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

Year 33 Exterior Monitoring Technical Report

(September 2014)





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Prepared by:

Environmental Assessment

And Standards Program

Maryland Department of the Environment

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 33

(September 2014– August 2015)

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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 33 marks the fifth 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 5 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 33 Exterior Monitoring Technical report, the companion *Year 33 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.

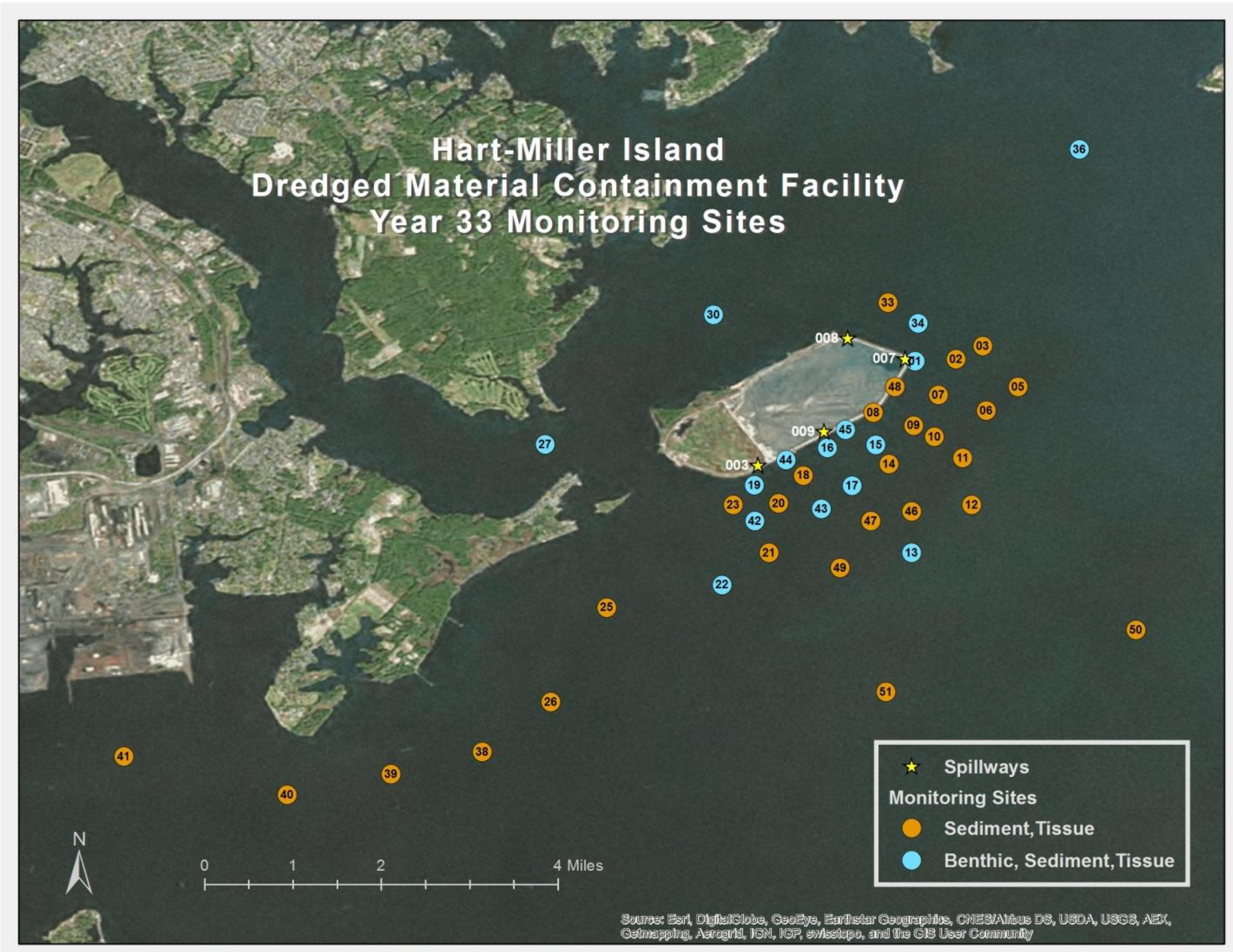
Year 33 represents the fifth consecutive year of post-closure monitoring, and unlike previous years with the exception of Year 32, no spring samples were taken. Now, monitoring continues but with a reduced sampling grid (15 sampling sites), which will be conducted every other year, only in the fall. 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 Port Administration (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 previous years. For Year 33, 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 Year 33 exterior monitoring program, MGS collected bottom sediment samples from 15 sites on September 10, 2014. Spring sampling was not conducted this year. The sampling grid was modified from the previous year, with the reduction of the number of sites from 43 to 15. 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).

An analysis of grain size distribution of the Year 33 sediment samples does not display any clear trends in sedimentation patterns when compared to the previous year. The clay to mud ratios illustrate that the depositional environment was similar during the last six monitoring years. Prior to the last six monitoring years, the depositional environment in the vicinity of HMI was unchanged between Year 27 and Year 28. The areas of high sand content were generally found around the perimeter of the dike in shallow waters and diminish with distance from HMI. The area extending off the northeast tip of HMI has the highest sand content typically around 90 percent. Between September 2008 and April 2009 (Year 27), there was a slight decrease in sand content. By September 2009 (Year 28) sand content in the northeast of HMI was 96 percent sand. At present, the general sediment distribution pattern is consistent with the findings of previous monitoring years dating back to 1988.

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, while at most sampling sites, concentrations of Ni exceed the Effect Range Medium (ERM) values. 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. Therefore, through the grain size normalization procedure that corrects the deficiencies and normalizes the data, findings reveal that Pb and Zn are significantly enriched in some samples compared to the baseline.

Presented in Appendix 1A, the groundwater monitoring report is a summary of the HMI well data collected from six wells on September 30, 2014, December 30, 2014, and June 23, 2014. 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.

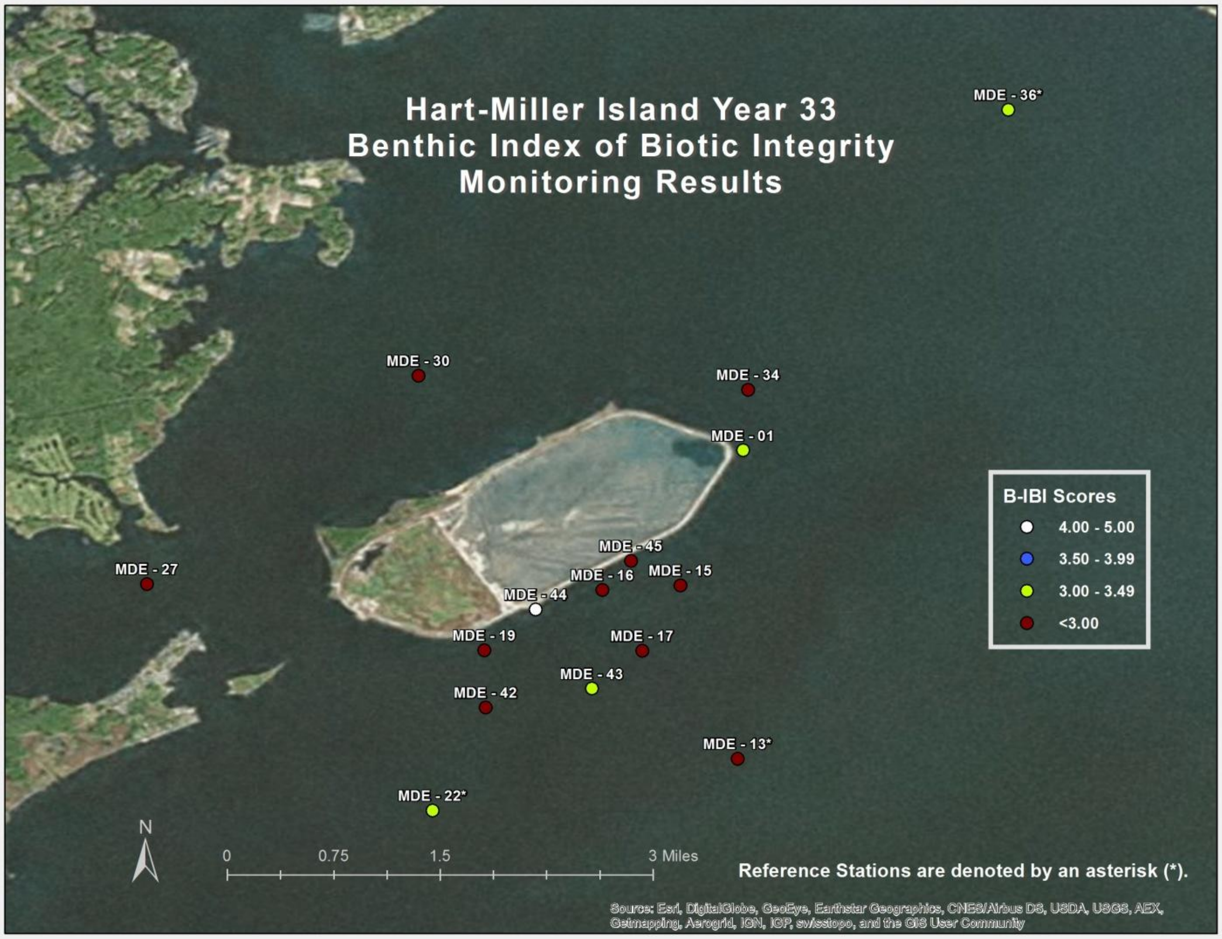
Maryland Environmental Service (MES) analyzed the water samples for the following parameters: pH, temperature, conductivity, dissolved oxygen (DO), oxygen-reduction potential (ORP), salinity, alkalinity, chloride (Cl^-), sulfate, total Kjeldahl nitrogen (TKN), total nitrogen (TN), nitrates/nitrites (NO_3^-/NO_2^-), P, aluminum (Al), arsenic (As), Cd, calcium (Ca), Cr, Cu, Fe, Pb, magnesium (Mg), Mn, potassium (K), silver (Ag), sodium (Na), and Zn. As part of the monitoring effort, the Maryland Geological Survey (MGS) evaluated the results of the MES analyses of the water samples.

Results show that the North Cell Well 2A is the only well that continues to have a reducing environment, whereas Wells 4A, and to a lesser degree, 6A, are more similar to the oxidizing environment seen in the South Cell wells. After October 2012, multiple field and metal parameters in all wells show irregular fluctuations, but they are not necessarily seasonal. These fluctuations in water chemistry are interpreted to be delayed responses to operation activities in the North Cell and to weather events; the degree of responses affected by a number of factors including well location, depth and differences in inflow (sediment) and dike wall composition. On average, metal concentrations in both the North and South Cell wells have shown a decreasing trend this monitoring year. Cu and Pb remain below the detection limit in both cells. Fe and Mn are the only metals with concentrations that exceed the EPA Secondary Maximum Concentration Levels (SMCL) in both cells.

PROJECT III: Benthic Community Studies

The benthic macroinvertebrate community in the vicinity of the HMI DMCF was studied for the thirty-third consecutive year under Project III of the HMI Exterior Monitoring Program. Benthic communities living close to the facility [Nearfield, South Cell Exterior Monitoring (formerly called South Cell Restoration Baseline), and Back River/Hawk Cove stations] were compared to communities located at some distance from the facility (Reference Stations). Water quality parameters, including dissolved oxygen concentrations, salinity, temperature, pH, conductivity, and Secchi depth were measured *in situ*. Fifteen stations (7 Nearfield, 3 Reference, 2 Back River/Hawk Cove, and 3 South Cell Exterior Monitoring stations) were sampled on September 18, 2014. Unlike previous years, no spring cruise was conducted due to scaling back of monitoring efforts.

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.



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

The health of the benthic macroinvertebrate community around HMI in Year 33 was worse than historical averages. In Year 33, as in Year 32, B-IBI's around the island were at or near historical lows at all sites. Ten of the 15 stations failed to meet the benchmark criteria of 3.00. 14 of the 15 stations performed below their historic averages. Five stations tied their historic lows; and no stations met their historic highs. Year 33 is the fifth consecutive year where B-IBI's have been trending downward. The exception to this trend was at the South Cell Exterior Monitoring stations, which improved from the past four years and were at their historic means. The five year decline in B-IBI's can be attributed to fluctuations in the invertebrate community. They include decreases in the relative abundance of the pollution sensitive bivalves' *R. cuneata* and *M. balthica*. Another fluctuation was a very high average abundance of the pollution indicative polychaete worm, *S. benedicti*. Lastly, the abundance of many organisms was especially high causing decreases in the total infaunal abundance metric scores and the relative Pollution Sensitive Taxa Abundance metric. The increase in *S. benedicti* contributed to a decline in the Shannon Weiner Diversity Index metric and a worsening in the Pollution Indicative Taxa Abundance metric scores.

The statistical analyses did not indicate that the stressed benthic invertebrate communities measured at stations in September 2014 were due to any adverse localized impacts from HMI operational discharges. Stressed benthic communities throughout the monitoring area were likely the result of large-scale Bay-wide and regional factors.

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 33 were to collect clams and associated sediment in the fall of 2014 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. Both sediment and clams were analyzed for mercury (Hg), methylmercury (MeHg), silver (Ag), selenium (Se) and Arsenic (As), and clams were also analyzed for lead (Pb) and cadmium (Cd). The concentrations of target trace elements in surface sediments in a number of stations were also determined.

Additionally, the clam *Rangia Cuneata* was collected from 15 stations in the fall (September) of 2014, and in general, concentrations of As, Se, Ag and Cd in these clams were similar to the each of the sites running mean concentration that was 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 33rd year exterior monitoring program, MGS collected bottom sediment samples from 15 sites on September 10, 2014. Spring sampling was not conducted this year. The sampling grid was modified from the previous year, with the reduction of the number of sites from 43 to 15. An analysis of grain size distribution of the Year 33 sediment samples does not display any clear trends in sedimentation patterns when compared to the previous year. 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 33.

This year's monitoring documents slight increases over the previous year in enrichment of Cd, Cu, and Ni around the HMI facility; however, concentrations of Cr, Fe, Mn, Pb, and Zn decreased compared to Year 32 sampling (compared to both the 43 sample stations and the overlapping 15 sample stations). For Year 33, enrichment of Ni was above background levels. These enriched levels indicate a need for continued monitoring, particularly since the facility has experienced water quality issues related to crust management operations and unusual weather events resulting in high influxes of fresh water to the facility.

Previously, metal concentrations were typically too high and pH was too low to discharge from the North Cell. This year, MES documented that Spillways 007 and 008 have a more neutral pH, and discharge was allowed for each of those spillways during the summer and/or fall of 2014. Metal concentrations and pH at Spillway 009 did not meet discharge permit limits. 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 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 33 was worse than historical averages. In year 33, as in year 32, B-IBI's around the island were at or near historical lows. Ten of the 15 stations failed to meet the benchmark criteria of 3.00. Fourteen of the 15 stations performed below their historic averages. Five stations tied their historic lows; and no stations met their historic highs. Year 33 is the fifth consecutive year where B-IBI's have been trending downward. The exception to this trend was at the South Cell Exterior Monitoring stations, which improved from the past four years and were at their historic means. The five year decline in B-IBI's can be attributed to fluctuations in the invertebrate community. They include decreases in the relative abundance of the pollution sensitive bivalves' *R. cuneata* and *M. balthica*. Another fluctuation was a very high average abundance of the pollution indicative polychaete worm, *S. benedicti*. Lastly, the abundance of many organisms was especially high causing decreases in the total infaunal abundance metric scores and the relative Pollution Sensitive Taxa Abundance metric. The increase in *S. benedicti* contributed to a decline in the Shannon Weiner Diversity Index metric and a worsening in the Pollution Indicative Taxa Abundance metric scores.

The statistical analyses did not indicate that the stressed benthic invertebrate communities measured at stations in September 2014 were due to any adverse localized impacts from HMI operational discharges. Stressed benthic communities throughout the monitoring area were likely the result of large-scale Bay-wide and regional factors. Future monitoring plans: MDE proposed and MPA accepted the continuation of benthic monitoring at a reduced level until stabilization of the island is complete. This will involve the continued sampling 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. This was also the case in 2014. However, only site MDE 43 had concentrations of more than one element above the standard deviation of previous measurements. Sediment concentrations of As have 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. Concentrations of trace elements in clams were similar to or below concentrations observed in previous years. Bioaccumulation of trace elements by clams was low in 2014 compared to previous years.

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APPENDIX 1: SEDIMENTARY ENVIRONMENT (PROJECT II)

(September 2014 - June 2015)

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 33rd year of the continuous monitoring of the sedimentary environment in the vicinity of the HMI Facility. As part of the 33rd year exterior monitoring program, MGS collected bottom sediment samples from 15 sites on September 10, 2014. Spring sampling was not conducted this year. The sampling grid was modified from the previous year, with the reduction of the number of sites from 43 to 15. In anticipation of reduced discharge from the facility, future monitoring will be conducted on a biennial basis, utilizing the modified sampling grid of 15 sites. 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 33 sediment samples do not show any clear trends in sedimentation patterns when compared to the previous year. The clay to mud ratios illustrate that the depositional environment was similar during the last six 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 33.

Elemental analyses data indicate that the sediment elemental concentrations are similar to the previous year including the anomalously high Cr value measured at a sampling site in the Baltimore Harbor Zone of Influence. This Zone has consistently exhibited high metals concentrations in previous years. 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.

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-9, -11, -13, -14, -18, 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. Zn concentrations in these samples are enriched from Baltimore Harbor and exhibit a decreasing enrichment from HMI. 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. Two sites in the HMI Zone showed significant enrichment of Ni in Year 33. This year, in terms of absolute concentration, Ni exceeds ERMs at most sites.

This year's monitoring documents slight increases over the previous year in enrichment of Cd, Cu, and Ni around the HMI facility; however, concentrations of Cr, Fe, Mn, Pb, and Zn decreased compared to Year 32 sampling (compared to both the 43 sample stations and the overlapping 15 sample stations). For Year 33, enrichment of Ni was above background levels. These enriched levels indicate a need for continued monitoring, particularly since the facility has experienced water quality issues related to crust management operations and unusual weather events resulting in high influxes of fresh water to the facility. Previously, metal concentrations were typically too high and pH was too low to discharge from the North Cell. This year, Maryland Environmental Service (MES) documented that Spillways 007 and 008 have a more neutral pH, and discharge was allowed for each of those spillways during the summer and/or fall of 2014. Metal concentrations were too high and pH was too low for discharge out of Spillway 009. 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 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.

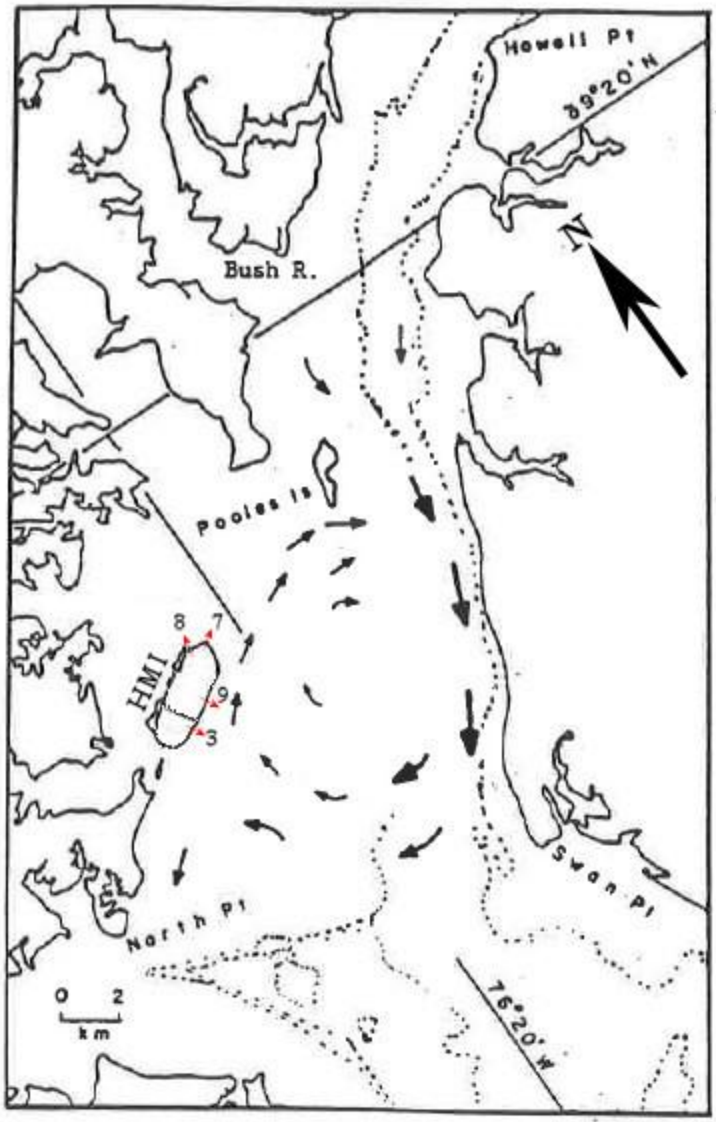


Figure 1- 1: Schematic surface gyre circulation in the upper Chesapeake Bay and relation to HMI DMCF (modified from Wang, 1993). Red arrows indicate approximate location of the HMI DMCF spillways; numbers 3, 7, 8 and 9 identify spillways 003, 007, 008 and 009, respectively.

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 for Year 33, 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 1997 sediment characterization of Baltimore Harbor and Back River (Baker *et al.*, 1998). During Year 22 monitoring, near record rainfall levels in the area strongly influenced the hydrodynamic flow, resulting in the incursion of Baltimore Harbor material into the HMI zone. This sampling period was the only time in the 33 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, but in the 33rd year, monitoring was reduced to 15 stations with a biennial sampling scheme in the fall. This year represents the fifth year of the post-closure monitoring phase and covers only the reduced number of stations for this fall sampling (Cruise 68). Figure 1-2 shows the sampling locations for Years 27-32 and Year 33 for sample collection comparison.

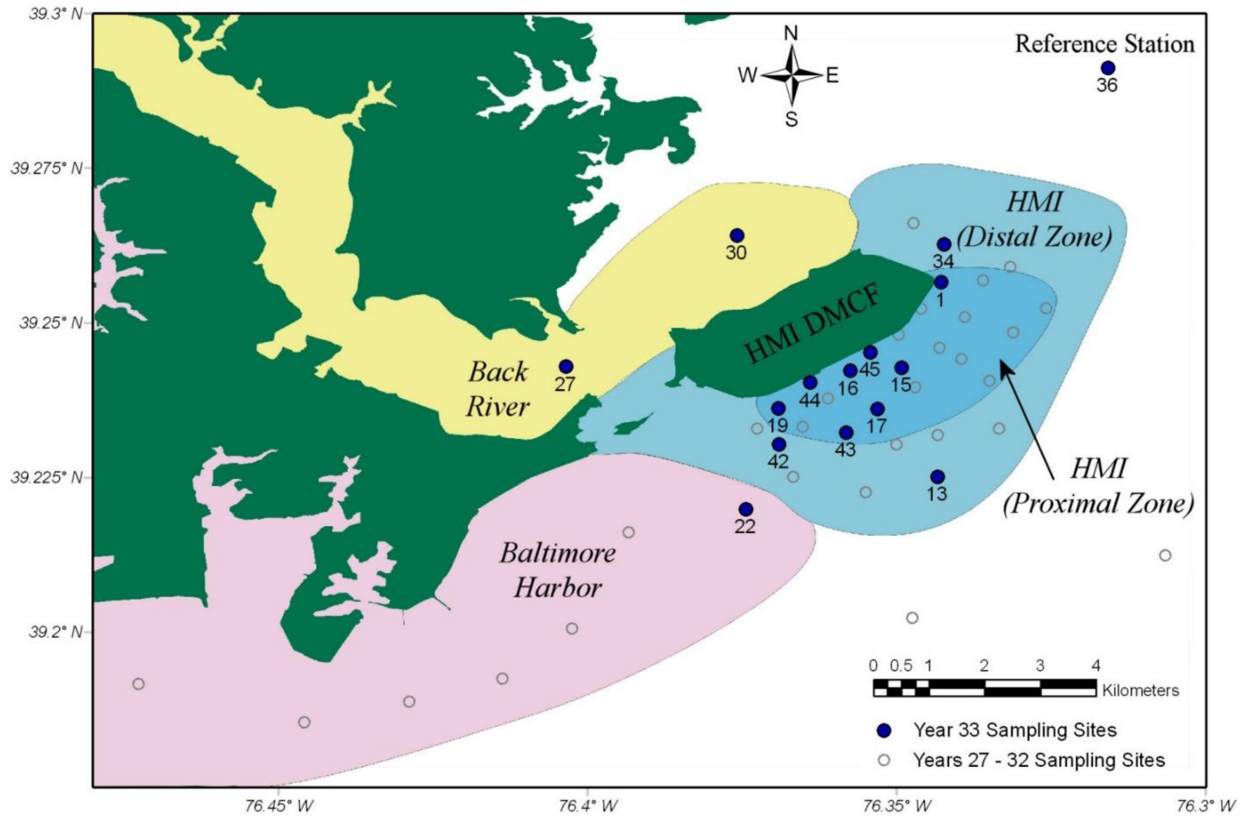


Figure 1- 2: Sampling locations for Year 33 (solid blue circles) and Years 27 through 32 (gray circles). Color areas show zones of influence found in previous studies. Stations 38 – 41 (not numbered) were added in Year 18 to measure the influence of Baltimore Harbor. Starting in Year 27, four stations 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 33 cruise (68) are summarized below. Information covering the period from April 1, 2014 to April 30, 2015 was provided by Carolyn Blakeney, 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 September 2013 and September 2014. The trend in monthly total precipitation recorded at HMI generally tracked that of BWI.

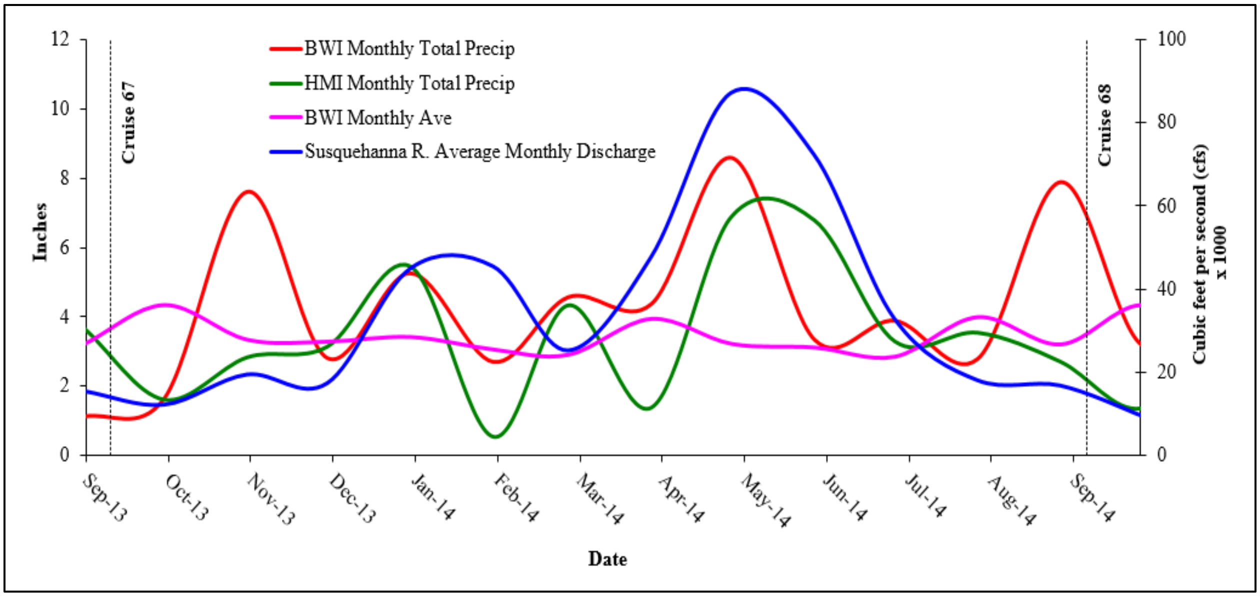


Figure 1-3: Comparison of monthly precipitation data collected at HMI Facility and at the National Weather Service (NWS) Station at BWI (NOAA, 2015) with the average monthly discharge of the Susquehanna River. BWI monthly averages were based on monthly precipitation data from 1983 to 2014. Susquehanna River data were obtained from the USGS website (U.S.G.S, 2014).

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 33,344 cubic feet per second (cfs), and the April-September average, representing the dry or low flow season, was 39,504 cfs. The April-September average is extremely high due to several multiple day rain events throughout the season. 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 at Spillway 009 (Amanda Peñafiel, pers. Comm. 10/20/2015). After having no discharges from the North Cell into the Bay due to water quality issues within the cell in Year 32, during the summer months of 2014, there was discharge from Spillways 007 and 008 (Amanda Peñafiel, pers. Comm. 10/1/2014). Discharge from the North Cell Spillways lasted several months (Figure 1-4) before the water quality degraded (e.g. Low pH) (Amanda Peñafiel, pers. Comm. 10/1/2014). All periods of discharge for Spillways 007 and 008 were very low flow (i.e. < 2.0 mgd). In October 2014, Spillway 009 monitoring continued to show low pH. No discharge occurred from Spillway 009 during the 33rd year of monitoring.
A lime plan was developed and discharge from Spillway 007 was treated in March 2015 and discharge from Spillway 008 was treated in April 2015 (Amanda Peñafiel, pers. Comm. 10/20/2015).

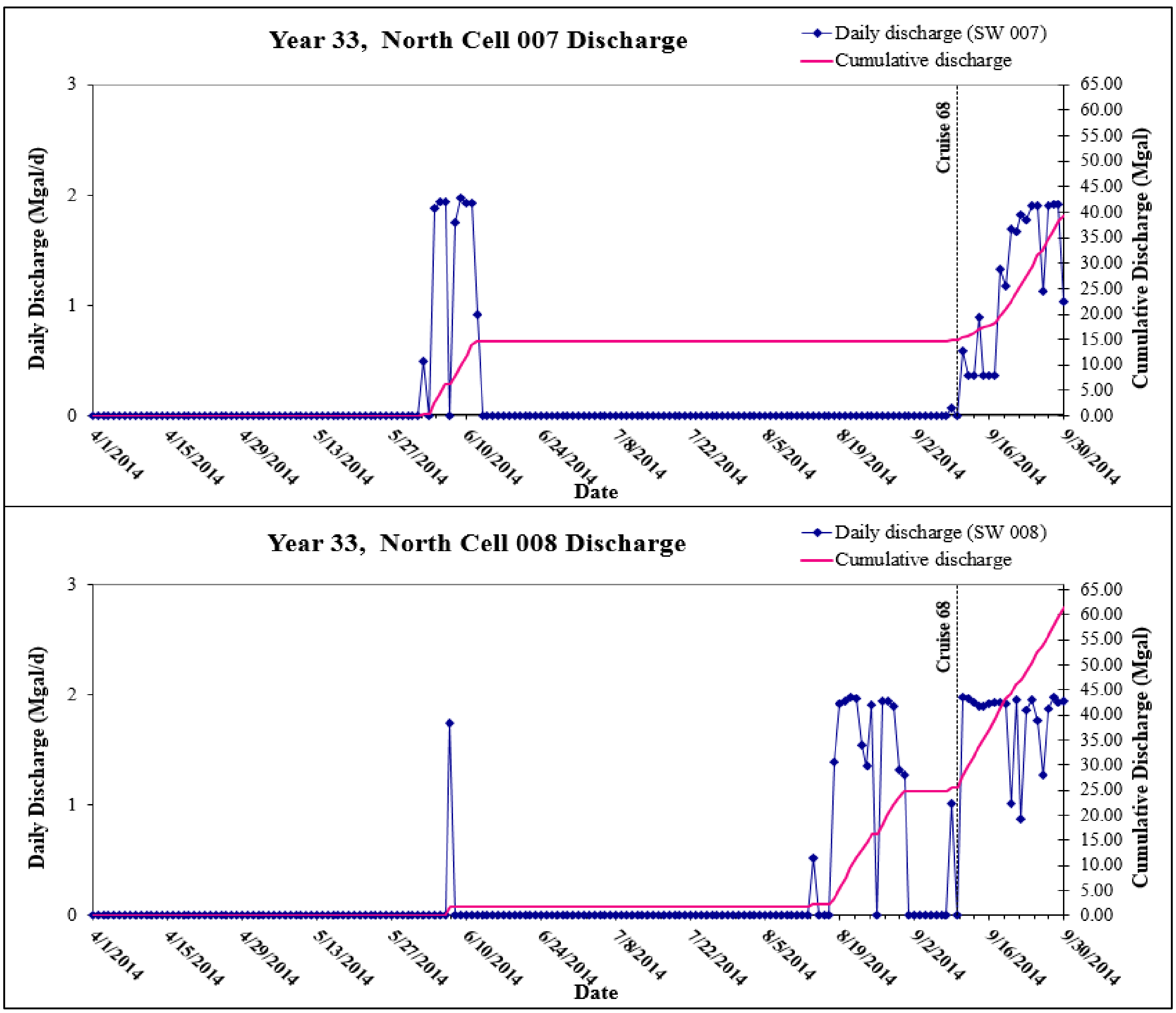


Figure 1- 4: Daily and cumulative discharge from North Cell Spillways 007 and 008 for the late spring to early fall time frame where discharge was released from the Spillways. This

year was the first time in several years that discharge was released from either of these spillways.

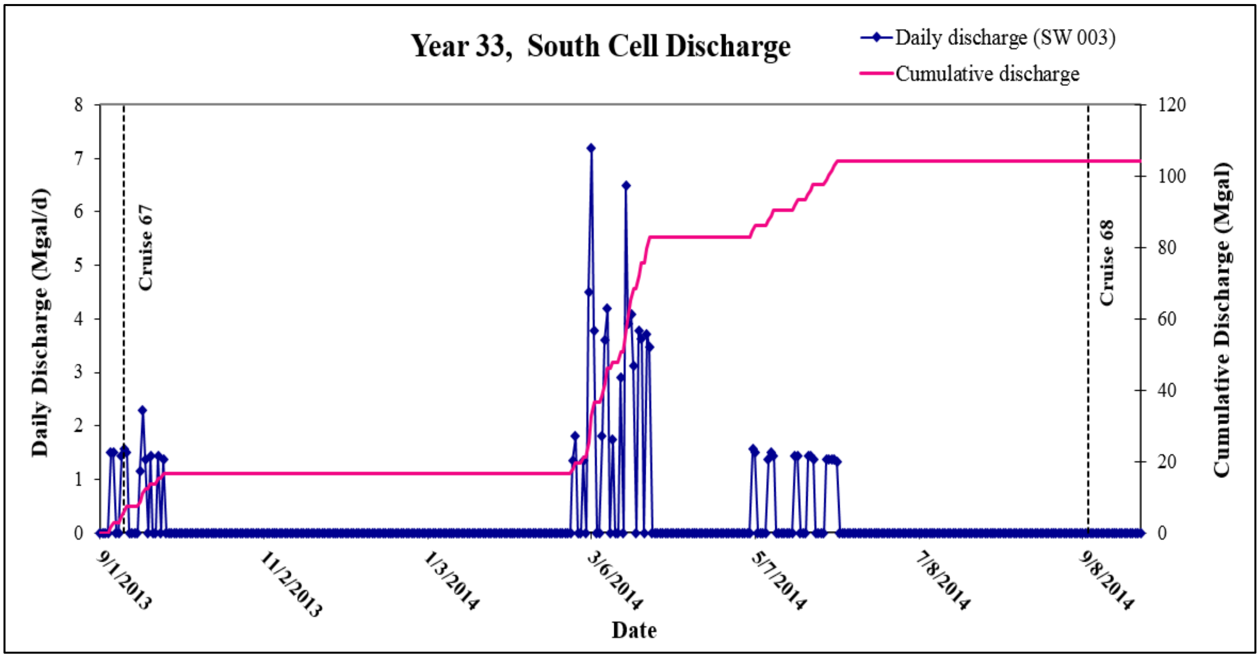


Figure 1- 5: Daily and cumulative discharge from the South Cell for the 13 month period covered in this report. The discharge from the South Cell is from SW003, which is the only discharge point for the cell. The three discharges from SW003 were done to maintain the pond level. Exterior sediment sampling events (*i.e.* sampling cruises) are marked by the vertical line.

There were two periods of very low flow (*i.e.*, < 2.0 mgd) discharges from the South Cell (Figure 1-5). Both discharges were done to reduce the pond level. Both discharges were within the discharge permit criteria. High discharge was released from the South Cell between February 27, 2014 and March 28, 2014, to reduce the pond level after locally high rainfall events. Year 32 sampling took place during the first discharge, while Year 33 sampling took place months after the third. Between Cruise 67 (September 10, 2013) and Cruise 68 (September 10, 2014), total cumulative discharge from the South Cell into the Bay was 98.4 million gallons.

OBJECTIVES

As with previous monitoring years, the main objectives of the Year 33 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 10, 2014 (Cruise 68) aboard the *R/V Kerhin*. This cruise was the first to have a reduced number of sample sites (15) and no samples were collected in the following spring, making it comparable to Year 32.

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 33 sample locations are reported in the companion *Year 33 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 more recent monitoring cruises.

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. A second subsample was taken from each grab at all stations and analyzed by the Chesapeake Biological Laboratory (CBL) for a different suite of trace metals. Field descriptions of samples are included as appendices in the *Year 33 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 sub-samples were placed in 18-ounce Whirl-Pak^{TM} bags and refrigerated. The samples were maintained at 4^{o} Celsius (C) until they could be processed in the laboratory. CBL's splits were handled in much the same way, except that these samples included the floc layer and were frozen instead of refrigerated.

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:

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

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

Water weight was determined by weighing approximately 25 g of the wet sample, drying the sediment at 65^{o}C, and reweighing it. The difference between total wet weight (Wt) and dry weight equals water weight (Ww). Bulk density was also determined from water content measurements.

The relative proportions of sand, silt, and clay were determined using the sedimentological procedures described in Kerhin *et al.*, (1988). The sediment samples were pre-treated with hydrochloric acid and hydrogen peroxide to remove carbonate and organic matter, respectively. Then the samples were wet sieved through a 62 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).

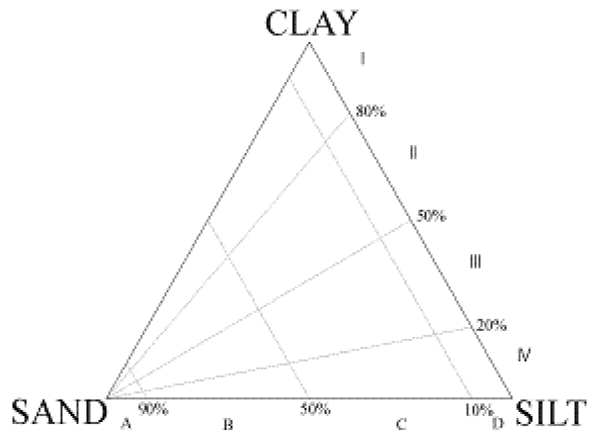


Figure 1- 6: Pejrup's Diagram (1988) classification of sediment type.

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 Neutron Activation Analysis (NAA) and a four acid “near total” digestion technique followed by analysis on an Inductively Coupled Argon Plasma Spectrometer (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 33 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 12 to 15 unknowns (samples) and standards. Replicates of every seventh sample were also run. As a secondary standard, one of several NIST SRMs was run after every six to seven 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 33 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 33 results are discussed with respect to the preceding Year 32 results, and where appropriate, with references to earlier monitoring year results.

All sampling sites visited during Year 33 yielded results that can be compared to those same stations measured in Year 32. Even though Year 32 had more samples, the station numbers that were collected during Year 33 are comparable to the station numbers collected prior to 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 32 for 43 sediment samples common to the past sampling scheme, alongside Year 32 and Year 33 sediment samples common to the current, 15 sample, sampling scheme.

Variable	Sept 2013 Year 32, Cruise 67 (43 samples)	Sept 2013 Year 32, Cruise 67 (15 samples)	Sept 2014 Year 33, Cruise 68 (15 Samples)
Sand (%)			
Mean	21.38	19.49	19.36
Median	3.35	3.35	3.55
Minimum	0.70	0.90	1.21
Maximum	95.36	92.24	96.70
Range	94.66	91.34	95.50
Count	43	15	15
Clay: Mud			
Mean	0.53	0.52	0.56
Median	0.53	0.53	0.56
Minimum	0.38	0.39	0.49
Maximum	0.65	0.61	0.63
Range	0.26	0.22	0.14
Count	43	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 67 and 68), most points lie above the 50% line (clay-silt boundary), indicating that the fine (muddy) fraction of the sediments contains more clay than silt.

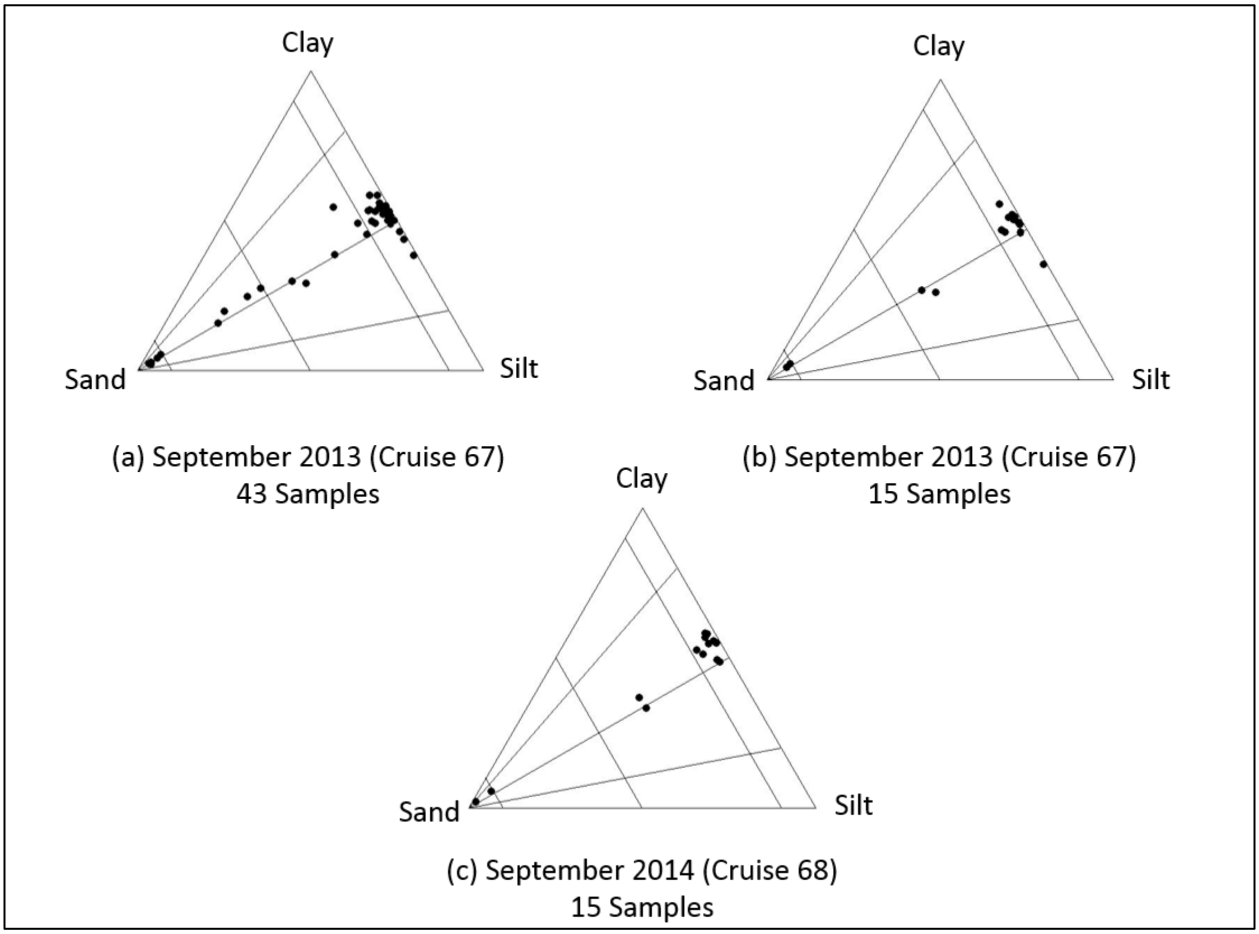


Figure 1- 7: Pejrup's diagrams showing the grain size composition of sediment samples collected in Years 32 and 33: (a) September 2013 results with all 43 samples collected that during that sampling cruise, (b) September 2013 results of only the 15 overlapping sampling sites that were sampled in Year 33, and (c) the 15 sites collected in September 2014. 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. The mean percentage of sand varied approximately 3% for both samplings, with all data from Cruise 67. When comparing the overlapping 15 stations from each year, sand content and clay: mud are nearly identical.

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 Figures 1-9 and 1-10, three contour levels represent 10%, 50%, and 90% sand, coinciding with the parallel lines in Pejrup's diagram (Figure 1-6). Generally, sand content diminishes with distance from the containment facility. Scattered around the perimeter of the dike, the sandiest sediments (>50% sand) are confined to relatively shallow (<15 ft) waters.

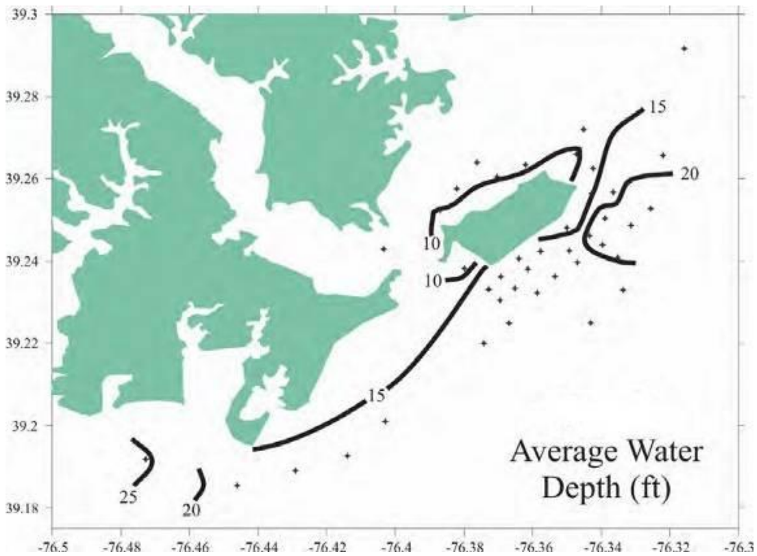


Figure 1- 8: Average water depths around HMI and vicinity, utilizing bathymetric data prior to Year 33 in order to have a larger sample size with more data. Contour interval = 5 ft.

Broadest north and west of the facility, the shoals are the erosional remnants of a larger neck of land. The once continuous landmass has been reduced to a series of islands, including Hart and Miller 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 (*e.g.,* MDE-30) contain less than 10% sand. The sand distribution map for Year 33, shown in Figure 1-9, is similar in appearance to the sand distribution map from the previous September (Cruise 67) (Wells *et al.,* 2014). Sand contents continue to be highest near the perimeter of HMI in shallow water depths. At the northeast end of the facility, the broad sand area, as defined by the 90% contour, underwent subtle seasonal shifts. The contour lines marked in Figure 1-9 for Year 33 are very similar to the contour lines from the previous year for that area. In general, the distribution of sand around HMI, according to the new 15 sample scheme, 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 slightly 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, 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. The small area of clay-rich sediment adjacent to Spillway 003 is slightly higher than historic ratios and the spillway effluent may be curious. The effluent may be contributing some clay-sized sediment, which is illustrated with the contours in Figure 1-10.

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.

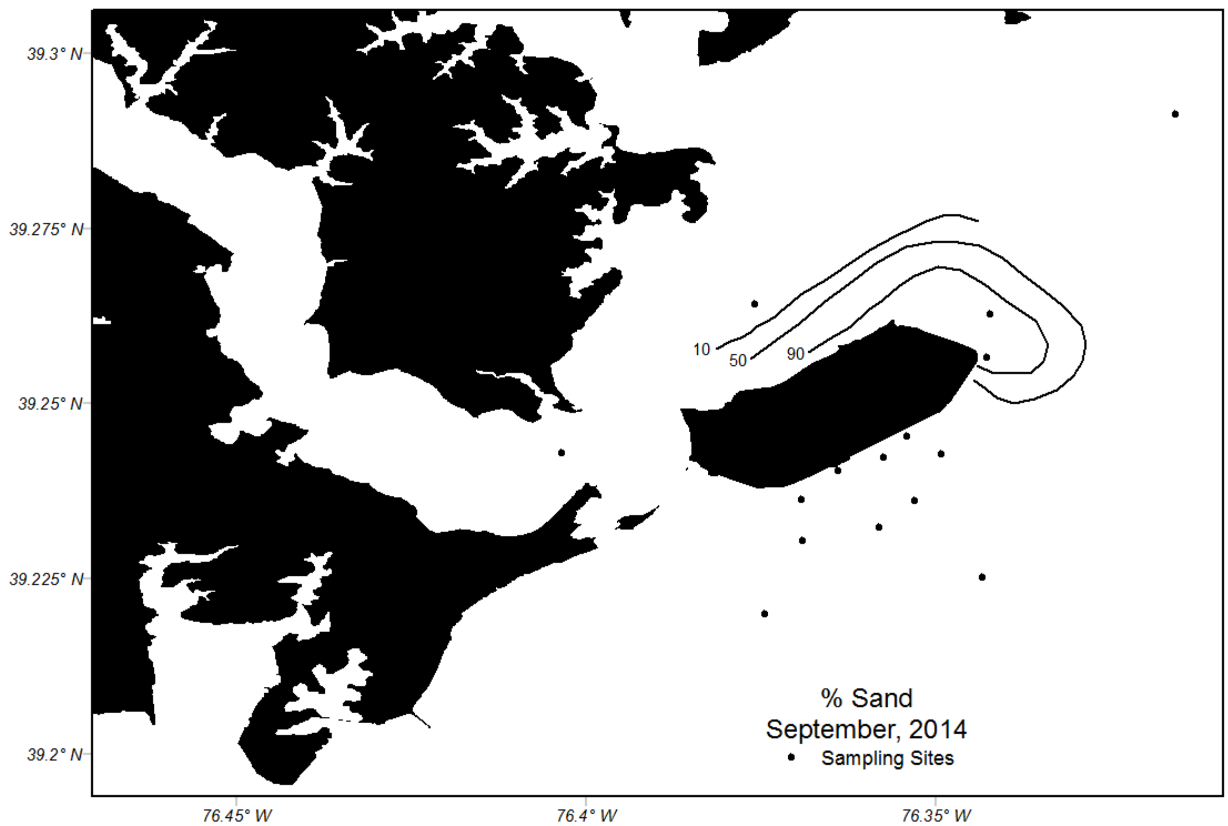


Figure 1- 9: Sand distribution for Monitoring Year 33 which included one sampling cruise: September 2014 (Cruise 68). Contour intervals are 10%, 50%, and 90% sand.

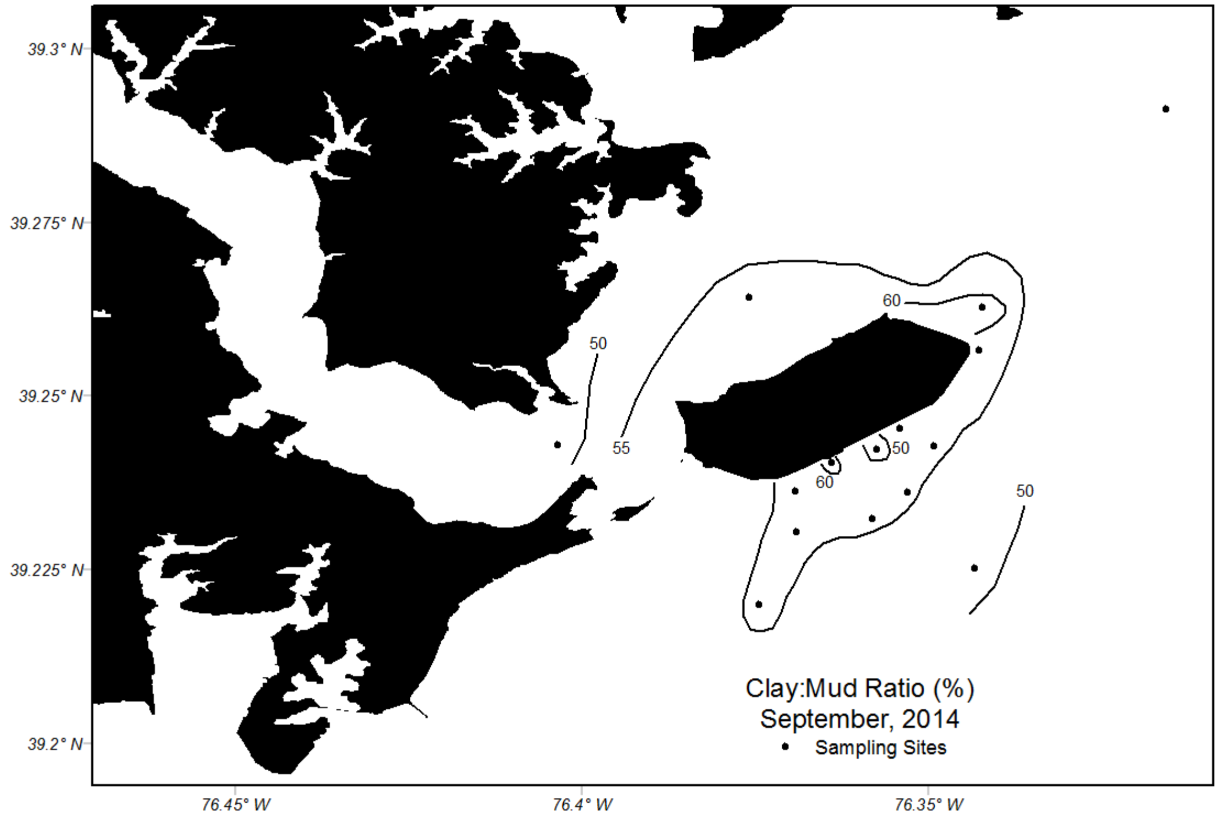


Figure 1- 10: Clay:Mud ratios for September 2014 (Cruise 68). Contour intervals are 50%, 55%, and 60% (clay:mud ratio expressed as %).

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 references 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) 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	71.92	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	0.82	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.

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

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

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

In Equation 3, 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 ±3σ can be within accepted background variability, but are considered marginal depending on the trends in the distribution. Any values falling outside this range indicate a significant perturbation to the environment. The standard deviation (σ) of the baseline data set (the data used to determine the coefficients in Equation 2) is the basis for determining the sigma level of the data. Each metal has a different standard deviation, as reflected in the R^2 values in Table 1-2. The sigma level for Zn is ~30% (e.g. 1σ = 30%, 2σ = 60%, etc.).

General Results

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 concentrations of Zn exceed the ERM values at some sites.

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 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.

Table 1-3: Summary statistics for elements analyzed for Year 33. All concentrations are in ug/g (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	0.5	87	42	3.95	2553	73	47	270
Std	0.1	43	21	2.03	1354	31	21	127
Min	0.3	10	7	0.39	656	15	10	56
Max	0.9	125	67	5.41	5110	103	81	398
N	11	15	15	15	15	15	15	15
ERL	1.3	81	34	n/a	n/a	21	47	150
#>ERL	0	12	12			14	11	12
ERM	9.5	370	270	n/a	n/a	52	218	410
#>ERM	0	0	0			11	0	0

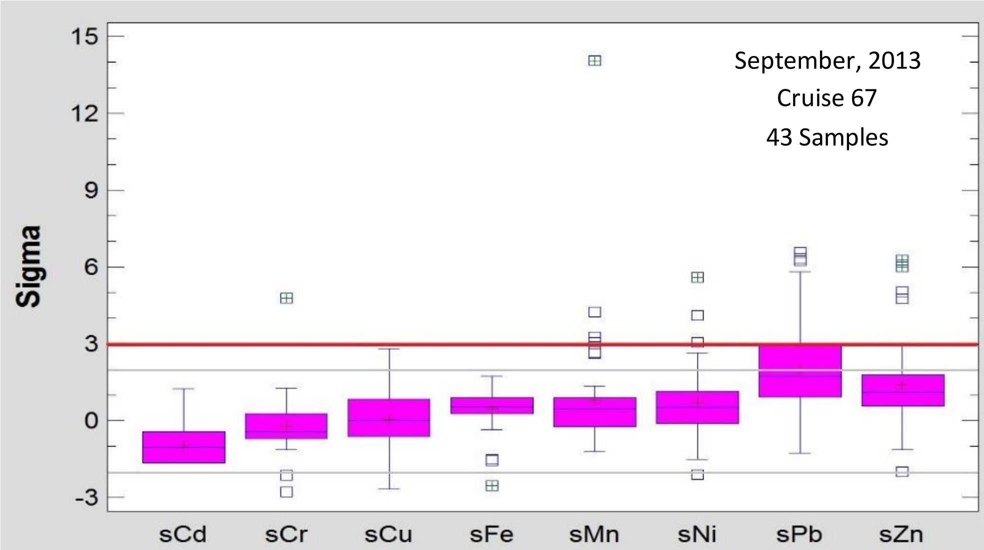
The values presented in Table 1-3 are the measured concentrations of metals in the sediment, not normalized with respect to grain size variability, as outlined in the preceding *Interpretive Techniques* section. Figure 1-11 shows the variation of the data from the predicted baseline behavior for each of the elements measured for the last two cruises (Cruise 67, all 43 samples and the selected 15 to be sampled in the future, and Cruise 68). 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 samples similar to both cruises, all but 8 samples came back within the range expected for normal baseline behavior (i.e., between +/- 2 sigma) in this area. Two of the 15 samples (MDE-27 and -30) contain Pb significantly exceeding the baseline levels (*i.e.*, >3 sigma levels, indicated by red line) and there is one sample (MDE-34) where Mn and Ni levels significantly exceed the baseline. For the most part, there has been a decrease in the overall enrichment of many of the elements within the 15 samples that are now collected. However, many of the previous sample sites with highly enriched sediments are no longer being collected (including, but not limited to, MDE-14, -18, -26, -38 and -39). 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:

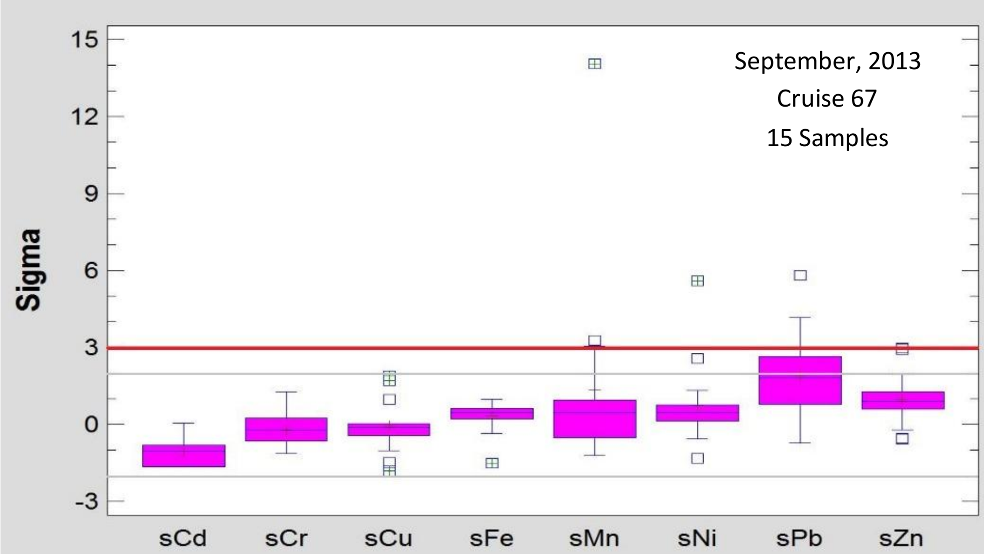
1. When the sigma level exceeds +2 [indicating enriched metals concentrations over baseline] and;
2. When the metals level exceeds the ERL with increased probability as the level exceeds the ERM [showing absolute concentrations that have exhibited adverse effects in other systems].

Sediments from a handful of sites met these conditions. Samples for the September 2014 cruise from sites within the Back River Zone contained multiple metals exceeding ERLs and ERMs or ERMs and sigma levels great 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 site MDE -45. Starting in Year 33, samples are no longer taken from the Baltimore Harbor Zone of Influence.

Figure 1- 11 (following page): A box and whisker diagrams showing the ranges of the sigma levels for the September cruise for Year 32 (one with all 43 samples and another with the 15 samples analyzed in Year 33) and September cruise for Year 33. 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).



September, 2013
Cruise 67
43 Samples
Sigma
15
12
9
6
3
0
-3
sCd
sCr
sCu
sFe
sMn
sNi
sPb
sZn



September, 2013
Cruise 67
15 Samples
Sigma
15
12
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0
-3
sCd
sCr
sCu
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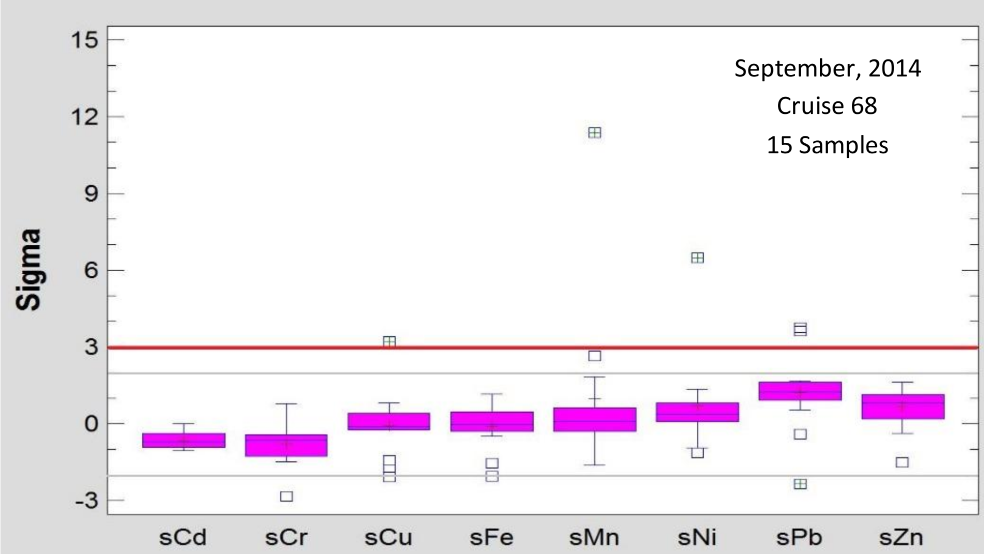
sZn



September, 2014
Cruise 68
15 Samples
Sigma
15
12
9
6
3
0
-3
sCd
sCr
sCu
sFe
sMn
sNi
sPb
sZn

Metal Distributions

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 33 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 Back River influence is seen for Pb, even though only two sites within this zone are sampled. Historically, Pb has been discharged by Back River during both of the sampling periods. Ni and Zn concentrations were less than 3 sigma for Year 33, consistent with the previous four years monitoring.

Baltimore Harbor – With Year 33 sampling, there are no longer any samples taken from this area surrounding HMI. Historically, elevated levels of Pb and Zn extend into the area southwest of HMI. In spite of the major storms affecting the area in the past, the distribution of Pb and Zn levels has remained separated from the HMI Zone of Influence adjacent to the island.

HMI – Historically, elevated levels of Ni, Pb and Zn are seen at isolated sites southeast of HMI; however, starting Year 33, many of these sites are no longer sampled. Generally, whether the absolute number of sites having elevated levels has decreased or increased since the previous fall depends on the metal. Comparing sigma levels of the sites that overlapped between Year 32 and 33, the most recent sampling did have lower concentrations of metals than the previous year, although there are still some outliers (Figure 1-11) within the new sample dataset. 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), but because there have been discharges from the North Cell (Spillway 007 and 008), enrichment may also be linked to that effluent. High discharge from the South Cell (February 27, 2014 – March 28, 2014) and from the North Cell (Spillways 007 and 008) occurred during relatively low flow of the Susquehanna River, but during a period of higher than normal rainfall locally, which resulted in higher flow out of the Patapsco River. This higher flow from this time period could have modified the flow of the circulation gyre, accounting for the distribution of the sites with elevated levels of metals.

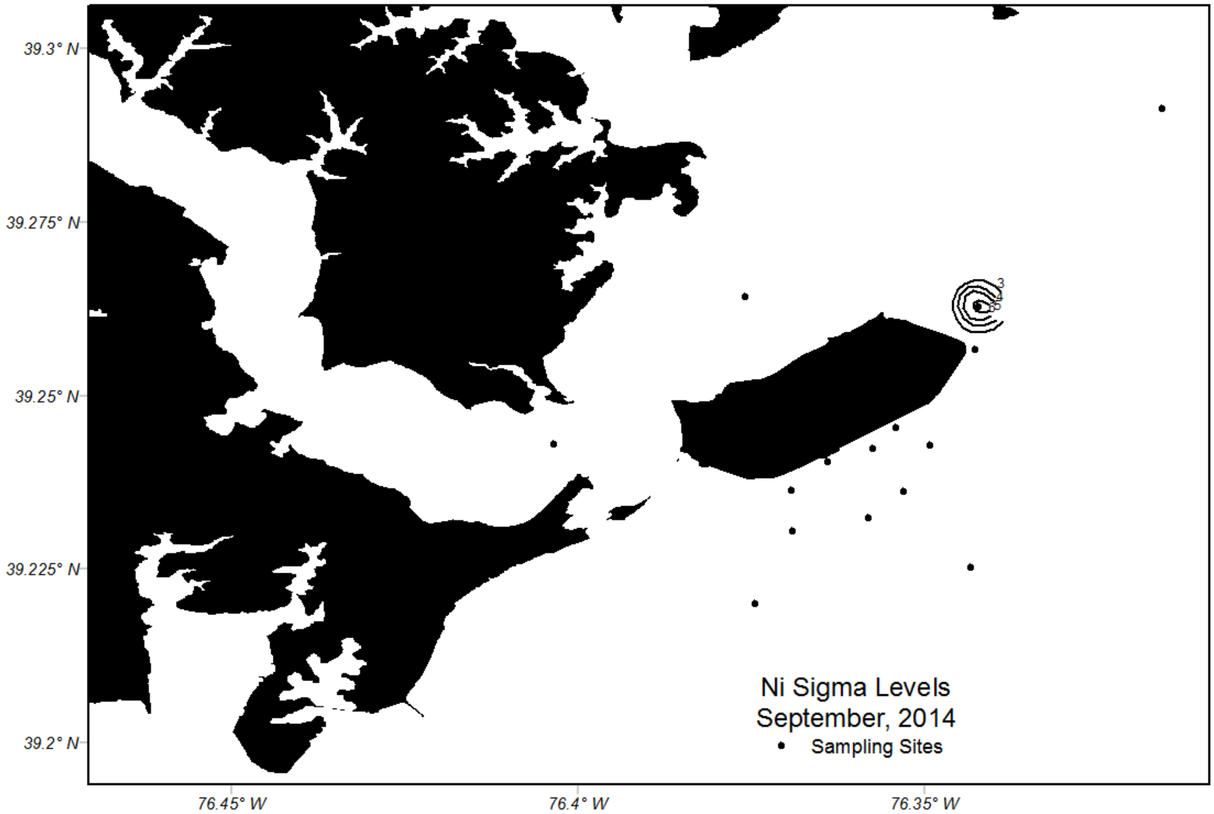


Figure 1- 12: Distribution of Ni sigma levels in the study area for the September 2014 sampling cruise. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (contour intervals less than 3 not shown), >3 = significantly enriched.

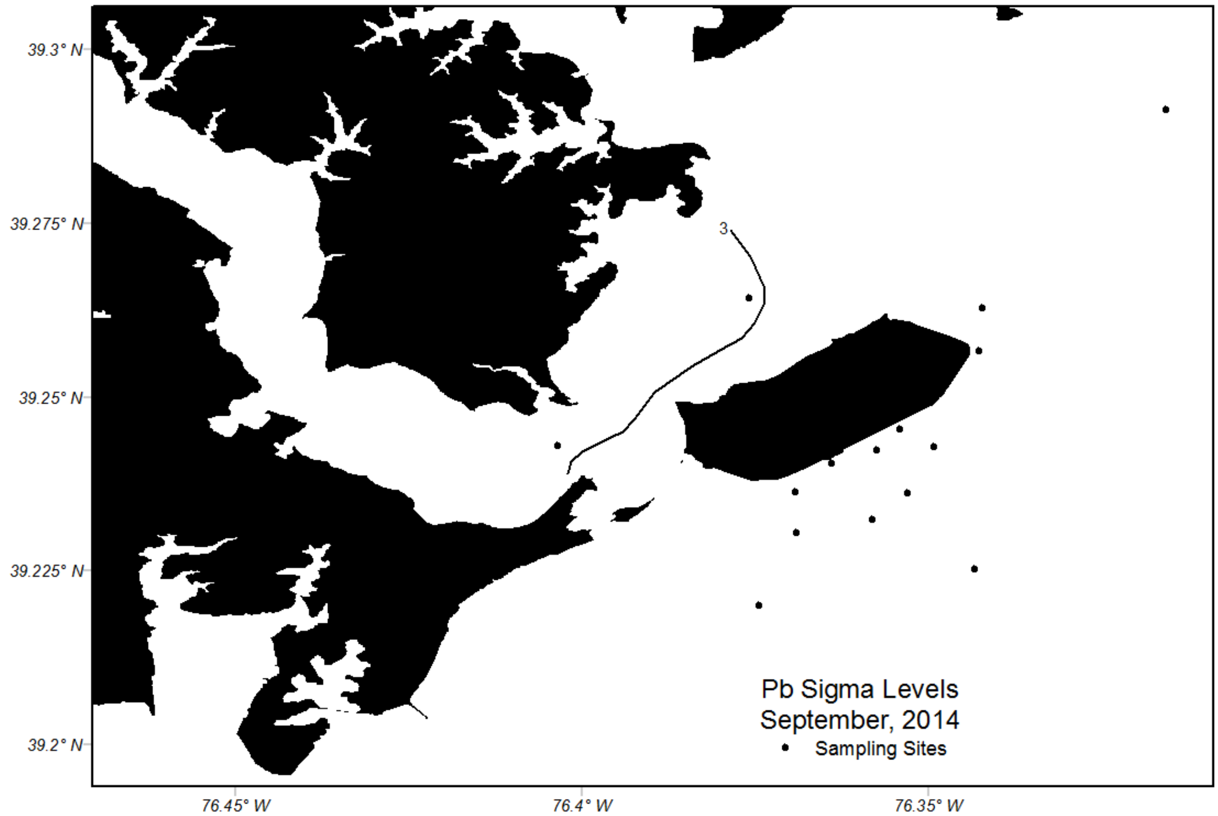


Figure 1- 13: Distribution of Pb in the study area for the September 2014 sampling cruise. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (contour intervals less than 3 not shown), >3 = significantly enriched.

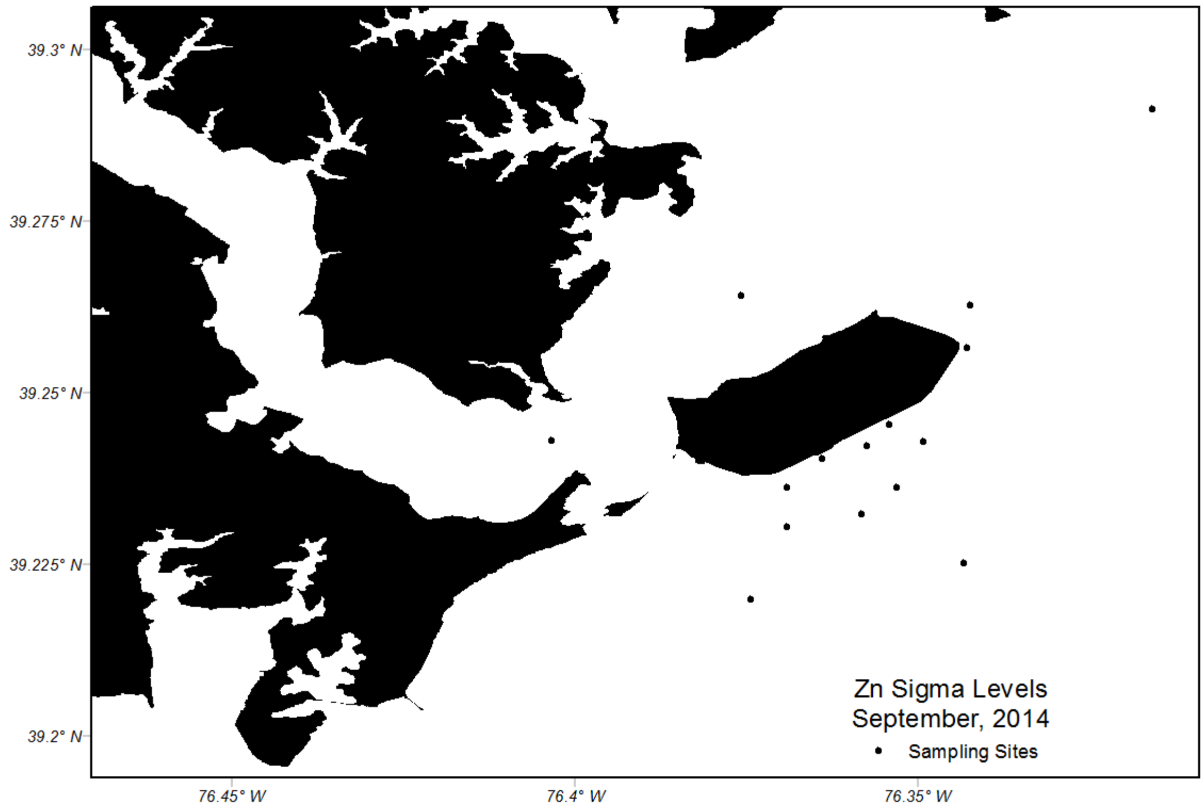


Figure 1- 14: Distribution of Zn in the study area for the September 2014 sampling cruise. There are no Zn significantly enriched sediments found during this year's cruise. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (contour intervals less than 3 not shown), >3 = significantly enriched.

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 33. The depositional environment continues to be very stable.

Elemental analyses data indicate that the sediments are 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 proposed criteria put forward by 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, 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. Pb showed lower enriched levels, both in terms of the number of sites and extended spatial distribution, compared to the previous year. In Year 31 and 32, sediments were slightly enriched (3 sigma levels) with Zn at two sites in the HMI zone; however, with the reduced sampling beginning Year 33, many of the more recent Zn enriched sediment are no longer being sampled. 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. During Year 31, sigma levels of Ni were within normal ranges in the HMI Zone. This year, two sites within the HMI Zone of Influence were enriched with Ni. In terms of absolute concentration, Ni continues to exceed the ERL threshold at most sites and the ERM threshold at some sites.

To illustrate the long-term trend of the data, the highest levels of Zn enrichment (% excess Zn) in the HMI zone of influence for all monitoring sampling events (cruises) are plotted in Figure 1-15 (next page). The data from this monitoring year, shown as the solid point, show a pronounced fluctuation over the past several monitoring years, but the overall trend is a slight increase in enrichment that began in 2011 (Year 29).

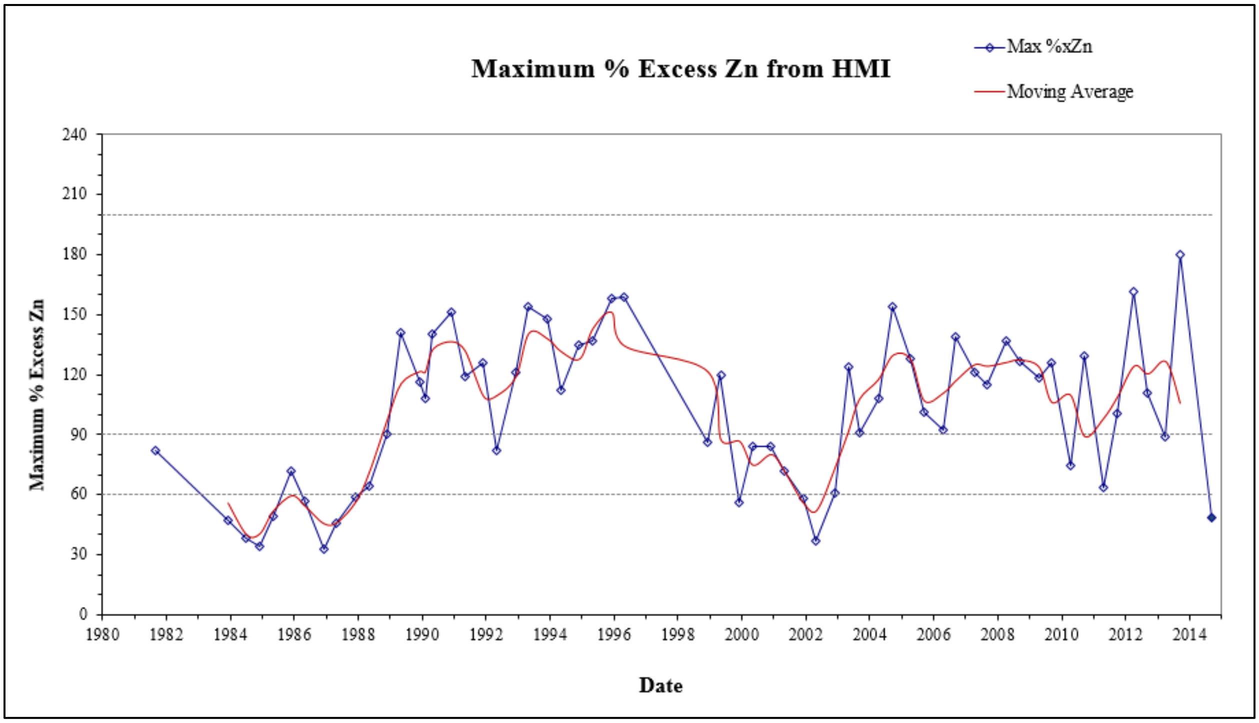


Figure 1- 15: Record of the maximum % excess Zn for all of the cruises for which MGS analyzed the sediments. The filled point is the maximum from this year's study (Cruise 68), which cannot completely be compared to the other prior cruises due to the reduction of the number of stations that were sampled.

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-27, -30, and -45 (Figure 1-16). The two samples located on the northeast side of HMI that are not currently exceeding ERLs or ERMs or have a sigma level greater than 2 (MDE- 1 and -34) are very high in sand content, meaning it is difficult to know just from those two samples what the discharge released by the North Cell Spillways (007 and 008) contain.

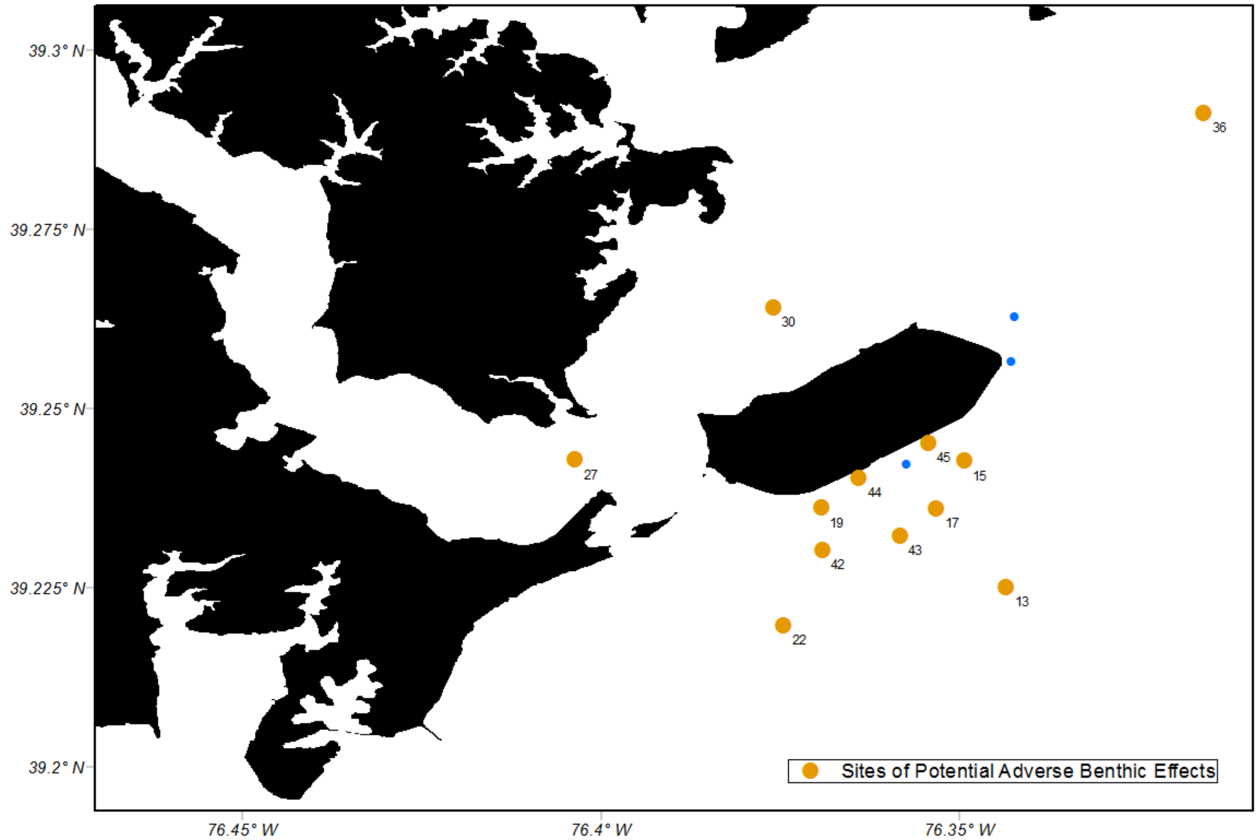


Figure 1- 16: Distribution of sites of potential adverse benthic effects for September 2014 (Cruise 68). At the sampling sites shown in orange, sediments contained multiple metals (primarily Ni, Pb or Zn) exceeding ERLs or ERMs, and sigma levels greater than 2.

This year's monitoring documents a high enrichment of Ni around the HMI facility. This persistent enriched level indicates 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. Different from previous years, MES documented better water quality (*i.e.*, more neutral pH, lower levels of metals) in two of the North Cell spillways, and water was allowed to be discharged from Spillways 007 and 008 (Amanda Peñafiel, pers. Comm. 10/1/2014). Although the amount 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 is important in this endeavor.

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APPENDIX 1A: HMI Groundwater Monitoring Wells 2014-2015 (PROJECT II)

INTRODUCTION

Groundwater samples from six wells were collected on September 30, 2014, December 30, 2014, and June 23, 2015. Maryland Environmental Service (MES) analyzed the water samples for the following parameters: pH, temperature, conductivity, dissolved oxygen (DO), oxygen-reduction potential (ORP), salinity, alkalinity, chloride (Cl^-), sulfate, 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 2A, 4A & 6A; South Cell 8A, 10A & 12A. These wells are part of 34 wells 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 6 wells (*i.e.*, ‘A’ wells) were installed to depths to monitor the shallow saturated groundwater zone; 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 the 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). Consequently, this meant that discharge from the facility would be limited to only the South Cell. This year, however, the facility released discharge from both the North and South Cells. To mitigate low pH conditions, a liming plan was developed 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 generally had a low pH, but this year the North Cell had a neutral pH, and two of the spillways (007 and 008) were able to discharge. A more detailed summary of the facility operations for the Year 33 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 during the 33rd 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).

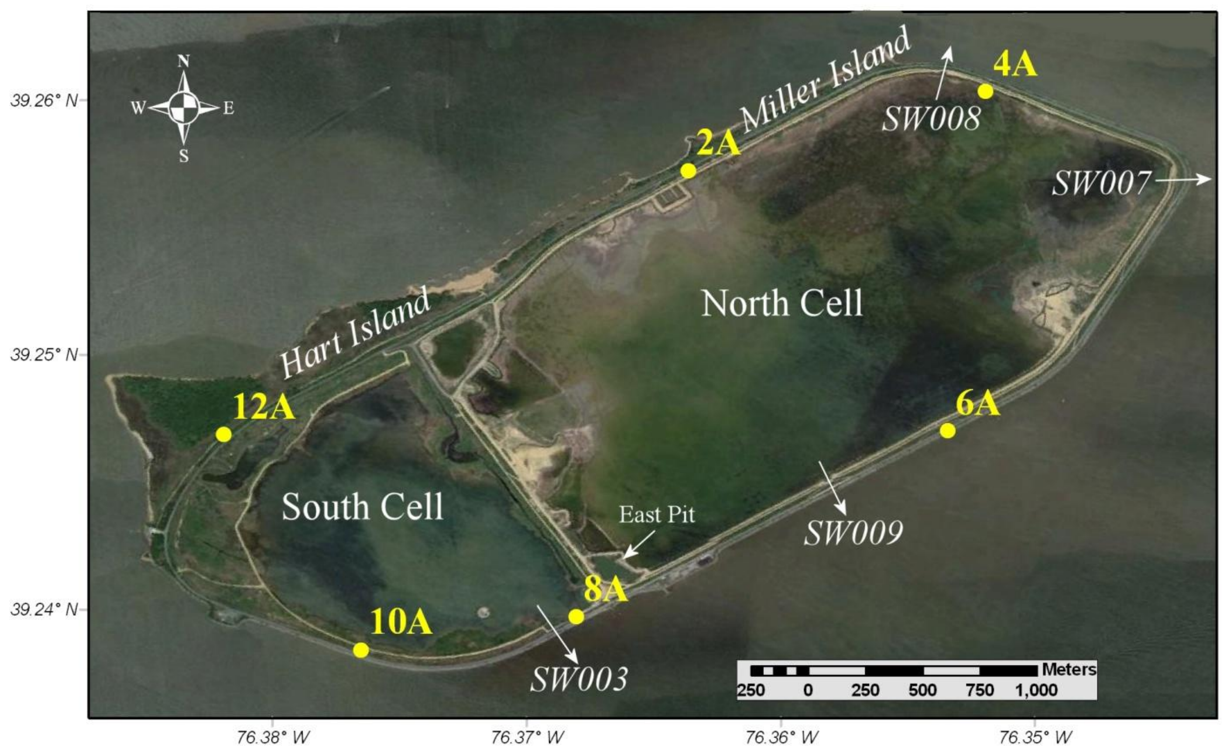


Figure 1A- 1: Aerial photograph of the HMI DMCF, taken on May 5, 2013, showing the locations of the groundwater monitoring wells (yellow dots) and the spillways (*SW; white arrows*). Aerial photography from Google Earth (2014).

SUMMARY OF WELL DATA

Trend plots of select field parameters and metal concentrations measured in well 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. All of the wells continue to be anoxic or hypoxic with dissolved oxygen (DO) levels less than 2.0 mg/L until the March 2013 sampling, when DO levels spiked in wells 2A, 8A and 12A (Figures 1A-3 and 1A-4. In March 2014, DO levels spiked in all the wells except 2A. The DO spike would also explain the redox (OPR) spike in the same wells for the March 2013 sampling. However, there was inconsistent spiking of redox for the March 2014 sampling. Currently, all of the wells are anoxic or hypoxic with DO levels less than 2.0 mg/L (Figures A1-2 and A1-3).

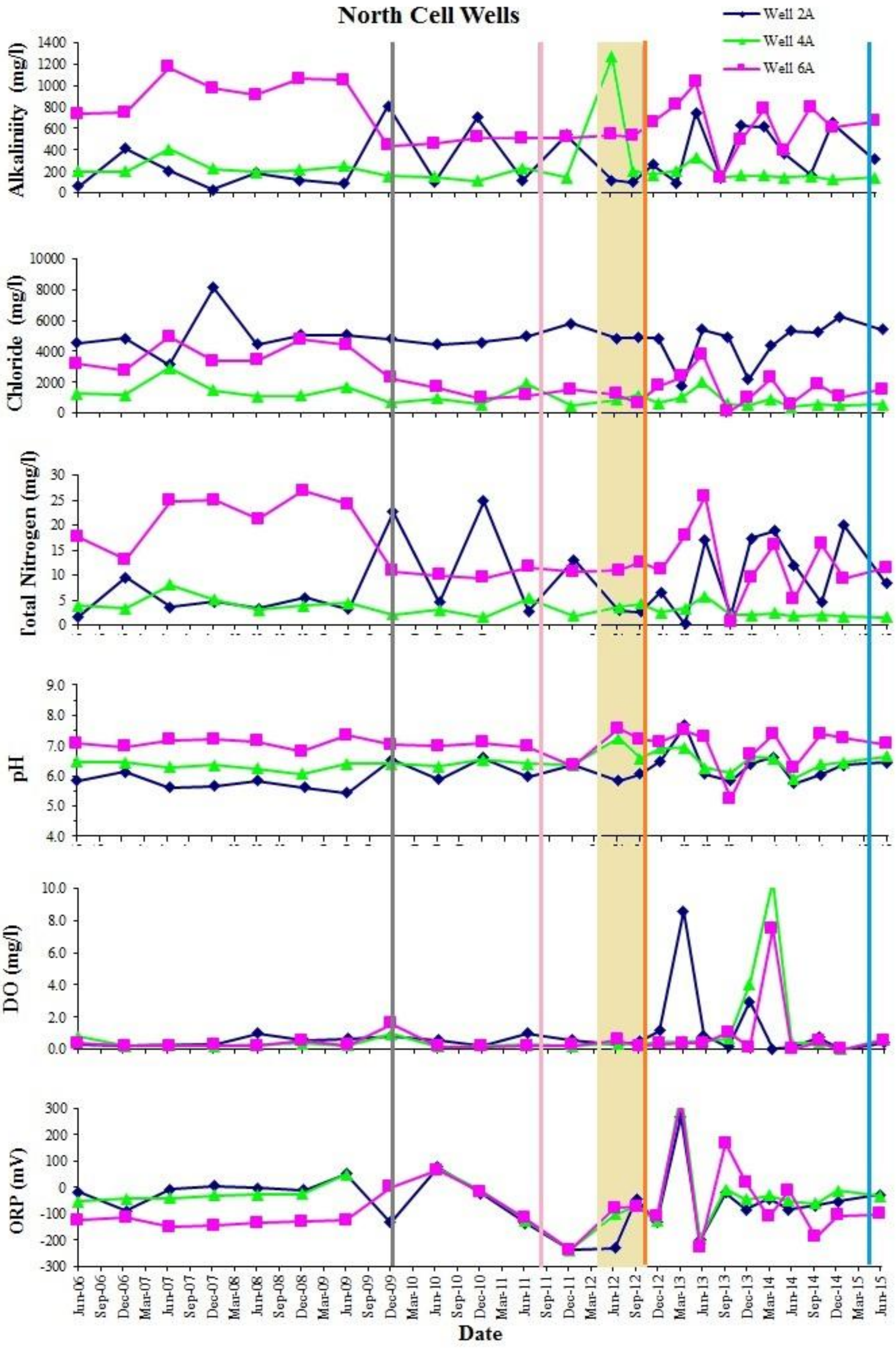
Due to limitations with the instrumentation used to get *in-situ* measurements, no sulfide measurements were taken. These measurements are not necessary, but their absence limits the information on the degree of anoxia and the processes occurring. URS (2003) found that sulfide concentrations in HMI groundwater were consistently at or below detection. The low levels were attributed to loss by precipitation, based on the relatively high Fe concentrations (Figures 1A-4 and 1A-5). Dissolved sulfide binds with many metals and restricts their mobility, and is preferentially used as a metal ligand releasing mineralized phosphate into the water.

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

North Cell Wells 2A, 4A and 6A

Figure 1A-6 shows the chloride (Cl^-) concentration from the September 30, 2014, December 30, 2014, and June 23, 2015 samplings as a function of the amount of excess sulfate, either removed from the water as a result of sulfate reduction (– excess sulfate) or added to the water as the result of sulfide oxidation in the sediment solids (+ excess sulfate). The predicted sulfate levels are calculated from the chloride concentration based on conservative mixing between rainwater and seawater. This year's plot, similarly to Year 32, has Cl^- plotted on a logarithmic scale, rather than a linear scale. Based on the depletion in sulfate in comparison to predicted concentrations, North Cell Well 2A is the only well that continues to have a reducing environment, whereas Wells 4A, and to a lesser degree, 6A, are more similar to the oxidizing environment seen in the South Cell wells. Well 2A, which is the deepest of the six monitoring wells (Table 1A-1), is located on the remnant of Miller Island. Well 2A is also the only well exhibiting seasonal fluctuations in alkalinity, total nitrogen, pH, phosphorus (not shown) and, to a lesser extent, Fe concentrations (Figures 1A-2 and 1A-4). These seasonal fluctuations become obvious starting at the end of 2009, about the same time the North Cell stopped receiving dredged material and operations focused on crust management (dewatering) activities. After October 2012, multiple field and metal parameters in all wells show irregular fluctuations, but they are not necessarily seasonal. These fluctuations in water chemistry are interpreted to be delayed responses to operation activities in the North Cell and to weather events; the degree of responses affected by a number of factors including well location, depth and differences in infill (sediment) and dike wall composition.

In the past, pH levels have been too low to discharge from the North Cell. This year, however, pH levels have become more neutral, allowing discharge from Spillways 007 and 008 to occur. In April 2014, a new discharge permit was put in place with reduced monitoring requirements; however, the limits have become stricter in regards to state water quality standards. (Amanda Peñafiel, pers. Comm. 10/1/2014).


North Cell Wells
Well 2A
Well 4A
Well 6A
Alkalinity (mg/l)
Chloride (mg/l)
Total Nitrogen (mg/l)
pH
DO (mg/l)
ORP (mV)
Date
Jun-06
Sep-06
Dec-06
Mar-07
Jun-07
Sep-07
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Mar-08
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Jun-15

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 coincides with end of liming); 5) Jun-15 (blue line) liming began and continued during every discharge event.

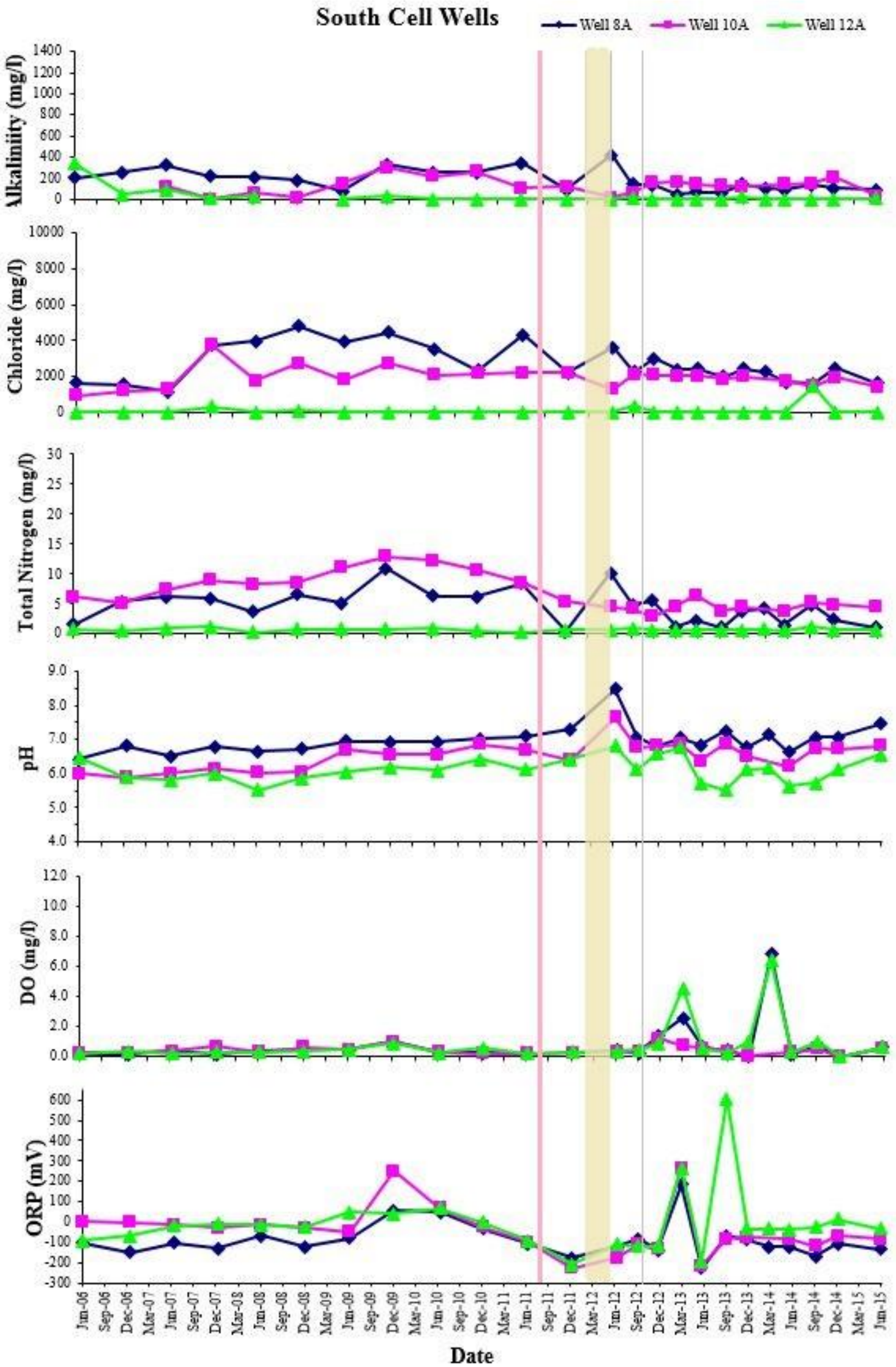

Figure 1A- 3: Trend plots for field parameters measured in groundwater samples collected since 2006 from South Cell wells. The vertical lines in the plots mark several notable events having an impact on the Facility: 1) Aug-Sept-11 (pink) Hurricane Irene and TS Lee; 2) Feb-12 to Jun-12 (yellow shading)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

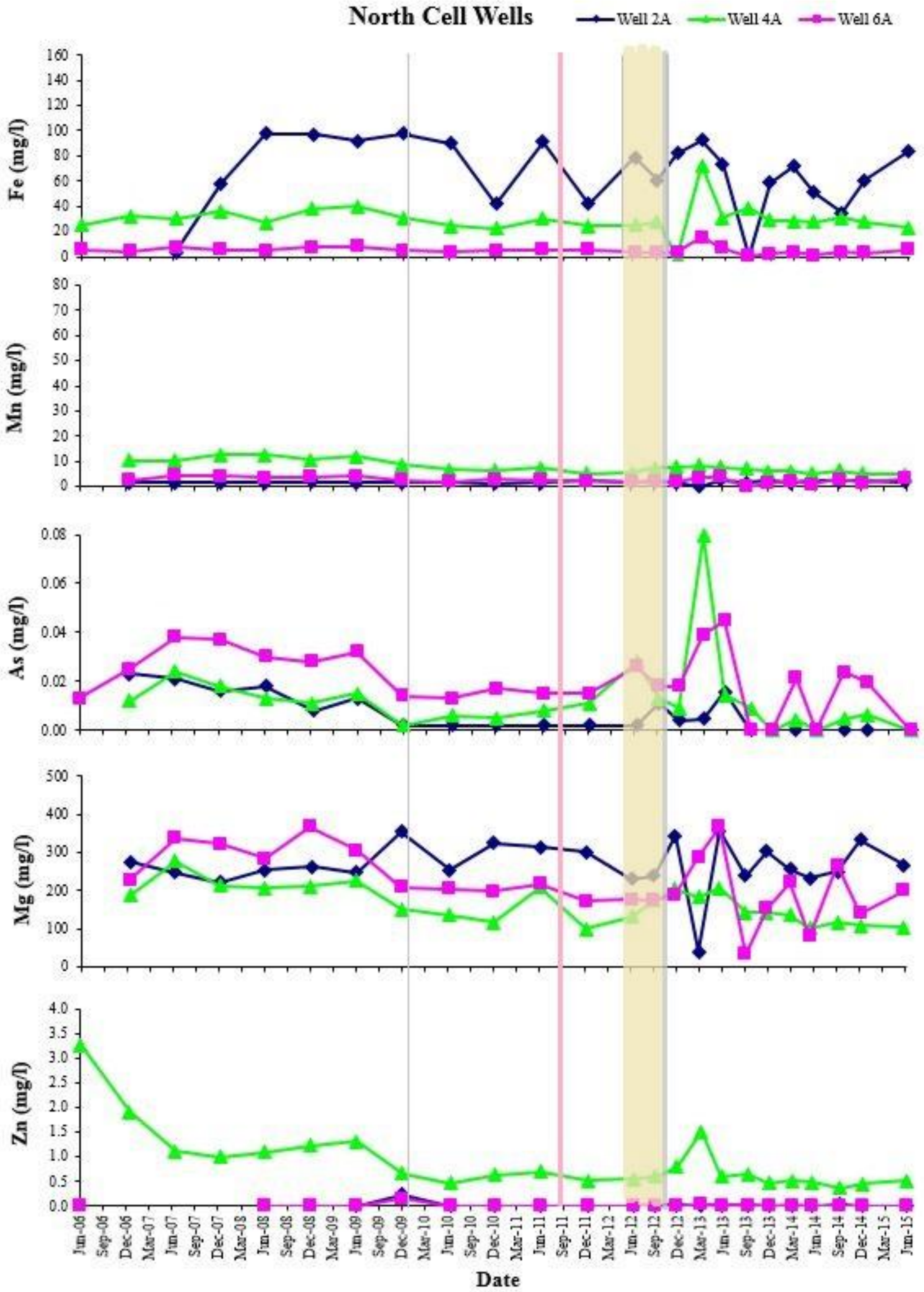

Figure 1A- 4: Trend plots for select metals measured in groundwater samples collected since 2006 from North Cell wells. The vertical lines in the plots mark several notable events having an impact on the Facility (refer to caption for Figure 1A-2 for explanation).

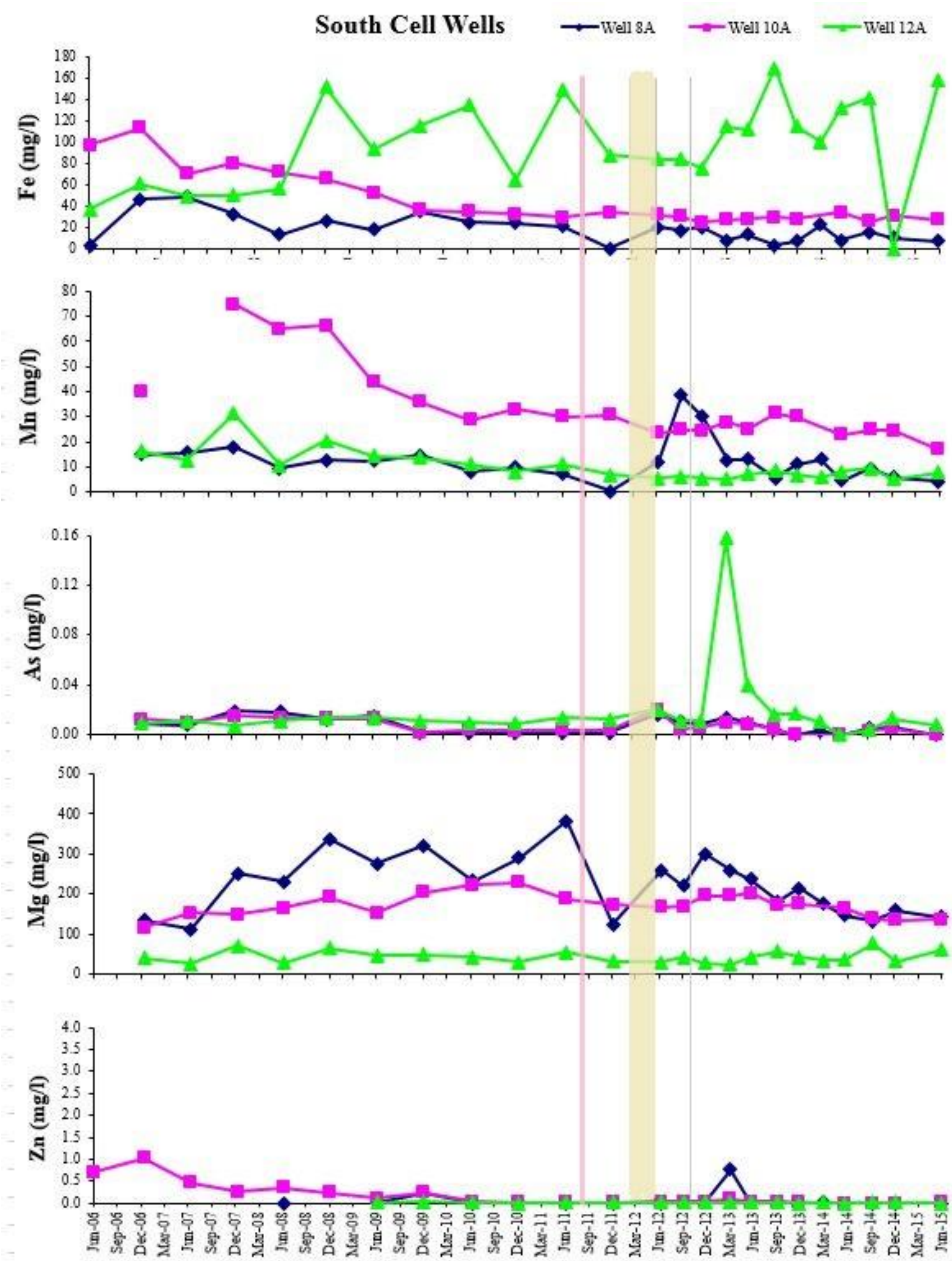

Figure 1A- 5: Trend plots for select metals measured in groundwater samples collected since 2006 from South Cell wells. The vertical lines in the plots mark several notable events having an impact on the Facility (refer to caption for Figure 1A-3 for explanation).

Figure 1A-7 shows ratios of K^+/Cl^- and Ca^{++}/Cl^- as a function of the amount of excess sulfate. The major cations are near the predicted conservative mixing concentrations. Since acid generally is not being generated in the vicinity of Well 2A, there is minimum mineral dissolution (specifically calcium carbonate) or ion exchange. In the rest of the wells, the hydrogen ion from acid is preferentially bound on ion exchange sites in the sediment releasing other adsorbed cations (*e.g.* K^+, Ca^{++}). The linear relation in the positive excess sulfate region is due to the process of acid production being directly related to neutralization and ion exchange. 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 (except for December 2009, 2010 and 2011, 2013 samplings for Well 2A and June 2012 for Well 4A) and the wells in the South Cell (Figures 1A-3 and 1A-5). The higher concentrations suggest that the alkalinity in this well still had not been neutralized by acid production and may be buffered somewhat, particularly during and after the liming period. 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.

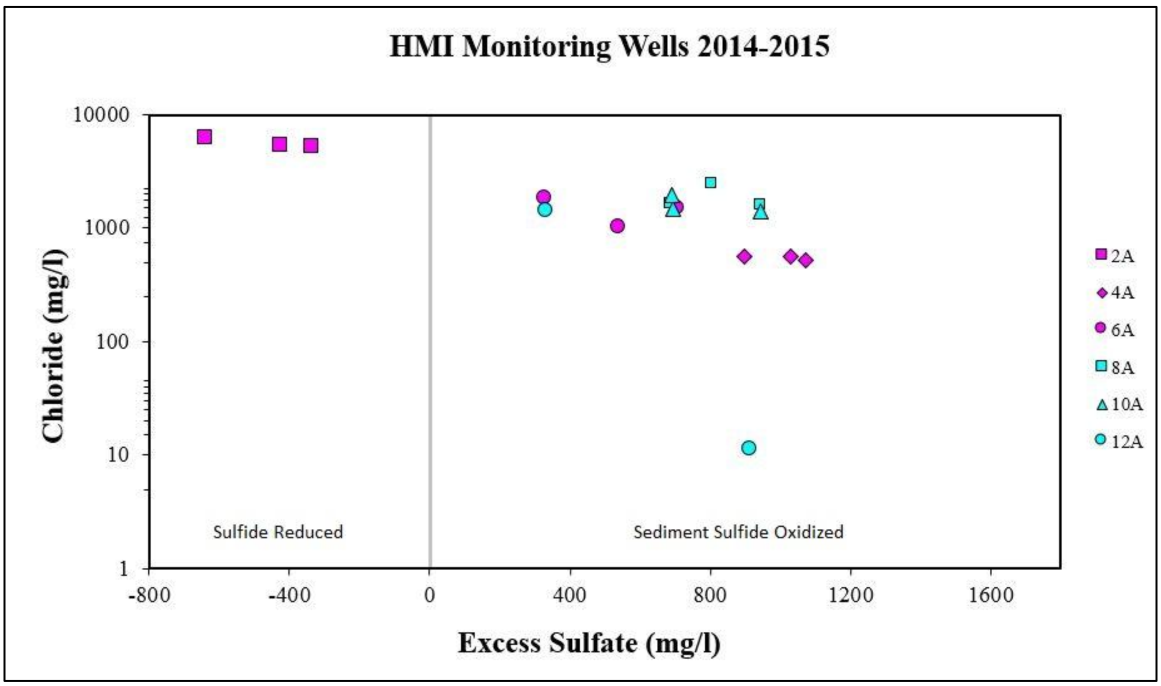

Figure 1A- 6: Groundwater chloride concentrations as a function of excess sulfate (the difference of the measured sulfate concentrations minus the predicted concentrations). Monitoring wells are grouped by general location; North Cell (pink) or South Cell (light blue).

The groundwater from the North Cell Well 2A continues to exhibit behavior typical of anoxic pore waters that have minimum 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.

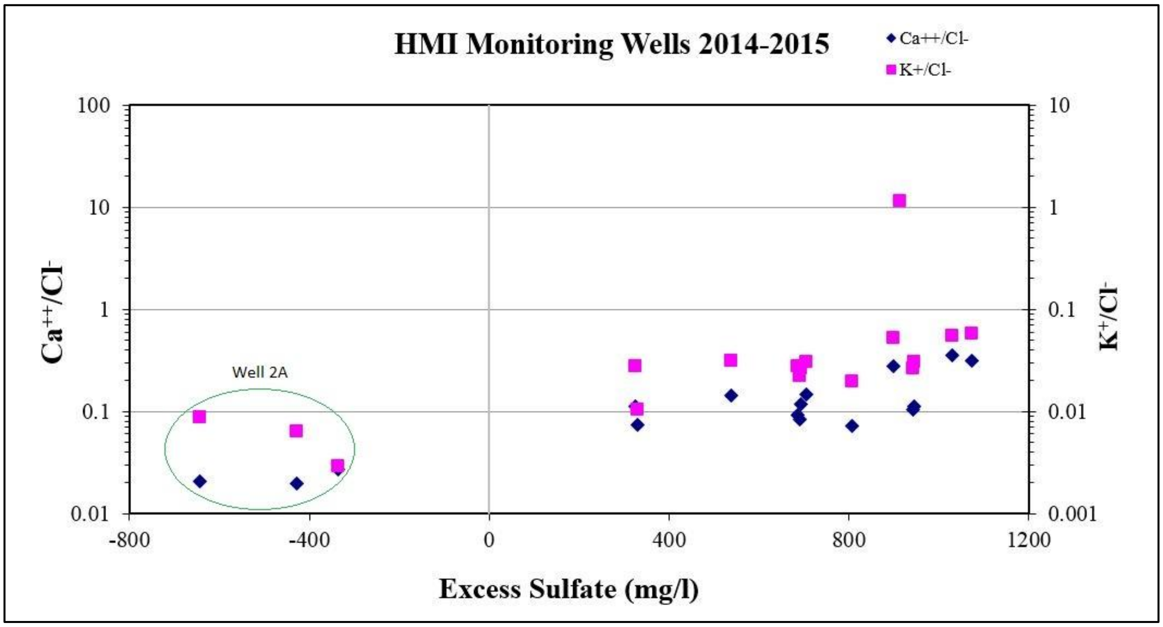

Figure 1A- 7: The ratios of K^+/Cl^- and Ca^{++}/Cl^- as a function of excess sulfate. For reference, the ratio for both of these cations in seawater is ~0.02. Note that scale of the y-axes are logarithmic to accommodate the relatively large ratios calculated for Well 12A; the ratios were high due the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

South Cell Wells 8A, 10A & 12A

The waters in the South Cell wells have been exposed to oxidized sediments, thus the higher levels of excess sulfate (Figure 1A-7). Chloride concentrations are high in Wells 8A and 10A. However, rainwater appears to be a major source of water to Well 12A, the waters of which appear to be entirely fresh water. The lowest level of chloride was observed in June, 2012 (Cl^- = 4.1 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 and cations are higher than the waters in the North Cell wells. 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 and metals 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 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 attributed to operations activities in the cell (e.g., liming to adjust pond pH) and extreme weather events.

PROCESSES OPERATING IN HMI GROUNDWATER

Figure 1A-8 shows a hypothetical cross section of HMI at the South Cell. Hydrodynamically, 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 associate pore fluids would be anoxic and would have the characteristics of normal Bay sediments. This is 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 sub-areal with rain water being the primary source of water to the system. The occluded water native to the dredged material is diluted by the fresh rain water; this lowers the dissolved load derived from dilution of sea water in the Bay waters. Since the hydrated sediment is exposed to atmospheric oxygen, the aerobic process is in operation. One of the most significant reactions is the oxidation of the naturally occurring sulfide minerals (primarily iron monosulfides and pyrite) that produces sulfuric acid. The acidified waters have sulfate concentrations in excess of conservative mixing. The oxidation of the sulfide minerals significantly increases the levels of Fe and Mn, and the free acid can react with the sediment to release other metals, acid soluble nutrients, and trace organic compounds. This acidified water is either entrained in surface water runoff or infiltrates into the sediment in the dike forming the groundwater flow through the dike. The surface water is monitored and controlled by MES.

2. *Dredged sediment in the dike.* When the acidified waters infiltrate into the dredged sediment they enter an organic rich environment that is isolated from the atmosphere. Here several processes occur: the acid is neutralized by naturally occurring material such as shell material which contains calcium carbonate; acid and metals are bound by ion exchange processes; the reduction in acidity causes precipitation of insoluble metal compounds (with anions such as phosphate, and carbonate), and; reduction occurs which removes oxygen and changes the environmental conditions waters are in. The flow of water through the dike is relatively fast compared to the rate of reduction since the concentrations of sulfate are high relative to conservative mixing (this is shown as the positive Excess Sulfate in the Figures 1A-6 and 1A-7). If strongly reducing conditions existed, all of the sulfate would be reduced and the sulfide produced would be significantly removed by sulfide mineral formation as in the North Cell.

3. *Movement through the dike walls.* The dike walls are made of clean sands and thus are relatively inert; however, they act as a mechanical filter. As a filter, the dike retains the fine sediment placed in the dike, and removes the precipitates that form as the water reacts in the contained sediment. Eventually as with any filter, the filter (*i.e.* the dike walls) 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 aerated and slightly alkaline. This water will react with the dike water oxidizing the reduced water and precipitating iron oxy-hydroxides and other redox sensitive species. These precipitates are effective in scavenging trace metals and phosphate.

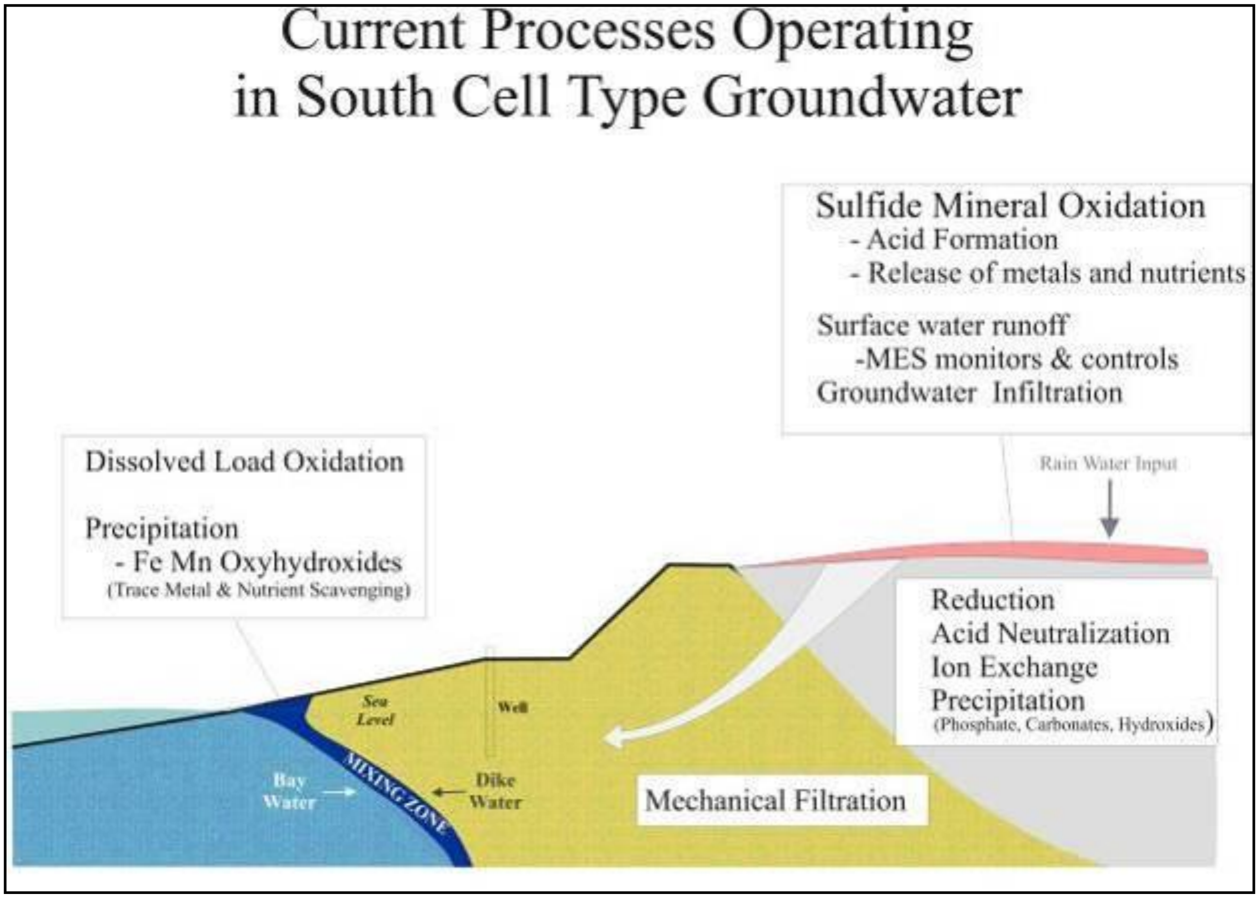

Figure 1A- 8: Schematic presentation of the processes which produce the groundwater similar to those found in the South Cell wells.

As noted, the sampling wells are located in the sandy matrix of the dike walls which act as a filter for the groundwater. Except for March 2013 and March 2014 samplings, groundwater has been anaerobic for all of the sampling wells; all wells except for Well 2A have undergone an initial oxidation stage. 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.

Table 1A-2 is a summary of the trace metal data for the groundwater sampled during this monitoring year (four sampling periods), listing the number of samples, the number below detection, the mean, maximum and minimum concentration and the EPA Maximum Concentration Level in drinking water (MCL) (U.S. EPA, 2002). On average, metal concentrations in both the North and South Cell wells have shown a decreasing trend this monitoring year. Cu and Pb remain below the detection limit in both Cells. Fe and Mn are the only metals with concentrations that exceed the SMCL in both Cells. These two metals are not considered a health risk but affect the taste and quality of the water. These metals precipitate from solution in aerobic conditions, so as the water mixes with Bay water further down the flow 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 2014 and 2015 (four sampling periods). Values in mg/L, unless otherwise indicated. Detection limits (*dl)* for Fe and Mn were not reported (highlighted in yellow).

				North Cell Type			
	n	***n>dl***	***dl***	***Mean***	***Min***	***Max***	***MCL***
Al	12	0	0.05	<dl	<dl	<dl	0.05 - 0.2*
As	12	2	0.01	0.009	<dl	0.024	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	0	0.005	<dl	<dl	<dl	1.3
Fe	12			32.4	2.9	83.5	0.3*
Pb	12	0	0.02	<dl	<dl	<dl	0
Mn	12			3.5	1.7	6.5	0.05*
Zn	12	7	0.005	0.155	<dl	0.512	5*
Ag	12	0	0.001	<dl	<dl	<dl	0.1*
				South Cell Type			
	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	0.006	0.003	0.013	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			38.0	<dl	142	0.3*
Pb	12	0	0.02	<dl	<dl	<dl	0
Mn	12			13.2	5.2	24.7	0.05*
Zn	12	8	0.005	0.009	<dl	8.000	5*
Ag	12	2	0.001	0.003	<dl	0.028	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

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APPENDIX II: BENTHIC COMMUNITY STUDIES (PROJECT III)

(September 2014 – August 2015)

Technical Report

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EXECUTIVE SUMMARY

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMIDMCF) was studied for the thirty-third consecutive year under Project III of the HMI Exterior Monitoring Program. Benthic communities living close to the facility [Nearfield, South Cell Exterior Monitoring (formerly called South Cell Restoration Baseline), and Back River/Hawk Cove stations] were compared to communities located at some distance from the facility (Reference Stations). Water quality parameters, including dissolved oxygen concentrations, salinity, temperature, pH, conductivity, and Secchi depth were measured *in situ*. Fifteen stations (7 Nearfield, 3 Reference, 2 Back River/Hawk Cove, and 3 South Cell Exterior Monitoring stations) were sampled on September 18, 2014. Unlike previous years, no spring cruise was conducted due to scaling back of monitoring efforts during the post closure era at HMI.

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 spacially and statistically.

The health of the benthic macroinvertebrate community around HMI in Year 33 was worse than historical averages. In year 33, as in year 32, B-IBI's around the island were at or near historical lows. Ten of the 15 stations failed to meet the benchmark criteria of 3.00. Fourteen of the 15 stations performed below their historic averages. Five stations tied their historic lows; and no stations met their historic highs. Year 33 is the fifth consecutive year where B-IBI's have been trending downward. The exception to this trend was at the South Cell Exterior Monitoring stations, which improved from the past four years and were at their historic means.

The five year decline in B-IBI's can be attributed to fluctuations in the invertebrate community. They include decreases in the relative abundance of the pollution sensitive bivalves' *R. cuneata* and *M. balthica*. Another fluctuation was a very high average abundance of the pollution indicative polychaete worm, *S. benedicti*. Lastly, the abundance of many organisms was especially high causing decreases in the total infaunal abundance metric scores and the relative Pollution Sensitive Taxa Abundance metric. The increase in *S. benedicti* contributed to a decline in the Shannon Weiner Diversity Index metric and a worsening in the Pollution Indicative Taxa Abundance metric scores.

The statistical analyses did not indicate that the stressed benthic invertebrate communities measured at stations in September 2014 were due to any adverse localized impacts from HMI operational discharges. Stressed benthic communities throughout the monitoring area were likely the result of large-scale Bay-wide and regional factors.

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. Over the years, a series of four spillways 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. However, during the stabilization phase of this project HMI management will continue to move sediment and manage storm water run-off, resulting in periodic discharge into Chesapeake Bay. As the island gradually stabilizes over the next several years post closure exterior benthic monitoring will be necessary to document long-term trends. Discussions are continuing to determine how much post closure monitoring is necessary to eventually certify that the island has stabilized and operations have settled into an established routine. Year 33 represents the fifth year of post closure data. However, during Year 33 samples were only collected during the fall and at a reduced (15) number of stations. The stations that were not sampled during Year 33 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 33 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 33. 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 33 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	39° 15.3948	-76° 20.5680	Sand	XIF5505
MDE-15	39° 14.5686	-76° 20.9526	Silt/clay	XIF4609
MDE-16	39° 14.5368	-76° 21.4494	Silt/clay	XIF4615
MDE-17	39° 14.1690	-76° 21.1860	Shell	XIF4285
MDE-19	39° 14.1732	-76° 22.1508	Silt/clay	XIF4221
MDE-34	39° 15.7650	-76° 20.5392	Silt/clay	XIF5805
MDE-45	39° 14.7198	-76° 21.2538	Silt/clay	N/A
Reference Stations				
MDE-13	39° 13.5102	-76° 20.6028	Silt/clay	XIG3506
MDE-22	39° 13.1934	-76° 22.4658	Silt/clay	XIF3224
MDE-36	39° 17.4768	-76° 18.9480	Silt/clay	XIG7589
Back River/Hawk Cove Stations				
MDE-27	39° 14.5770	-76° 24.2112	Silt/clay	XIF4642
MDE-30	39° 15.8502	-76° 22.5528	Silt/clay	XIF5925
South Cell Exterior Monitoring Stations				
MDE-42	39° 13.8232	-76° 22.1432	Silt/clay	XIF3879
MDE-43	39° 13.9385	-76° 21.4916	Silt/clay	XIF3985
MDE-44	39° 14.4229	-76° 21.8376	Silt/clay	XIF4482

Figure 2-1: Year 33 benthic sampling stations for the HMI exterior monitoring program.

The fifteen stations sampled in Year 33 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 2014. Water quality parameters were measured at approximately 0.5 m (1.6 feet) below the surface and 0.5 m above the bottom. The Secchi depth was measured at all stations.

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 33 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.

[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"

Six major measures of benthic community condition were examined, including: total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa, the Shannon-Wiener diversity index, 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 2014. 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 33 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 2014 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 2014. The statistical analyses were performed using SAS, Version 9.1 and SPSS, Version 11.5.

RESULTS AND DISCUSSION

Water Quality

Select water quality parameters (water temperature and salinity) were recorded during all 33 years of the HMI benthic sampling project. Additional water quality parameters were included during year 17 as the project responsibility transitioned from Chesapeake Biological Laboratories (CBL to MDE). MDE added Dissolved Oxygen (DO), Secchi, pH, and Conductivity to the water quality parameter list during this period.

Minimal variations between surface and bottom values for salinity, temperature, DO, conductivity, and pH values during the 2014 cruise (Table 2-5) indicated that water column stratification was not prevalent.

Secchi depths ranged from 0.60 m-1.20 m and averaged 0.75 m ± 0.16 m (Table 2-3). Water quality and Secchi depth measurements provide a snapshot of the conditions prevalent at the time of sampling, but do not necessarily reflect the dominant conditions for an extended period. The mean Secchi depth was 0.06 m less than the 17-year historic average of 0.81 m.

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 33, bottom water temperatures showed little variation. The mean bottom water temperature ranged from 22.07°C – 23.04°C and averaged 22.64°C ± 0.26°C (Table 2-3). This mean was 1.40ºC lower than the 28-year fall average of 24.04ºC.

The mean bottom DO concentration exceeded the water quality standard (5.0 ppm) to protect aquatic life (Maryland Code of Regulations COMAR) during Year 33. The bottom DO ranged between 7.30 – 8.65 ppm and had a mean of 7.87 ppm ± 0.39 ppm(Table 2-3). This mean was 0.46 ppm higher than the 17-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 29-year mean fall bottom salinity is 6.25 ppt, ± 2.81 ppt. Low Mesohaline conditions (5-12 ppt) were found during the fall 2014 sampling season.

In Year 33 salinity values varied slightly (Table 2-5, mean=7.31 ppt ± 0.90 ppt, range = 5.65 ppt – 8.94 ppt) and the mean fall salinity was 1.06 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 33 physical parameters measured *in situ* at all HMI stations on September 18, 2014.**

MDE Station	Time	Tide	Water Depth (m)	Wave Height (m)	Wind Direction	Wind Speed (knots) Min.	Wind Speed (knots) Max	Air Temp. (°C)	Cloud Cover (%)	Weather Past 24 hrs.	Weather Today	Observed Bottom Sediment (%) silt/clay	sand	shell	gravel	detritus
MDE-01	12.:01	Ebb	4.47	0.1	NA	0	0	18.9	40	0	0	0	85	15	0	0
MDE-13	10:42	Ebb	5.40	0.1	NA	0	0	16.7	40	0	0	90	0	10	0	0
MDE-15	11:45	Ebb	5.08	0.1	NA	0	0	17.8	40	0	0	90	0	10	0	0
MDE-16	11:20	Ebb	4.77	0.1	NA	0	0	17.2	40	0	0	90	0	10	0	0
MDE-17	11:05	Ebb	5.48	0.1	NA	0	0	17.2	40	0	0	65	0	35	0	0
MDE-19	9:58	Ebb	4.73	0.1	NA	0	0	16.1	40	0	0	65	0	35	0	0
MDE-22	9:01	Ebb	5.90	0.1	NA	0	0	16.1	40	0	0	90	0	10	0	0
MDE-27	12:52	Ebb	3.28	0.1	NA	0	0	20.0	40	0	0	75	0	15	0	10
MDE-30	12:29	Ebb	3.00	0.1	NA	0	0	19.4	40	0	0	60	0	40	0	0
MDE-34	12:13	Ebb	3.60	0.1	NA	0	0	18.9	40	0	0	90	0	10	0	5
MDE-36	13:22	Ebb	4.04	0.1	NA	0	0	20.6	40	0	0	70	0	30	0	0
MDE-42	9:29	Ebb	5.22	0.1	NA	0	0	16.1	40	0	0	95	0	5	0	0
MDE-43	10:27	Ebb	4.66	0.1	NA	0	0	16.7	40	0	0	90	0	10	0	0
MDE-44	10:13	Ebb	5.27	0.1	NA	0	0	16.1	40	0	0	90	0	5	0	5

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

Table 2-3: Year 33 water quality parameters measured *in situ* at all HMI stations on September 18, 2014.

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	5.95	22.21	8.41	7.88	1.0	10,540
		Bottom	3.97	6.28	22.20	7.97	7.86		11,040
MDE-15	XIF4609	Surface	0.5	6.21	22.31	7.95	7.87	0.7	10,890
		Bottom	4.58	7.30	22.59	7.30	7.81		12,720
MDE-16	XIF4615	Surface	0.5	6.71	22.45	7.77	7.82	0.6	11,750
		Bottom	4.27	7.35	22.62	7.54	7.81		12,820
MDE-17	XIF4285	Surface	0.5	6.45	22.42	8.24	7.88	0.7	10,980
		Bottom	4.98	8.13	22.90	7.99	7.83		14,000
MDE-19	XIF4221	Surface	0.5	6.82	22.48	7.78	7.60	0.7	11,890
		Bottom	4.23	7.82	22.89	7.78	7.57		13,550
MDE-34	XIF5805	Surface	0.5	6.31	22.32	8.21	7.87	0.8	11,100
		Bottom	3.10	6.38	22.31	8.06	7.89		11,200
MDE-45	N/A	Surface	0.5	6.71	22.74	7.89	7.82	0.7	11,730
		Bottom	4.45	7.10	22.49	7.39	7.81		12,390
Reference Stations									
MDE-13	XIG3506	Surface	0.5	7.58	22.84	8.70	7.88	0.7	13,140
		Bottom	4.90	7.80	22.72	8.23	7.83		13,500
MDE-22	XIF3224	Surface	0.5	6.74	22.32	8.55	7.15	0.7	11,790
		Bottom	5.40	8.94	23.04	7.75	6.93		15,330
MDE-36	XIG7589	Surface	0.5	5.57	22.36	7.81	7.90	1.2	9,880
		Bottom	3.54	6.53	22.53	7.41	7.92		11,460
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.5	5.58	22.07	11.62	8.68	0.6	9,890
		Bottom	2.78	6.42	22.37	8.65	8.11		11,290
MDE-30	XIF5925	Surface	0.5	5.20	22.70	10.77	8.26	0.7	9,290
		Bottom	2.5	5.65	22.35	8.48	7.99		10,030
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.5	6.63	22.44	7.92	7.49	0.7	11,630
		Bottom	4.72	8.08	22.94	7.68	7.43		13,960
MDE-43	XIF3985	Surface	0.5	6.88	22.46	7.96	7.77	0.8	11,950
		Bottom	4.16	8.09	22.86	8.09	7.75		13,940
MDE-44	XIF4482	Surface	0.5	6.91	22.48	7.52	7.65	0.7	12,040
		Bottom	4.77	7.83	22.84	7.72	7.64		13,550

BENTHIC MACROINVERTEBRATE COMMUNITY

Taxa Richness and Dominance

A total of 29 invertebrate taxa were found in Year 33. This is lower than the 12-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. 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). Thirteen taxa of Arthropoda were found in Year 33. The most common types of arthropods were the amphipods (including *Leptocheirus plumulosus*) and the isopods (including *Cyathura polita*). Six taxa of annelid worms in the Class Polychaeta were found. Five species of bivalve mollusks were found. Overall, infaunal bivalve average abundance was lower in Year 33 than previous years (Table 2-4).

Table 2-4: Average and total abundance (individuals per square meter) of each taxon found at HMI during the September 2014 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 33.

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	962.56	14438.40	1096.86	115.20	64.00	866.74	1203.20	2012.80	245.33
Carinoma tremophoros	11.09	166.40	10.83	19.20	6.40	17.37	4.27	6.40	6.40
Bivalvia	10.24	153.60	11.32	0.00	6.40	15.54	4.27	6.40	6.40
Macoma sp.	3.84	57.60	3.45	6.40	6.40	2.74	0.00	12.80	4.27
Macoma balthica	45.65	684.80	51.69	12.80	0.00	11.89	110.93	6.40	85.33
Macoma mitchelli	22.19	332.80	23.63	25.60	0.00	21.03	17.07	35.20	21.33
Rangia cuneata	199.25	2988.80	222.03	44.80	57.60	364.80	93.87	38.40	25.60
Ischadium recurvum	0.85	12.80	0.98	0.00	0.00	1.83	0.00	0.00	0.00
Mytilopsis leucophaeata	94.29	1414.40	107.82	0.00	12.80	192.91	17.07	3.20	2.13
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	26.45	396.80	29.54	12.80	0.00	26.51	29.87	3.20	38.40
Spionidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Marenzelleria viridis	333.23	4998.40	347.08	83.20	403.20	433.37	505.60	80.00	96.00
Streblospio benedicti	1567.57	23513.60	1654.65	1260.80	742.40	2351.54	928.00	1683.20	300.80
Polydora cornuta	2.56	38.40	2.95	0.00	0.00	5.49	0.00	0.00	0.00
Boccardiella ligerica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nereidae	0.43	6.40	0.49	0.00	0.00	0.91	0.00	0.00	0.00
Neanthes succinea	2.56	38.40	2.95	0.00	0.00	0.91	8.53	3.20	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	17.49	262.40	19.69	0.00	6.40	28.34	19.20	3.20	0.00
Naididae sp.	760.32	11404.80	853.17	256.00	57.60	679.31	409.60	2304.00	270.93
Amphipoda	72.53	1088.00	73.35	121.60	12.80	63.09	32.00	86.40	125.87
Gammaridea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ameroculodes spp complex	10.24	153.60	5.91	0.00	76.80	16.46	8.53	6.40	0.00
Leptocheirus plumulosus	645.97	9689.60	706.46	243.20	262.40	564.11	475.73	1088.00	712.53
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	252.59	3788.80	279.63	102.40	51.20	210.29	138.67	336.00	409.60
Corophiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apocorophium lacustre	47.79	716.80	55.14	0.00	0.00	102.40	0.00	0.00	0.00
Cyathura polita	258.99	3884.80	277.17	128.00	153.60	273.37	309.33	185.60	224.00
Edotea triloba	23.47	352.00	27.08	0.00	0.00	50.29	0.00	0.00	0.00
Chiridotea almyra	11.09	166.40	9.35	0.00	44.80	22.86	0.00	3.20	0.00
Ciripedia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Balanus improvisus	0.43	6.40	0.49	0.00	0.00	0.91	0.00	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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Membranipora sp	+	+	+	+	+	+	+	0.00	+
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.	35.84	537.60	40.86	6.40	0.00	12.80	32.00	147.20	19.20
Polypedilum	0.43	6.40	0.49	0.00	0.00	0.91	0.00	0.00	0.00
Cryptochironomus sp.	4.27	64.00	3.94	12.80	0.00	4.57	0.00	16.00	0.00
Tvetenia sp.	0.43	6.40	0.49	0.00	0.00	0.91	0.00	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	2.13	32.00	2.46	0.00	0.00	3.66	2.13	0.00	0.00
Copepoda spp.	+	+	+	0.00	+	+	+	+	+
Hydrozoa	2.13	32.00	2.46	0.00	0.00	1.83	6.40	0.00	0.00

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

Of the 29 taxa found in Year 33, fourteen are considered truly infaunal, eleven 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 33 were the amphipod *L. plumulosus*, the polychaete worms *M. viridis* and *S. benedicti*, the bivalve *R. cuneata*, worms from the family Naididae, and the isopod *C. polita*. The most common epifaunal species were the amphipod *M. nitida* and the bivalve *M. leucopheata*.

Nearfield station MDE-34 had the highest number of taxa (26 taxa, Table 2-5).The station with the fewest number of taxa (13 taxa) was South Cell Exterior Monitoring station MDE-43 (Table 2-5). Overall, average taxa richness was highest at Nearfield stations but did not vary greatly between station types (average taxa richness: Nearfield=17.0 taxa, Reference=16.7 taxa, Back River/Hawk Cove=15.5 taxa, South Cell Exterior Monitoring=13.7 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 simply be an artifact of sample size. No trend of increasing/decreasing taxa richness associated with distance from HMI could be discerned.

Table 2-5: Summary of metrics for each HMI benthic station surveyed during the Year 33 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	1779.20	1900.80	15	9	1.42	34.53	45.32	N/A	N/A	N/A	3.00
MDE-15	3417.60	3500.80	17	10	0.78	9.36	79.40	N/A	N/A	N/A	2.00
MDE-16	3033.60	3289.60	16	12	1.44	16.24	58.02	N/A	N/A	N/A	2.00
MDE-17	2208.00	2336.00	15	10	1.28	12.17	68.99	N/A	N/A	N/A	2.50
MDE-19	4313.60	4985.6	17	10	1.36	7.72	60.24	N/A	N/A	N/A	2.00
MDE-34	15577.60	18323.20	26	14	1.89	33.89	61.75	N/A	N/A	N/A	2.50
MDE-45	3680.00	4044.80	16	10	1.40	7.48	67.65	N/A	N/A	N/A	2.00
MEAN	**4859.00**	**5483.00**	**17**	**11**	**1.37**	**17.34**	**63.05**	**N/A**	**N/A**	**N/A**	**2.29**
Reference Stations											
MDE-13	2355.20	2444.80	18	13	1.62	23.64	61.14	N/A	N/A	N/A	2.50
MDE-22	2073.60	2342.40	17	13	2.15	29.63	37.96	N/A	N/A	N/A	3.00
MDE-36	4428.80	4672.00	15	9	1.76	42.63	43.79	N/A	N/A	N/A	3.00
MEAN	**2952.50**	**3153.10**	**16.7**	**11.7**	**1.84**	**31.97**	**47.63**	**N/A**	**N/A**	**N/A**	**2.83**
Back River/Hawk Cove Stations											
MDE-27	9043.20	9920.00	17	11	1.24	4.74	80.40	N/A	N/A	N/A	1.00
MDE-30	2016.00	2188.80	14	8	1.18	9.52	49.84	N/A	N/A	N/A	2.50
MEAN	**5529.60**	**6054.40**	**15.5**	**9.5**	**1.21**	**7.13**	**65.12**	**N/A**	**N/A**	**N/A**	**1.75**
South Cell Exterior Monitoring Stations											
MDE-42	2700.80	3481.60	14	10	1.87	15.64	37.68	N/A	N/A	N/A	2.50
MDE-43	1747.20	2022.40	13	10	1.91	23.44	37.73	N/A	N/A	N/A	3.00
MDE-44	1273.60	1542.40	14	10	1.78	36.18	7.54	N/A	N/A	N/A	4.00
MEAN	**1907.20**	**2348.80**	**13.7**	**10.0**	**1.85**	**25.08**	**27.65**	**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 33 was no exception. Nine of the ten most dominant taxa in Year 33 have been consistently dominant through the years. Those are: the amphipods *L. plumulosus*, *A. lacustre,* and *M. nitida*, oligochaete worms of the family Naididae, the polychaete worms *M. viridis,* and *S. benedicti,* the isopod *C. polita,* and the bivalves, *R. cuneata* and *M. balthica*. Falling out of the most dominant taxa was the polycheate worm *N. succinea*. The average abundance of each taxon (individuals per square meter) found at each station during the cruise are provided in Table 2-6 through Table 2-7.

Table 2-6: Average number of individuals collected per square meter at each station during HMI Year 33, 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 33.

	Station						
Taxon	MDE-01	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Nemata	64	12.8	390.4	556.8	115.2	3596.8	6.4
Carinoma tremaphoros	6.4	6.4	19.2	12.8	19.2	12.8	6.4
Bivalvia	6.4	0	0	0	0	0	0
Macoma sp.	6.4	0	0	0	6.4	0	0
Macoma balthica	0	6.4	12.8	6.4	12.8	12.8	326.4
Macoma mitchelli	0	25.6	6.4	12.8	25.6	44.8	19.2
Rangia cuneata	57.6	25.6	115.2	89.6	44.8	19.2	32
Ischadium recurvum	0	0	0	0	0	0	0
Mytilopsis leucophaeata	12.8	6.4	12.8	0	0	0	0
Amphicteis floridus	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0
Heteromastus filiformis	0	44.8	12.8	6.4	12.8	25.6	44.8
Spionidae	0	0	0	0	0	0	0
Marenzelleria viridis	403.2	51.2	44.8	76.8	83.2	44.8	19.2
Streblospio benedicti	742.4	1030.4	2528	1305.6	1260.8	1427.2	441.6
Polydora cornuta	0	0	0	12.8	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0
Nereidae	0	0	0	0	0	0	0
Neanthes succinea	0	12.8	0	6.4	0	0	6.4
Eteone heteropoda	6.4	44.8	0	0	0	0	12.8
Naididae sp.	57.6	364.8	172.8	441.6	256	1158.4	326.4
Amphipoda	12.8	19.2	19.2	76.8	121.6	108.8	44.8
Gammaridea	0	0	0	0	0	0	0

Table 2-6 – (continued)

	Station						
Taxon	MDE-01	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Ameroculodes spp complex	76.8	12.8	0	0	0	0	6.4
Leptocheirus plumulosus	262.4	236.8	339.2	665.6	243.2	1203.2	550.4
Gammarus sp.	0	0	0	0	0	0	0
Melitadae	0	0	0	0	0	0	0
Melita nitida	51.2	76.8	44.8	243.2	102.4	633.6	262.4
Corophiidae	0	0	0	0	0	0	0
Apocorophium lacustre	0	0	0	0	0	0	0
Cyathura polita	153.6	473.6	147.2	320	128	256	236.8
Edotea triloba	0	0	0	0	0	0	0
Chiridotea almyra	44.8	0	0	0	0	0	0
Ciripedia	0	0	0	0	0	0	0
Balanus improvisus	0	0	6.4	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	0	0	0	0	0	0
Membranipora sp	0	+	+	+	+	+	+
Chironomidae	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	12.8	12.8	6.4	12.8	6.4
Polypedilum sp.	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	0	12.8	12.8	0
Tvetenia sp.	0	0	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	6.4	6.4	0	0	12.8	0
Copepoda	+	0	0	0	0	+	0
Hydrozoa	0	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 33, 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 33.

	Station							
Taxon	MDE-27	MDE-30	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45
Nemata	313.6	3712	108.8	3590.4	537.6	44.8	153.6	1235.2
Carinoma tremaphoros	0	12.8	44.8	0	6.4	6.4	6.4	6.4
Bivalvia	12.8	0	102.4	12.8	0	19.2	0	0
Macoma sp.	25.6	0	0	0	6.4	6.4	0	6.4
Macoma balthica	12.8	0	32	0	102.4	121.6	32	6.4
Macoma mitchelli	70.4	0	12.8	6.4	25.6	25.6	12.8	44.8
Rangia cuneata	64	12.8	2182.4	224	19.2	25.6	32	44.8
Ischadium recurvum	0	0	12.8	0	0	0	0	0
Mytilopsis leucophaeata	6.4	0	1324.8	44.8	0	0	6.4	0
Amphicteis floridus	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0
Heteromastus filiformis	0	6.4	96	0	64	38.4	12.8	32
Spionidae	0	0	0	0	0	0	0	0
Marenzelleria viridis	83.2	76.8	2291.2	1446.4	32	12.8	243.2	89.6
Streblospio benedicti	3193.6	172.8	7532.8	1312	377.6	486.4	38.4	1664
Polydora cornuta	0	0	25.6	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0
Nereidae	0	0	6.4	0	0	0	0	0
Neanthes succinea	6.4	0	0	6.4	0	0	0	0
Eteone heteropoda	6.4	0	192	0	0	0	0	0
Naididae sp.	3884.8	723.2	1888	537.6	633.6	172.8	6.4	780.8
Amphipoda	102.4	70.4	70.4	32	160	153.6	64	32
Gammaridea	0	0	0	0	0	0	0	0

Table 2-7 – (continued)

	Station							
Taxon	MDE-27	MDE-30	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45
Ameroculodes spp complex	12.8	0	38.4	6.4	0	0	0	0
Leptocheirus plumulosus	1337.6	838.4	390.4	640	1011.2	454.4	672	844.8
Gammarus sp.	0	0	0	0	0	0	0	0
Melitadae	0	0	0	0	0	0	0	0
Melita nitida	627.2	44.8	89.6	76.8	768	249.6	211.2	307.2
Corophiidae	0	0	0	0	0	0	0	0
Apocorophium lacustre	0	0	716.8	0	0	0	0	0
Cyathura polita	268.8	102.4	774.4	217.6	268.8	249.6	153.6	134.4
Edotea triloba	0	0	352	0	0	0	0	0
Chiridotea almyra	0	6.4	115.2	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	0	0	0	0	0	0
Membranipora sp	0	+	+	+	0	+	0	+
Chironomidae	0	0	0	0	0	0	0	0
Coelotanypus sp.	185.6	108.8	0	89.6	6.4	0	51.2	44.8
Polypedilum sp.	0	0	6.4	0	0	0	0	0
Cryptochironomus sp.	19.2	12.8	6.4	0	0	0	0	0
Tvetenia sp.	0	0	6.4	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	0	0	0	0	0	0	0	6.4
Copepoda	+	0	0	0	+	0	0	+
Hydrozoa	0	0	12.8	19.2	0	0	0	0

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

Infaunal Taxa Abundance

In Year 33, total infaunal abundance at the various stations ranged from 1,779.20 to 15,577.60 organisms per square meter (individuals/m^2) and averaged 3,976.53 individuals/m^2 (Table 2-8). In general, total infaunal abundances were above average for all stations. The highest abundance was found at the Nearfield station MDE-34, due primarily to large numbers of the polycheate worms *S. benedicti* and *M. viridis,* and the bilvave *R. cuneata*. The lowest infaunal abundance was found at the Nearfield station MDE-01 (Table 2-8). The average total infaunal abundance was highest at Back River/Hawk Cove stations (5,529.60 individuals/m^2) followed by Nearfield stations (4,859.00 individuals/m^2), Reference stations (2,952.53 individuals/m^2), and South Cell Exterior Monitoring stations (1,907.20 individuals/m^2). While the relative differences between mean abundances at the various station types are historically typical, they are all above average. The 33-year mean (4,704.82 individuals/m^2) of fall abundance for the Back River stations is much higher than the Reference (1,988.92 individuals/m^2) and Nearfield (2,319.91 individuals/m^2) means. It is also higher than the eleven-year average for South Cell Exterior Monitoring stations (1,578.29 individuals/m^2).

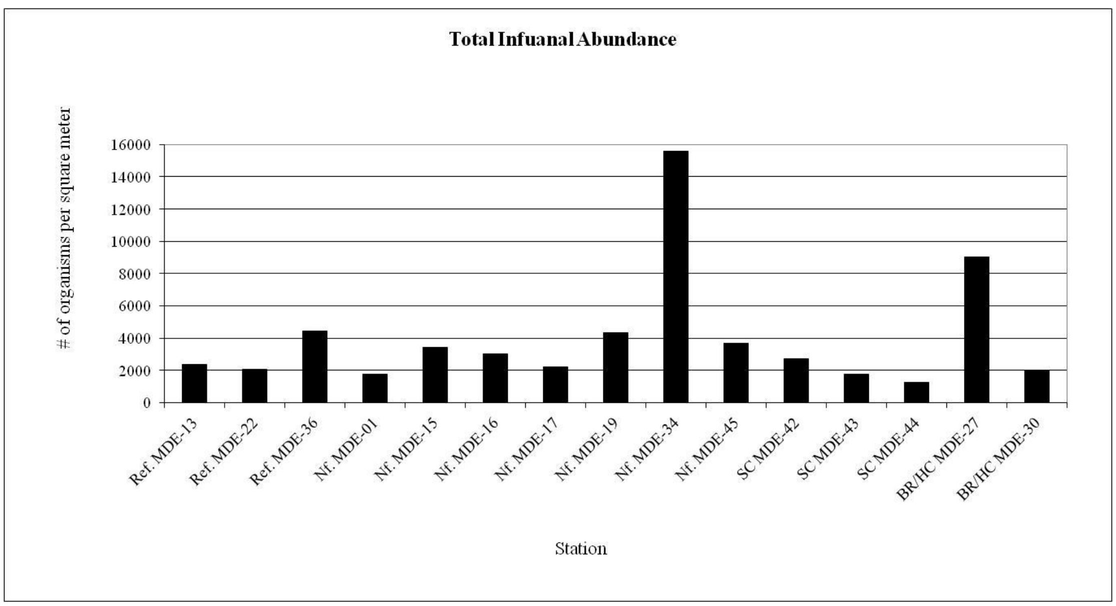

Figure 2-2: Total abundance of infaunal taxa collected at each HMI station in Year 33, September 2014 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove). Note: for Year 33 metrics, the ideal abundance range is between 1,500 and 2,500 individuals/m^2.

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 33, total infaunal abundance was similar to total abundance, typically accounting for ≥85 percent of all organisms at all stations, except MDE-42 (78%) and MDE-44 (82%). 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 33 are presented in Table 2-8 and 2-9.

SWDI values in Year 33 averaged 1.54± 0.36 in September 2014. The fall average diversity was below the 17-year mean fall SWDI of 2.26. The lowest SWDI value occurred at Nearfield station MDE-15 (0.78, Figure 2-3). This was due to the large percentage of the Polycheate worm *S. benedicti*, which accounted for 74 percent of total infaunal abundance at this station. The highest diversity value (2.15) occurred at Reference station MDE-22.

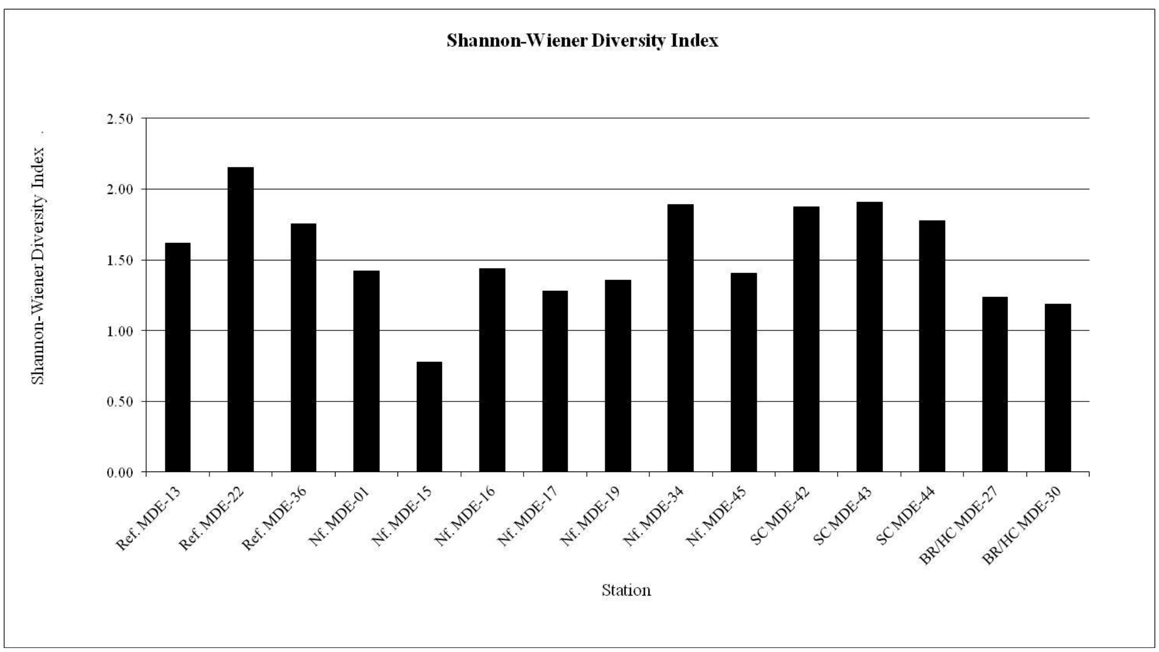

Figure 2-3: Shannon-Wiener Diversity Index (SWDI), HMI Year 33, September 2014 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell; BR/HC = Back River Hawk Cove).

On average, Nearfield and Back River/Hawk Cove stations had diversity values below reference stations. Comparing station types, the lowest average SWDI was 1.21 at the Back River/Hawk Cove stations followed by the Nearfield stations at 1.37, and Reference stations at 1.84. The highest average SWDI occurred at the South Cell Exterior Monitoring stations at 1.85 (Table 2-8 Historically, the 27-year mean SWDI values, ranked from lowest to highest, are associated with the following station types: Back River/Hawk Cove (2.08), Nearfield (2.30), Reference (2.38), and South Cell Exterior Monitoring (2.40, n=11 yrs).

Pollution Sensitive Taxa Abundance (PSTA)

Four taxa found during Year 33 were designated as "pollution-sensitive" according to Alden et al. (2002). These were the polychaete worms *M. viridis*, the bivalves *R. cuneata* and *M. balthica*, and the isopod crustacean *C. polita*. The calculation of the PSTA is a ratio of the relative PSTA abundance to total infaunal abundance.

Small changes in salinity (causing conditions to be either above or below 5.0 ppt) can greatly affect the sensitivity/tolerance designation of several organisms, and correspondingly alter calculated abundances. Because this metric is, 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 33, the fall salinity regime was low mesohaline.

Pollution sensitive taxa occurred at all station types. PSTA ranged from 4.74 percent at MDE-27 (Back River/Hawk Cove station) to 42.63 percent at MDE-36 (Reference station- Table 2-8; Figure 2-4). The average PSTA for all stations was 20.46 percent. Comparing station types, the lowest average PSTA was 7.13 percent at the Back River/Hawk Cove stations, followed by the Nearfield stations at 17.34 percent, followed by the South Cell Exterior Monitoring stations at 25.09 percent. The highest average PSTA was 31.97 percent at Reference stations. Historically, the 32-year mean fall PSTA values, ranked from lowest to highest, are associated with the following station types: South Cell Exterior Monitoring (23.88 percent, n=10 years), Back River/Hawk Cove (28.60 percent), Nearfield (36.36 percent), and Reference (39.96 percent).

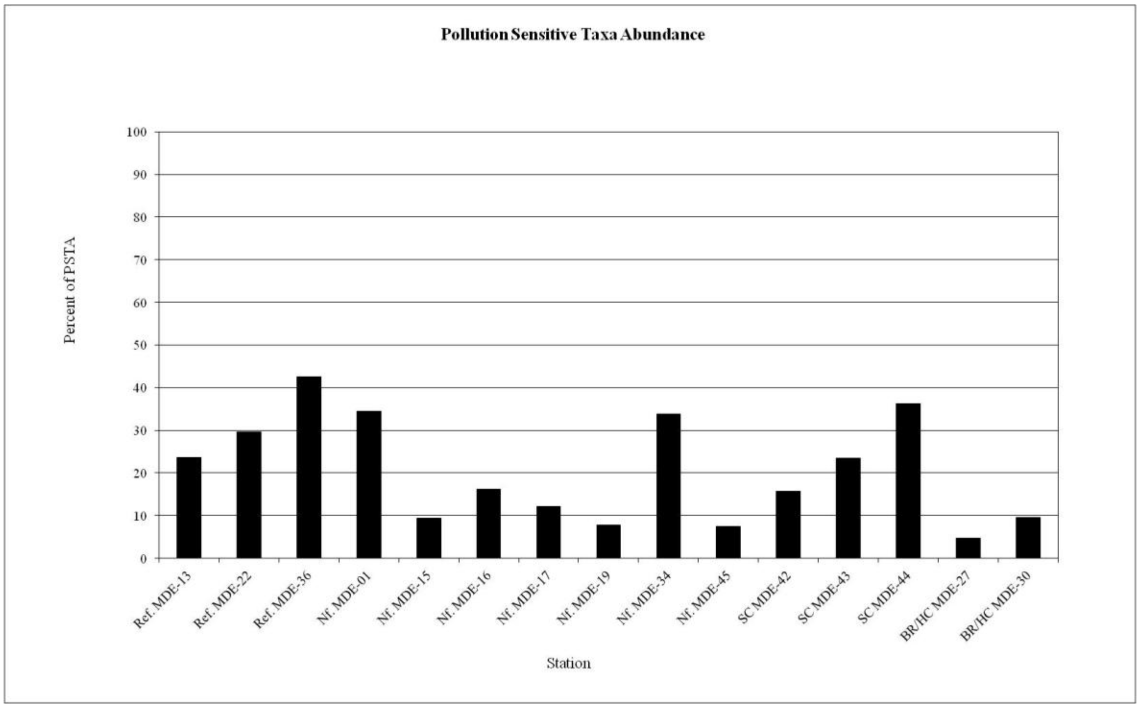

Figure 2-4: Percent abundance comprised of pollution sensitive species (PSTA), HMI Year 33 September 2014 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

Pollution Indicative Taxa Abundance (PITA)

Five taxa found during the Year 33 benthic monitoring were designated as "pollution-indicative" according to Alden et al. (2002): the Chironomids *Coelotanypus* sp. and *Polypedillum* sp., the polychaete worms *S. benedicti* and *E. heteropoda*, and oligochaete worms of the family Naididae. The calculation of the PITA is a ratio of the relative PITA abundance to total infaunal abundance.

Pollution indicative taxa occurred at all station types. The PITA ranged from 7.54 percent at MDE-44 (South Cell Exterior Monitoring station) to 80.40 percent at MDE-27 (Back River/Hawk Cove station) (Table 2-8; Figure 2-5). The average PITA for all stations was 53.16 percent. Comparing station types, the lowest average PITA was 27.65 percent at the South Cell Exterior Monitoring stations, followed by 47.63 percent at the Reference stations, and 63.05 percent at Nearfield stations. The highest average PITA occurred at the Back River/Hawk Cove stations at 65.12 percent. Historically, the 33-year mean fall PITA values, ranked lowest to highest, are associated with the following station types: Reference (23.19 percent), Nearfield (26.38 percent), South Cell Exterior Monitoring (38.42 percent, n = 11 years), and Back River/Hawk Cove (39.48 percent).

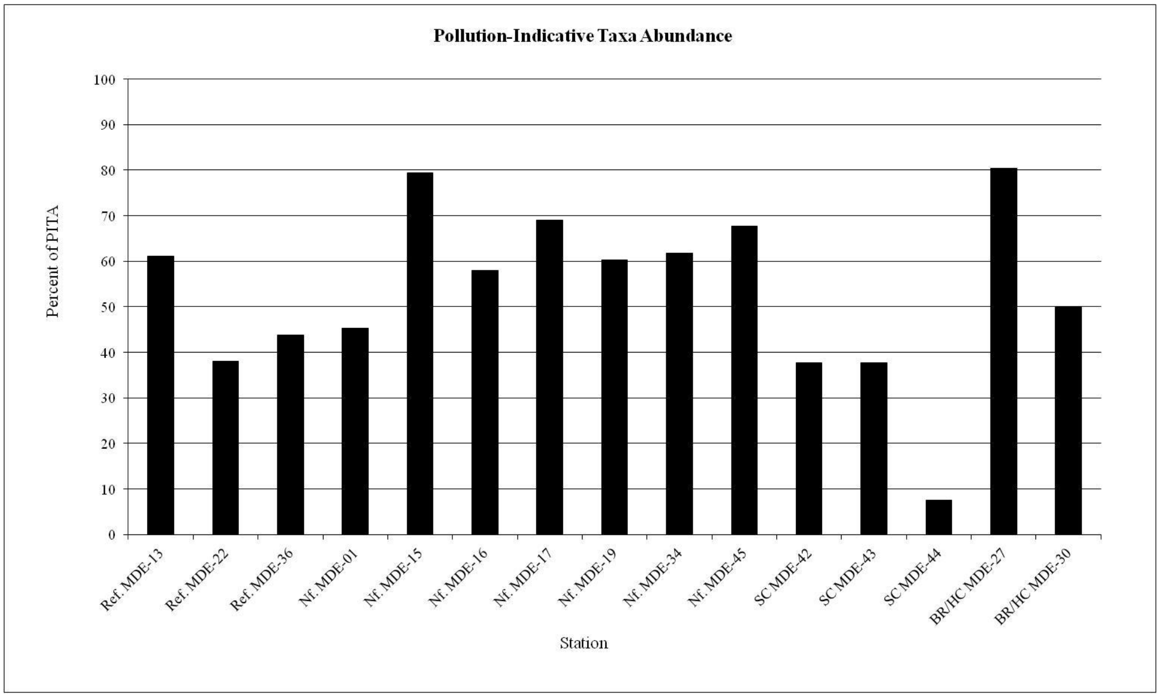

Figure 2-5: Percent abundance comprised of pollution indicative species (PITA), HMI Year 33 September 2014 grouped by station type (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

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 2-8. 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 33 were compared to this benchmark.

Table 2-8: Low mesohaline scoring criteria for measures used in calculating the Chesapeake Bay B-IBI in September 2014 (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 32, individual station B-IBI Scores increased at 6 stations, remained the same at 5, and decreased at 4 stations. Five of the fifteen stations met or exceeded the benchmark criteria of 3.0 in Year 33. In Year 33, the following stations failed to meet the benchmark criteria of 3.0 (Table 2-8, Figure 2-6): Back River/Hawk Cove stations MDE-27 (1.00) and MDE-30 (2.50), Reference station MDE- 13 (2.50), Nearfield Stations MDE-15 (2.00), MDE-16 (2.00), MDE-17 (2.50), MDE-19 (2.00), MDE-34 (2.50), and MDE-45 (2.00), and South Cell Exterior Monitoring station MDE-42 (2.50). Fourteen stations were below their historic averages and one station (South Cell Exterior Monitoring station MDE-44) was above the historic averages for B-IBI. In addition to fourteen stations being below their historic average five tied a historic low (Nearfield stations MDE-25, MDE-17, MDE-19 and MDE-34, and Back River Hawk Cove station MDE-27). No stations set new historic lows. No stations set new historic highs.

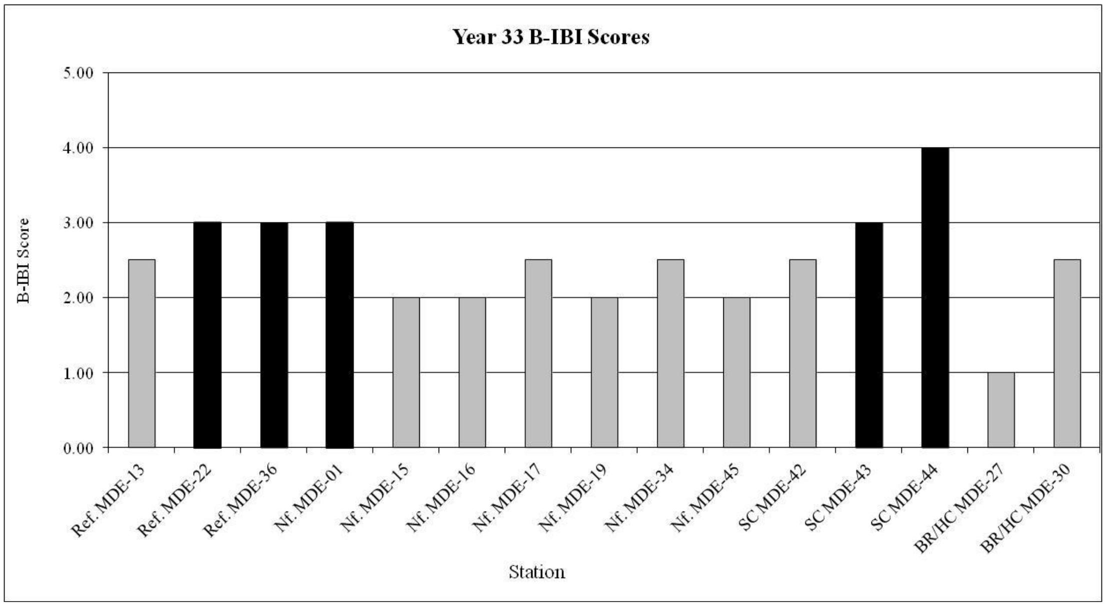

Figure 2-6: B-IBI Scores for all stations in September 2014 grouped by station type (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

The mean B-IBI for Nearfield, Back River/Hawk Cove and Reference 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 32, the mean B-IBI decreased for Nearfield and Back River/Hawk Cove stations, while South Cell Exterior Monitoring and Reference station types increased. The Year 33 mean B-IBI's for all station types were below their historic averages (eleven year average for South Cell Exterior Monitoring Stations, Table 2-8).

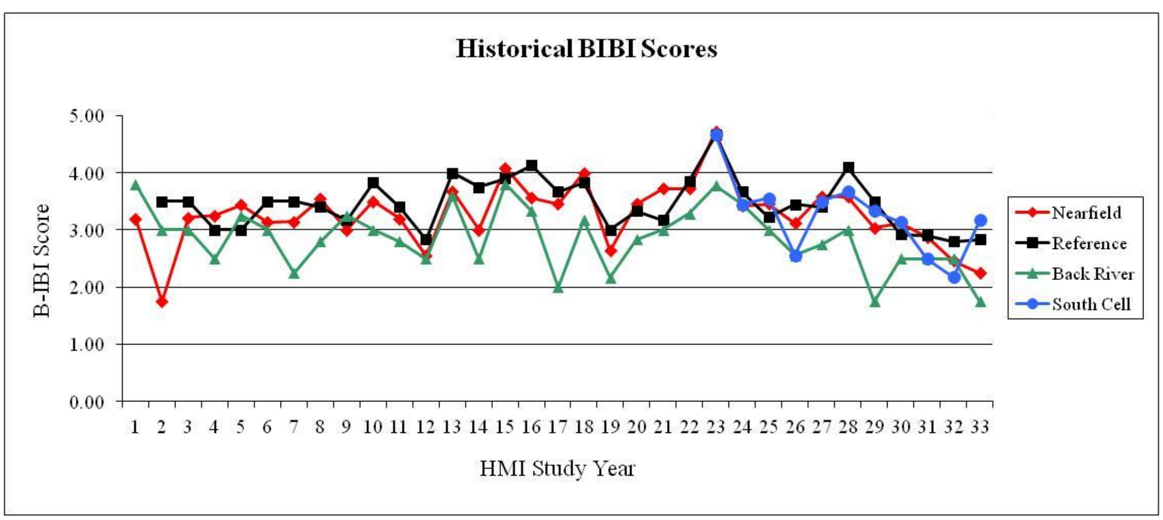

Figure 2-7: Average B-IBI Scores by station type at HMI for Monitoring Years 1-33.

There was no trend of increasing or decreasing B-IBI scores associated with proximity to HMI in Year 33. Compared to other station types, Nearfield and Back River/Hawk Cove stations had the lowest mean IBI's in Year 33. Back River/Hawk Cove stations have had the lowest average 27 of 33 years.

The Year 33 low B-IBI's were attributable to several variations in the invertebrate community. Dropping and historically low B-IBI's have been observed for the last five years throughout the HMI Region. Compared to historic means, all four metrics that combine to create a B-IBI score have dropped at most stations.

Total infaunal abundances have been and are exceptionally high. 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 three years, abundances are approximately three times higher than ideal at most stations. These high abundances depressed the total infaunal abundance metric and adversely affect the other metrics as well.

The Pollution Sensitive Taxa Abundance (PSTA) metric has been very low over the last five years as well. 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 bivalve, *R. cuneata* (a sensitive taxon) were about half their historic mean. They have increased since their low in Year 31 when they were less than ten percent the historic mean.

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, to 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 oligochate worms in the family Niadidae (0pollution indicative taxa) have also contributed to this effect.

The Shannon-Weiner Diversity Index (SWDI) scores have 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 33 the species that contributed most to this imbalance was the polychaete worm, *S. benedicti*, however in past years it has been other species. In Year 32 the two species which depressed this metric were the polychate worm *P. cornuta* and the amphipod, *A. lacustre*.

Based on B-IBI's, Year 33 was among the poorest years since HMI monitoring began. All station types except South Cell Monitoring and Back River/Hawk Cove stations have shown a four or five year declining trend in B-IBI. While B-IBI's at most stations are at historic lows, so is the mean at Reference Stations, implying a regional decline is being recorded.

Clam Length Frequency Distribution

In September 2014, 467 *R. cuneata* were collected. The greatest average abundance of *R. cuneata* occurred at the Nearfield stations (57.00 clams/station), followed by the Reference stations (14.67 clams/station), the Back River/Hawk Cove stations (6.00 clams/station), and the South Cell Exterior Monitoring stations (4.00 clams/station). The greatest abundance of *R. cuneata* was found in the 16-20 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 (≥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 Year 32 we recorded the beginning of a recovery of the population (an increase to 10.6 clams/station in the smallest size class). This trend has continued in Year 33, where 31.1 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 16 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 33, 115 *M. balthica* were collected with 52 coming from Reference stations, 40 from South Cell Exterior Monitoring stations, 13 from Nearfield stations, and 10 from Back River/Hawk Cove stations. The greatest abundance of *M. balthica* was found in the 7-12 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 (≥ 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. Eighteen 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 33, 60 *M. mitchelli* were collected, with 31 coming from Nearfield stations, 11 from Back River/Hawk Cove stations, 10 from South Cell Exterior Monitoring stations, and 8 from Reference stations. The greatest abundance of *M. mitchelli* was found in the 9-10 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 17 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 33 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-eight 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 highly variable between years. A more consistent year to year pattern had been the identification of outlier stations (e.g. 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 (eleven times since Year 19) and MDE-34 (seven times since Year 19).

The cluster dendrogram for September 2014 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. Three station clusters were apparent at $R^2 > 0.90$, indicating high similarity in their benthic invertebrate assemblages. Stations MDE-19 and MDE-45 were connected into a group at $R^2 = 0.97$ and were joined to station MDE-42 at an $R^2 = 0.93$. These three stations were identified as Cluster Group 1. Cluster Group 2, consisting of five stations (MDE-15, MDE-16, MDE-17, MDE-43 and MDE-44), was fully formed at an $R^2 = 0.95$. Cluster Group 3 consisted of the pair of stations MDE-30 and MDE-36, which connected at an $R^2 = 0.91$. In addition to the strong within-group linkage for each of these three groups, they also demonstrated moderately high between-group linkage, as all three stations were joined together at $R^2 = 0.80$. The last identified station group, Cluster Group 4, consisted of MDE-13 and MDE-22 and was weakly linked ($R^2 = 0.77$), indicating relatively less similarity between their benthic invertebrate assemblages compared to the within-group and among-group similarity of benthic invertebrate assemblages of the other three groups. The cluster dendrogram projected MDE-34 as a strong outlier with little to no linkage to the other stations ($R^2 = 0.0$), indicating that the benthic invertebrate assemblage at this station was unique and dissimilar from the benthic communities at the other stations. The remaining two stations, MDE-1 and MDE-27, were identified as weak outliers or intermediate stations because their R^2 values were less than 0.75 but greater than a R^2 of 0.50. 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 2014 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-19, MDE-42 and MDE-45) had stressed benthic invertebrate assemblages (all three stations with B-IBI < 3.00). Stations of Cluster Group 2 - 4 (Group 2: MDE-15, MDE-16, MDE-17, MDE-43 and MDE-44; Group 3: MDE-30 and MDE-36; Group 4: MDE-13 and MDE-22) were composed of stations with both "failing" and "passing" B-IBI scores, so neither of these cluster groups could be definitively characterized with respect to benthic community health. The strong outlier station MDE-34 and the weak outlier/intermediate station MDE-27were identified by the B-IBI as having stressed benthic invertebrate assemblages. Station MDE-01, the other weak outlier/intermediate station had an unstressed benthic community (B-IBI = 3.0). The pairing of Back River station MDE-30 with the far Reference station MDE-36 for the second year in a row in a cluster group and the repeated identification of MDE-27 as an outlier station indicates that their benthic communities and the hydrologic and sediment dynamics that affect these communities on the west side of HMI are distinct and detached from conditions occurring at the benthic communities of stations on the east side of HMI. Likewise, the repeated identification in recent years of MDE-01 and MDE-34 as outlier stations indicates that unique factors influencing their benthic communities are occurring on this northeast corner of the island.

As in previous years, the relationship between identified cluster groups and station type (Nearfield, Reference, Back River and South Cell) was poor except for Cluster Group 4 (both Reference stations). Likewise, bottom type correlated poorly with identified cluster groups because of the prevalence of silt/clay bottom in the HMI area.

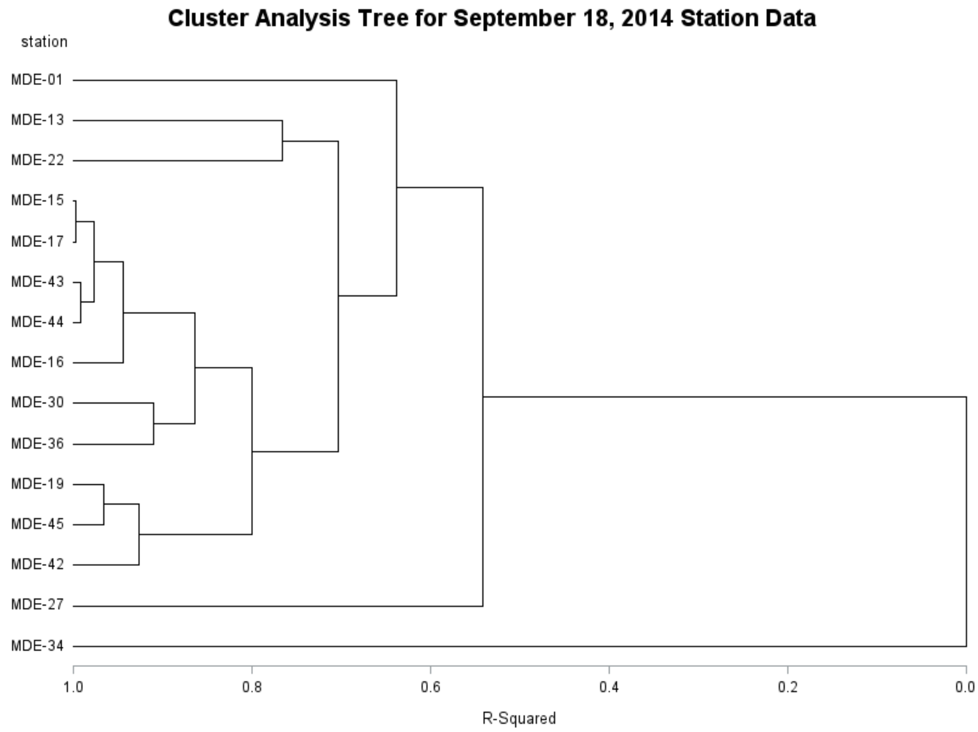

Figure 2-8: September 2014 Cluster Analysis tree.

Average distance between stations in Cluster Group 1 (4,792 ft) and Cluster Group 2 (3,085 ft), along with distance between station pairs in Cluster Group 4 (9,004 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. However, spatial proximity was less of an influencing factor in Cluster Group 3 formation, with distance between the two stations (19,666 feet) greater than the overall station to station average distance.

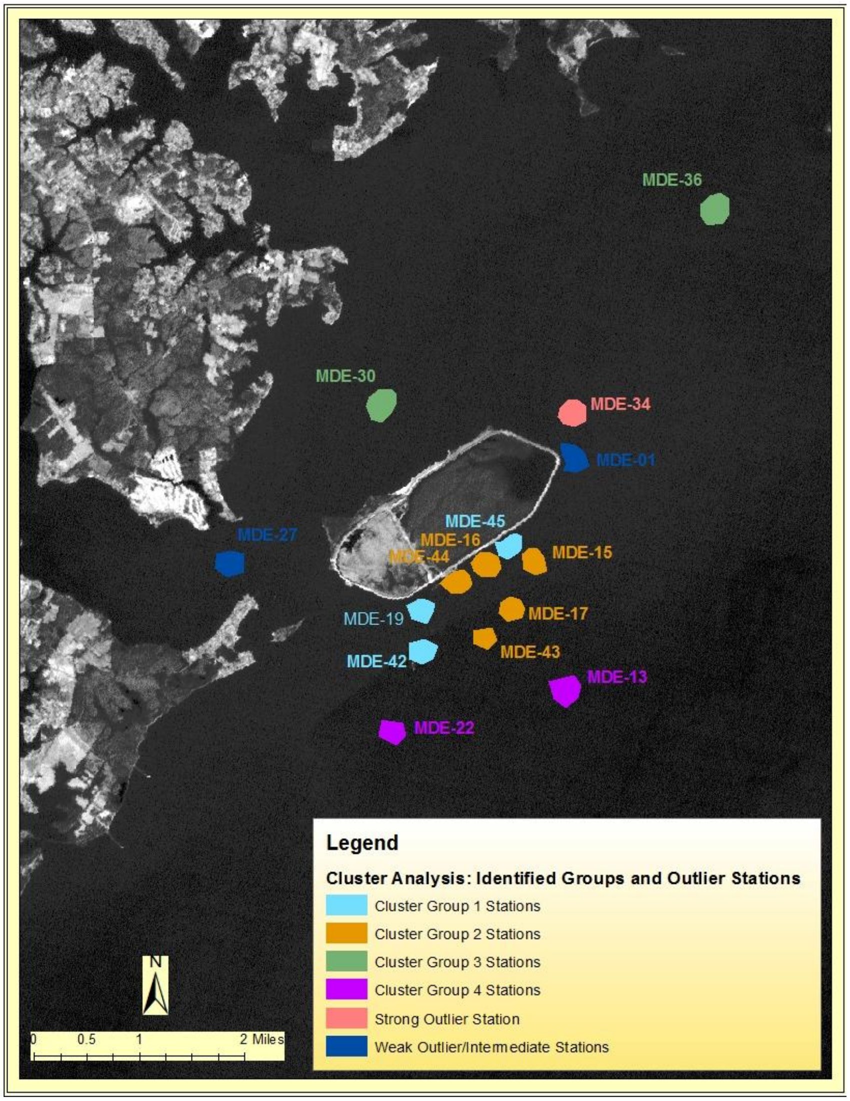

Figure 2-9: Identified Cluster Groups, Strong Outlier and Weak Outliers/Intermediate Areas for September 2014

Color-coding of identified cluster groups 1 - 4, the strong outlier station MDE-34, and the two weak outlier/intermediate stations MDE-01 and MDE-27(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 33 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 33 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 2014 (P = 0.146). Significant Friedman results occur infrequently (only 8 times in the 18 HMI monitoring years the statistical test has been utilized), 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 2014'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) = 5.37, p = 0.146.

Station Type	Average Rank	Mean	Std. Dev.
Nearfield	3.10	604	658
Reference	2.50	408	397
Back River	1.80	229	220
South Cell	2.60	773	916

CONCLUSIONS

In Year 33, 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 33. 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 spatially and statistically.

The health of the benthic macroinvertebrate community around HMI in Year 33 was worse than historical averages. BIBI's around the island were at or near historical lows. Ten of the 15 stations failed to meet the benchmark criteria of 3.00. Five stations tied their historic lows. No stations set new historic lows or met their historic highs. Year 33 is the fifth consecutive year where B-IBI's have been trending downward, except at South Cell Exterior Monitoring stations.

The mean B-IBI for all station types, except South Cell Exterior Monitoring, failed to meet the benchmark of 3.0 and were below historic averages. The mean B-IBI score for Nearfield stations (2.25) was 0.98 lower than the historic average and the second lowest in 33 years. The Reference stations mean (2.83) was 0.68 below average and was tied for the second lowest in 33 years. The Back River/Hawk Cove stations mean (1.75) was 1.16 below average and was tied for the lowest in 33 years. In contrast, the South Cell Exterior Monitoring stations mean (3.17) was only 0.08 below average and near the historic median (eleven years).

The five year decline in B-IBI's and the Year 33 low B-IBI's were attributable to several variations in the invertebrate community. Total infaunal abundances were exceptionally high for many organisms (mainly pollution indicative and non-designated species). These high abundances depressed all of the four metrics that lead to the B-IBI throughout the region. The percentage of pollution sensitive species was diluted by other taxa. The fact that many of the increased abundances were pollution indicative, increased the percentage of indicative organisms and unbalanced the community somewhat, decreasing the Shannon-Weiner diversity metric.

As in most years with poor B-IBI's, the abundances of some pollution sensitive taxa were below average. Among these, the bivalves, *M. balthica* and *R. cuneata*, while rebounding from recent die-offs, were still below average in abundance. The abundances of pollution indicative taxa were also above historic averages. The polychaete worm, *S. benedicti* was particularly abundant. Worms in the family Naididae were also above average but less than in Years 31 and 32, also years with poor B-IBI's.

The multivariate cluster analysis identified three station groups that had strongly similar benthic invertebrate assemblages ($R^2 \geq 0.91$). Cluster Group 1 (MDE-19, MDE-42, MDE-45) and Cluster Group 2 (MDE-15, MDE-16, MDE-17, MDE-42, MDE-43) were composed of stations all located on the east side of the island. These two groups consisted of a combination of Nearfield and South Cell stations and primarily stressed benthic invertebrate communities. Cluster Group 3 (MDE-30 and MDE-36) had poor spatial proximity between the two stations and both stations had stressed benthic invertebrate communities. The last identified cluster group, Group 4 (MDE-13 and MDE-22) was located south of HMI and had relatively weaker similarity between their benthic communities (R2 = 0.77). The strong outlier station identified by the cluster dendrogram (MDE-34) had characteristics of its benthic community that were highly divergent from benthic communities at all other HMI stations but was stressed overall. The remaining two stations (MDE-27 and MDE-01)) were characterized as neither belonging to one of the identified groups nor being a strong outlier, indicating the benthic macroinvertebrate communities at these stations were weakly similar to Cluster Groups 1 – 4.

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, as a general pattern of stressed benthic invertebrate communities prevailed across the entire monitoring area. In future dredge disposal monitoring projects the statistical analysis could be improved by modifying the sampling design to be more adaptive to changing conditions. To better focus on examining impacts to the benthic community from operational discharges, the extent of discharge plumes should be identified to improve the validity of designated station types. The current station types could then be modified to include: Discharge Impacted stations, Nearfield stations, Reference stations and Back River stations.

Future monitoring plans: MDE proposed and MPA accepted the continuation of benthic monitoring at a reduced level until stabilization of the island is complete. This will involve the continued sampling at fifteen sites, during the fall, every other year, in even numbered years through 2018.

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APPENDIX III: ANALYTICAL SERVICES (PROJECT IV)

(September 2014 – August 2015)

Technical Report

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OBJECTIVES

The Year 33 HMI Exterior Monitoring project goals were to continue to measure and evaluate the levels of select trace elements in the sediment in the vicinity of HMI 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 33 were to collect clams and associated sediment in the fall of 2014 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 (Hg), Methylmercury (MeHg), Silver (Ag), Selenium (Se) and Arsenic (As), and clams were also analyzed for Lead (Pb) and Cadmium (Cd) to support MGS sediment studies.

METHODS AND MATERIALS

Sampling Procedures

In September 2014, 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 and 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 $60^{o}C$ (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 $90^{o}C$ 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 $60^{o}C$ overnight. Upon drying, samples were then reweighed and a dry/wet ratio was calculated.

RESULTS AND DISCUSSION

Trace Elements in Sediment, September 2014

Concentrations of As in the sediment collected around HMI in Year 33 (fall 2014) are generally close to the running mean and median calculated from historic values (Figure 3-1). Stations MDE 15, 16, 30, 36, 42, 43, 44 and 45 had As concentrations above the mean and median, but only 1 site (MDE 43) had a concentration elevated above the standard deviation of the running mean.

Concentrations of Se in sediment were above the historical running mean and median at sites MDE 16, 19, 36, 43 and 44. 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-36 in 2014 were again lower than the median and average concentrations of previous years (Figure 3-2). Only site MDE 44 had sediment concentrations of Ag above mean of previous collections. This same condition, lower than average Ag concentrations in sediment has been observed for the past 5 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 above the running mean calculated from previous years with concentrations, the exceptions being site MDE 1, 34 and 43. Site MDE 16 and 17 had concentrations falling above the standard deviation of measurements made between 1998 and 2013 (Figure 3-2). The sites with sediment elevated in T-Hg concentration are distributed all around the island and even the reference site, MDE-36, was elevated. Concentrations of T-Hg in sediment were also elevated in 2013 (Y32).

Concentrations of MeHg in sediment collected in the fall of 2014 were ubiquitously lower than previous years collections (Figure 3-3). The low MeHg concentrations are present despite higher T-Hg concentrations (Figure 3-2). The percent of mercury that occurred as MeHg was less than 1% at all sites and was much lower than in previous years (Figure 3-3). The low percentage of MeHg in sediment is largely driven by the higher than normal T-Hg concentrations.

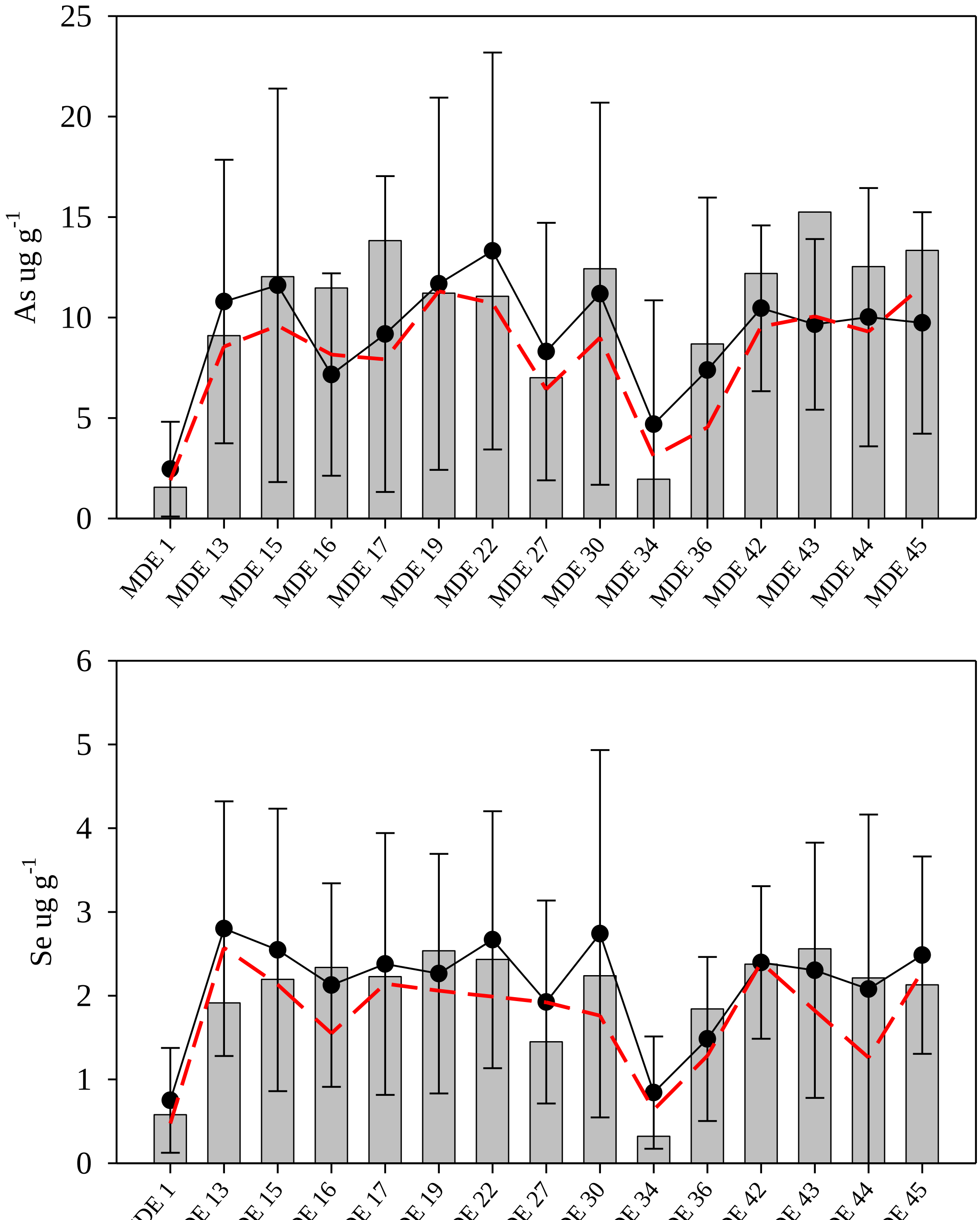


Figure 3- 1: As and Se in sediment, expressed as dry weight concentration, collected by MGS in the fall of 2014 (bars) and the 1998-2013 mean (circles) with standard deviation (error bars) and the 1998-2013 median (dashed line).

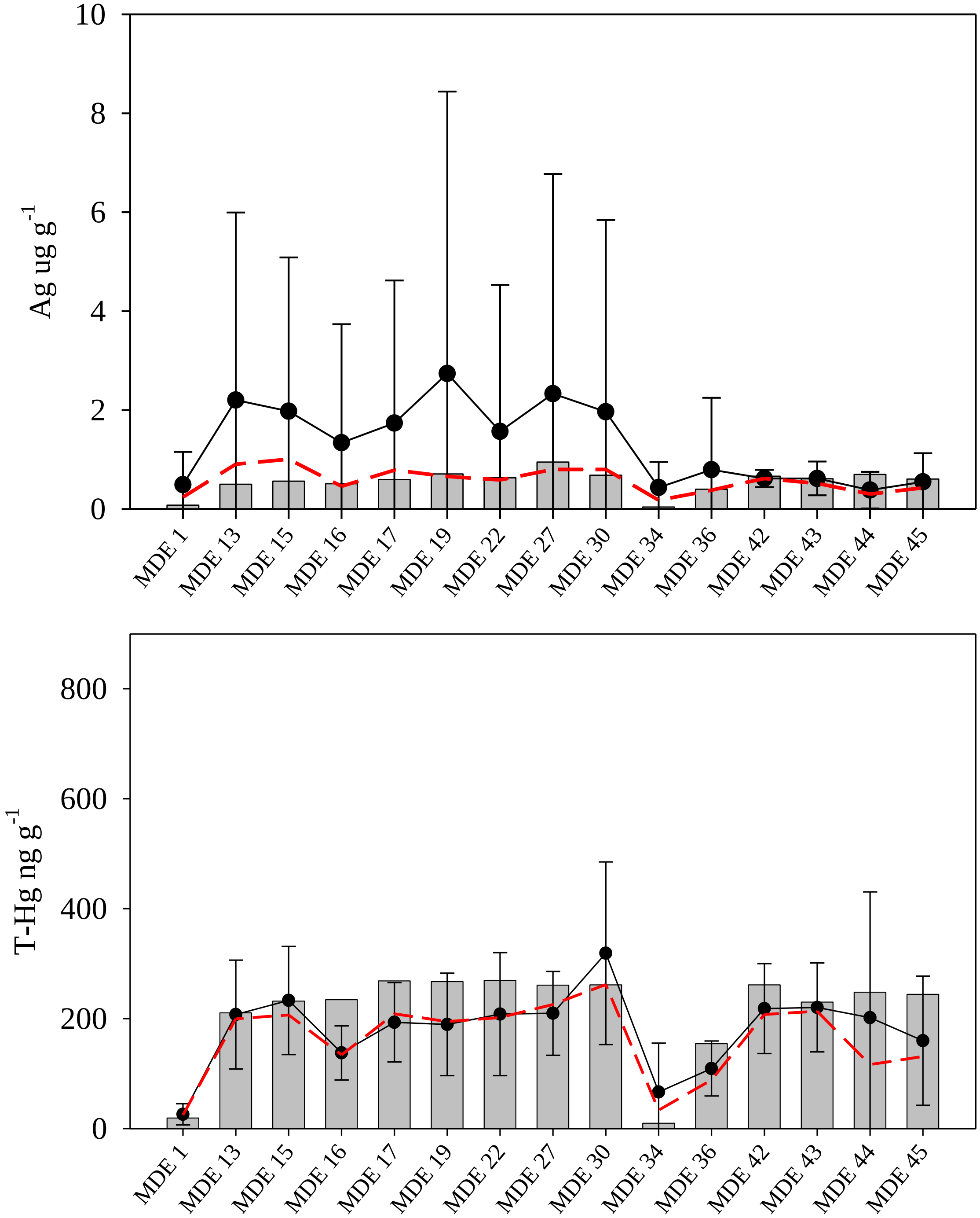


Figure 3- 2: Ag and T-Hg concentrations in sediment, expressed as dry weight concentration, collected by MGS in the fall of 2014 (bars) and the 1998-2013 mean (circles) with standard deviation (error bars) and the 1998-2013 median (dashed line).

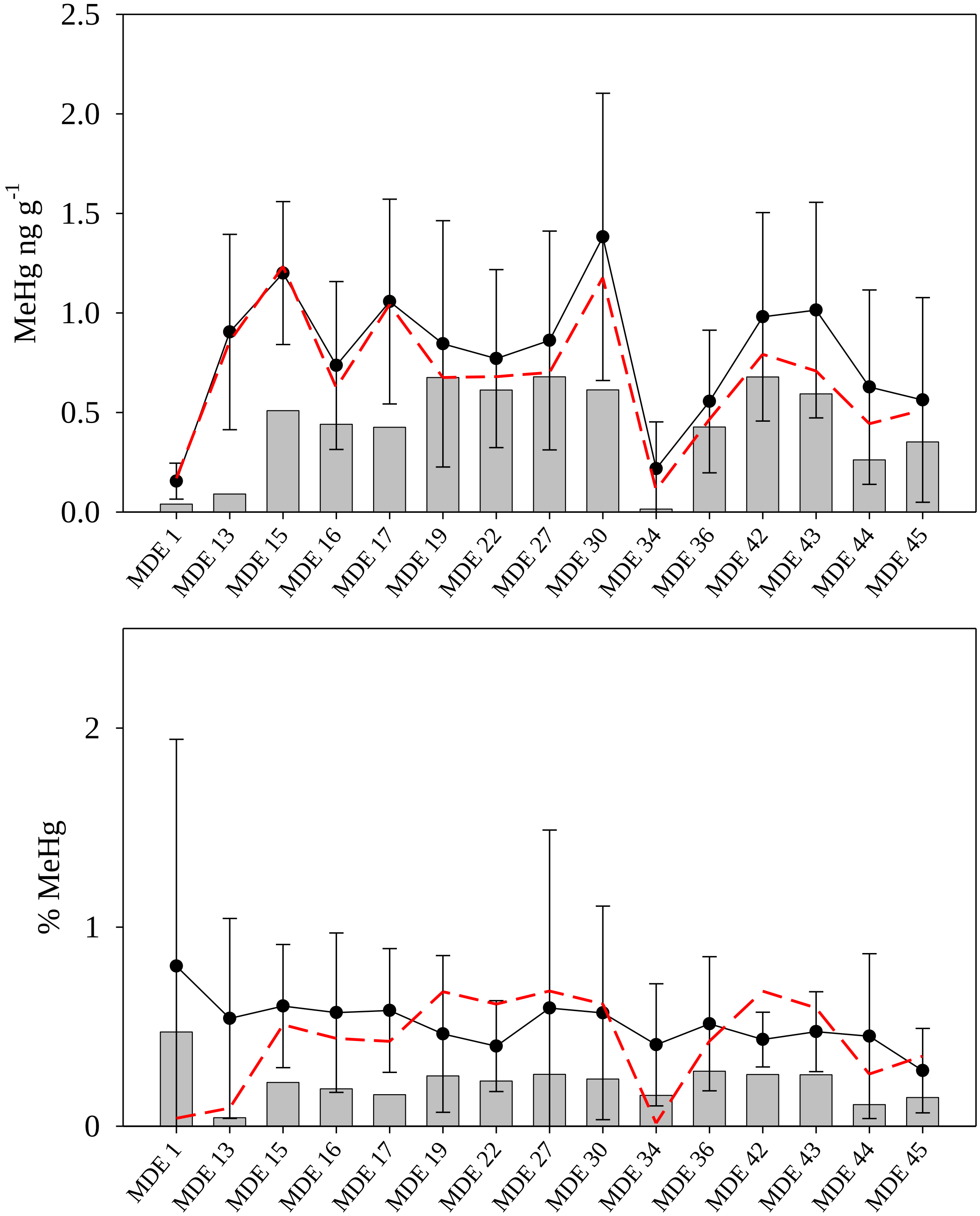


Figure 3- 3: MeHg, expressed as dry weight concentrations, and percent of T-Hg as MeHg in sediment collected by MGS in the fall of 2014 (bars), and the 1998-2013 mean (circles), with standard deviation (error bars), and the 1998-2013 median (dashed line).

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 1998-2014

In general concentrations of As in sediment are temporally coupled, meaning concentrations in an area around HMI increase and decrease together over time (Figure 3-4 and 3-6). Prior to 2001, concentrations of As were high and varied at all sites. 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 upward. This upward trend has 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.

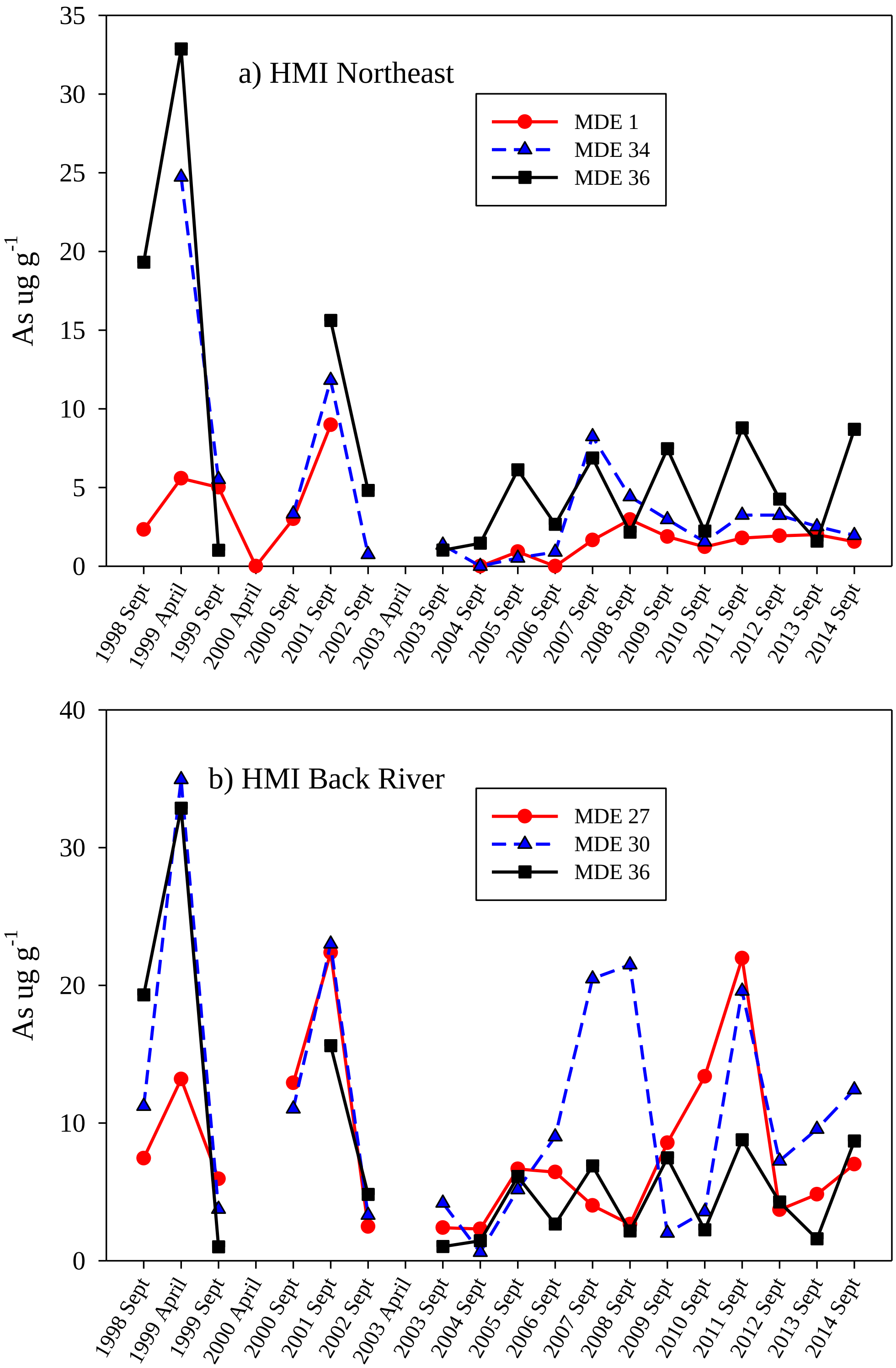
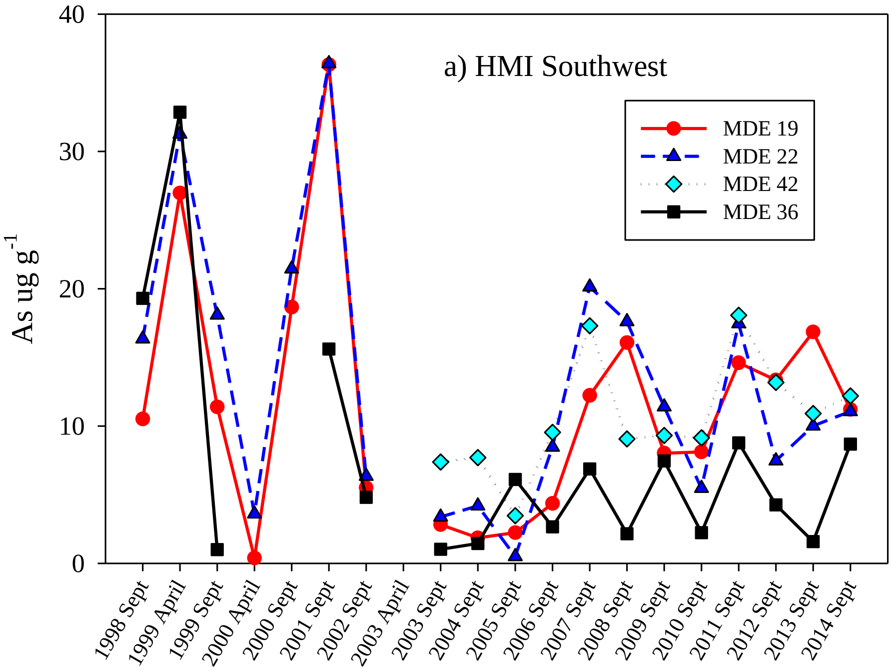


Figure 3- 4 Arsenic (As) concentrations in sediment from the a) northeast side of the island and b) Back River influenced side of the island from 1998 to 2014. MDE station 36 is shown for reference.



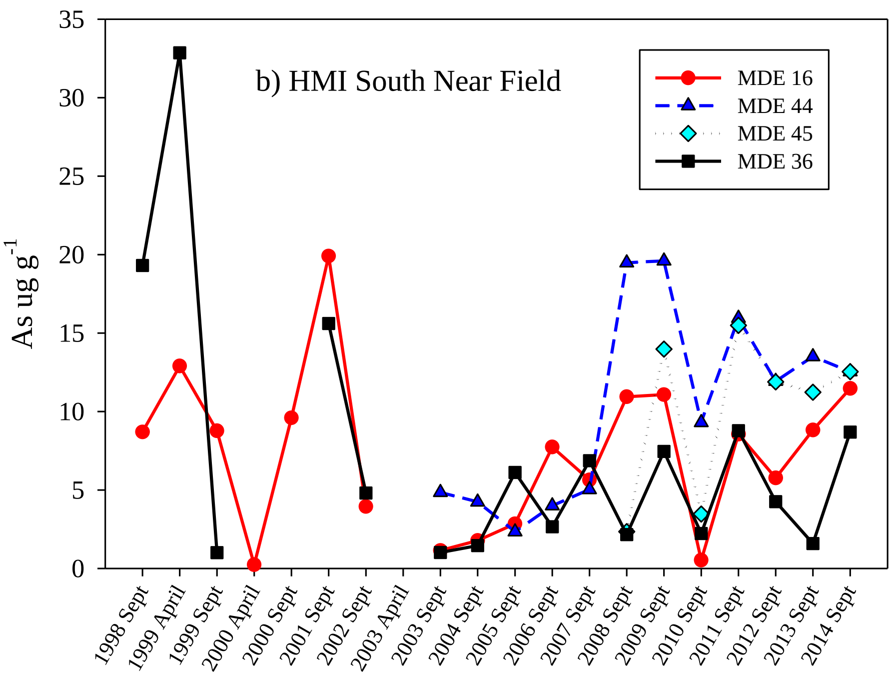


Figure 3- 5: Arsenic (As) concentrations in sediment from a) Southwest side of the island and b) close to the south side of the island (near field) from 1998 to 2014. MDE station 36 is shown for reference.

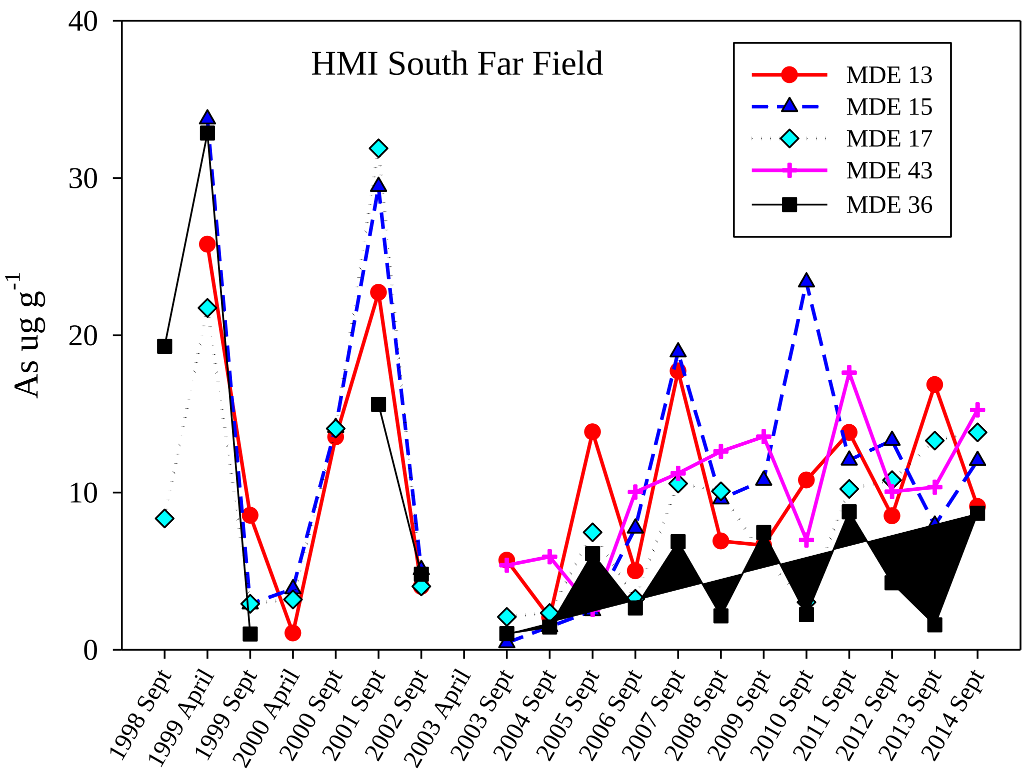


Figure 3-6: Arsenic (As) concentrations in sediment from South Side of the island Far Field stations 1998 to 2014. Station MDE 36 is shown for reference.

Selenium in Sediment 1998 to 2014

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 three 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 trend of lower Se concentrations may again be developing as concentrations at the same site have remained low and similar from 2012 to 2014. 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.

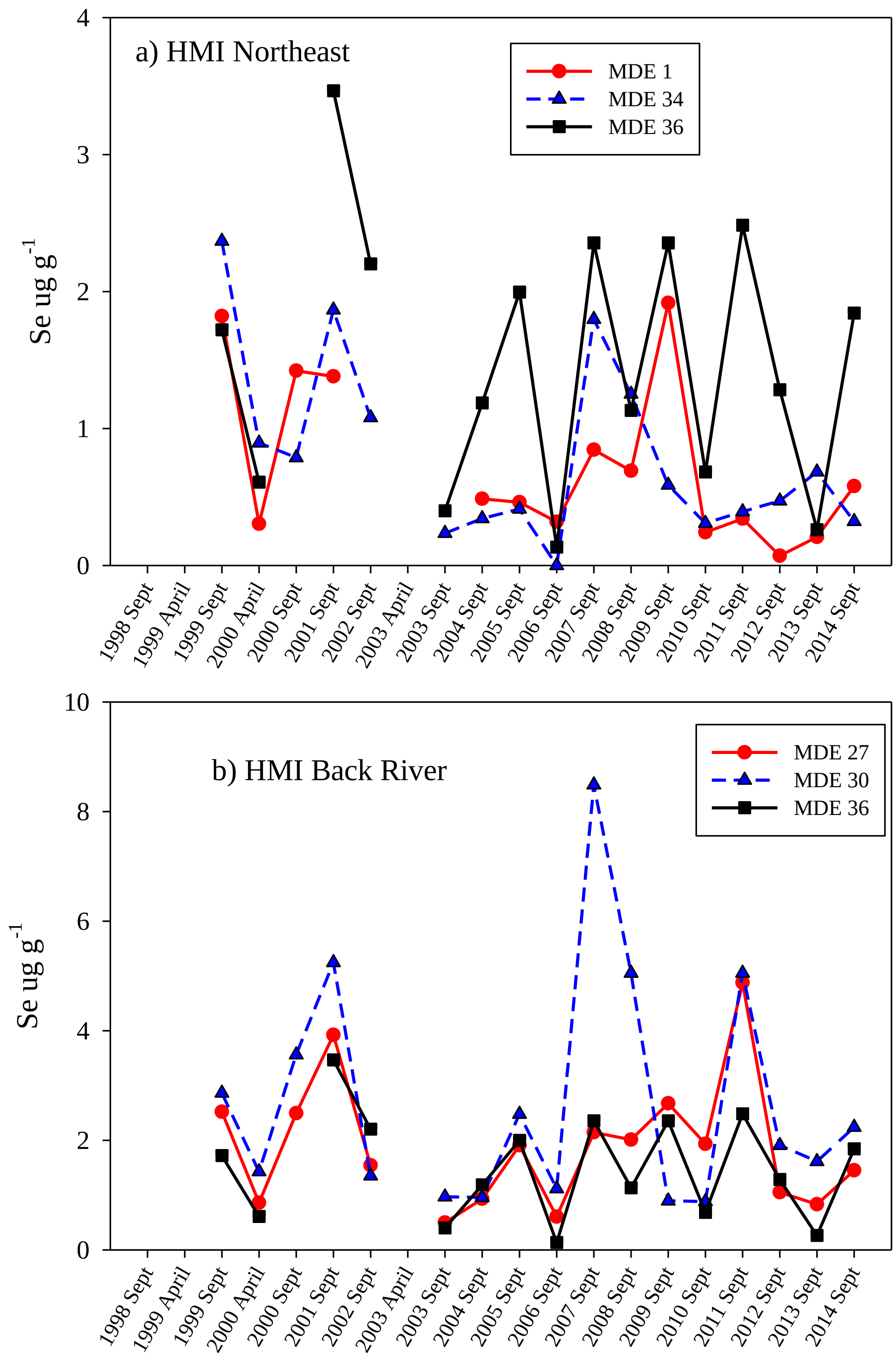


Figure 3-7: Se concentrations in sediment from the a) northeast side of the island and b) Back River influenced side of the island from 1998 to 2014. MDE station 36 is shown for reference.

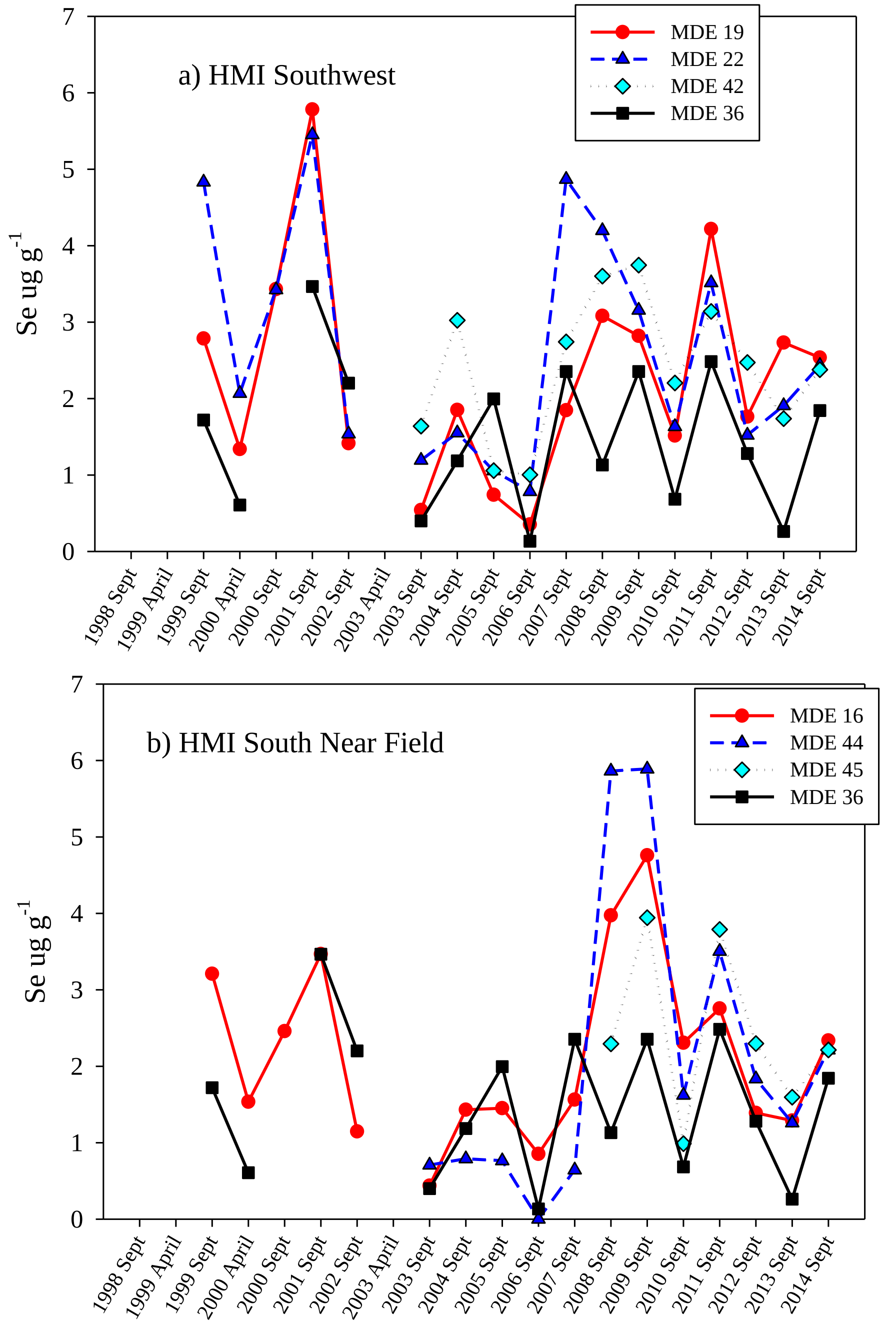


Figure 3-8: Selenium (Se) concentrations in sediment from a) Southwest side of the island and b) close to the south side of the island (near field) from 1998 to 2014. MDE station 36 is shown for reference.

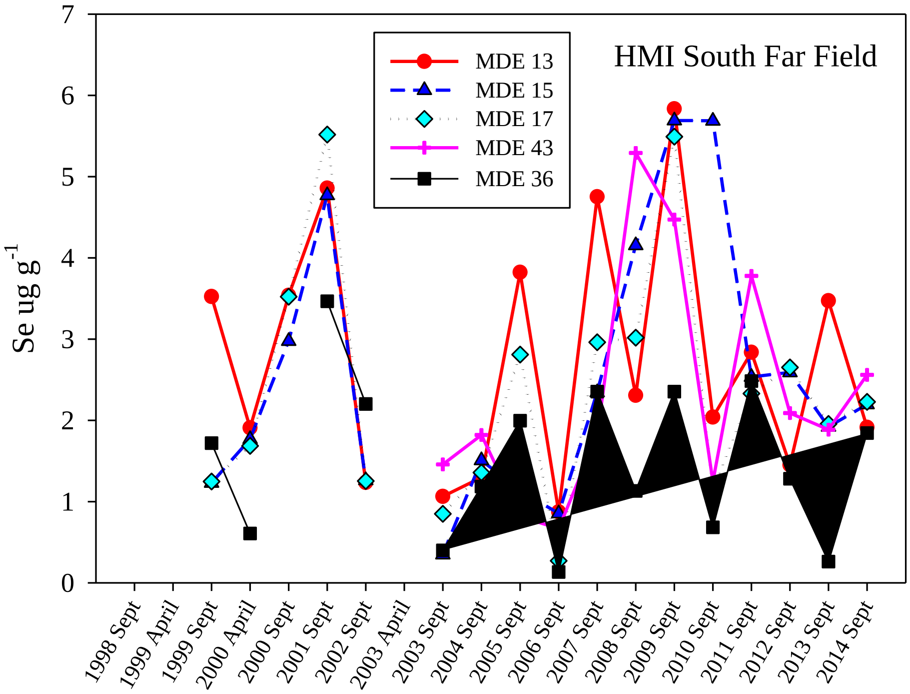


Figure 3- 9: Selenium (Se) concentrations in sediment from South Side of the island far field stations 1998 to 2014. Station MDE 36 is shown for reference.

Silver in Sediment 1998 to 2013

As reported for the other trace elements the concentrations of Ag in sediment vary in temporal synchrony, concentrations across the sites increasing and decreasing in unison. 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 in 2009 with concentrations as high as 2 ug g^{-1} observed at some stations. While the two peaks in Ag sediment concentration (2009 and 2000-2001) differ in magnitude, the pattern of a slow increase from 1998-2001 and 2006 to 2009 are followed by dramatic decreases in the subsequent years. From 2010 to 2014, Ag concentrations in sediment are low and generally less than 1 ug g^{-1}.

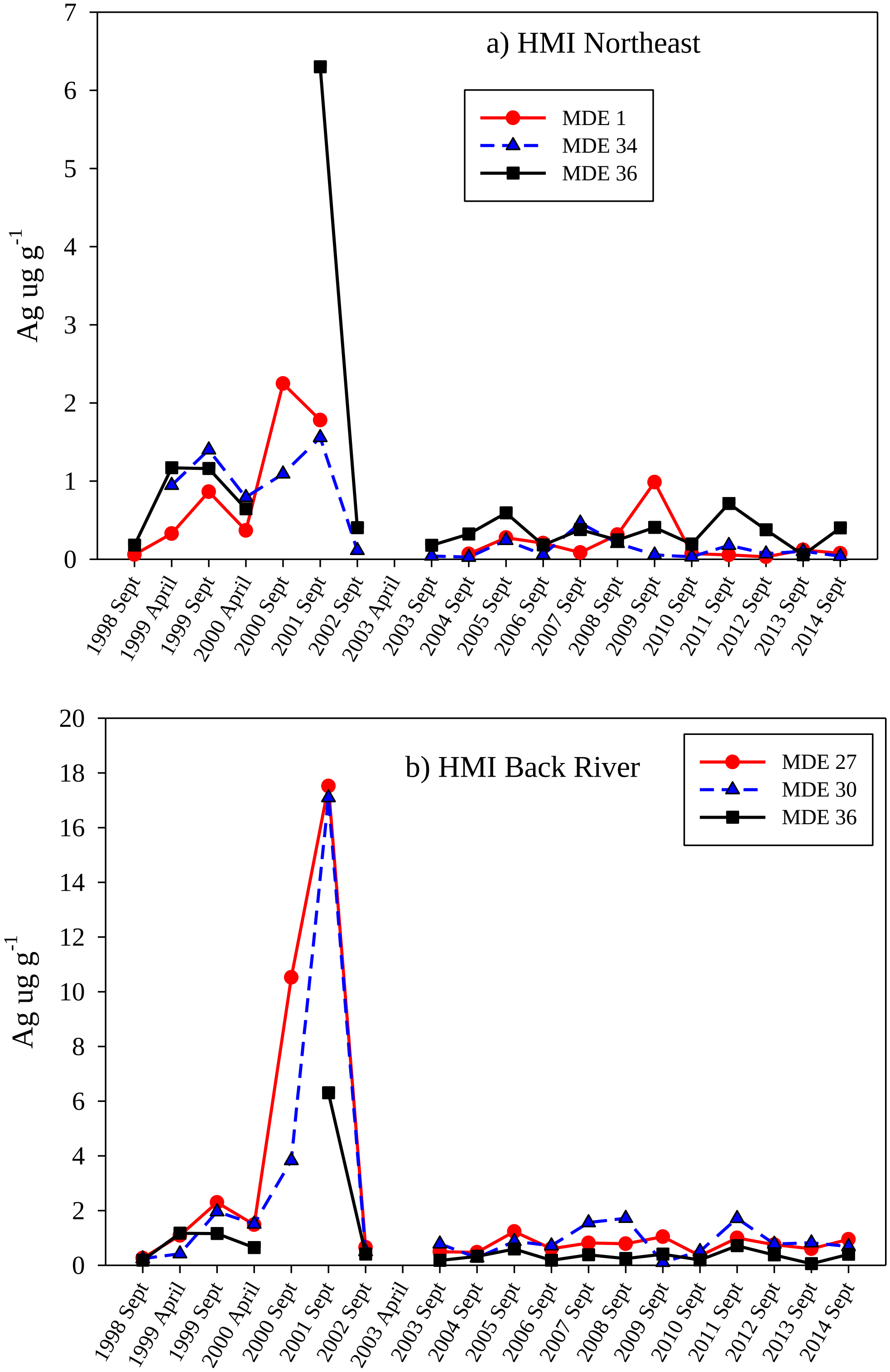


Figure 3-10: Silver (Ag) concentrations in sediment from the a) northeast side of the island and b) Back River influenced side of the island from 1998 to 2014. MDE station 36 is shown for reference.

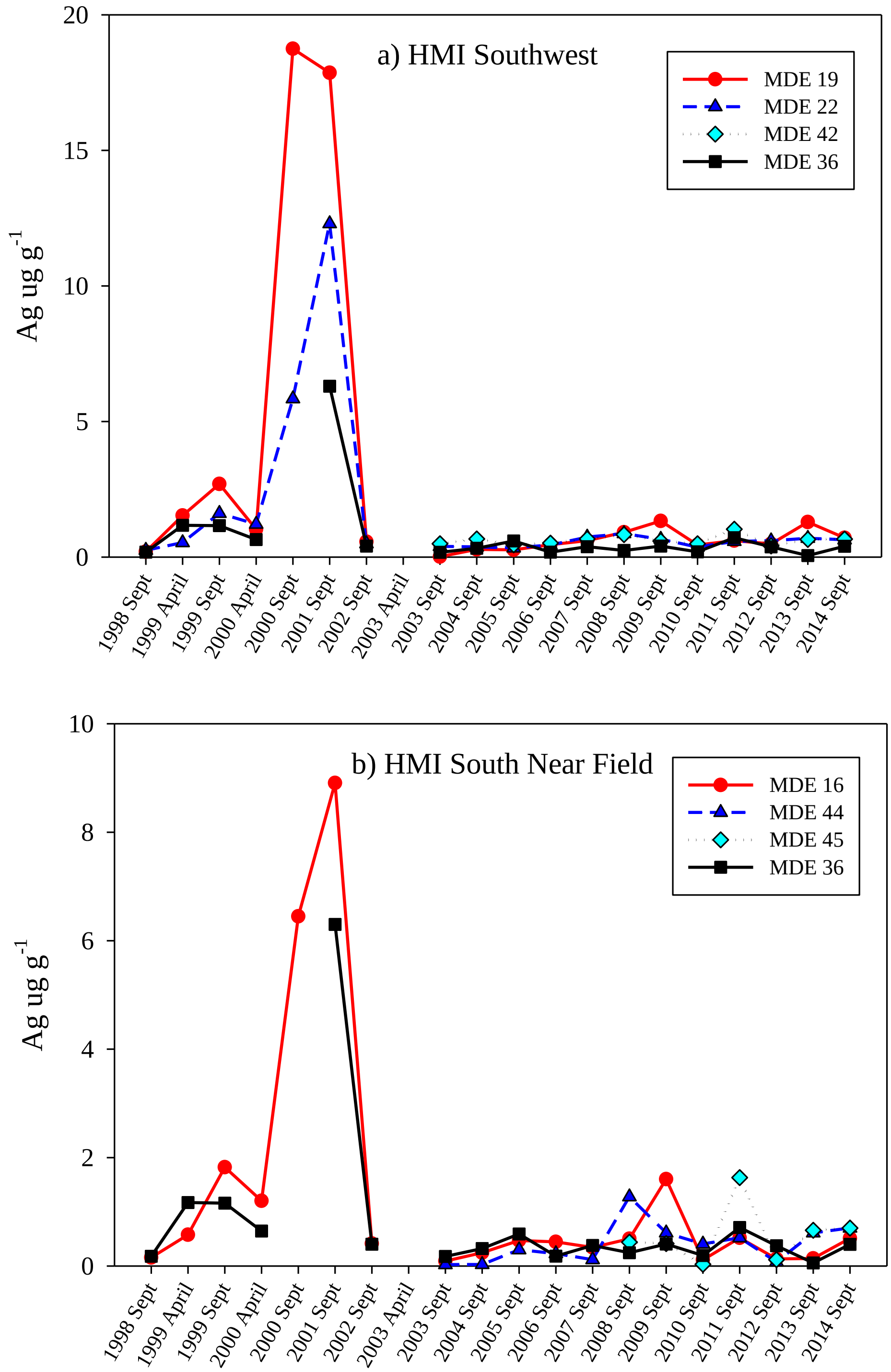


Figure 3- 11: Silver (Ag) concentrations in sediment from a) Southwest side of the island and b) close to the south side of the island (near field) from 1998 to 2014. MDE station 36 is shown for reference.

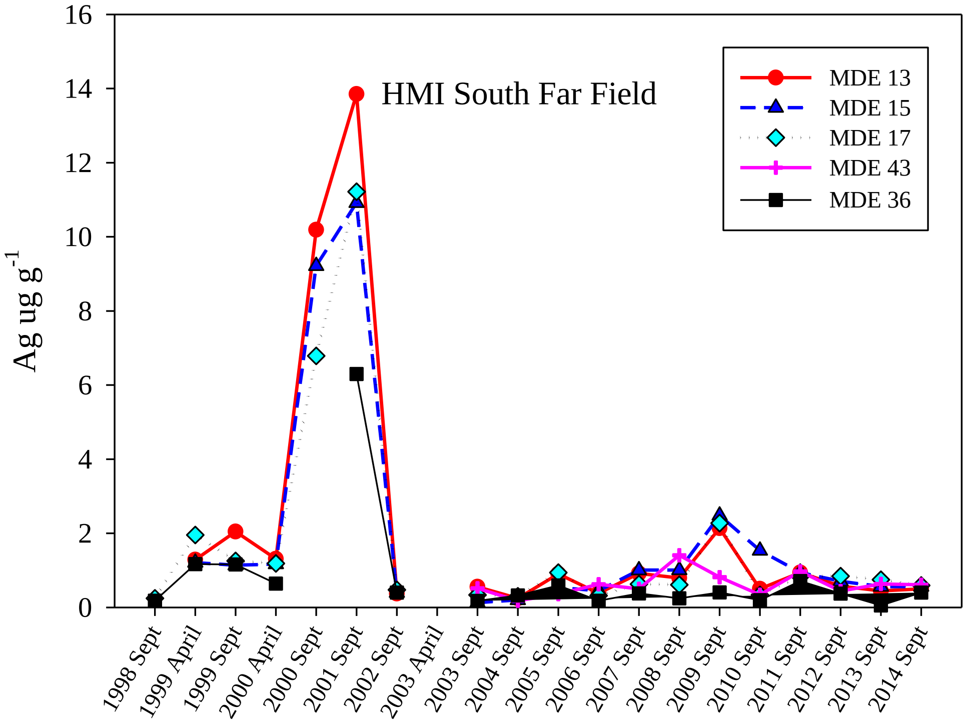


Figure 3-12: Silver (Ag) concentrations in sediment from South Side of the island far field stations 1998 to 2014. Station MDE 36 is shown for reference.

Mercury in Sediment 1998 to 2014

During the period from 1998 to 2014, T-Hg concentrations in sediment have fluctuated by as much as a factor of 5 at individual sites (e.g. MDE 22 and MDE 44) (Figure 3-13 to 3-15). Even sediment from site MDE-36 has shown considerable variation. In 2014, high sediment T-Hg concentrations were observed at approximately half of the sites monitored. Since 2010 T-Hg concentrations have been trending upward but this also occurs at the reference site MDE 36. Within this trend year to year variability is high. For example sediment T-Hg concentrations in 2014 were lower than 2013 but similar to 2012. 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. The fact that the increase appears regional but does not occur at all sites suggests some local influence and warrants close attention in future years.

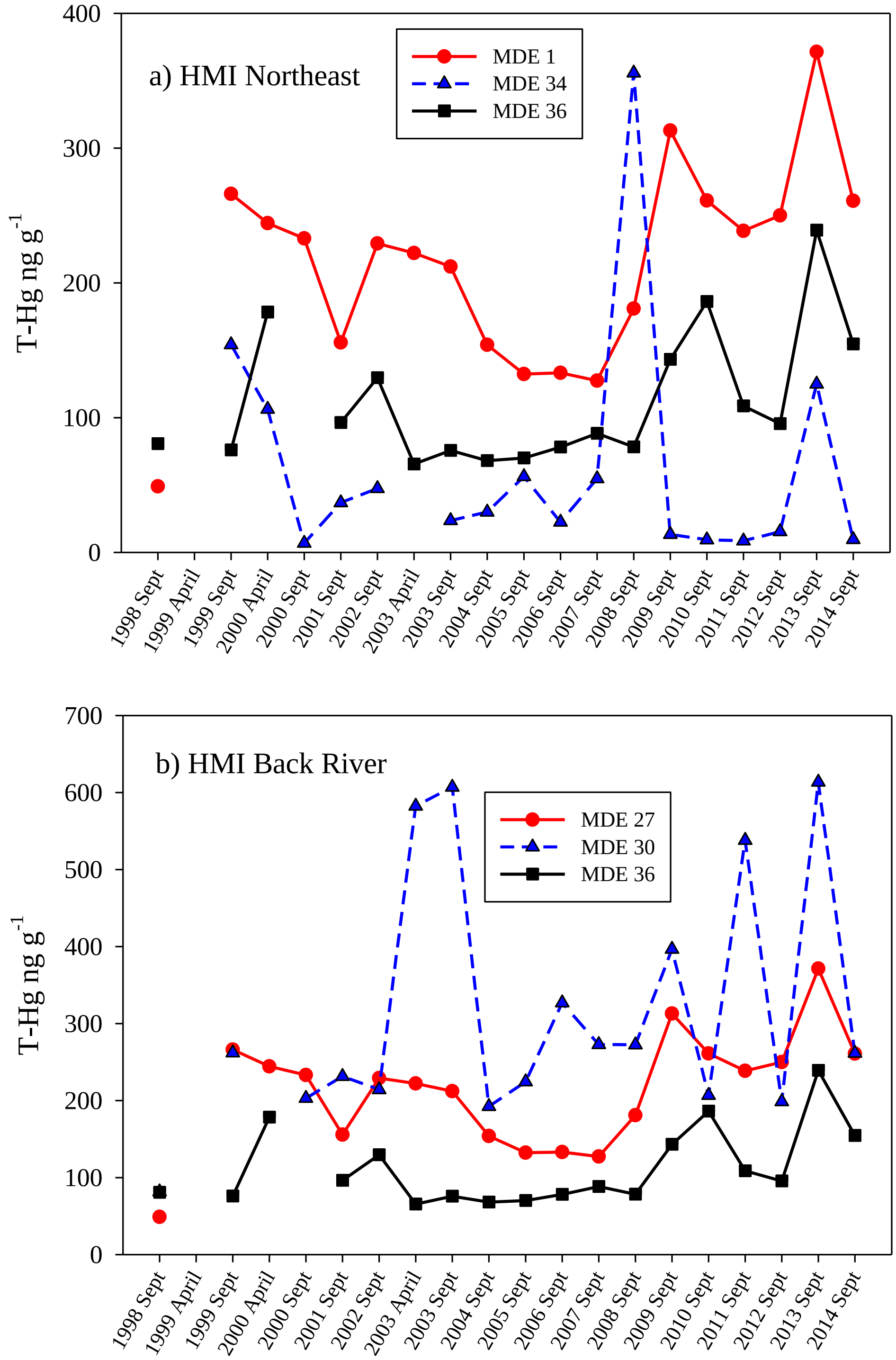


Figure 3-13: Total Mercury (T-Hg) concentrations in sediment from the a) northeast side of the island and b) Back River influenced side of the island from 1998 to 2014. MDE station 36 is shown for reference.

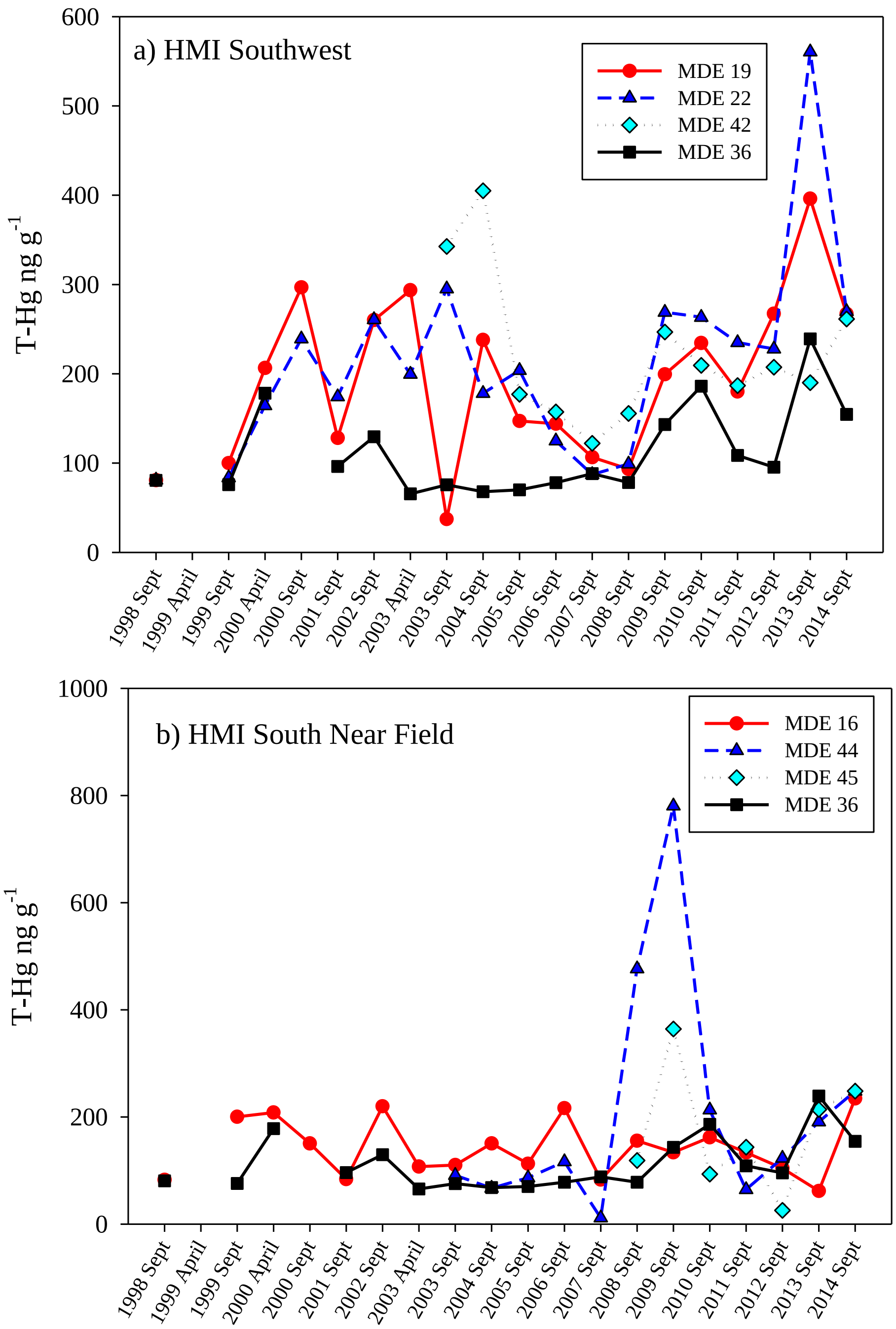


Figure 3- 14: Total Mercury (T-Hg) concentrations in sediment from a) Southwest side of the island and b) close to the south side of the island (near field) from 1998 to 2014. MDE station 36 is shown for reference.

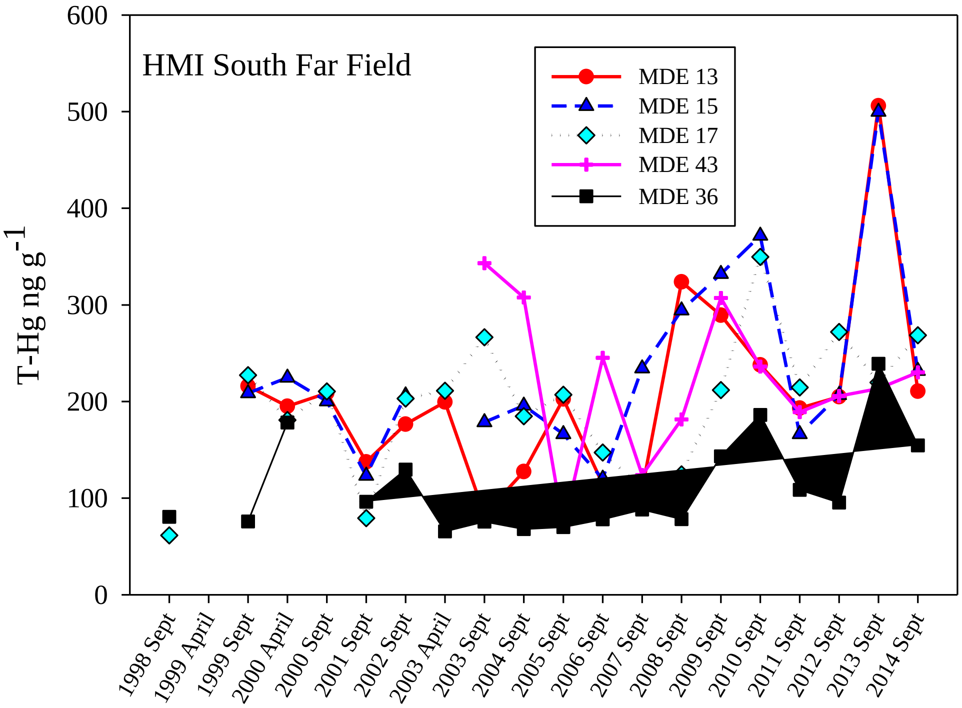


Figure 3-15: Total Mercury (T-Hg) concentrations in sediment from South Side of the island far field stations 1998 to 2014. Station MDE 36 is shown for reference.

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. As a result no strong temporal trends are apparent.

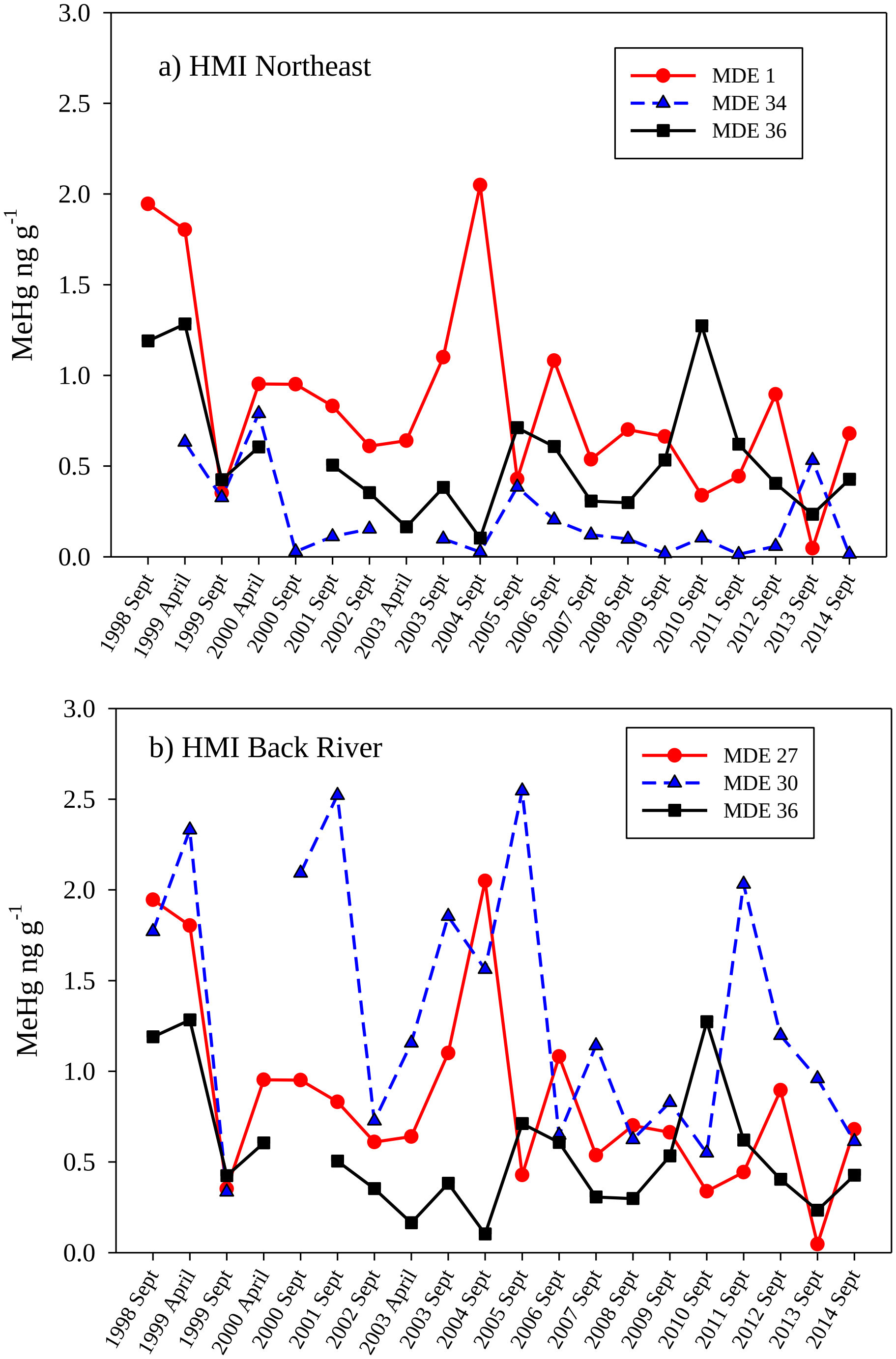


Figure 3-16: Methylmercury (MeHg) concentrations in sediment from the a) northeast side of the island and b) Back River influenced side of the island from 1998 to 2014. MDE station 36 is shown for reference.

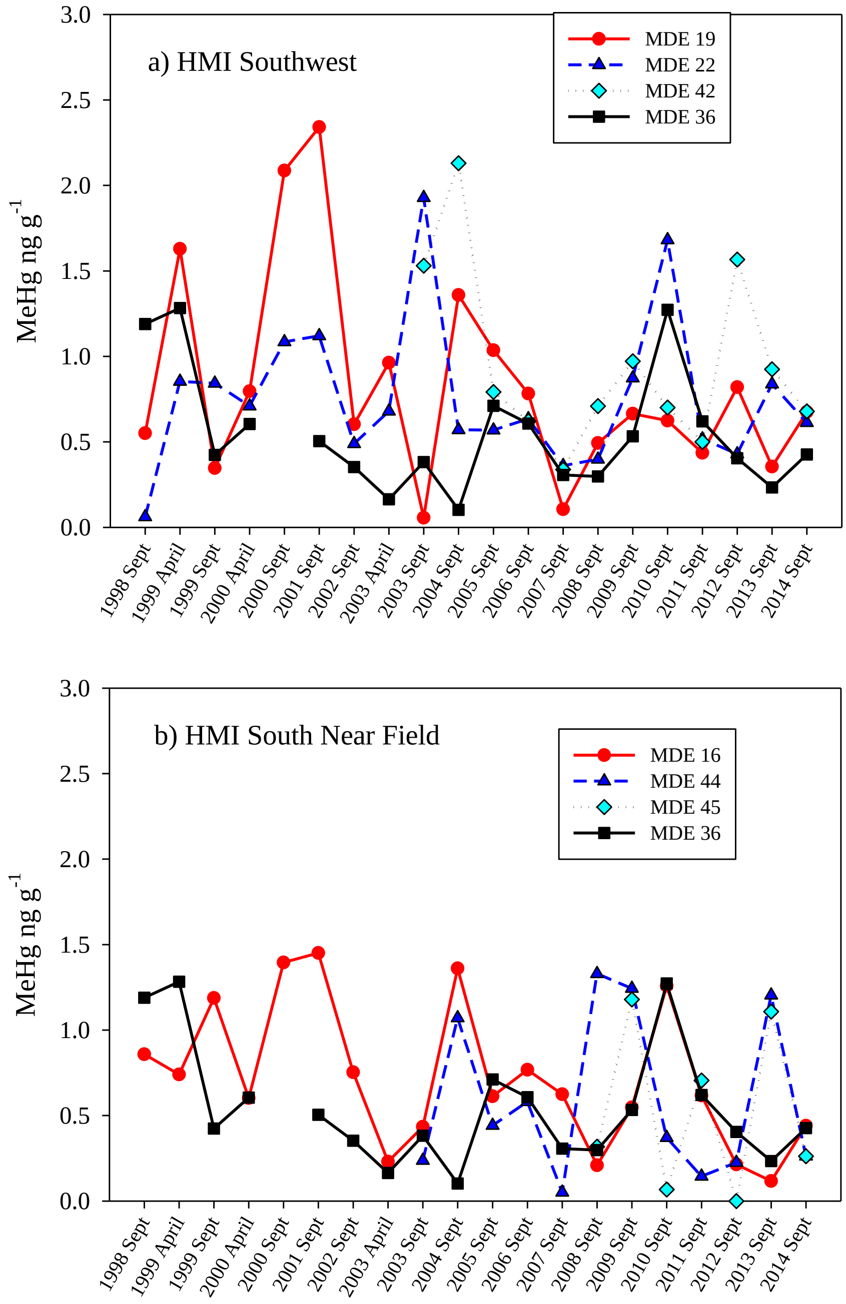


Figure 3- 17: Methylmercury (MeHg) concentrations in sediment from a) Southwest side of the island and b) close to the south side of the island (near field) from 1998 to 2014. MDE station 36 is shown for reference.

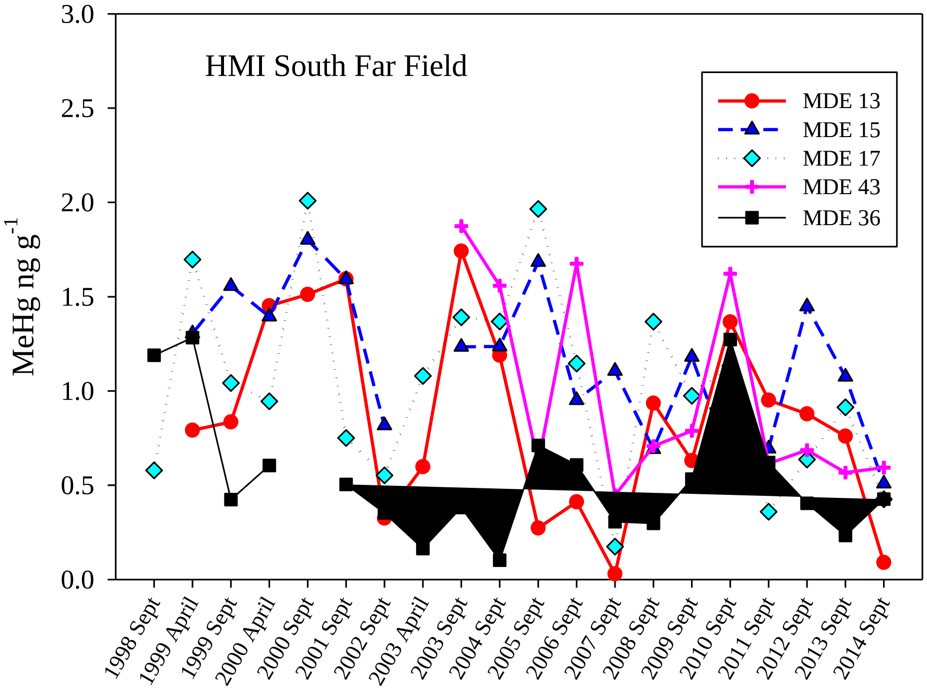


Figure 3-18: Methylmercury (MeHg) concentrations in sediment from South Side of the island far field stations 1998 to 2014. Station MDE 36 is shown for reference.

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 in 2014 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 2013. In the fall of 2014 the relationship between As and Se was moderate (r^2 = 0.52). This is despite the number of stations in 2014 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 2014. 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.

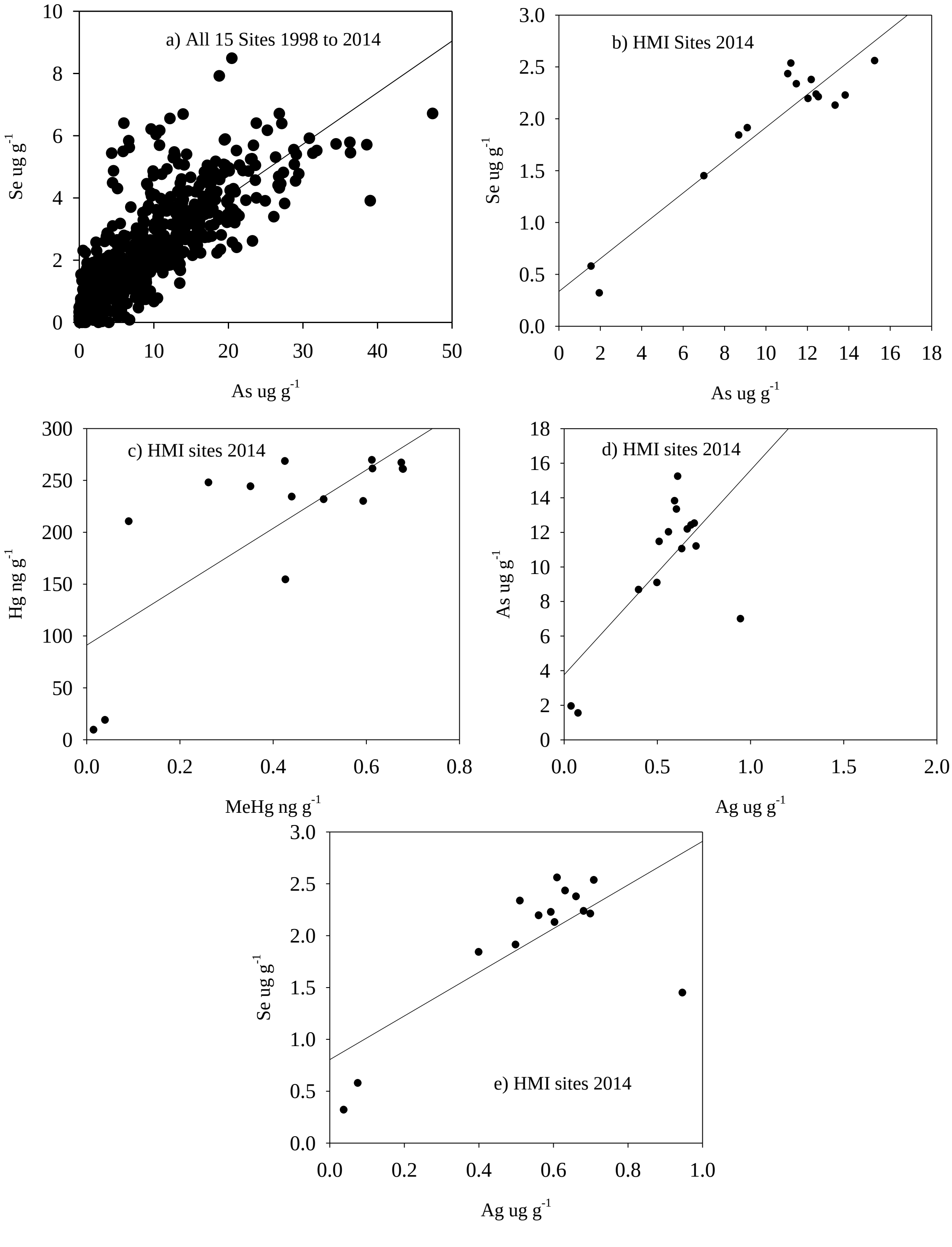


Figure 3-19: Se vs As in sediment (ug g^{-1} dry weight) for a) HMI stations 1998 – 2014 sampled in 2014; b) sampled in the fall of 2014; c) correlation of T-Hg and MeHg concentration in September 2014, d) As vs Ag concentrations in September 2014 and e) Se vs Ag concentrations in September 2014.

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 2014, with the reduced number of sampling sites compared to other years, the relationship between sediment T-Hg and MeHg concentration was moderate ($r^2 = 0.58$) (Figure 3-15c). At any one sampling site, the relationship between sediment T-Hg and MeHg concentration over the 1998 to 2014 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 2014, sediment T-Hg concentrations are average to slightly above average of past years, but MeHg was observed to be on the lower end of the range observed over the past 17 years suggesting the enriching Hg was either not bioavailable, Hg methylating activity was depressed or MeHg demethylation was enhanced in 2014.

Silver

Concentrations of Ag in sediment are poorly correlated with most other element concentrations over the 1998 to 2014 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 2014, concentrations of As in sediment was again well correlated with concentrations of Ag ($r^2 = 0.47$) in sediment (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 again strong (r^2 of 0.52) (Figure 3.15e) but a continued decrease in the strength of the relationship would suggest a divergence of source or change in diagenetic state, and is something to be monitored in the coming years.

When individual sites are examined over time, concentrations of Ag in sediment 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-Se $r^2 = 0.70$) (Ag-As $r^2 = 0.51$) and 44 (Ag-Se $r^2 = 0.70$) (Ag-As $r^2 = 0.58$) which lie off the south side of the island.

Relationships between trace element concentrations with other site characteristics

The relationship between sediment trace elements and other sediment variables such as organic carbon content, clay, silt and sand content was investigated and 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 2014, the relationship between T-Hg and carbon was very weak as it was in 1998 (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.

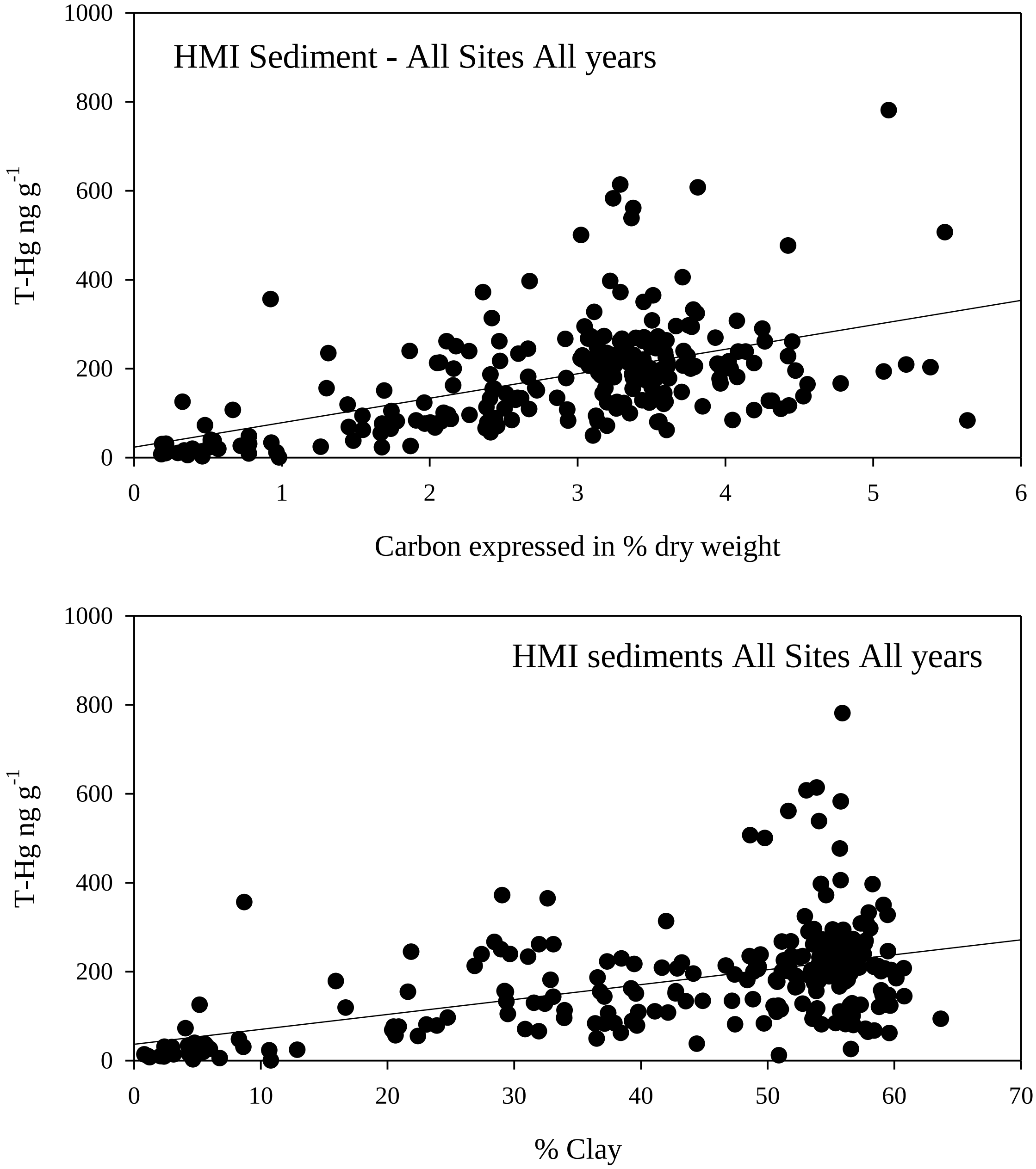


Figure 3-20: Total-Hg concentration and carbon content (upper) and clay (lower) in sediment for all sites and all years.

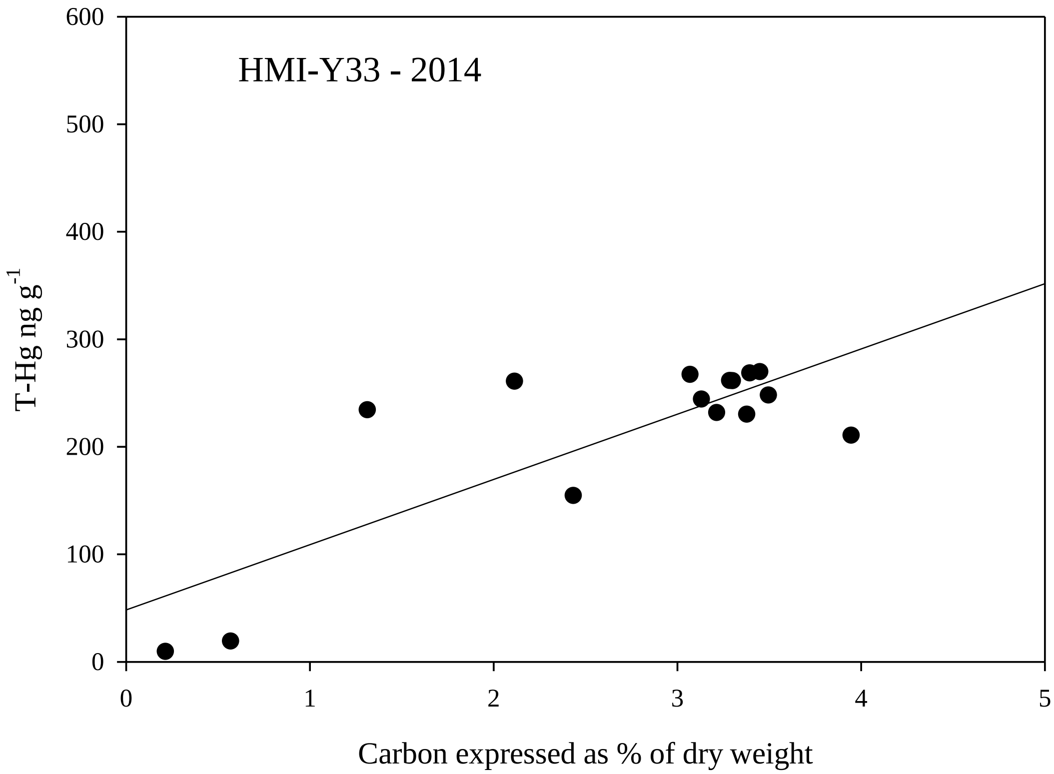


Figure 3-21: Sediment total mercury and carbon concentration in Y33 – September 2014 (r^2 = 0.65).

General Conclusions Regarding Trace Element Concentrations

In the past some stations have had enrichments of more than one trace element when compared to the sites running means. In 2014, a number of sites had enrichment in As, Hg and Se relative to their respective previous means. These include MDE 16, 17, 19, 36, 42, 43, 44 and 45.

Concentrations of As in sediment have been trending upward at a large number of sites since 2005. It is unclear if this trend has ended in 2014. The concentrations do not exceed concentrations seen in the early years of the study 1998-2001, thus the mean and median concentrations for the study period are not changing very quickly in response. The trend is worth watching and maybe simply be part of a normal oscillation, following a period of low concentrations between 2002 and 2005. Increases in As concentrations are not occurring at all sites.

Concentrations of Se in sediment appear to be trending downward, as concentrations in 2014 appear similar to 2012 and 2013. Concentrations of Ag in sediment remain unchanged over the last few years where as T-Hg concentrations in sediment are trending upward at many sites. What is unusual about the increase in sediment T-Hg concentration is that while the increase can be seen at sites from all around the island, many sites do not show increases in T-Hg concentration, and they are also found all around the island.

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 NE of the island 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 2014 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 2014. The stations visited included MDE 1, 13, 15, 16, 17, 19, 22, 27, 30, 34, 36, 42, 43, 44 and 45. In general, concentrations of As, Se, Ag and Cd in these clams were similar to the each of the sites running mean concentration that was determined from the measurements made in previous years. At a few sites, trace element concentrations exceed the standard deviation around the running mean. Those were MDE 16 and 22 for Se, and MD 43 for Ag, MDE 16, 19 and 44 for Cd (Figure 3-18). Concentrations of Pb were extremely low at all sites compared to those measured in previous years. Concentrations of T-Hg in clams were close to the running mean of most of the station from which they were collected (Figure 3-23). The exceptions being MDE 13, 17, and 30, were concentrations were outside the standard deviation around the mean. The concentration of MeHg in clams collected at each site in 2014 was lower than the respective mean clam concentration for that site calculated from previous years measurements. The proportion of T-Hg that occurred as MeHg (%MeHg) was also low when compared to previous years (Figure 3-23).

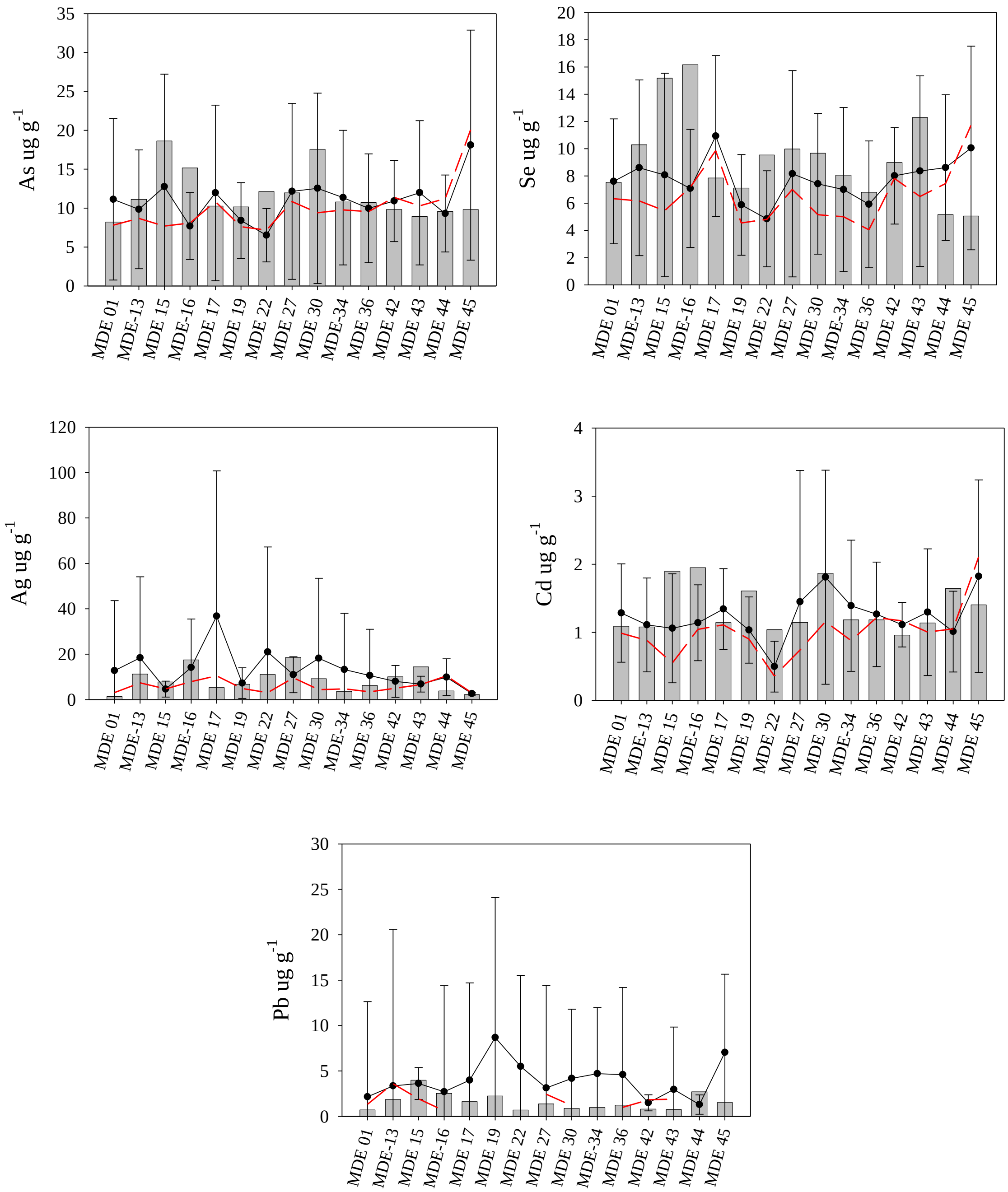


Figure 3- 22: Concentrations of Pb, Cd, As, Se, Ag in clams collected in September 2014. Concentrations (bars) are dry weight based and the 1998-2013 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2013 median (dashed line).

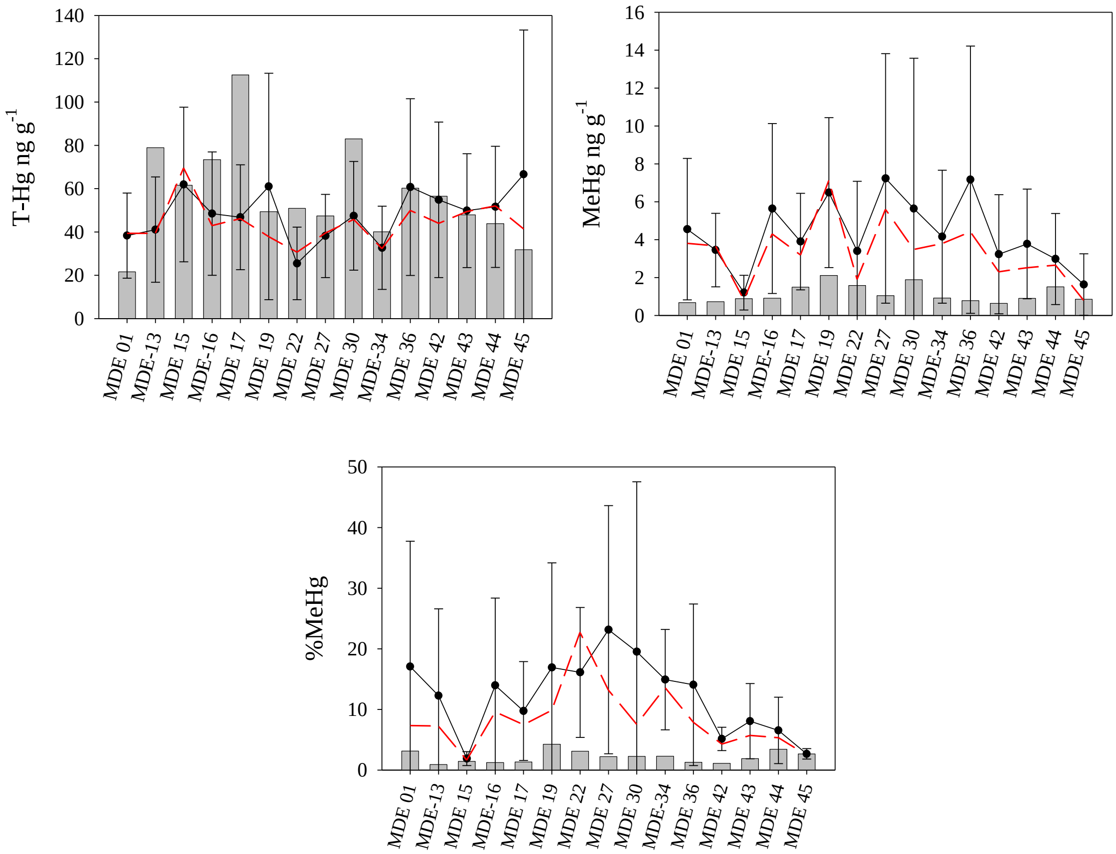


Figure 3-23: Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent of Hg that is MeHg in clams, collected in September 2014 (bars) and the 1998-2013 mean (circles) with standard deviation (error bars) and the 1998-2013 median (dashed line).

Bioaccumulation Factors

The bioaccumulation factors (BAFs) for the trace elements Cd, Pb, As, Ag, Se, T-Hg and MeHg (Figure 3-24) 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 2014 the BAFs for Pb (not shown in Figures 3-24, 3-25) were less than 1 for all sites, indicating no bioaccumulation of Pb from sediment to clams occurred. BAFs of less than 1 for Pb have been occurring for the duration of the study.

In September 2014 little bioaccumulation of As, Se, Cd, T-Hg and MeHg 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. Of the 15 sites sampled in 2014, clams collected from MDE-34 had the greatest accumulation factors for the trace elements measured. The larger BAFs at MDE-34 were driven by concentrations in the sediment being low rather than clam concentrations being high when compared to other sites in 2014 and the historical sediment data (Table 3-1). Of the individual elements measured, Ag showed the greatest accumulation by clams. This is believed to be the result of the low sediment concentrations of As as the Ag concentrations in clams were typical of past years.

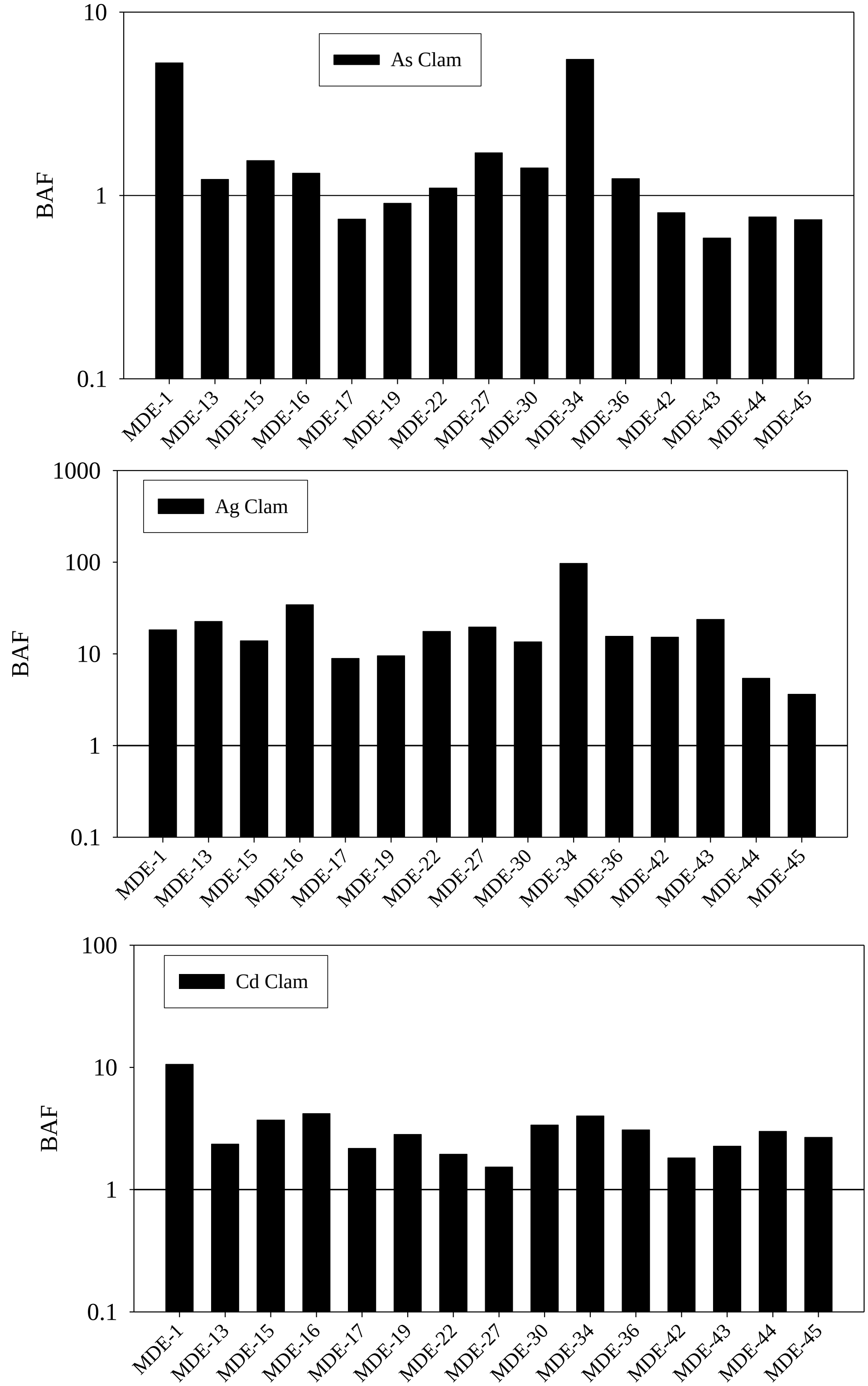


Figure 3-24: Bioaccumulation factors for the metals As, Ag and Cd September 2014. Note BAF is presented on a log scale.

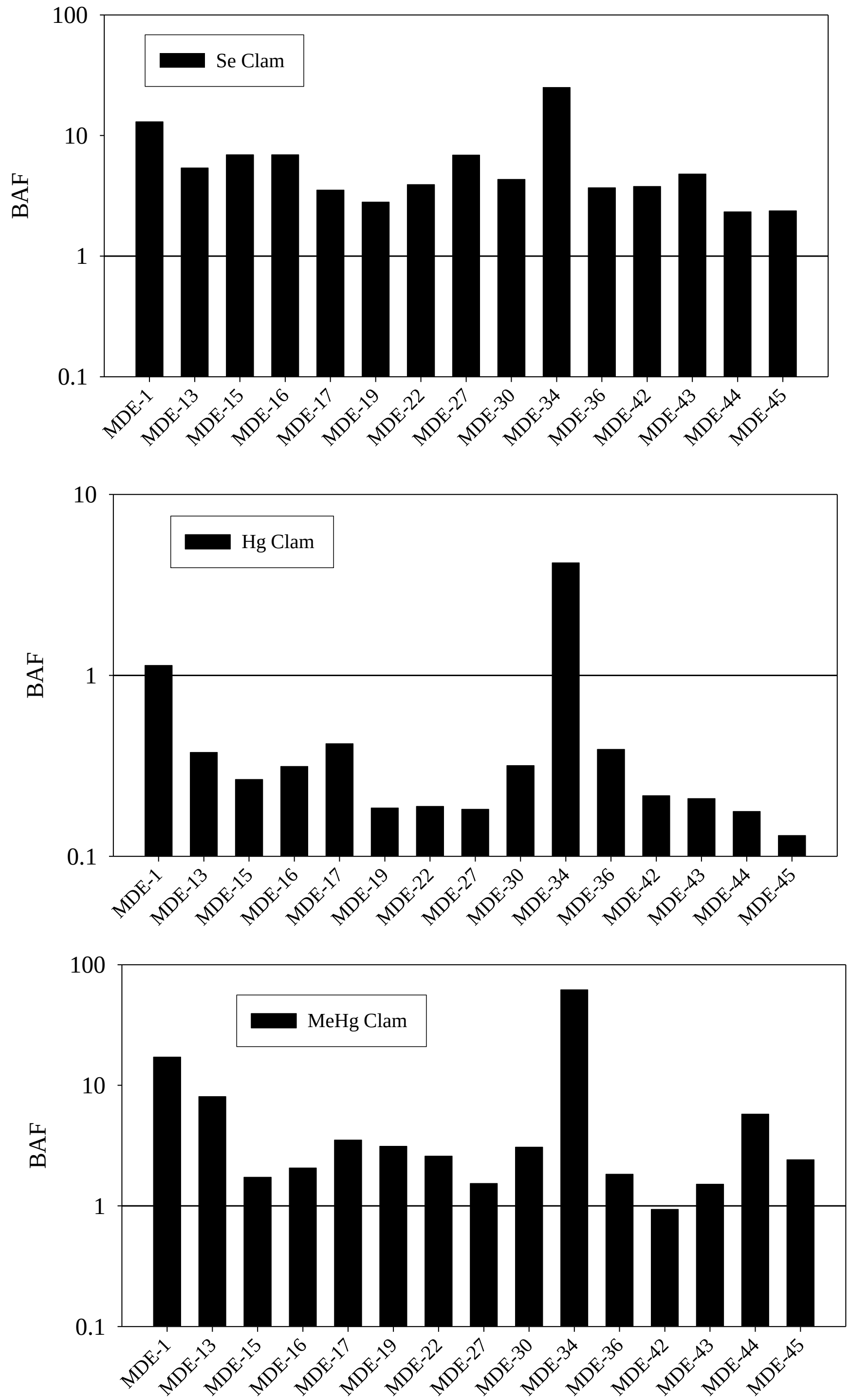


Figure 3- 25: Bioaccumulation factors for Se, Hg and MeHg in September 2014. Note BAF is presented on a log scale.

Table 3- 1: Trace element concentrations in sediment (dry weight) collected along with clams by CBL and MDE in September 2014. 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	1.55	0.58	0.08	0.10	7.85	19.1	0.04
MDE-13	9.10	1.91	0.50	0.46	44.67	210.6	0.09
MDE-15	12.03	2.19	0.56	0.51	56.41	231.8	0.51
MDE-16	11.47	2.34	0.51	0.47	47.95	234.3	0.44
MDE-17	13.83	2.23	0.59	0.53	55.66	268.6	0.43
MDE-19	11.21	2.54	0.71	0.57	63.56	267.2	0.68
MDE-22	11.05	2.43	0.63	0.53	57.19	269.7	0.61
MDE-27	7.00	1.45	0.95	0.75	56.20	260.9	0.68
MDE-30	12.42	2.24	0.68	0.55	57.81	261.4	0.61
MDE-34	1.95	0.32	0.04	0.30	9.27	9.6	0.01
MDE-36	8.68	1.84	0.40	0.38	34.43	154.5	0.43
MDE-42	12.19	2.38	0.66	0.53	60.58	261.3	0.68
MDE-43	15.25	2.56	0.61	0.50	59.85	230.1	0.59
MDE-44	12.53	2.21	0.70	0.55	58.87	248.0	0.26
MDE-45	13.34	2.13	0.60	0.52	58.67	244.3	0.35

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 2014.

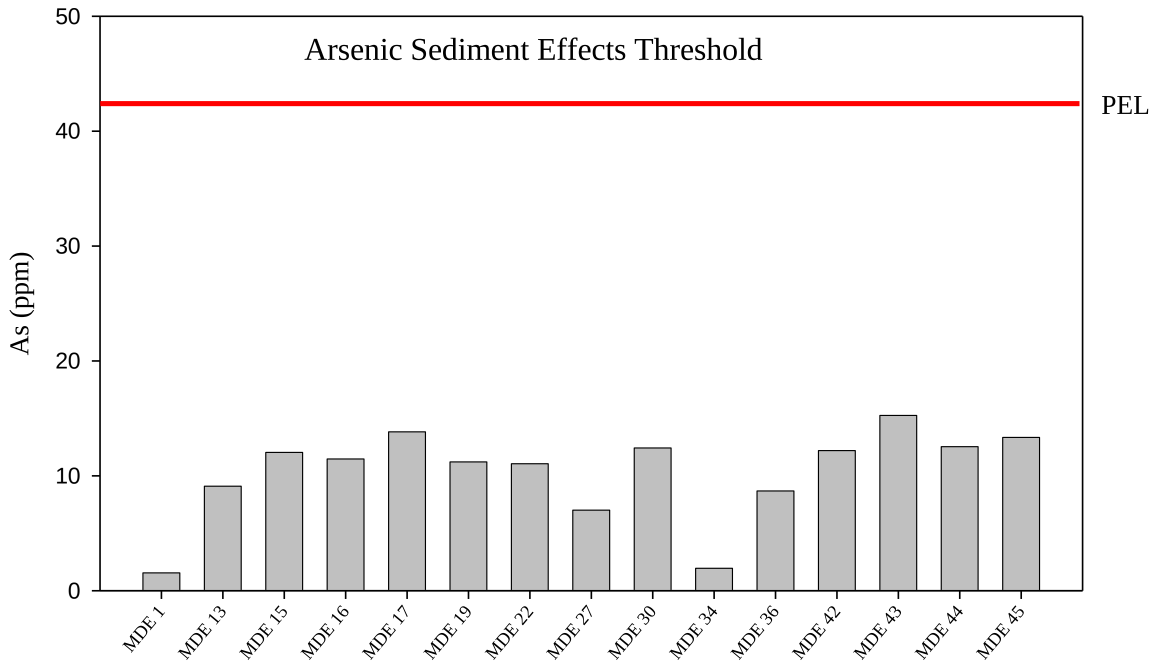
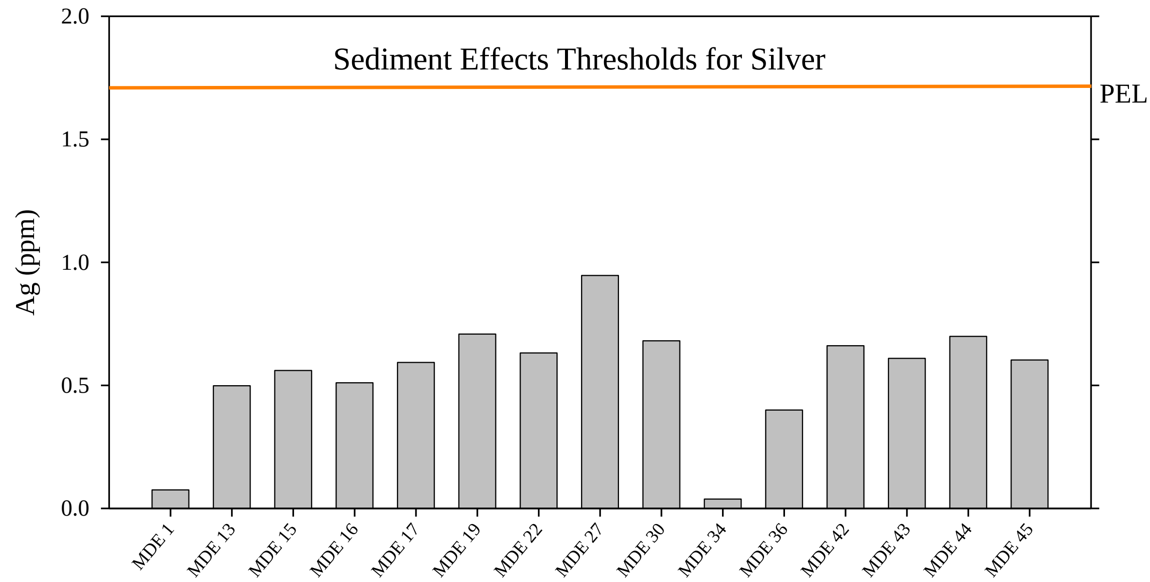


Figure 3- 26: Arsenic (As) concentrations in sediment (MGS collections) along with the Probable Effects Level (PEL) as identified by NOAA for marine sediment.



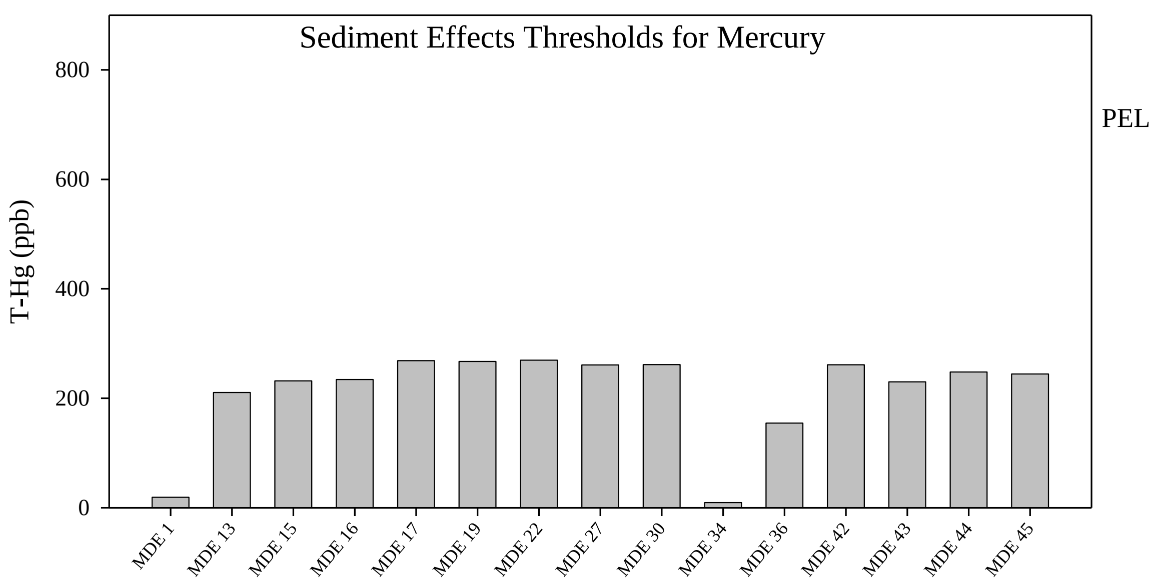


Figure 3- 27: Mercury (Hg) and Silver (Ag) concentrations in sediment (MGS collections) along with Probable Effects Level (PEL) as identified by NOAA for marine sediment.

SECTION SUMMARY

In past years we have observed sediments of 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. This was also the case in 2014. However, only site MDE 43 had concentrations of more than one element above the standard deviation of previous measurements. Sediment concentrations of As have 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. Concentrations of trace elements in clams were similar to or below concentrations observed in previous years. Bioaccumulation of trace elements by clams was low in 2014 compared to previous years.

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