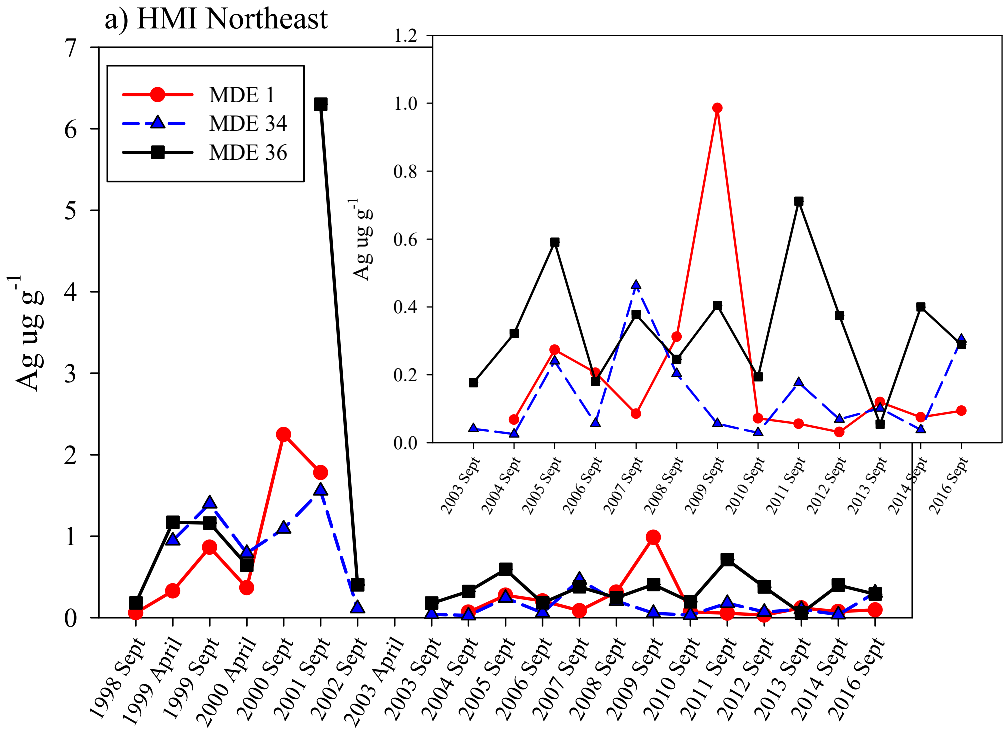


Figure 3- 9: Selenium (Se) concentrations in sediment from South Side of the island far field stations 1998 to 2016. Station MDE 36 is shown for reference.

Silver in Sediment 1998 to 2016

As reported for the other trace elements, the concentrations of Ag in sediment at any one site have varied with time. The concentrations of Ag in sediment around HMI can be divided into distinct periods (Figures 3-10, 3-11 and 3-12). Following a period of low concentrations from 1998 and 1999, sediment concentrations of Ag were very high between 2000 and 2002 being almost a factor of 10 higher than in any other period studied. It has been difficult to provide an explanation for these high Ag concentrations in sediment, given elevated concentrations were observed at all sites including the reference site. From 2002 to 2006, Ag concentrations were low, generally being less than 1 ug g^{-1}. In years after 2007, sediment Ag concentrations increased each year peaking around 2009 with concentrations as high as 2 ug g^{-1} observed at some stations. With more time points temporal patterns in Ag, discussed in past reports, have degraded into variability. From

2010 to 2016, Ag concentrations in sediment are low and generally less than 1 ug g^{-1} with fluctuations around the mean greatly reduced.



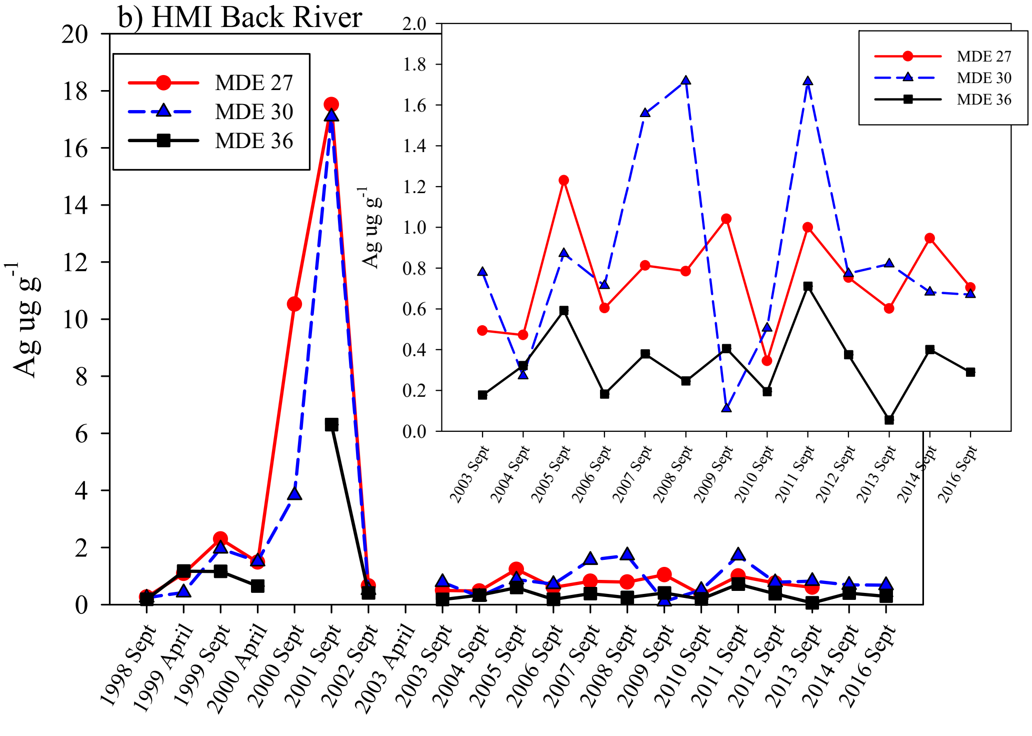
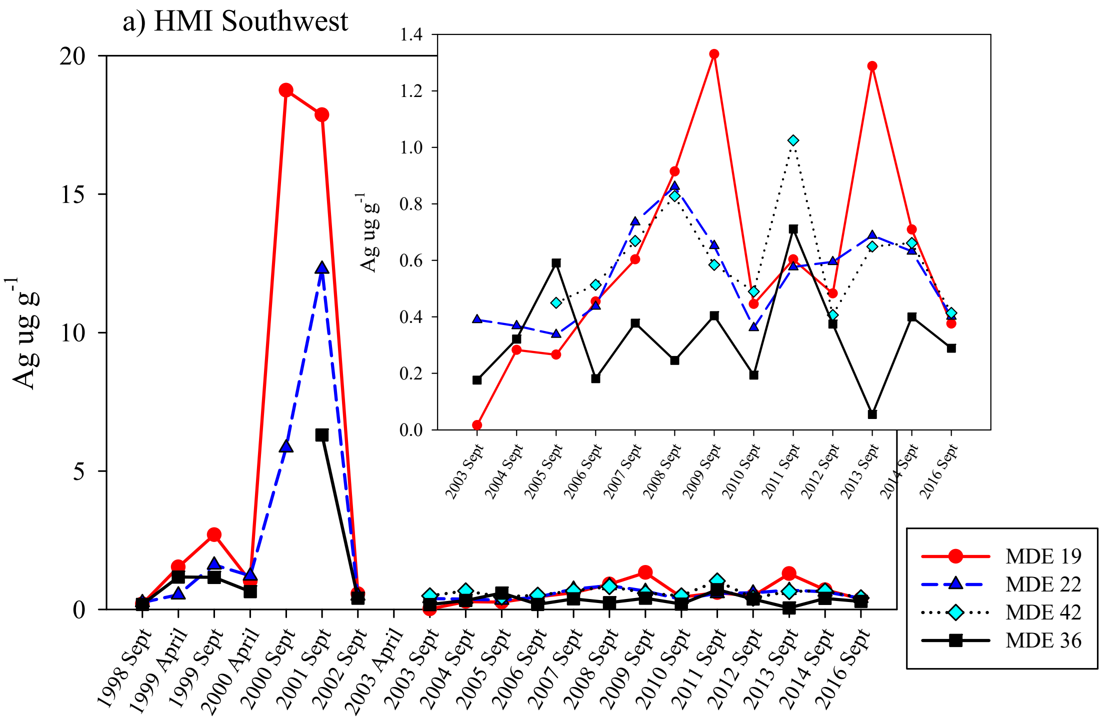


Figure 3-10: Silver (Ag) concentrations in sediment from the a) northeast side of the island and b) Back River influenced side of the island from 1998 to 2016. MDE station 36 is shown for reference and 2003-2016 shown in the inset.



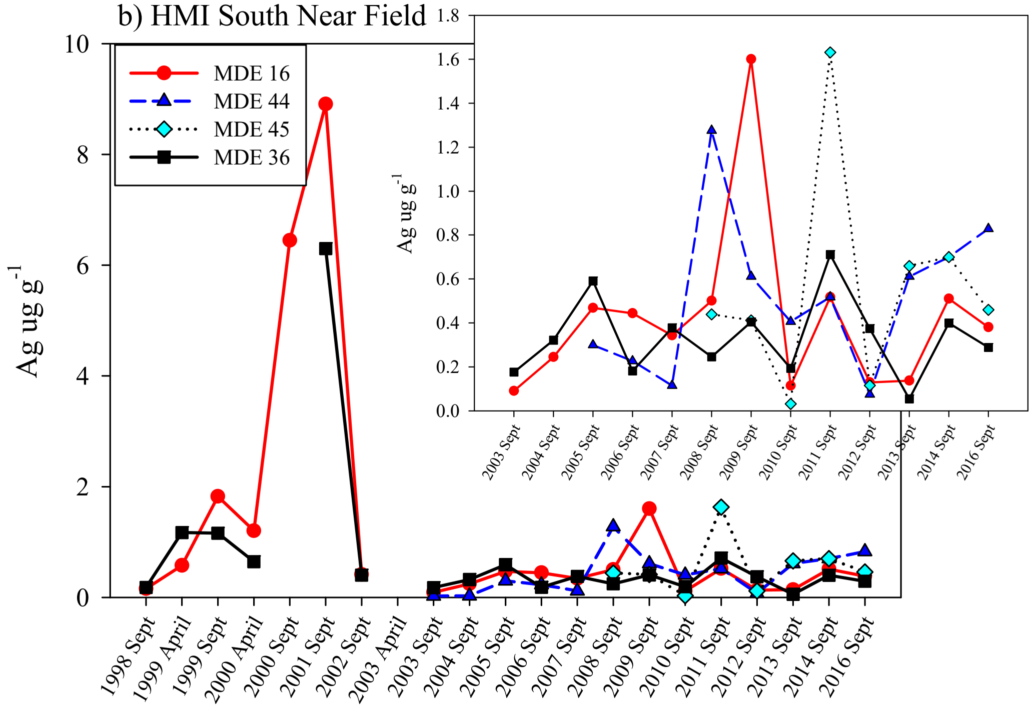


Figure 3- 11: Silver (Ag) concentrations in sediment from a) Southwest side of the island and b) close to the south side of the island (near field) from 1998 to 2016. MDE station 36 is shown for reference and 2003-2016 shown in the inset.

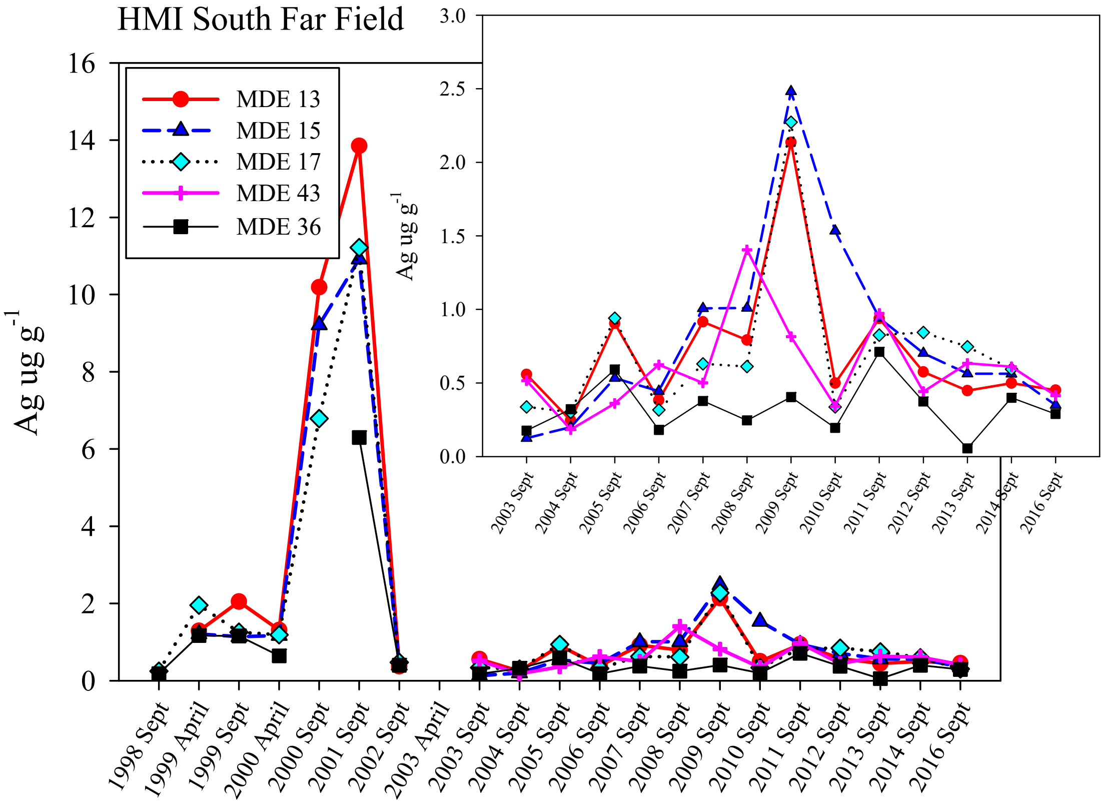


Figure 3-12: Silver (Ag) concentrations in sediment from South Side of the island far field stations 1998 to 2016. Station MDE 36 is shown for reference and 2003-2016 shown in the inset.

Mercury in Sediment 1998 to 2016

During the period from 1998 to 2016, T-Hg concentrations in sediment have fluctuated by as much as a factor of 5 at individual sites (e.g. MDE 22, MDE 30 and MDE 44) (Figure 3-13 to 3-15). Even sediment from site MDE-36 has shown considerable variation in T-Hg concentration. In 2016, T-Hg concentrations were near average at most sites. Between 2010 and 2013, T-Hg concentrations trended upward at all sites including the reference site (MDE 36). No changes in carbon or clay content have been observed at these sites (discussed below), so changes in sediment concentrations are caused by T-Hg enrichment, not a change in sediment composition. For 2016, T-Hg concentrations have returned to more “typical” concentrations.

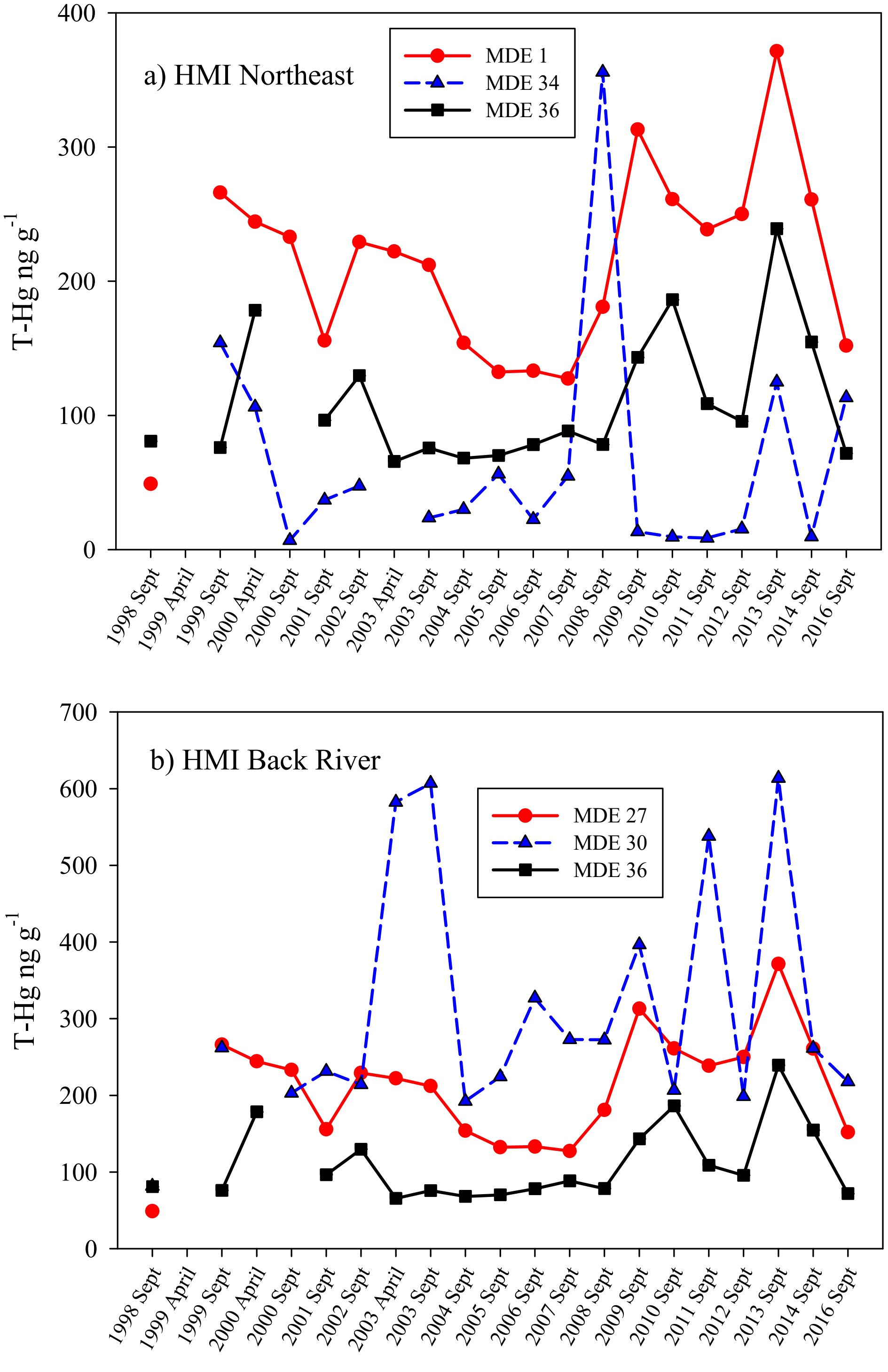


Figure 3-13: Total Mercury (T-Hg) concentrations in sediment from the a) northeast side of the island and b) Back River influenced side of the island from 1998 to 2016. MDE station 36 is shown for reference.

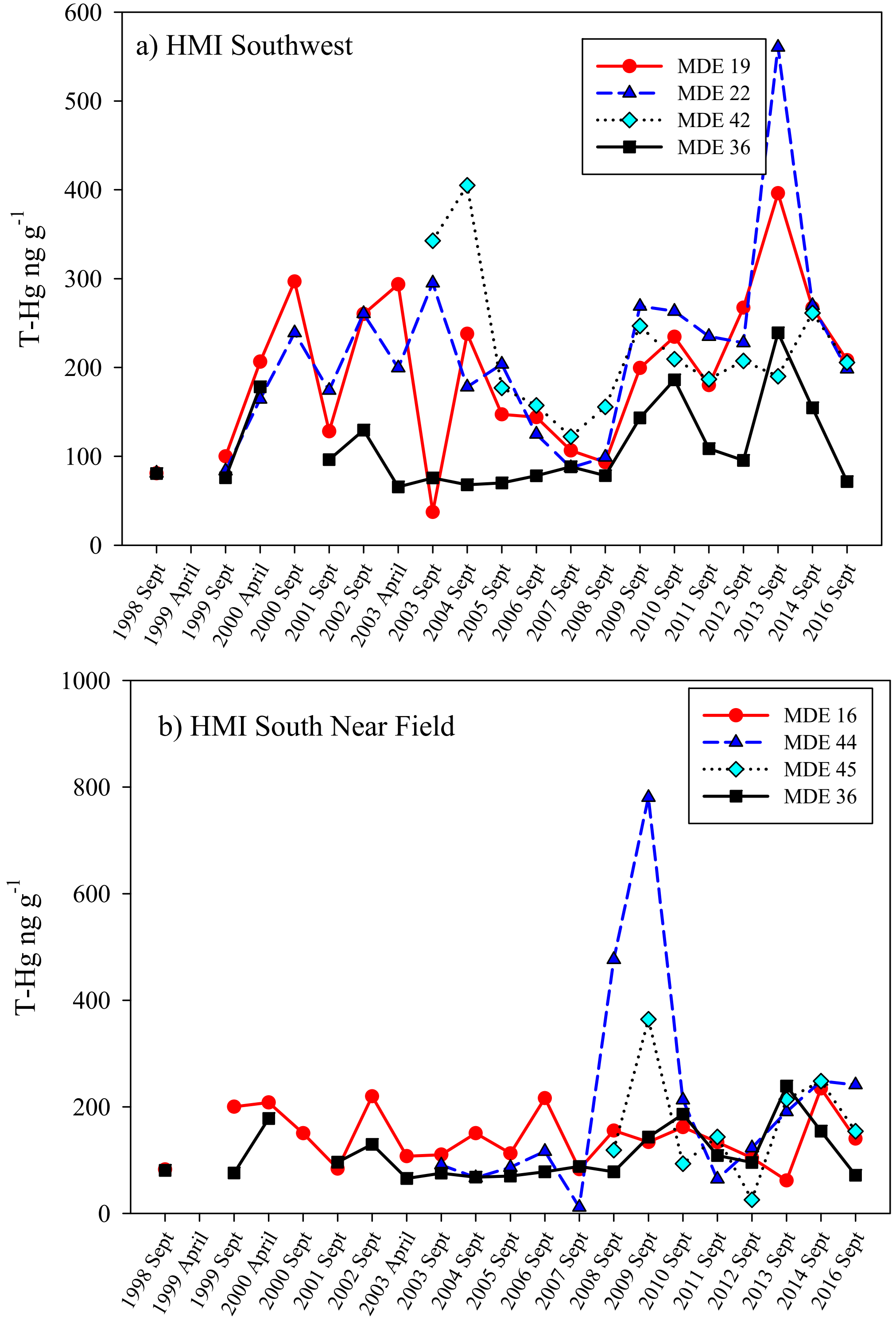


Figure 3- 14: Total Mercury (T-Hg) concentrations in sediment from a) Southwest side of the island and b) close to the south side of the island (near field) from 1998 to 2016. MDE station 36 is shown for reference.

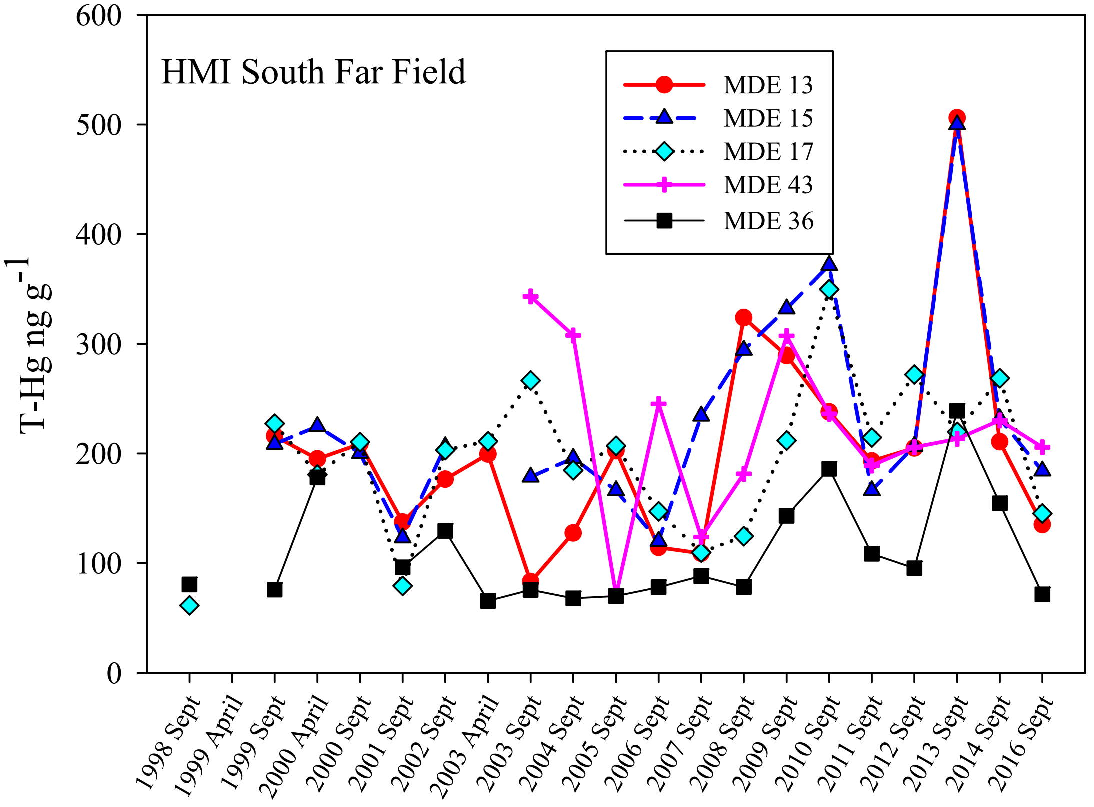


Figure 3-15: Total Mercury (T-Hg) concentrations in sediment from South Side of the island far field stations 1998 to 2016. Station MDE 36 is shown for reference.

Methylmercury in Sediment 1998-2014

The concentrations of methylmercury (MeHg) were generally less than 2 ng g^{-1} at all sites over the study period. MeHg concentrations at individual sites fluctuated greatly over time, and year to year variability is substantial. However, there is a weak downward trend in MeHg concentration at many sites including the reference site. It does not appear this is related to the amount of Hg present, but could be caused by a decrease in Hg availability or shift in microbial activity, either by stimulating demethylation or decreasing methylation.

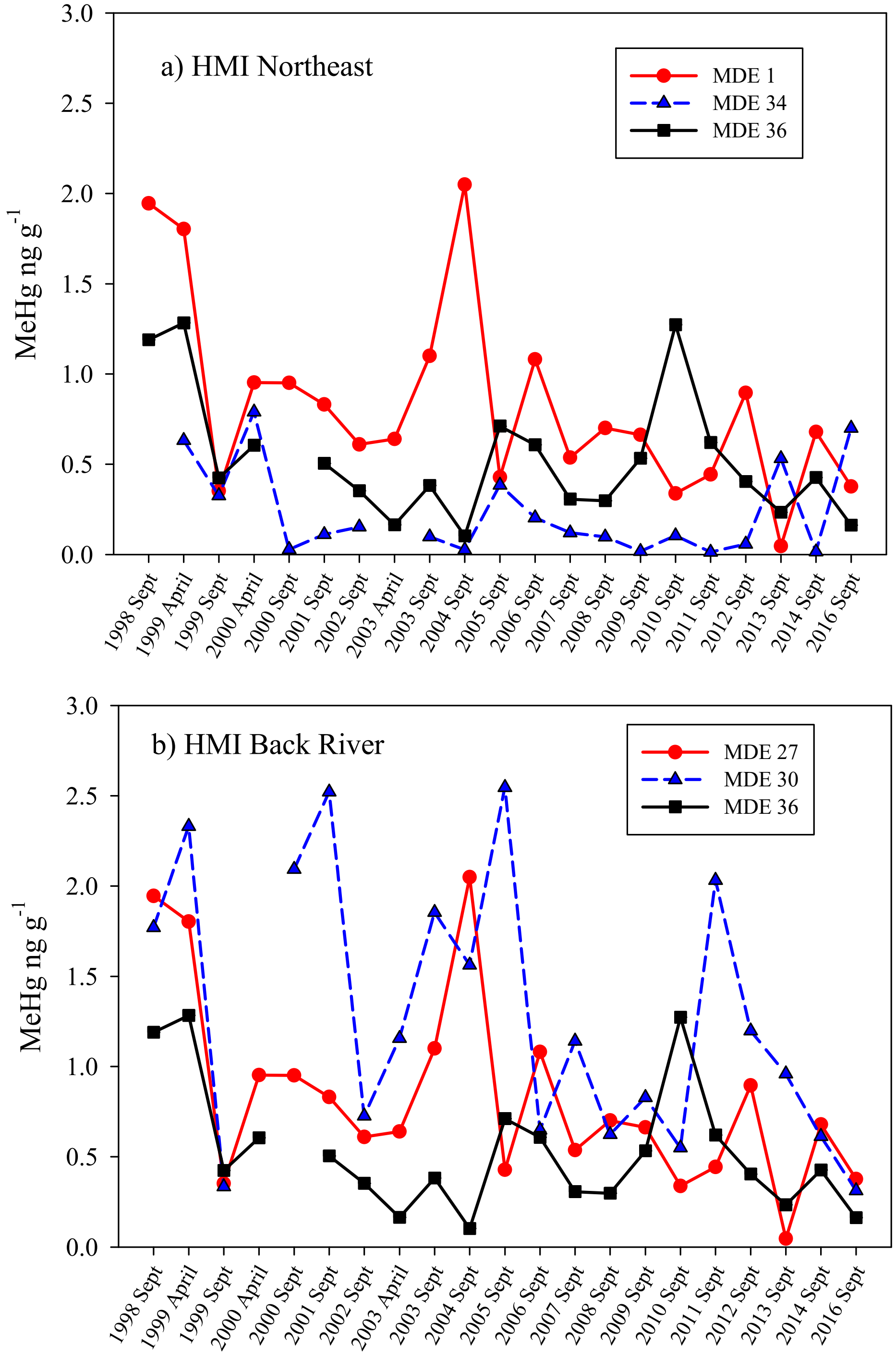


Figure 3-16 Methylmercury (MeHg) concentrations in sediment from the a) northeast side of the island and b) Back River influenced side of the island from 1998 to 2016. MDE station 36 is shown for reference.

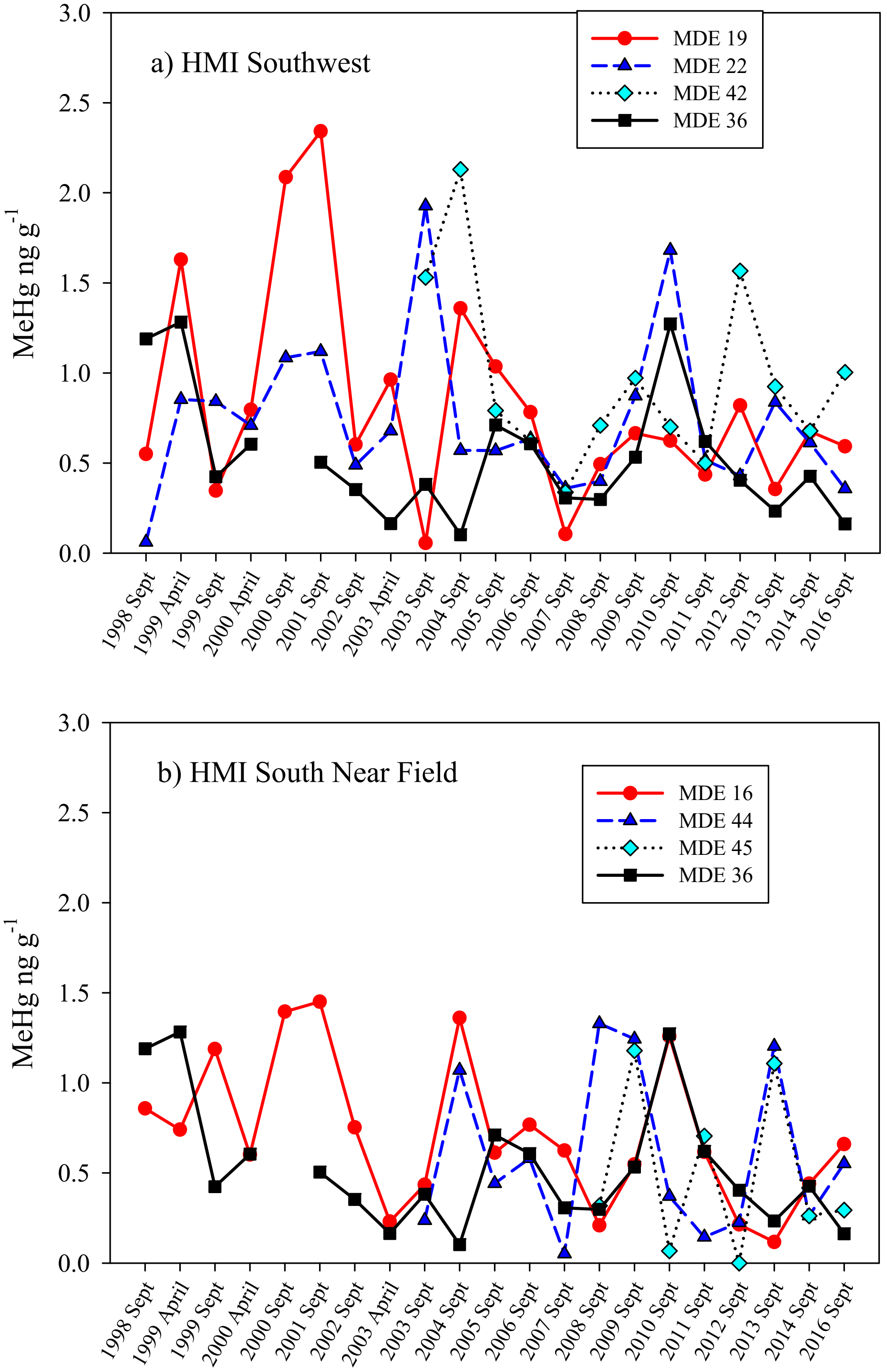


Figure 3- 17: Methylmercury (MeHg) concentrations in sediment from a) Southwest side of the island and b) close to the south side of the island (near field) from 1998 to 2016. MDE station 36 is shown for reference.

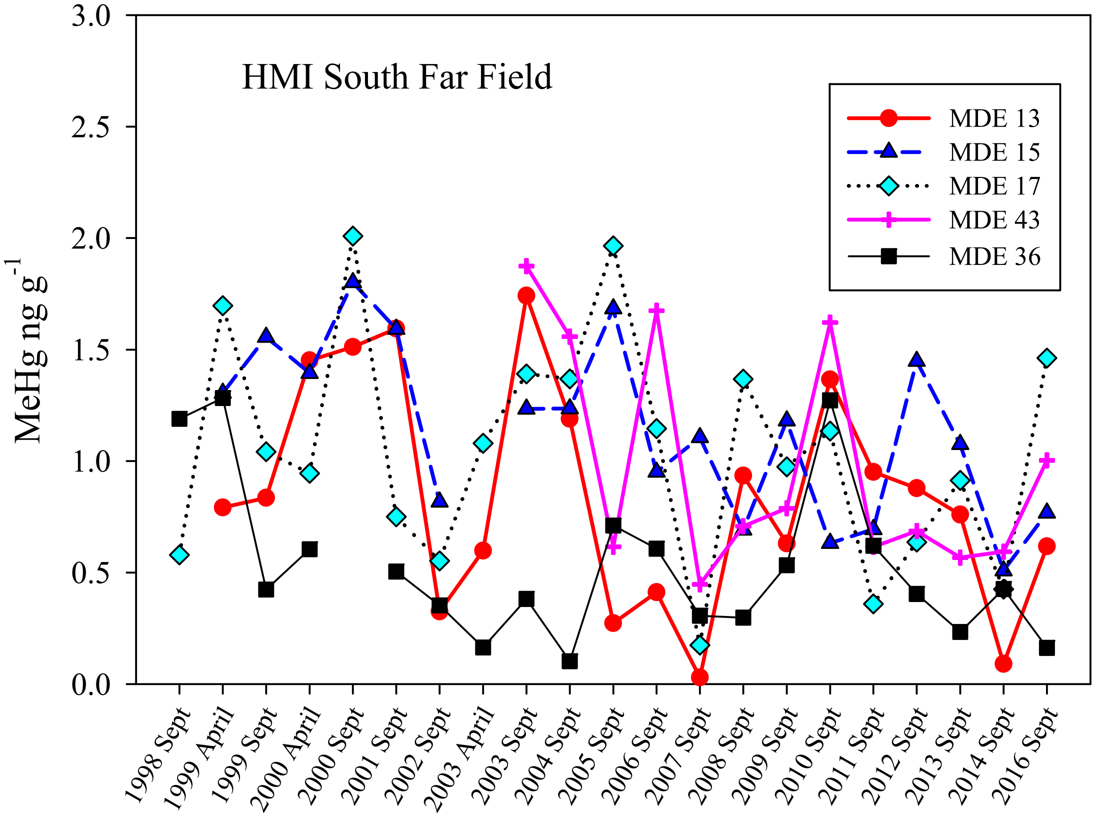


Figure 3-18: Methylmercury (MeHg) concentrations in sediment from South Side of the island far field stations 1998 to 2016. Station MDE 36 is shown for reference.

Relationships among trace elements in Sediment

Trace elements may be co-released from activities such as coal combustion and industrial activity, so relations and temporal deviations among the elements may help in determining sources. Such relationships between trace elements in sediment are seldom reported in the literature.

Arsenic and Selenium

From the data collected around HMI, a generally strong correlation between As and Se concentrations in sediment is present when all the past data from all the sites measured through 2016 are compiled (Figure 3-19a). There is some variability in the strength of the relationship between As and Se, when the entire 17 years of data is broken into individual years. The annual correlation r^2, have ranged from 0.22 to 0.84 between 1999 and 2014. In the fall of 2016 the relationship between As and Se was moderate (r^2 = 0.46). This is despite the number of stations in 2016 being less than half that of previous years (Figure 3-15b). At the level of individual sites, the correlation between the two elements is generally not as strong, with the r^2 ranging from 0.30 to 0.86 between 1999 and 2016. In general, As and Se concentrations are related and should increase and decrease together. Sustained departures from this relationship in time and space may suggest a change in element source.

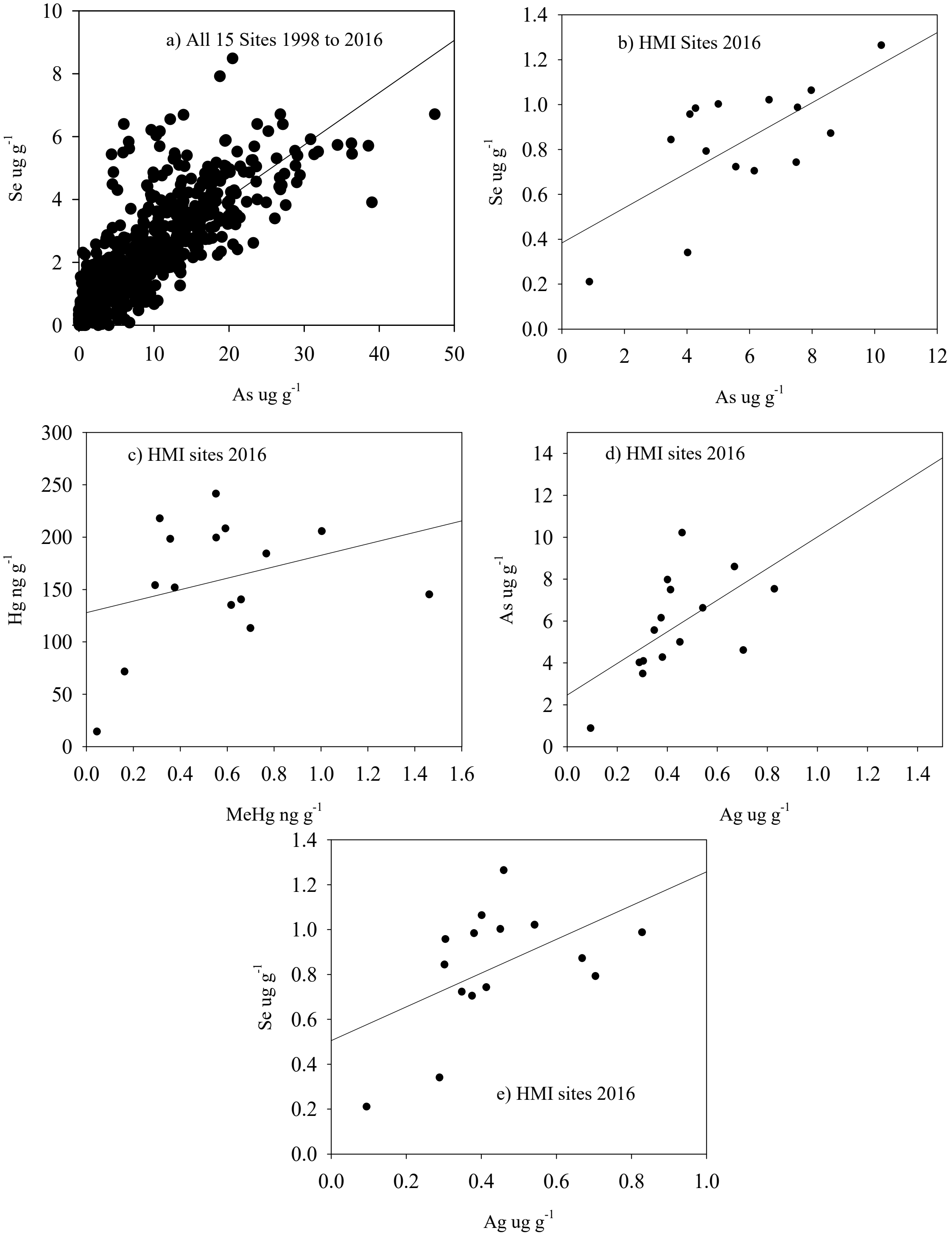


Figure 3- 19: Se vs As in sediment (ug g^{-1} dry weight) for a) HMI stations 1998 – 2016 sampled in 2016; b) sampled in the fall of 2016; c) correlation of T-Hg and MeHg concentration in September 2016, d) As vs Ag concentrations in September 2016 and e) Se vs Ag concentrations in September 2016.

Mercury and Methylmercury

Sediment concentrations of T-Hg are not well correlated with sediment concentrations of Se, As or Ag at the HMI stations either in time or space. Site MDE-44 remained the only site with a strong correlation between sediment concentrations of T-Hg and As, T-Hg and Se, and T-Hg and Ag. When data from all sites within a single year are pooled, sediment T-Hg concentration is generally weakly correlated with sediment MeHg concentration over most of the years with r^2 from linear regressions ranging for 0.11 to 0.48. In 2010, 2008 and 1998, no relationship was observed between T-Hg and MeHg sediment concentrations. In 2016, with the reduced number of sampling sites compared to other years, the relationship between sediment T-Hg and MeHg concentration was poor ($r^2 = 0.10$) (Figure 3-15c). At any one sampling site, the relationship between sediment T-Hg and MeHg concentration over the 1998 to 2016 period ranged from non-existent to strong. The small amount of data collected for sites MDE 45 through MDE 51 makes the temporal assessments of these sites much less robust. The dependence of MeHg on T-Hg is expected, but in the Chesapeake Bay the relationship is often weakened by factors other than T-Hg concentration influencing MeHg production (Heyes et al. 2006). In 2016, sediment T-Hg and MeHg concentrations were near average.

Silver

Concentrations of Ag in sediment are poorly correlated with most other element concentrations over the 1998 to 2016 study period. The high sediment concentrations of Ag observed in 2000 and 2001 drastically skew the temporal results. When the data from these two years are removed, correlations between Ag and As and Ag and Se are generally strong. On an annual basis and independent of location, regressions between As and Ag concentrations in sediment generated r^2 ranged from 0.32 to 0.71 between 2002 and 2012. The exception occurred in 2009 when no relationship between As and Ag was found. In 2016, concentrations of As in sediment was correlated with concentrations of Ag ($r^2 = 0.35$) in sediment, although the correlation was weaker than most years (Figure 3-15d).

Concentrations of Ag and Se in sediment were also well correlated across the years, with r^2 ranging from 0.44 to 0.70 between 2002 and 2011. In 2014, the relationship was weak (r^2 of 0.26) (Figure 3.15e) signaling a return to the decrease in the strength of the relationship seen in recent years. This suggests a divergence of source or change in diagentic state, and is something to be monitored in the coming years.

When individual sites are examined over time, concentrations of Ag in sedment are not often well correlated with concentrations of the other elements. If the anomalous years of 2000 and 2001 are removed from the data set, correlations between Ag and other elements strengthen somewhat at most sites, but r^2 are generally less than 0.5. Interestingly, the temporal correlations between Ag and As and Ag and Se are fewest in number from the sites on NE side of the island. The strongest relationships are at sites MDE-43 (Ag-As $r^2 = 0.42$) and 44 (Ag-Se $r^2 = 0.45$) (Ag-As $r^2 = 0.47$) which lie off the south side of the island. These trends appear to be weakening with additional data, in other words weakening over time.

Relationships between trace element concentrations with other site characteristics

The relationship was investigated between sediment trace elements and other sediment variables such as organic carbon content, clay, silt and sand content measured by the Maryland Geological Service. Some trace elements associate with clay sized particles, while others bind strongly with organic matter. A high sand content is indicative of an environment where trace elements are unlikely to accumulate. At any particular site, As and Se concentrations in sediment seldom correlate with these other site variables over time. Thus changes in carbon or clay content do not appear to influence As and Se concentrations at individual sites. This poor relationship also exists when all sites for any given year are considered together, or when the even for the entire data set independent of site or year.

When the data from all sites and times is combined and examined together, Hg is well correlated with carbon and clay content, unlike As and Se. (Figure 3-20). Furthermore, sediment T-Hg concentration is usually well correlated with carbon content and clay content among the sites in any one year; with the exception being1998. In 2016, the relationship between T-Hg and carbon was moderately strong (Figure 3-17).

When individual sites are examined over time T-Hg and carbon and T-Hg and clay content the relationship is not nearly as strong with Hg concentration correlated with sediment carbon content at only 8 sites and with clay content at only 6 sites. The reason for this is that the concentration of carbon and clay at a single site does not vary much over time thereby weakening the potential for temporal relationships. Hence, when the range in carbon and clay content are expanded by looking across sites within a year, the relationship between carbon and Hg strengthens greatly.

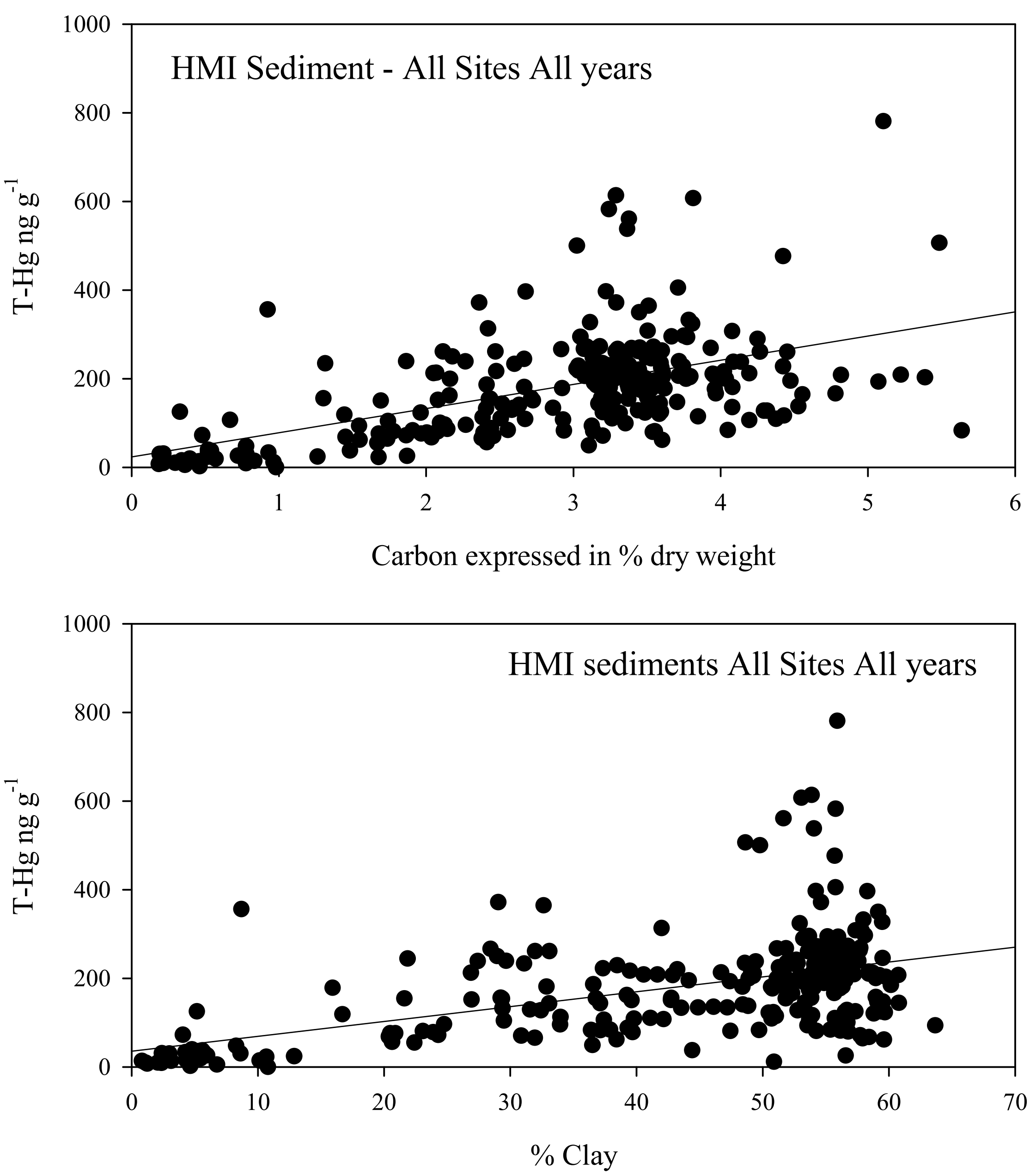


Figure 3-20: Total-Hg concentration and carbon content (upper) and clay (lower) in sediment for all sites and all years.

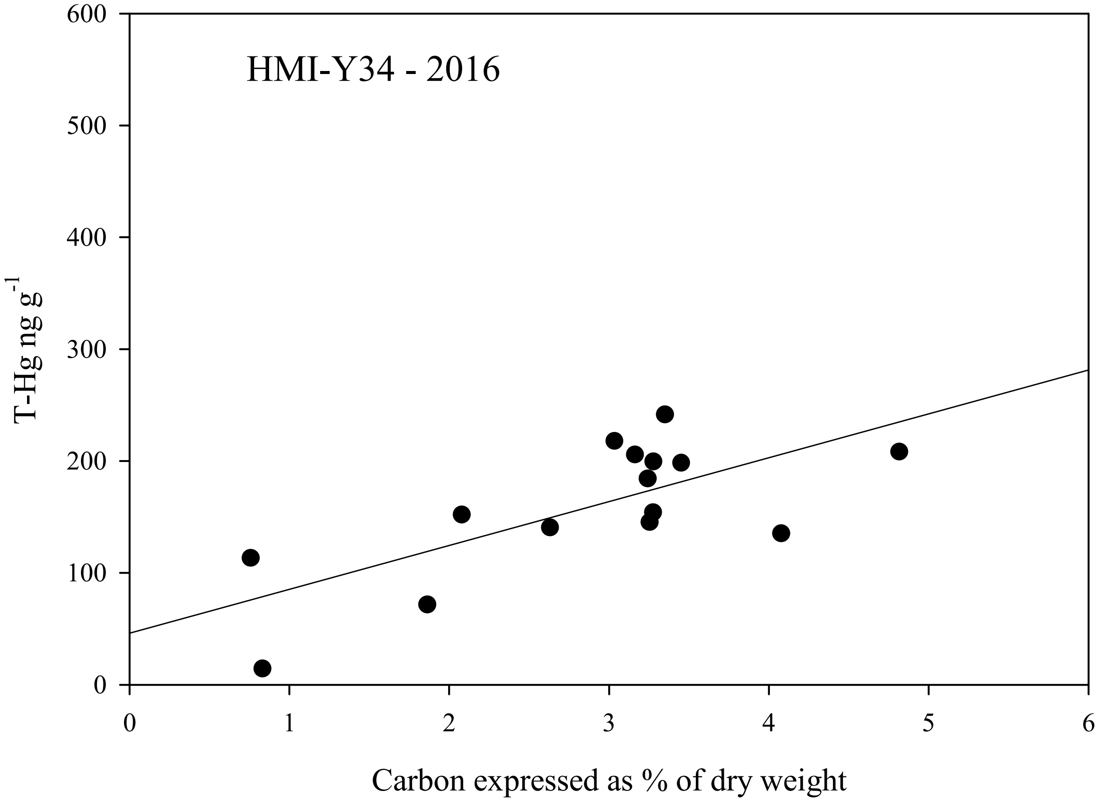


Figure 3-21: Sediment total mercury and carbon concentration in Y34 – September 2016 ($r^2 = 0.51$).

General Conclusions Regarding Trace Element Concentrations

In previous monitoring years, some stations had enrichments in element concentrations when compared to the sites running means. In 2016, only one site was enriched above the standard deviation of the previous years running mean. That was MDE44, and only for Ag.

Concentrations of Se in sediment appear to be trending downward, as concentrations in 2016 appear similar to 2012 through 2014. Concentrations of Ag and As in sediment remain unchanged over the last few years, with As fluctuating more widely. T-Hg concentrations in sediment had been trending upward but this no longer seems to be the case. MeHg concentrations appear to be trending downward in recent years but given the observed temporal variability in other elements it remains to be seen if this is a long lived trend.

The relationships between As, Se and Ag concentrations in sediment suggest either that they either had a similar origin or they had a similar diagenetic behavior once deposited in the sediments around HMI complex for most of the study period. The continued lack of a correlation between Ag and As at sites located Northeast of HMI suggest a different mechanism of delivery or retention for these elements in this area compared to sites elsewhere around the complex. The weakening relationship between Ag and Se from 2011 to 2016 may indicate a divergence of the respective metal sources at some sites or in the diagenetic behavior is changing. The behavior of T-Hg in HMI sediments is different from the other trace elements. T-Hg is seldom correlated with other trace elements, and is more dependent on organic matter and clay content of sediment than the other elements. This might imply a different source such as broad scale atmospheric deposition as being the main driver of Hg distribution but this does not explain the spikes in T-Hg concentration seen in some years at some sites.

Inter-annual variations in the relationships between trace elements, indicated by changing slopes of regression lines is sufficiently great that predicting one element concentration from another elements concentration is not possible. The strength of element to element relationships actually comes from the diversity of sites, not from temporal changes within a site. Spatial and temporal studies of multiple trace elements are rare. Concentrations of Ag, As and Se observed in sediments around HMI are marginally higher than concentrations observed in a study by Moss Landing in 2007 (Sigala et al. 2007) for California Harbors. This is expected given the amount of current and past industrialization of the Baltimore Harbor area compared to these other sites.

Trace Elements in Clams

The clam *Rangia* was collected from 15 stations in the fall (September) of 2016. The stations visited included MDE 1, 13, 15, 16, 17, 19, 22, 27, 30, 34, 36, 42, 43, 44 and 45. Very few clams were observed and collected from MDE 1. In general, concentrations of As, Se, Ag and Cd in these clams are less than the sites running mean concentration determined from the measurements made in previous years. Clams collected from site MDE 45 had Ag concentrations above the mean and median concentration determined from previous years measures (Figure 3-22). Clams at this site has the lowest mean Ag concentration of all sites, are similar to other sites, and the site has a shorter history than most other sites study site. Therefore this observation should not be of concern. Concentrations of Pb were extremely low at all sites compared to those measured in previous years, except those collected from MDE 44. The Pb concentration measured in clams from MDE 44 was 4.2 ug g^{-1}, which is more than twice what has been observed at the site on previous occasions. Such a concentration has been seen at other locations in the past but is unusual both for MDE 44 and compared to other sites studied in Y34.

Concentrations of T-Hg in clams collected in 2016 were close to the running mean of most of the stations from which they were collected (Figure 3-23). The exceptions are MDE 1 and 44, where concentrations were above the mean and median but not outside the standard deviation around the mean determined from previous years measures. The concentration of MeHg in clams collected in 2016 where all lower than the respective mean concentration from previous years measurements with exception being from site MDE 44. At MDE 44, MeHg concentrations were only slightly above the running mean. The proportion of T-Hg that occurred as MeHg (%MeHg) was also low when compared to previous years (Figure 3-23).

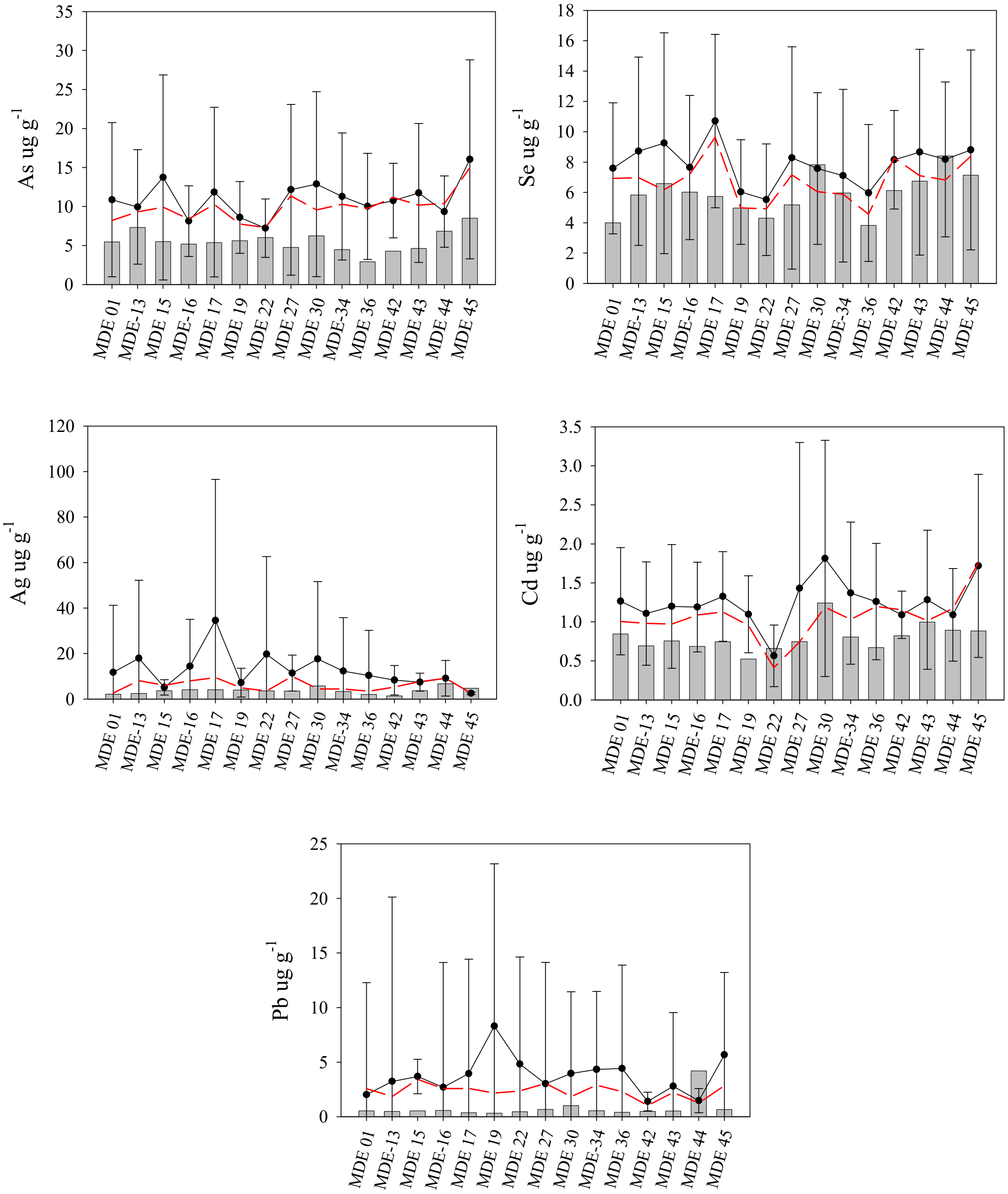


Figure 3- 22: Concentrations of Pb, Cd, As, Se, Ag in clams collected in September 2016. Concentrations (bars) are dry weight based and the 1998-2014 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2014 median (dashed line).

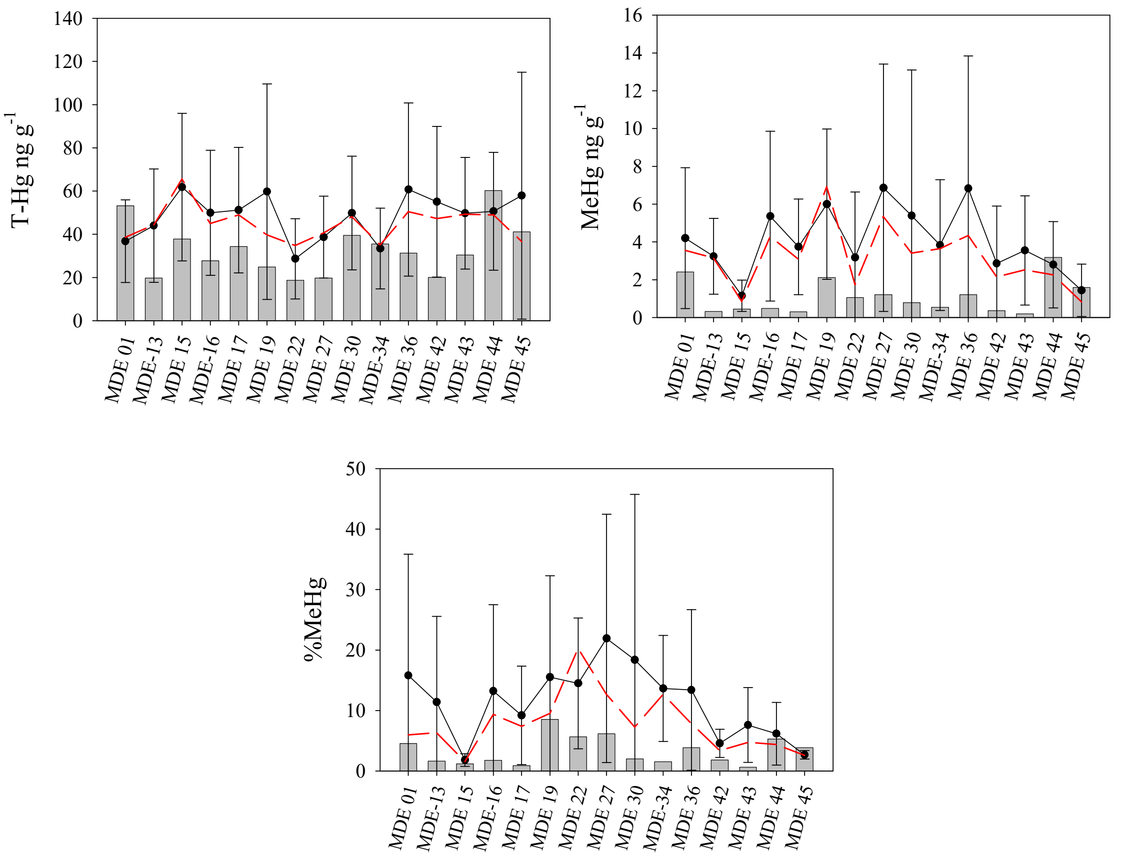


Figure 3- 23: Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent of Hg that is MeHg in clams, collected in September 2016 (bars) and the 1998-2014 mean (circles) with standard deviation (error bars) and the 1998-2014 median (dashed line).

Bioaccumulation Factors

The bioaccumulation factors (BAFs) for the trace elements Cd, Pb, As, Ag, Se, T-Hg and MeHg (Figure 3-24, 3-25) for clams were calculated using clam concentrations in Figures 3-22, 3-23 and sediment in table 3-1. While the station co-ordinates are the same as MGS, boat drifting might result in poor day to day sample co-ordination. Thus, to ensure the best sediment-clam matching, sediment was collected along with the clam collection and analyzed for Cd, Pb, As, Ag, Hg and MeHg.

In September 2016 the BAFs for Pb (not shown in Figures 3-24, 3-25) were less than 1 for all sites. In September 2016 little bioaccumulation of As and Se by the clams was observed (BAFs typically less than 10, Figure 3-24, 3-25). Moderate bioaccumulation of Ag occurred, as BAFs were on the order of 10 or less. No enrichment of T-Hg was recorded except for clams at site MDE 1. Clams at MDE 1 were also enriched in MeHg (BAF of 53) compared to other sites. Sites other than MDE 1had MeHg enrichment factors from 5 to no enrichment at all. Few clams were collected from MDE 1, potentially biasing the data. MDE 1 sediment in Year 34 were very low in both T-Hg and MeHg, which also moves the BAF number toward enrichment

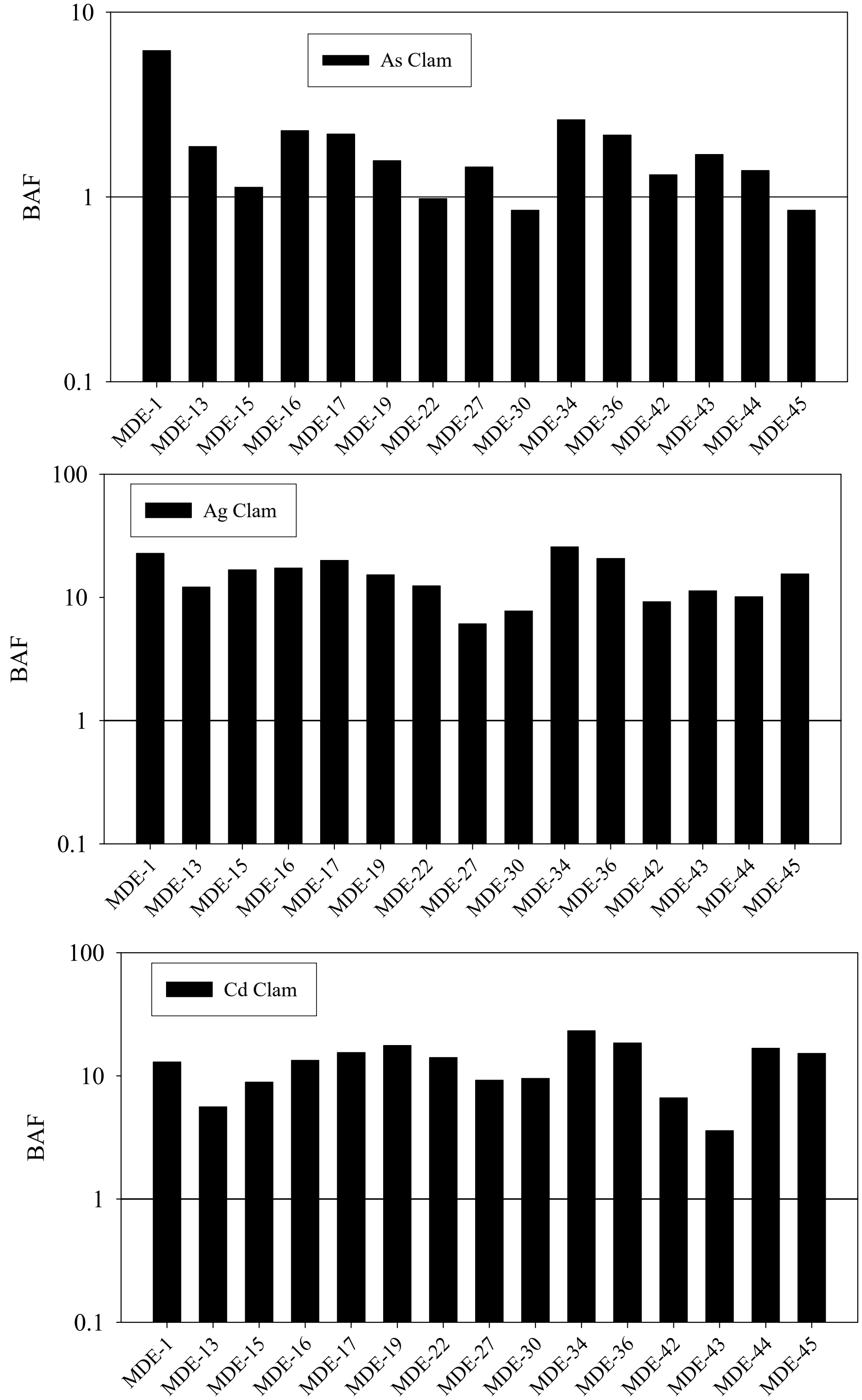


Figure 3- 24: Bioaccumulation factors for the metals As, Ag and Cd September 2016. Note BAF is presented on a log scale.

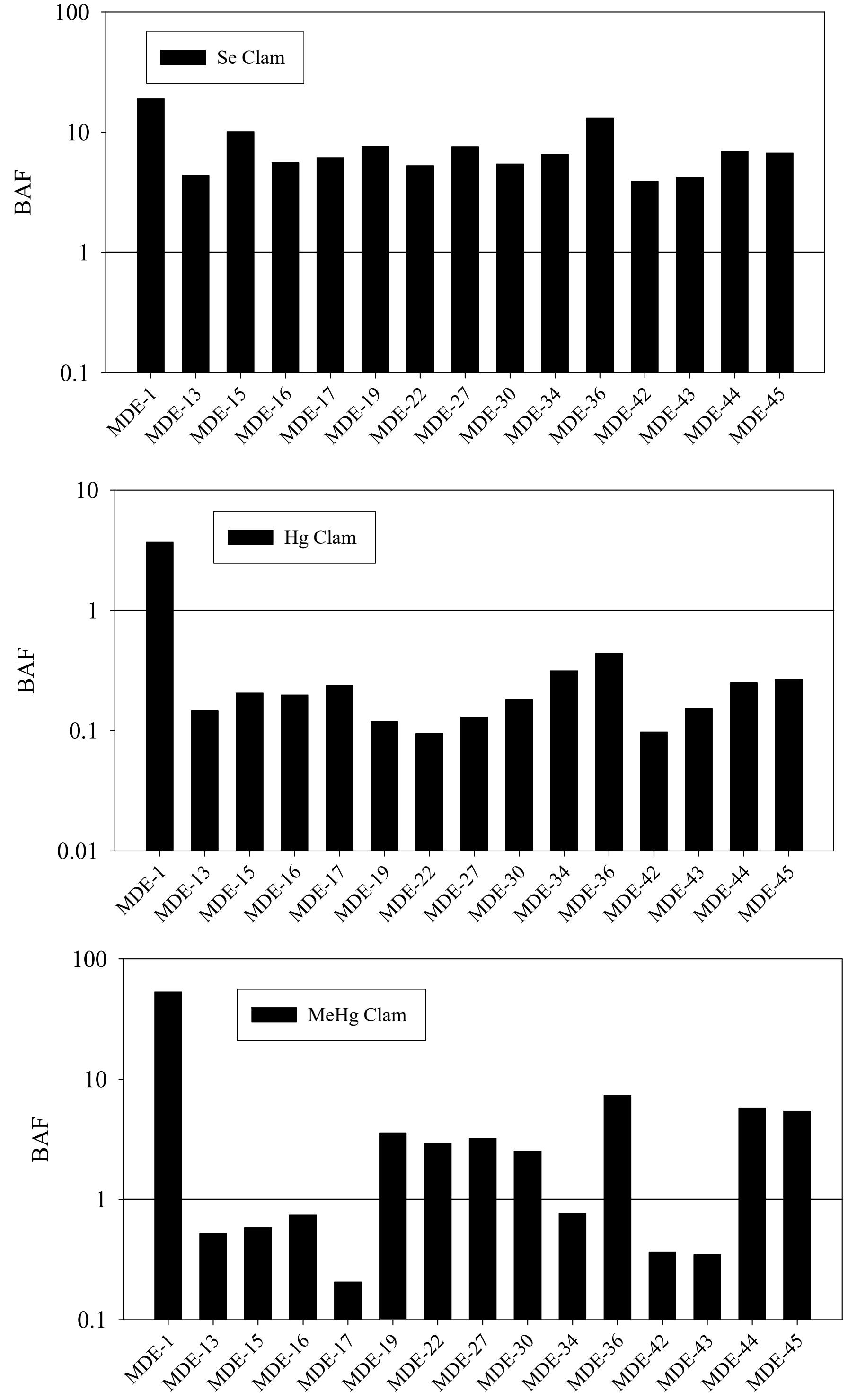


Figure 3- 25: Bioaccumulation factors for Se, Hg and MeHg in September 2016. Note BAF is presented on a log scale.

Table 3- 1: Trace element concentrations in sediment (dry weight) collected along with clams by CBL and MDE in September 2016. The sediment was taken from the same sites but on different dates hence the data is different from what is shown in figures 3-24, 3-25.

Sediment	As	Se	Ag	Cd	Pb	T-Hg	MeHg
Sept.	ug/g dry	ug/g dry	ug/g dry	ug/g dry	ug/g dry	ng/g dry	ng/g dry
MDE-1	0.88	0.21	0.09	0.07	3.99	14.4	0.05
MDE-13	5.00	1.00	0.45	0.35	30.53	135.2	0.62
MDE-15	5.56	0.72	0.35	0.28	28.63	184.3	0.77
MDE-16	4.28	0.98	0.38	0.28	26.36	140.4	0.66
MDE-17	3.49	0.84	0.30	0.27	26.31	145.3	1.46
MDE-19	6.16	0.70	0.38	0.23	26.97	208.2	0.59
MDE-22	7.97	1.06	0.40	0.28	33.91	198.3	0.36
MDE-27	4.61	0.79	0.70	0.39	33.85	151.9	0.38
MDE-30	8.59	0.87	0.67	0.37	41.34	217.9	0.31
MDE-34	4.09	0.96	0.30	0.25	22.36	113.2	0.70
MDE-36	4.02	0.34	0.29	0.18	15.06	71.6	0.16
MDE-42	7.49	0.74	0.41	0.30	35.30	205.6	1.00
MDE-43	6.62	1.02	0.54	0.38	37.85	199.5	0.55
MDE-44	7.53	0.99	0.83	0.40	42.77	241.4	0.55
MDE-45	10.22	1.26	0.46	0.31	34.91	154.08	0.29

Investigating Potential Metal Toxicity

For some trace metals, toxicological affects criteria or guidelines have been established by the National Oceanic and Atmospheric Agency (NOAA). These guidelines have been used as a frame of reference for the overall condition of the sediment around HMI for the elements available. The Probable Effects Levels (PEL) has been plotted along with the sediment trace element concentrations (Figures 3-26 and 3-27). For the metals As, Ag and T-Hg, sediments were below the PEL at all sites sampled in 2016.

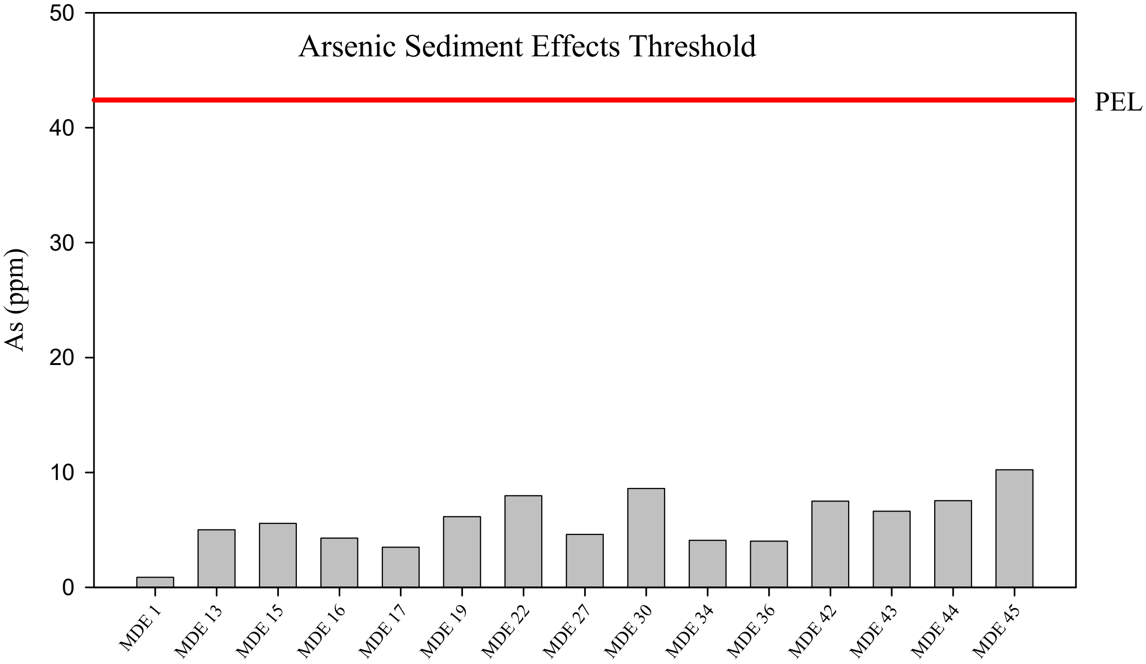


Figure 3- 26: Arsenic (As) concentrations in sediment (MGS collections) along with the Probable Effects Level (PEL) as identified by NOAA for marine sediment.

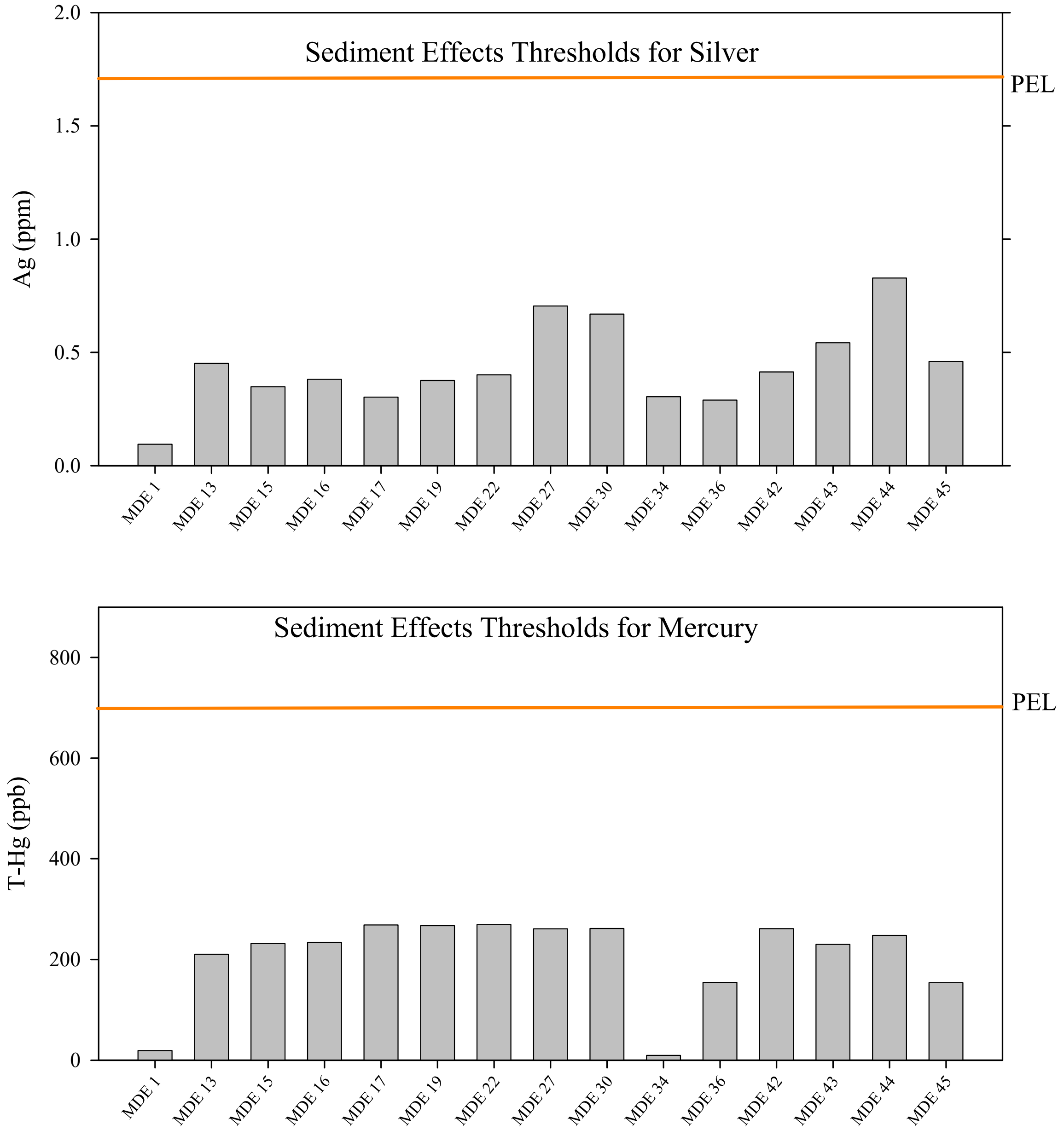


Figure 3- 27: Mercury (Hg) and Silver (Ag) concentrations in sediment (MGS collections) along with Probable Effects Level (PEL) as identified by NOAA for marine sediment.

SECTION SUMMARY

In past years, sediments have been observed from a few sites to be enriched in more than one trace element to a degree well above the sites historic mean concentration calculated from period leading up to that years analysis. In 2016, only site MDE 44 had concentrations of one element (Ag) above the standard deviation of previous measurements. Sediment concentrations of As had been trending upward in recent years, but this may simply be part of the temporal variability that we have observed for it and other trace elements. Sediment concentrations of trace elements tend to rise and fall over a period of years. A prolonged deviation however would suggest changes in source or a change in diagenetic behavior. MeHg concentrations have been trending downward but this may also be part of a longer term cycle.

Concentrations of trace elements in clams were similar to or below concentrations observed in previous years. Bioaccumulation of trace elements by clams was typical in 2016 compared to previous years.

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