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**Water Quality Analysis of Chromium in
Northwest Branch and Bear Creek Portions of the Patapsco River
Mesohaline Tidal Chesapeake Bay Segment, Baltimore City and
Baltimore County, Maryland**

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Table of Contents

List of Figures..... i

List of Tables ii

List of Abbreviations iii

EXECUTIVE SUMMARYv

1.0 INTRODUCTION.....1

2.0 GENERAL SETTING3

3.0 BACKGROUND9

4.0 REVIEW OF PAST MDE STUDIES ADDRESSING CHROMIUM LISTINGS IN NORTHWEST BRANCH AND BEAR CREEK.....10

4.1 Water Quality Analysis of Chromium in the Northwest Branch and Bear Creek Portions of Baltimore Harbor..... 10

4.2 Toxicity, Identification, and Evaluation and Long-Term Contaminant Trends in the Baltimore Harbor 14

5.0 REVIEW OF STUDIES INVESTIGATING CHROMIUM TOXICITY IN BALTIMORE HARBOR SEDIMENTS17

5.1 John’s Hopkins University Studies Investigating Chromium Speciation and Benthic Toxicity in Baltimore Harbor Sediments 17

5.1.1 Bioassay Testing of Baltimore Harbor Sediments Spiked with Cr (VI)..... 17

5.1.2 The Sediment Ingestion Pathway as a Source of Toxicity in the Baltimore Harbor ...22

5.1.3 Geochemical Influences on Chromium Speciation and Fate in Estuarine Sediments 23

5.2 Data Evaluation and Screening Level Human Health and Ecological Risk Assessment for Bear Creek Sediments 29

5.3 Ecological Risk Assessment for Dundalk Marine Terminal..... 32

6.0 CONCLUSION35

7.0 REFERENCES.....37

Appendix A: Tables for Ecological Risk Assessment for Dundalk Marine Terminal..... A-1

List of Figures

Figure 2.1: Location Map of Northwest Branch Embayment.....4
Figure 2.2: Location Map of Bear Creek Embayment.....5
Figure 2.3: Land Use Map of Northwest Branch Watershed.....7
Figure 2.4: Land Use Map of Bear Creek Watershed.....8
Figure 2.5: Land Use Distribution in Northwest Branch and Bear Creek Watersheds9
Figure 4.1.1: Chromium WQA Monitoring Stations11
Figure 4.2.1: Baltimore Harbor TIE Study Stations15
Figure 5.1.1(a): Baltimore Harbor Sediment Test Stations19
Figure 5.1.1(b): Whole Sediment Chronic Toxicity Test Results (Baseline & Spiked Levels)20
Figure 5.1.3(a): Baltimore Harbor Sediment Stations25
Figure 5.1.3(b): Sediment Concentration Data (Trace Metals)25
Figure 5.1.3(c): Sediment Concentration Data (Fe).....26
Figure 5.1.3(d): AVS/SEM Sediment Concentrations.....26
Figure 5.1.3(e): Cr (VI) Concentration vs. Time (Cr (III) suspension under Aerobic conditions)27
Figure 5.1.3(f): Cr (VI) Concentration vs. Time (Complete Reduction of Cr (VI) suspension to Cr (III) followed by aeration)28
Figure 5.1.3(g): Cr (VI) Concentration vs. Time (Complete Reduction of Cr (VI) suspension to Cr (III) followed by aging (4.5 hr, 1 day, and 5 day) and subsequent aeration).....29
Figure 5.2.1: Bear Creek Sediment Stations (EPA Data Evaluation and BSM).....30
Figure 5.3.1: Location of Dundalk Marine Terminal32
Figure 5.3.2: Dundalk Marine Terminal Water Quality Stations33

List of Tables

Table 4.1.1: Northwest Branch and Bear Creek Water Column and Pore water Chromium Concentration Data12

Table 4.1.2: Northwest Branch and Bear Creek Sediment Concentration Data13

Table 4.2.1: Baltimore Harbor TIE Study Sediment Concentration Data (Pore water and AVS/SEM)16

Table 5.1.1(a): Total Chromium Sediment Concentration Data (Baseline & Spiked Levels)19

Table 5.1.1(b): Whole Sediment Chronic Toxicity Test Results (Baseline & Spiked Levels)19

Table 5.1.1(c): Total Chromium and Cr (VI) Concentration Data (Baseline & Spiked Levels).....21

Table 5.1.1(d): Cr (VI)/AVS Molar Ratios (Spiked Levels)21

Table 5.2.1: Total Cr and Cr (VI) Sediment Concentration Data (EPA Data Evaluation).....30

Table 5.2.2: 1996 Total Chromium Sediment Concentration Data (BSM)31

Table A-1: Total Cr and Cr (VI) Surface Water Concentration Data (ERA DMT) A-1

Table A-2: Total Cr and Cr (VI) Pore Water Concentration Data (ERA DMT) A-6

Table A-3: Total Cr & Geochemical Parameter Sediment Concentration Data (ERA DMT) A-8

Table A-4: AVS/SEM Sediment Concentration Data (ERA DMT) A-13

List of Abbreviations

AVS	Acid Volatile Sulfides
BIBI	Benthic Index of Biotic Integrity
BOD	Biological Oxygen Demand
BSM	Spatial Mapping of Sedimentary Contaminants in the Baltimore Harbor
CBF	Chesapeake Bay Foundation
CBL	Chesapeake Biological Laboratory
CFR	Code of Federal Regulations
COMAR	Code of Maryland Regulations
COPR	Chrome Ore Processing Residue
Cr	Chromium
Cr (III)	Trivalent Chromium
Cr (VI)	Hexavalent Chromium
CTFR	Center for Contaminant Transport, Fate, and Remediation
CWA	Clean Water Act
DMT	Dundalk Marine Terminal
DO	Dissolved Oxygen
EPA	US Environmental Protection Agency
ERA	Ecological Risk Assessment
ERM	Effects Range Median
Fe	Iron
Fe (II)	Divalent (Ferrous) Iron
FIBI	Fish Index of Biotic Integrity
JHU	Johns Hopkins University
LOAEL	Lowest Observed Apparent Effects Level
MDE	Maryland Department of the Environment
mg/kg	Milligrams per Kilogram
Mn	Manganese
Mn (II)	Divalent Manganese
Mn (III)	Trivalent Manganese
Mn (IV)	Tetravalent Manganese
ND	Non-detect
PAH	Polyaromatic Hydrocarbon
PATMH	Patapsco River Mesohaline
Pb	Lead
PCB	Polychlorinated Biphenyl
PBDE	Polybrominated Diphenyl Ether
PEL	Probable Effects Level
ppt	Parts per Thousand
SCS	Soil Conservation Service
SEM	Simultaneously Extracted Metals
SHA	State Highways Administration
SQG	Sediment Quality Guideline
SQT	Sediment Quality Triad
TIE	Toxicity Identification and Evaluation

FINAL

TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
UM	University of Maryland
UMCES	University of Maryland Center for Environmental Sciences
μmole/g	Micromole/gram
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
WREC	Wye Research and Education Center
Zn	Zinc
μg/L	Micrograms per Liter

FINAL

EXECUTIVE SUMMARY

This document, upon approval by the U.S. Environmental Protection Agency (EPA), presents a Water Quality Analysis (WQA) of chromium (Cr) in the Northwest Branch and Bear Creek (Maryland 8-Digit basin number: 02130903) portion of the Patapsco River Mesohaline (PATMH) Tidal Chesapeake Bay Segment (2012 *Integrated Report of Surface Water Quality in Maryland* Assessment Unit ID: MD-PATMH-NORTHWEST_BRANCH / MD-PATMH-BEAR_CREEK). Section 303(d) of the federal Clean Water Act (CWA) and the EPA's implementing regulations direct each State to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS listed on the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a WQA that water quality standards are being met (CFR 2012).

Maryland's Surface Water Use Designations in the Code of Maryland Regulations (COMAR) state that all surface waters of Maryland shall be protected for water contact recreation, fishing, and the protection of aquatic life and wildlife (COMAR 2012a). In addition, the specific designated use of the Northwest Branch and Bear Creek portions of PATMH is Use II (*Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting*) (COMAR 2012b,c).

The Maryland Department of the Environment (MDE) has identified the PATMH Tidal Chesapeake Bay Segment (Integrated Report Assessment Unit ID: PATMH) on the State's 2012 Integrated Report as impaired by nutrients – nitrogen and phosphorus (1996), sediments – total suspended solids (1996), and impacts to biological communities (2004). The Baltimore Harbor portion of the PATMH Tidal Chesapeake Bay Segment has been individually identified on the 2012 Integrated Report as impaired by chlordane (1996) and polychlorinated biphenyls (PCBs) (1998) (MDE 2012b). The Middle Branch (Ferry Bar Park to Harbor Hospital Center extending westward) and the Northwest Branch (Hull Street Pier to Canton Waterfront Park) portions of the PATMH Tidal Chesapeake Bay Segment have been individually identified on the 2012 Integrated Report as impaired by trash (2008) (MDE 2012b). The Northwest Branch portion of the PATMH Tidal Chesapeake Bay Segment has been individually identified on the 2012 Integrated Report as impaired by chromium in sediments (1998), lead (Pb) in sediments (1998), zinc (Zn) in sediments (1998), and enterococcus (2010) (MDE 2012b). The Bear Creek portion of the PATMH Tidal Chesapeake Bay Segment has been individually identified on the 2012 Integrated Report as impaired by chromium in sediments (1998), Zn in sediments (1998), and PCBs (1998) (MDE 2012b). The Integrated Report specifies that the chromium impairments in the Northwest Branch and Bear Creek portions of the PATMH Tidal Chesapeake Bay Segment do not support the protection of aquatic life designated use of the waterbodies. From this point forward in the report, the Baltimore Harbor, Northwest Branch, and Bear Creek portions of the PATMH Tidal Chesapeake Bay Segment will simply be referred to as Baltimore Harbor, Northwest Branch, and Bear Creek.

The WQA presented herein by MDE will address the 1998 chromium listings for Northwest Branch and Bear Creek, for which a data solicitation has been conducted, and all readily available data from the past five years have been considered. The nutrient listings for the

FINAL

PATMH Tidal Chesapeake Bay Segment and Baltimore Harbor have been addressed through a TMDL approved by EPA on December 17, 2007. The Chesapeake Bay TMDL, which was approved by the EPA on December 29, 2010, has also addressed the nutrient listings for the PATMH Tidal Chesapeake Bay Segment and is currently under reevaluation to determine whether previously developed TMDLs would be superseded by the corresponding Bay TMDL. The sediment listing for the PATMH Tidal Chesapeake Bay Segment has also been addressed via the Chesapeake Bay TMDL. The trash listings for the Middle Branch and Northwest Branch portions of the PATMH Tidal Chesapeake Bay Segment are being addressed through a TMDL currently under development and planned for submittal to EPA in 2013. The listing for impacts to biological communities in the PATMH Tidal Chesapeake Bay Segment will be addressed separately at a future date. The listing for chlordane in Baltimore Harbor has been addressed through a TMDL approved by EPA on March 23, 2001. The listings for PCBs in Bear Creek and Baltimore Harbor have been addressed through a TMDL submitted to EPA on September 30, 2011. The listings for Pb, Zn, and enterococcus in the Northwest Branch and Zn in Bear Creek will be addressed separately at a future date.

The original 1998 listings for chromium in the sediments of Northwest Branch and Bear Creek from Maryland's Integrated Report were established using the Sediment Quality Triad (SQT) approach, the designated methodology for assessing waters of the State for toxic impairments in sediment as Maryland has no numeric sediment quality criterion for chromium (MDE 2012a). Water quality data demonstrated that sediment toxicity and a degraded benthic community were present within the Northwest Branch and Bear Creek and sediment concentrations for total chromium exceeded the sediment quality guideline (SQG) Effects Range Median (ERM). These findings indicated that the sediment was impaired for chromium. In retrospect this approach was methodologically flawed as a comparison of total chromium sediment concentrations and the ERM for total chromium did not take into consideration the relative toxicity associated with the speciation of Cr (III) and Cr (VI). The Cr (VI) species is highly toxic while the Cr (III) species is relatively non-toxic at levels typically found within the environment.

MDE submitted a WQA to EPA in August 20, 2004, presenting newly collected water quality data at the time that demonstrated chromium was not a source of toxicity to aquatic life inhabiting the water column or sediment. The sediments of the Northwest Branch and Bear Creek support a reducing environment which facilitates the conversion of Cr (VI) to Cr (III). Therefore under these conditions Cr (III), the relatively non-toxic species, will be the predominant form of chromium within the sediments. EPA supported the findings of this WQA through a delayed approval, contingent upon the results of a toxicity, identification, and evaluation (TIE) study underway at the time. The results of the TIE study were inconclusive; therefore, chromium was not delisted and remained in Category 5 of Maryland's Integrated Report.

This document presents the findings of recent studies completed by Johns Hopkins University (JHU), an Ecological Risk Assessment (ERA) of Dundalk Marine Terminal (DMT) and an EPA Data Evaluation of Bear Creek sediments which all support the conclusions of the original WQA that toxicity in the sediments of Baltimore Harbor is not due to the presence of chromium. Therefore, a TMDL for chromium is not necessary to achieve water quality standards supportive of the protection of aquatic life designated use in Northwest Branch and Bear Creek.

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Barring the receipt of contradictory data, this report will be used to support a revision of the 2012 Integrated Report chromium listing for Northwest Branch and Bear Creek from Category 5 (“waterbody is impaired, does not attain the water quality standard, and a TMDL is required”) to Category 2 (“waterbodies meeting some [in this case chromium related] water quality standards, but with insufficient data to assess all impairment”) when MDE proposes revision of the State’s Integrated Report. Although the tidal waters of Northwest Branch and Bear Creek do not display signs of a chromium impairment to aquatic life in the water column or sediment, the State reserves the right to require future controls if evidence suggests that chromium from the watershed is contributing to downstream water quality problems.

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1.0 INTRODUCTION

This document, upon approval by the U.S. Environmental Protection Agency (EPA), presents a Water Quality Analysis (WQA) of chromium (Cr) in the Northwest Branch and Bear Creek (Maryland 8-Digit basin number: 02130903) portions of the Patapsco River Mesohaline (PATMH) Tidal Chesapeake Bay Segment (2012 *Integrated Report of Surface Water Quality in Maryland* Assessment Unit ID: MD-PATMH-NORTHWEST_BRANCH / BEAR CREEK). Section 303(d) of the federal Clean Water Act (CWA) and the EPA's implementing regulations direct each State to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS listed on the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a WQA that water quality standards are being met (CFR 2012).

A segment identified as a WQLS may not require the development and implementation of a TMDL if more recent information invalidates previous findings. The most common scenarios that would eliminate the need for a TMDL are: 1) analysis of more recent data indicating that the impairment no longer exists (i.e., water quality standards are being met); 2) results of a more recent and updated water quality model demonstrate that the segment is now attaining water quality standards; 3) refinements to water quality standards or to the interpretation of those standards accompanied by analysis demonstrating that the standards are being met; or 4) identification and correction of errors made in the initial listing. This document presents a WQA that eliminates the need for a TMDL for chromium in the Northwest Branch and Bear Creek portions of the Patapsco River Mesohaline Chesapeake Bay Segment (PATMH) incorporating the third scenario stated above.

Maryland's Surface Water Use Designations in the Code of Maryland Regulations (COMAR) state that all surface waters of Maryland shall be protected for water contact recreation, fishing, and the protection of aquatic life and wildlife (COMAR 2012a). In addition, the specific designated use of the Northwest Branch and Bear Creek portions of the PATMH Tidal Chesapeake Bay Segment is Use II (*Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting*) (COMAR 2012b,c).

The Maryland Department of the Environment (MDE) has identified the PATMH Tidal Chesapeake Bay Segment (Integrated Report Assessment Unit ID: PATMH) on the State's 2012 Integrated Report as impaired by nutrients – nitrogen and phosphorus (1996), sediments – total suspended solids (1996), and impacts to biological communities (2004). The Baltimore Harbor portion of the PATMH Tidal Chesapeake Bay Segment has been individually identified on the 2012 Integrated Report as impaired by chlordane (1996) and polychlorinated biphenyls (PCBs) (1998) (MDE 2012b). The Middle Branch (Ferry Bar Park to Harbor Hospital Center extending westward) and the Northwest Branch (Hull Street Pier to Canton Waterfront Park) portions of the PATMH Tidal Chesapeake Bay Segment have been individually identified on the 2012 Integrated Report as impaired by trash (2008) (MDE 2012b). The Northwest Branch portion of the PATMH Tidal Chesapeake Bay Segment has been individually identified on the 2012

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Integrated Report as impaired by chromium in sediments (1998), lead (Pb) in sediments (1998), zinc (Zn) in sediments (1998), and enterococcus (2010) (MDE 2012b). The Bear Creek portion of the PATMH Tidal Chesapeake Bay Segment has been individually identified on the 2012 Integrated Report as impaired by chromium in sediments (1998), Zn in sediments (1998), and PCBs (1998) (MDE 2012b). The Integrated Report specifies that the chromium impairments in the Northwest Branch and Bear Creek portions of the PATMH Tidal Chesapeake Bay Segment do not support the protection of aquatic life designated use of the waterbodies. From this point forward in the report, the Baltimore Harbor, Northwest Branch, and Bear Creek portions of the PATMH Tidal Chesapeake Bay Segment will simply be referred to as Baltimore Harbor, Northwest Branch, and Bear Creek.

The WQA presented herein by MDE will address the 1998 chromium listings for Northwest Branch and Bear Creek, for which a data solicitation has been conducted, and all readily available data from the past five years has been considered. The nutrient listings for the PATMH Tidal Chesapeake Bay Segment and Baltimore Harbor have been addressed through a TMDL approved by EPA on December 17, 2007. The Chesapeake Bay TMDL, which was approved by the EPA on December 29, 2010, has also addressed the nutrient listings for the PATMH Tidal Chesapeake Bay Segment and is currently under reevaluation to determine whether previously developed TMDLs would be superseded by the corresponding Bay TMDL. The sediment listing for the PATMH Tidal Chesapeake Bay Segment has also been addressed via the Chesapeake Bay TMDL. The trash listings for the Middle Branch and Northwest Branch portions of the PATMH Tidal Chesapeake Bay Segment are being addressed through a TMDL currently under development and planned for submittal to EPA in 2013. The listing for impacts to biological communities in the PATMH Tidal Chesapeake Bay Segment will be addressed separately at a future date. The listing for chlordane in Baltimore Harbor has been addressed through a TMDL approved by EPA on March 23, 2001. The listings for PCBs in Bear Creek and Baltimore Harbor have been addressed through a TMDL submitted to EPA on September 30, 2011. The listings for Pb, Zn, and enterococcus in the Northwest Branch and Zn in Bear Creek will be addressed separately at a future date.

The original 1998 listings for chromium in the sediments of Northwest Branch and Bear Creek from Maryland's Integrated Report were established using the Sediment Quality Triad (SQT) approach, the designated methodology for assessing waters of the State for toxic impairments in sediment as Maryland has no numeric sediment quality criterion for chromium (MDE 2012a). Water quality data demonstrated that sediment toxicity and a degraded benthic community were present within the Northwest Branch and Bear Creek and sediment concentrations for total chromium exceeded the sediment quality guideline (SQG) Effects Range Median (ERM). These findings indicated that the sediment was impaired for chromium. This approach was methodologically flawed as a comparison of total chromium sediment concentrations and the ERM for total chromium did not take into consideration the relative toxicity associated with the speciation of Cr (III) and Cr (VI). The Cr (VI) species is highly toxic while the Cr (III) species is relatively non-toxic at levels typically found within the environment.

MDE submitted a WQA to EPA in August 20, 2004, presenting newly collected water quality data at the time that demonstrated chromium is not a source of toxicity to aquatic life inhabiting the water column and sediment. The sediments of the Northwest Branch and Bear Creek support

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a reducing environment which facilitate the conversion of Cr (VI) to Cr (III), therefore under these conditions Cr (III), the relatively non-toxic species, will be the predominant form of chromium within the sediments. EPA supported the findings of this WQA through delayed approval of the delisting, contingent upon the results of a stressor identification study underway at the time. The results of the study were inconclusive; therefore, chromium was not delisted and remains in Category 5 of Maryland's Integrated Report.

This document presents the findings of recent studies completed by Johns Hopkins University (JHU), an Ecological Risk Assessment (ERA) of Dundalk Marine Terminal (DMT) and an EPA Data Evaluation of Bear Creek sediments which all support the conclusions of the original WQA that toxicity in the sediments of Baltimore Harbor is not due to the presence of chromium. Therefore, a TMDL for chromium is not necessary to achieve water quality standards supportive of the protection of aquatic life designated use in Northwest Branch and Bear Creek. The WQA supports the removal of the chromium impairment listings for Northwest Branch and Bear Creek, when MDE proposes the revision of the State's Integrated Report.

The remainder of this report includes the general setting of the Northwest Branch and Bear Creek watershed, background information on chromium chemistry and chromium sources within the Baltimore Harbor, a review of previous MDE studies addressing the chromium listings in Northwest Branch and Bear Creek, a review of the JHU studies, ERA of DMT, and EPA Data Evaluation of Bear Creek sediments investigating the toxicity of chromium in Baltimore Harbor sediments and conclusions regarding an evaluation of these studies.

2.0 GENERAL SETTING

The Northwest Branch and Bear Creek are located within the Baltimore Harbor. The Northwest Branch watershed (embayment plus drainage area) covers 43,046 acres and include the Jones Falls watershed, which flows into the Northwest Embayment. The Bear Creek watershed (embayment plus drainage area) covers 7,460 acres. The locations of the Northwest Branch and Bear Creek embayments are displayed in Figure 2.1 and 2.2, respectively.

There are no "high quality," or Tier II, stream segments (Benthic Index of Biotic Integrity (BIBI) and Fish Index of Biotic Integrity (FIBI) aquatic life assessment scores > 4 (scale 1-5)) located within the embayment's watershed requiring the implementation of Maryland's anti-degradation policy (COMAR 2012d; MDE 2011). The total population in the Northwest Branch and Jones Falls watershed is approximately 176,198 and 368,879, respectively. The total population in the Bear Creek watershed is approximately 57,414 (US Census Bureau 2010).

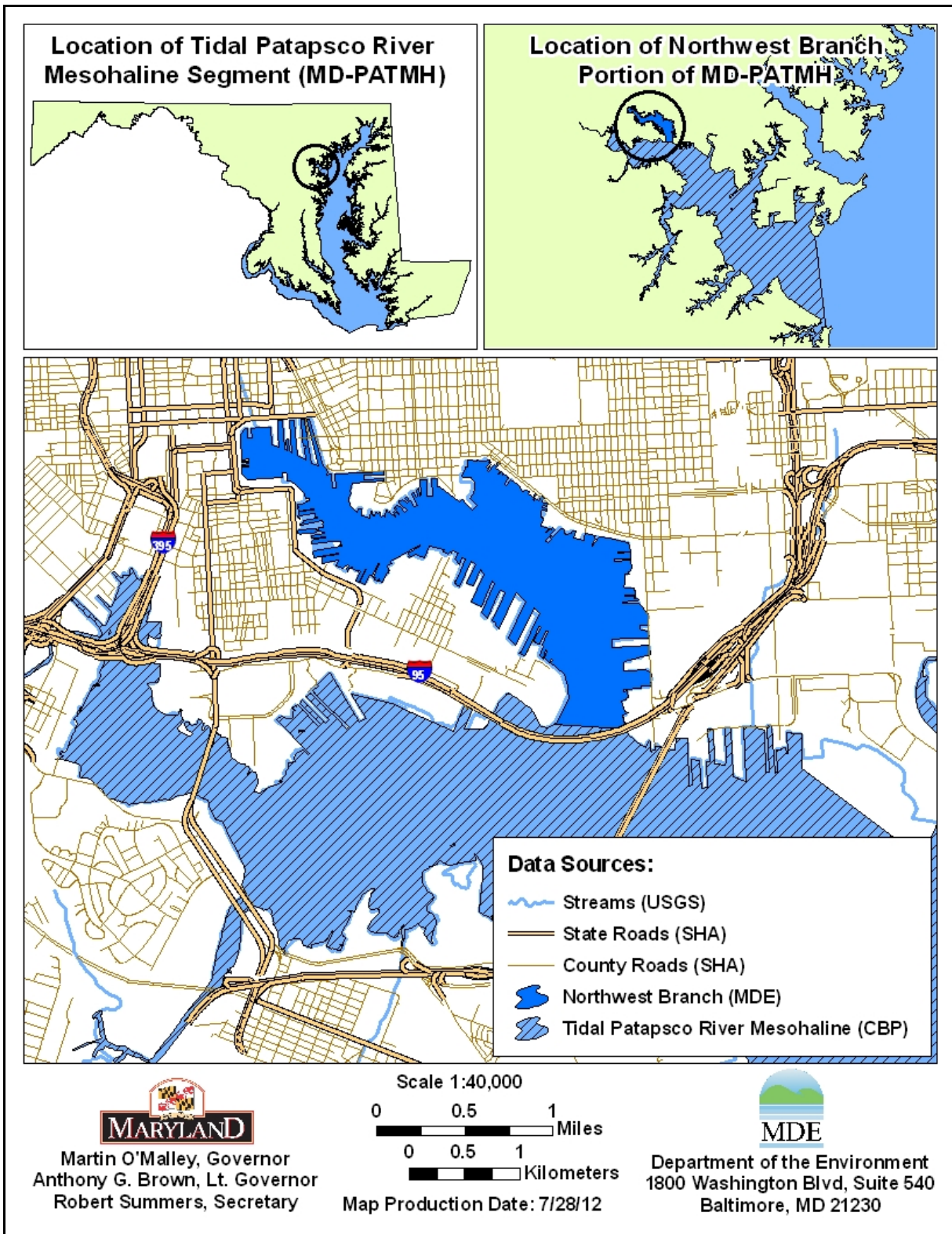


Figure 2.1: Location Map of Northwest Branch Embayment

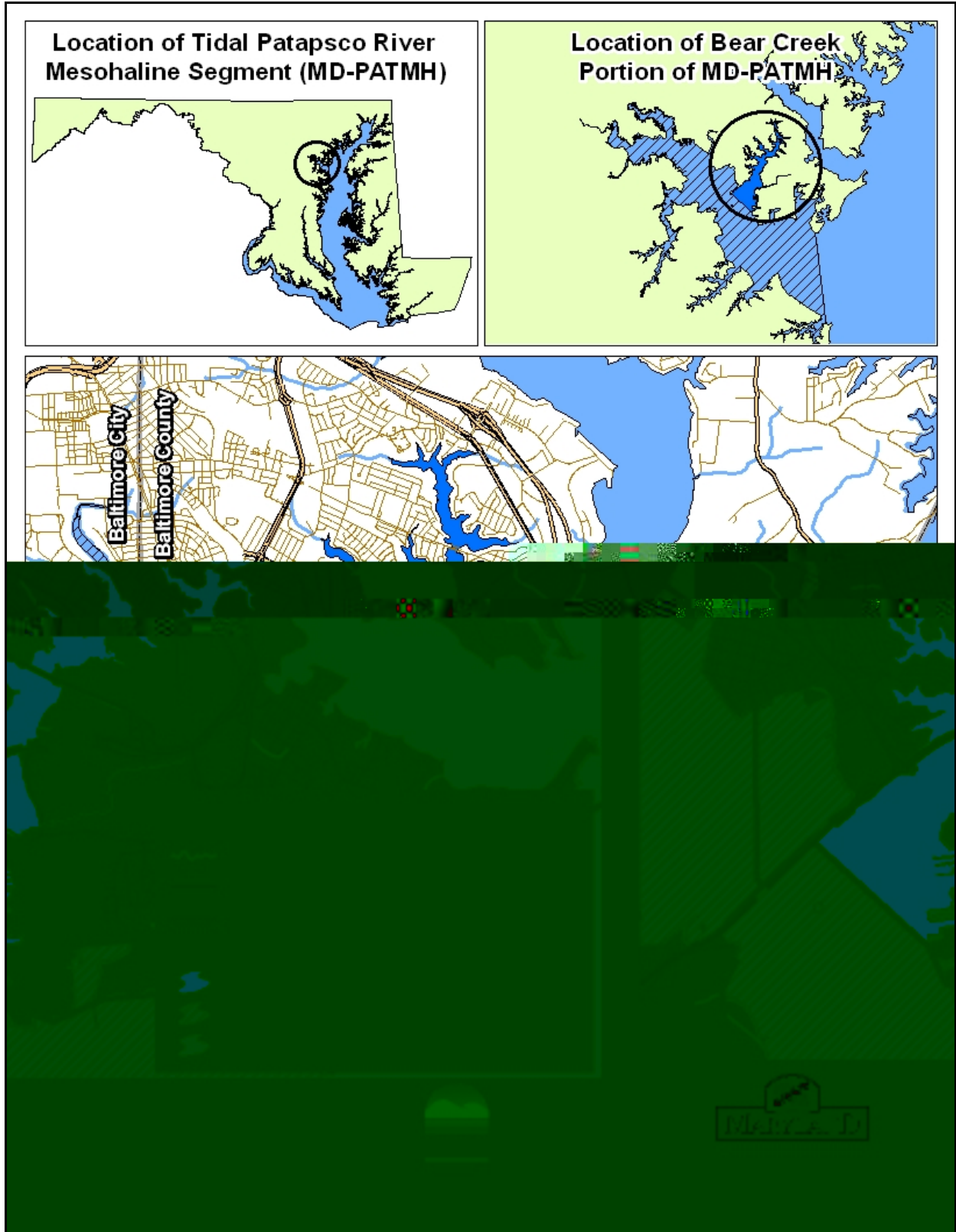


Figure 2.2: Location Map of Bear Creek Embayment

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Geology/Soils

The Northwest Branch and Bear Creek watersheds lie within the Coastal Plain geologic province of Maryland. A portion of the Jones Falls watershed which drains to the Northwest Branch embayment lies within the Piedmont geologic province. The Coastal Plain geologic province is characterized by broad upland areas with low slopes, gentle drainage, and deep sedimentary soil complexes that support broad meandering streams. The sediments of the Coastal Plain dip eastward at a low angle, generally less than one degree and range in age from Triassic to Quaternary. The mineral resources of the Coastal Plain are primarily sand and gravel, which are used as aggregate materials by the construction industry. The Piedmont geologic province is characterized by gentle to steep rolling topography, low hills and ridges. The surficial geology is characterized by crystalline igneous and metamorphic rocks of volcanic origin consisting primarily of schist and gneiss (DNR 2012; MGS 2012).

Soil type for the Northwest Branch and Bear Creek watersheds are categorized by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) into four hydrologic soil groups: Group A soils have high infiltration rates and are typically deep well drained/excessively drained sands or gravels; Group B soils have moderate infiltration rates and consist of moderately deep-to-deep and moderately well-to-well drained soils, with moderately fine/coarse textures; Group C soils have slow infiltration rates with a layer that impedes downward water movement, and they primarily have moderately fine-to-fine textures; Group D soils have very slow infiltration rates consisting of clay soils with a permanently high water table that are often shallow over nearly impervious material. The Northwest Branch including the Jones Falls watershed is composed primarily of Group B soils at 43.6%, with Group D, Group C, and Group A soils accounting for 32.0%, 20.3%, and 4.1% of the remaining watershed, respectively. The Bear Creek watershed is composed primarily of Group A soils at 48.9%, with Group C, Group B, and Group D accounting for 28.6%, 12.3%, and 10.2% of the remaining watershed, respectively (USDA 2013).

Land Use

According to the United States Geological Survey (USGS) 2006 land-cover data modified for the Chesapeake Bay watershed (USGS 2011), land-use in the Northwest Branch, including the Jones Falls Watershed and Bear Creek watershed can be classified as predominately urban. Urban land occupies approximately 65.79 % (28,319 acres) of the Northwest Branch watershed, while 26.46 % (11,391 acres) is forest, 5.25 % (2,261 acres) is agricultural, 2.50 % (1,075 acres) is covered by water (e.g., open waters of the embayment itself, streams, ponds, etc), and 0.3 % (137 acres). Urban land occupies approximately 72.56 % (5,414 acres) of the Bear Creek watershed, while 26.08 % (1,946 acres) is covered by water, 1.34 % (100 acres) is forest, and 0.02 % (2 acres) is agricultural. The land use for Northwest Branch and Bear Creek watershed, are displayed in Figures 2.3 and 2.4, respectively. The land use distributions (%) for Northwest Branch and Bear Creek watershed are presented in Figure 2.5.

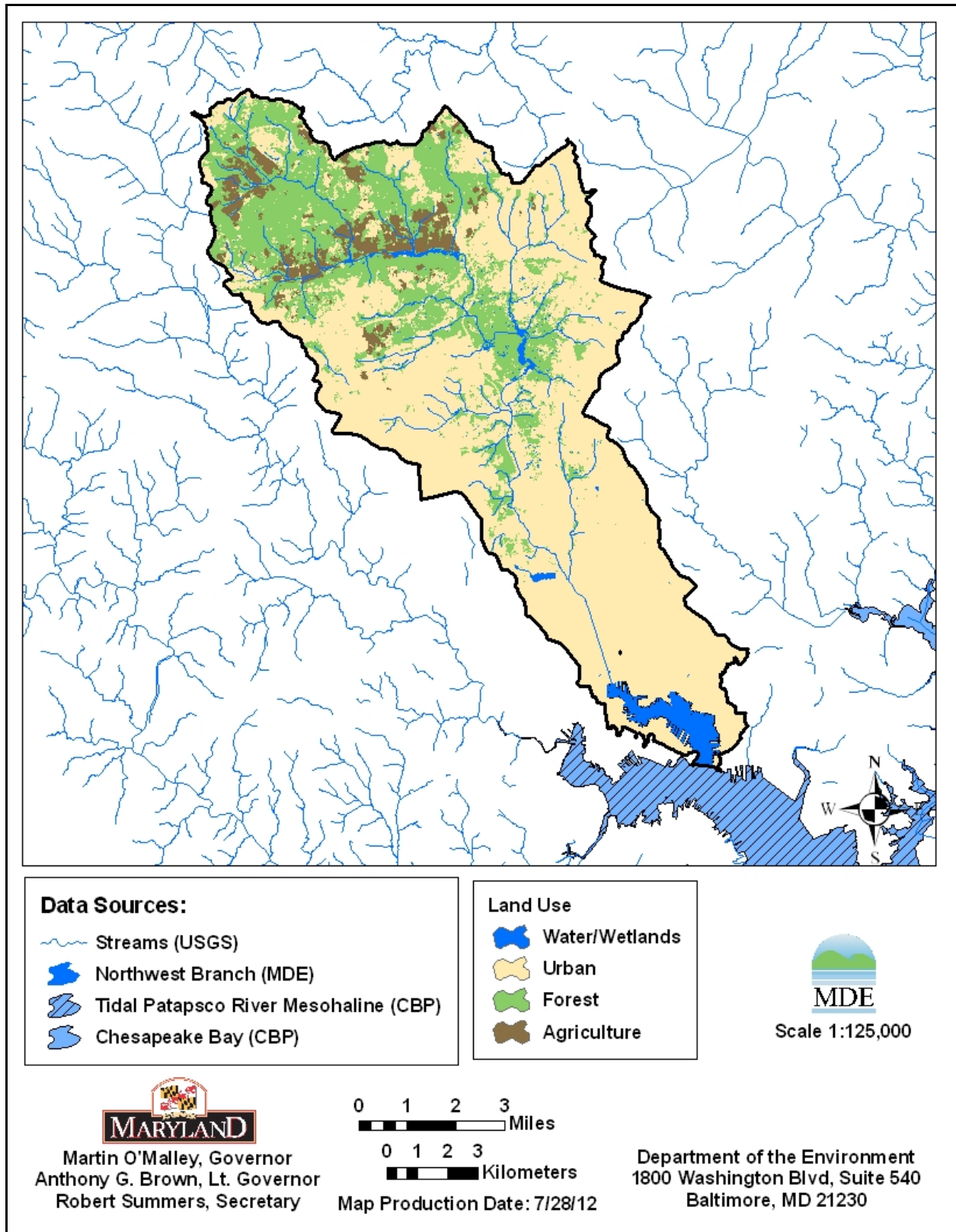


Figure 2.3: Land Use Map of Northwest Branch Watershed

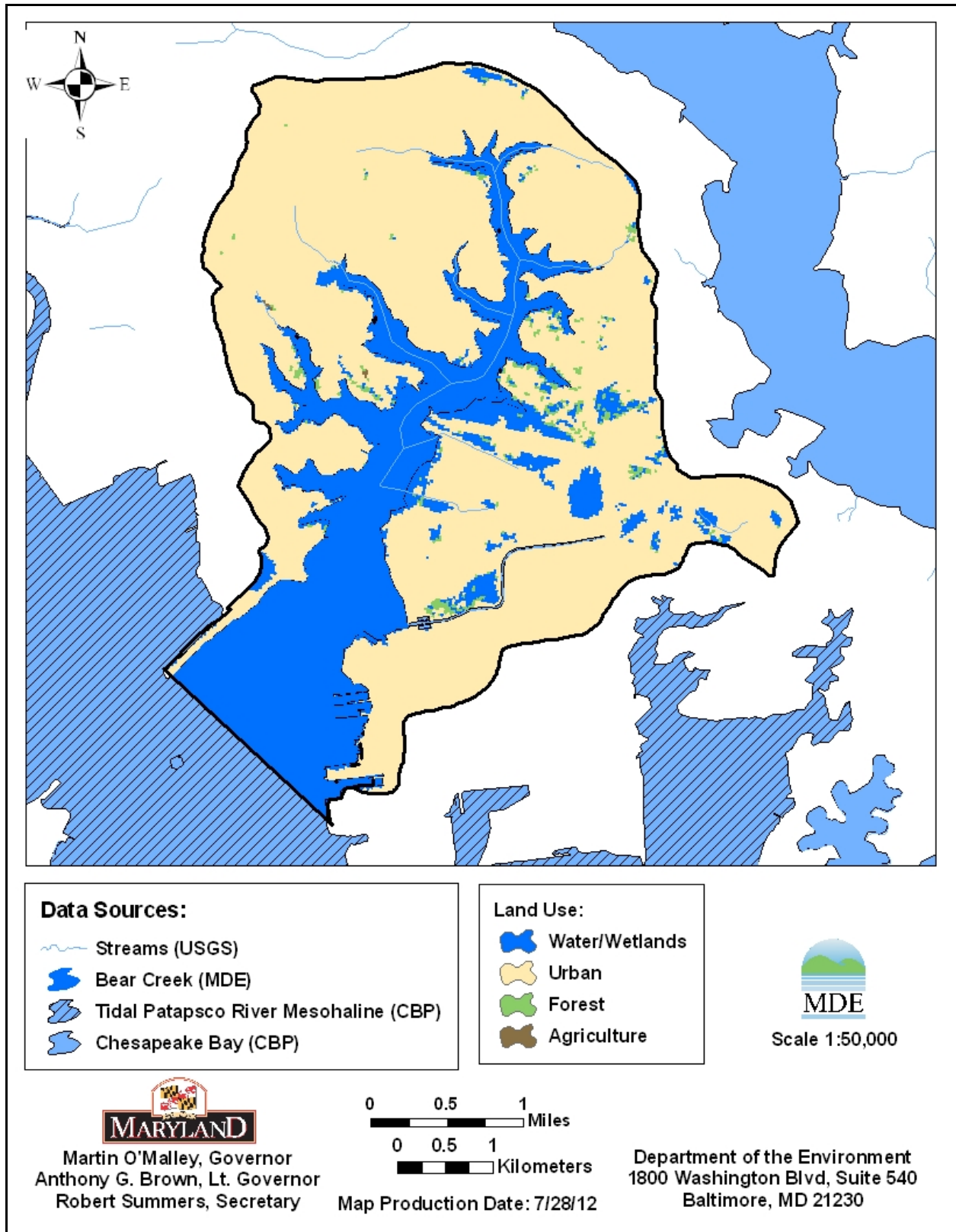


Figure 2.4: Land Use Map of Bear Creek Watershed

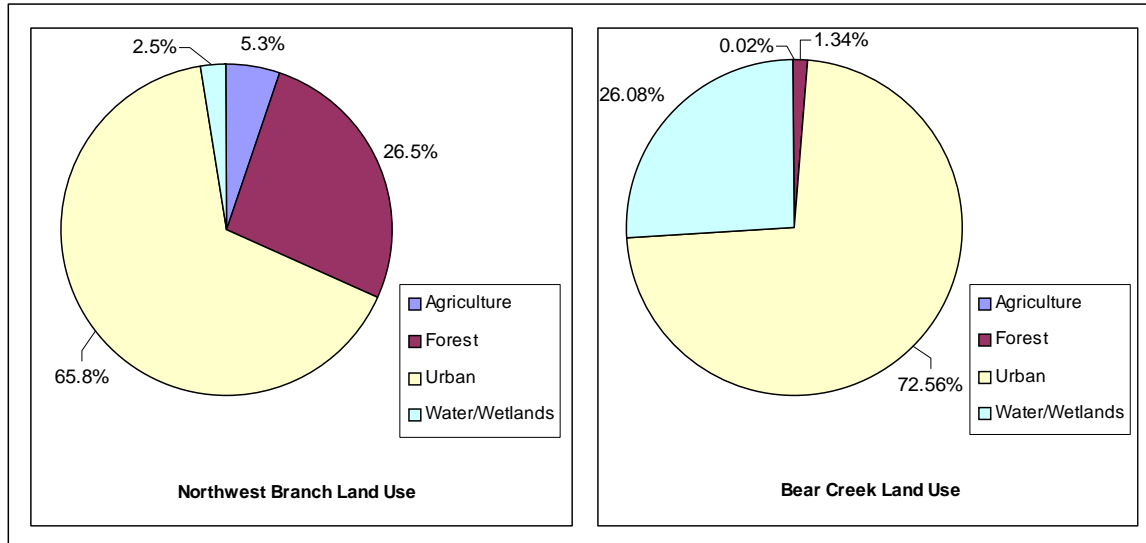


Figure 2.5: Land Use Distribution in Northwest Branch and Bear Creek Watersheds

3.0 BACKGROUND

A major source of chromium within the Baltimore Harbor is Chrome Ore Processing Residue (COPR) which was historically applied as land fill material at DMT and extensively throughout the Baltimore Harbor watershed. Chromium leaches from COPR material when in contact with water and subsequently transports to the Baltimore Harbor through groundwater as well as stormwater discharges due to infiltration within the sewer system. COPR was a byproduct of a chrome processing and manufacturing plant operated for more than 140 years by the Mutual Chemical Company and Allied Chemical in Baltimore City. Operations at the plant ceased in 1985 and the COPR is no longer applied as fill material. The former industrial site underwent Brownfields redevelopment and is now designated as Harbor Point, which is currently being developed as a commercial and residential property within the Baltimore Harbor (Honeywell International Inc. 2007).

Chromium present within the aquatic environment (water column or sediment) exists in two oxidation states, trivalent (Cr (III)) or hexavalent (Cr (VI)). The distinction between these two oxidation states is significant due to the toxicity associated with each species; Cr (III) is relatively non-toxic at levels typically found within the environment and Cr (VI) is highly toxic. Reduction/oxidation (Redox) conditions within the water column or sediment govern the speciation of chromium. Within Northwest Branch and Bear Creek, low levels of dissolved oxygen (DO) in the water column and elevated levels of biologically oxygen demanding (BOD) substances, produce anoxic conditions within the sediment supporting a reducing environment. Reductants present within the sediment (total organic carbon (TOC), acid volatile sulfides (AVS), and divalent iron (Fe (II))) facilitate the conversion of Cr (VI) to Cr (III). Cr (III) exhibits low solubility and will undergo reactions to form stable oxides/hydroxides resulting in partitioning from pore water to sediment. As Cr (III) is not present in the pore water at elevated levels under these conditions, it is no longer bioavailable to sediment dwelling organisms through the mechanisms of respiration and dermal absorption. Therefore, chromium remains bound in the sediment in its trivalent state and has no toxicological impact on benthic life.

4.0 REVIEW OF PAST MDE STUDIES ADDRESSING CHROMIUM LISTINGS IN NORTHWEST BRANCH AND BEAR CREEK

MDE completed a WQA in 2004 in order to remove the impairment listings of chromium in sediments for Northwest Branch and Bear Creek from Maryland's Integrated Report. EPA delayed approval of this delisting contingent upon the findings of a Toxicity Identification and Evaluation (TIE) study in Baltimore Harbor sediments underway at the time. The TIE study was unsuccessful due to experimental error and thus failed to demonstrate that metals including chromium are not a source of toxicity in the sediments of Baltimore Harbor. Therefore, the delisting decision could not be approved by EPA and the chromium impairment listings remained in Category 5 of Maryland's Integrated Report. The following sections present a summary of the 2004 WQA and TIE study.

4.1 Water Quality Analysis of Chromium in the Northwest Branch and Bear Creek Portions of Baltimore Harbor

A WQA of chromium in the Northwest Branch and Bear Creek portions of Baltimore Harbor was originally submitted to EPA in August 20, 2004. The WQA presented an assessment of newly collected water quality data which indicated that toxicity was present in the sediments of Northwest Branch and Bear Creek, but the source of toxicity could not be attributed to the presence of chromium and TMDL development would therefore be unnecessary. The WQA stated that the chromium listings in Maryland's Integrated Report should be removed from Category 5 ("waterbody is impaired, does not attain the water quality standard, and a TMDL is required") and placed in Category 2 ("waterbody in meeting some [in this case chromium related] water quality standards, but with insufficient data to assess all impairments"). The WQA also stated that the Northwest Branch and Bear Creek embayments should remain listed for biological impacts due to the presence of sediment toxicity from existing data presented in the WQA (MDE, 2004).

The original listings for chromium in sediments from Maryland's 1998 Integrated Report were established using the Sediment Quality Triad (SQT) approach, the designated methodology for assessing waters of the State for toxic impairments in sediment as Maryland has no numeric sediment quality criterion for chromium (MDE 2012a). Water quality data demonstrated that sediment toxicity and a degraded benthic community were present within the Inner Harbor/Northwest Branch and Bear Creek and sediment concentrations for total chromium exceeded the Sediment Quality Guideline (SQG) Effects Range Median (ERM). These findings indicated that the sediment was impaired for chromium. In retrospect this approach was methodologically flawed as a comparison of sediment concentrations and the ERM for total chromium of 370 mg/kg did not take into consideration the relative toxicity associated with the speciation of Cr (III) and Cr (VI). The sediments within the Northwest Branch and Bear Creek support a reducing environment indicating that Cr (III), the relatively non-toxic species at levels typically found within the environment, is the predominant form of chromium present within the sediment (MDE, 2004).

FINAL

Water column and sediment samples were collected at ten monitoring stations within the Northwest Branch and Bear Creek in August of 2003. A map displaying the monitoring station locations is presented in Figure 4.1.1. Water column samples were analyzed for dissolved phase concentrations of Cr (III) and Cr (VI). Sediment samples were analyzed for Cr (III) and Cr (VI) in pore water and total Cr in sediments. AVS-Simultaneously Extracted Metals (SEM) analyses were also conducted on sediment samples (MDE, 2004).

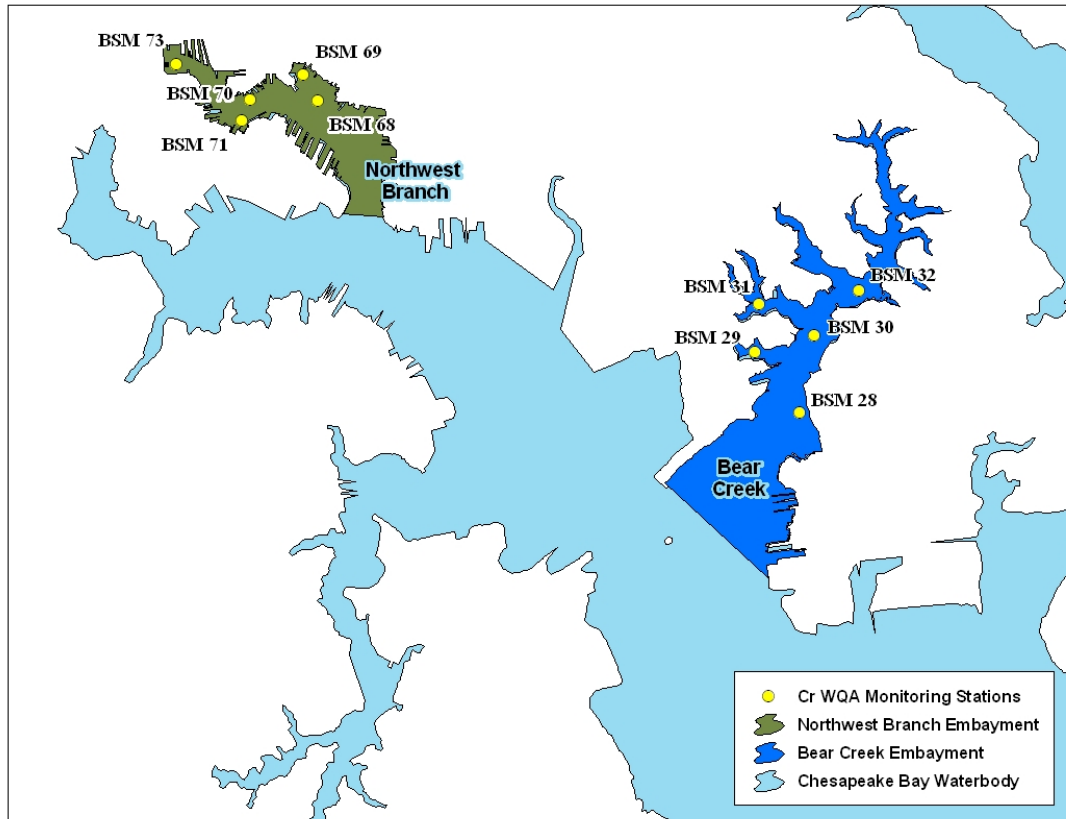


Figure 4.1.1: Chromium WQA Monitoring Stations

In order to evaluate the water quality data for this WQA, a comparison was made between the dissolved water column and sediment pore water concentrations for Cr (III) and Cr (VI) and the aquatic life water column chronic criterion for Cr (VI) (11 $\mu\text{g/L}$ for freshwater and 50 $\mu\text{g/L}$ for saltwater). The mean concentration of dissolved water column data for Cr (III) and Cr (VI) in the Northwest Branch was 0.131 $\mu\text{g/L}$ and 0.203 $\mu\text{g/L}$, respectively. The mean concentration of dissolved water column data for Cr (III) and Cr (VI) in Bear Creek was 0.212 $\mu\text{g/L}$ and 0.162 $\mu\text{g/L}$, respectively. The mean concentration of pore water data for Cr (III) and Cr (VI) in the Northwest Branch was 0.35 $\mu\text{g/L}$ and non-detect (ND), respectively. The method detection level for the Cr (VI) analysis was 0.022 $\mu\text{g/L}$. The mean concentration of pore water data for Cr (III) and Cr (VI) in Bear Creek was 0.11 $\mu\text{g/L}$ and ND, respectively. Water column and pore water Cr concentration data is presented in Table 4.1.1 (MDE, 2004).

Table 4.1.1: Northwest Branch and Bear Creek Water Column and Pore water Chromium Concentration Data

Embayment	Station	Water Column Concentration (µg/L)		Pore Water Concentration (µg/L)		Cr (VI) Aquatic Life Chronic Criterion (µg/L)	
		Cr (III)	Cr (VI)	Cr (III)	Cr (VI)	Freshwater	Saltwater
Northwest Branch	BSM68	0.222	0.279	0.07	ND	11	50
	BSM69	0.129	0.163	0.31	ND	11	50
	BSM70	0.125	0.262	0.50	ND	11	50
	BSM71	0.109	0.131	0.50	ND	11	50
	BSM73	0.070	0.178	0.36	ND	11	50
Bear Creek	BSM28	0.263	0.176	0.05	ND	11	50
	BSM29	0.171	0.175	0.12	ND	11	50
	BSM30	0.355	0.143	0.09	ND	11	50
	BSM31	0.138	0.168	0.12	ND	11	50
	BSM32	0.132	0.148	0.17	ND	11	50

All dissolved water column and pore water concentration data were well below the most conservative threshold of 11 µg/L for the freshwater aquatic life chronic (Cr (VI)) criterion. No Cr (VI) was detected in any pore water sample. The freshwater criterion was applied in this analysis as the salinity for these waters ranged between 1 and 10 parts per thousand (ppt) and MDE (2012) designates that the most conservative of the freshwater and saltwater criterion should be applied under these conditions (MDE, 2004).

The mean sediment concentration of total chromium in Northwest Branch was 752 mg/kg. The mean SEM concentration for Chromium, mean SEM concentration for remaining divalent metals and mean AVS concentration and mean excess sulfide concentration in the Northwest Branch was 3.40 micromoles (µmole)/g, 8.17 µmole/g, 210.94 µmole/g, and 199.37 µmole/g, respectively. The mean sediment concentration of total chromium in Bear Creek was 741 mg/kg. The mean SEM concentration for Cr, mean SEM concentration for remaining divalent metals, mean AVS concentration and mean excess sulfide concentration in the Bear Creek was 6.93 µmole/g, 22.23 µmole/g, 332.75 µmole/g, and 303.58 µmole/g, respectively. Sediment concentration data for Northwest Branch and Bear Creek is presented in Table 4.1.2 (MDE, 2004).

Table 4.1.2: Northwest Branch and Bear Creek Sediment Concentration Data

Embayment	Station	Total Cr (mg/kg)	SEM Cr (μmole/g)	SEM Metals (μmole/g)	AVS (μmole/g)	Excess Sulfide (μmole/g)
Northwest Branch	BSM 68	443	1.60	7.46	78.75	69.69
	BSM 69	480	2.11	7.91	369.38	359.36
	BSM 70	1,068	4.66	7.59	173.44	161.19
	BSM 71	1,286	6.60	10.78	196.88	179.50
	BSM 73	500	2.01	7.13	236.25	227.11
Bear Creek	BSM 28	705	6.92	19.42	144.06	117.72
	BSM 29	724	6.20	21.29	304.06	276.58
	BSM 30	827	10.80	31.58	340.63	298.25
	BSM 31	847	4.73	19.14	500.00	476.13
	BSM 32	601	6.00	19.78	375.00	349.22

The SEM concentration for chromium and total metals were well below the AVS portion present within the sediments of Bear Creek and Northwest Branch providing excess capacity for reducing all chromium within the sediment from Cr (VI) to Cr (III) as well as the formation of sulfide complexes with all remaining divalent metals significantly reducing the bioavailability of these metals to sediment dwelling organisms. The presence of excess AVS indicates that Cr will partition primarily to the sediment as oxide/hydroxide compounds as indicated by the low pore water concentrations of Cr (III) and Cr (VI). While sediment concentrations for Total Cr exceeded the ERM of 370 mg/kg, this is not an indication of toxicity, as the sediments are composed primarily of Cr (III), the relatively non-toxic species of chromium at levels typically found within the environment (MDE, 2004).

The water quality data presented in support of this WQA demonstrated that while sediment toxicity was present, the source of toxicity could not be attributed to the presence of chromium and TMDL development would therefore be unnecessary (MDE, 2004).

The EPA upon review of this WQA provided MDE with a decision rationale letter regarding their approval of this document on January 18, 2005. EPA believed that MDE used the best available science and appropriate methodology in determining that chromium is not a source of

FINAL

toxicity within the sediments of Bear Creek and Northwest Branch and did not dispute the results or MDE's conclusions contained within the WQA. However, at the time, MDE was conducting a TIE study to assist in identifying the pollutant(s) responsible for the biological impairment in the Baltimore Harbor which would determine whether there was a need to develop chromium TMDL(s) for the listed segments. For this reason, EPA chose to defer the delisting decision for chromium until the study was complete. Upon confirmation from the TIE study that metals were not a cause of toxicity, the delisting would be approved (US EPA 2005). Description and outcomes of the TIE study are presented below in Section 4.2.

4.2 Toxicity, Identification, and Evaluation and Long-Term Contaminant Trends in the Baltimore Harbor

University of Maryland Center for Environmental Science (UMCES) Chesapeake Biological Laboratory (CBL) and University of Maryland (UM) Wye Research and Education Center (WREC) submitted the "Toxicity, Identification, and Evaluation (TIE) and Long-Term Contaminant Trends in the Baltimore Harbor" report to MDE on February 2007. The objective of this study was to use innovative whole sediment TIE methods to determine the class of chemical contaminants most likely responsible for observed sediment toxicity in the Baltimore Harbor. The sediments of the Baltimore Harbor contain elevated levels of many different chemical contaminants which are highly toxic to the benthic community making it difficult to directly link toxicity to a specific chemical compound or class of chemical contaminants (Klosterhaus *et al.* 2007).

A field survey was conducted to evaluate the chemical composition and toxicity of sediments from locations throughout the Baltimore Harbor. Sediment samples were analyzed for organic contaminants (PCBs, polyaromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs), etc...) oragnotins (i.e., tributyltin), and metals in pore water and sediment. Sediment bioassays were conducted with the amphipod *Leptocheirus plumulosus*, an estuarine benthic organism commonly applied by MDE in evaluating sediment toxicity. Eight stations were selected for this study based on toxicity and prevalence of chemical contamination for a multitude of toxic substances observed in previous studies. Four of the stations, BSM 28, BSM 33, BSM 68, and BSM 71 are located in Bear Creek and Northwest Branch. A map displaying the TIE Study station locations is presented in Figure 4.2.1 (Klosterhaus *et al.* 2007).

The whole sediment TIE methods applied in this study were developed by the Atlantic Ecology Division of the EPA in Narragansett, RI which applied the marine amphipod *Ampelisca abdita*, a species generally found in coastal waters with high salinity. *A. abdita* is not a resident species in the Northern Chesapeake Bay due to salinities which fall outside its range of adaptability. Test water for sediment bioassays would require an adjustment to salinity to ensure *A. abdita* survival introducing a potential confounding factor. Therefore the amphipod *L. plumulosus* was applied in this study, as it is a resident species and all previous sediment toxicity work for Baltimore Harbor was conducted using this organism (Klosterhaus *et al.* 2007).

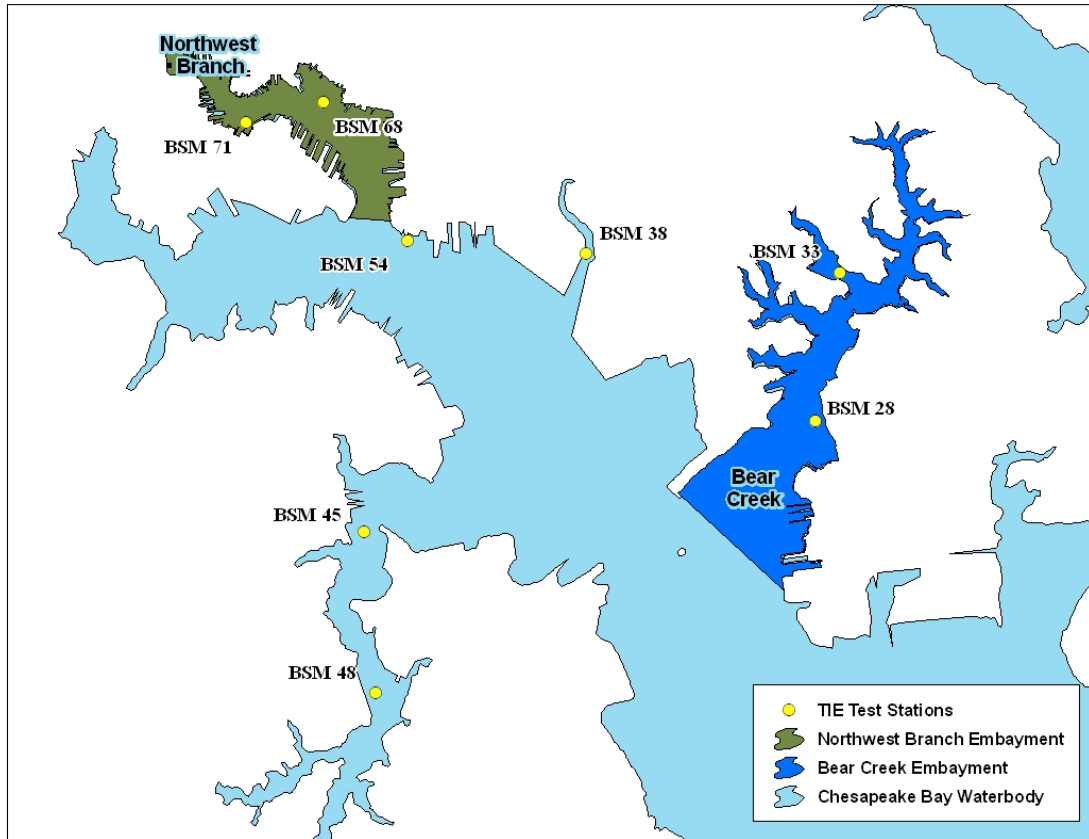


Figure 4.2.1: Baltimore Harbor TIE Study Stations

As the TIE methods were previously developed for *A. abdita* it was necessary to establish that test conditions alone would not result in toxicity to the *L. plumulosus*. Trial laboratory testing was necessary to determine that the sediment manipulations were not directly toxic to the organism by conducting the toxicity test with the individual resin or charcoal and clean sediments to ensure there were no confounding toxicants. In addition, testing was done to ensure beaker size, sediment volume, and test duration did not affect toxicity results (Klosterhaus *et al.* 2007).

Trial testing was successful and the whole sediment TIE method was conducted using the *L. plumulosus*. Sediment manipulations during trial testing were successful in removing each individual class of compounds (ammonia, organics, and metals) with the relevant resin/charcoal to eliminate toxicity in spiked control sediments. However, upon completion, the study was unsuccessful in identifying a class of compounds responsible for toxicity within the sediments of the Baltimore Harbor because when this approach was applied to field sediments, the treatments did not successfully remove toxicity. The TIE methods were successful in removing organics and ammonia, though the resin chosen to sequester metals failed to entirely remove all metals present in the sediment. It is believed that the elevated levels of sulfides in these sediments interfered with the ability of the resin to remove metals from the pore water. In fact, the concentrations of several metals increased in the pore water following manipulation with the resin. Therefore, it was not possible to definitively determine whether metals are a source of toxicity within the sediments of Baltimore Harbor (Klosterhaus *et al.* 2007).

FINAL

While the TIE study was unsuccessful in determining that metals are not a source of toxicity within Baltimore Harbor sediments, several pore water toxicity tests were also conducted on un-manipulated sediments. These tests found no observed toxicity at several stations, including stations BSM 28, BSM 33, and BSM 68 indicating that metals are not present in pore water at levels that pose a risk to the health of benthic organisms and thus, an unlikely source of toxicity in these sediments. This assessment falls in line with EPA's equilibrium partitioning theory based on the concept that the primary pathway of toxicity in sediments for benthic organisms is from exposure to compounds in pore water through respiration and dermal absorption. Pore water and sediment samples were also collected and analyzed for total Cr and AVS-SEM under the TIE study. The concentrations of total chromium in pore water ranged from 1.48 to 9.04 µg/L for stations located in Northwest Branch and Bear Creek. These levels were all below Maryland's saltwater and freshwater aquatic life chronic Cr (VI) criterion of 50 µg/L and 11 µg/L, respectively. The AVS-SEM analysis demonstrated that AVS concentrations were greater than SEM concentrations for total metals, providing sufficient capacity for reducing chromium to its trivalent state and binding all remaining metals as sulfide complexes in the sediment. Pore water and AVS-SEM concentration data are presented in Table 4.2.1 (Klosterhaus *et al.* 2007).

Table 4.2.1: Baltimore Harbor TIE Study Sediment Concentration Data (Pore Water and AVS/SEM)

Station	Pore Water Total Cr (µg/L)	SEM Cr (µmole/g)	SEM Metals (µmole/g)	AVS (µmole/g)	Excess Sulfide (µmole/g)
BSM 28	1.48	7.84	21.50	16,700	16,678.50
BSM 33	4.33	7.21	5.45	24,700	24,694.55
BSM 38	11.60	0.93	5.45	18,000	17,994.55
BSM 45	1.88	1.76	8.64	2,460	2,451.36
BSM 48	1.98	0.87	6.08	8,920	8,913.92
BSM 54	3.24	1.08	4.96	4,620	4,615.04
BSM 68	4.54	1.93	8.24	4,710	4,701.76
BSM 71	9.04	6.08	14.60	13,100	13,085.40

5.0 REVIEW OF STUDIES INVESTIGATING CHROMIUM TOXICITY IN BALTIMORE HARBOR SEDIMENTS

The results of the TIE study were inconclusive regarding the toxicity of metals in Baltimore Harbor sediments, therefore EPA delayed the delisting decision supported by the Chromium WQA submitted in 2004. Chromium remained listed as an impairing substance in Northwest Branch and Bear Creek on Maryland's Integrated Report. The John's Hopkins University (JHU) Center for Contaminant Transport, Fate, and Remediation (CTFR), under the direction of Dr. Edward Bouwer, professor and department chair of Geography and Environmental Engineering, conducted several studies investigating the relationship between toxicity and the exposure of chromium to benthic organisms, sediment ingestion as a pathway of toxicity, and stability of Cr (III) under oxygenation in the sediments of Baltimore Harbor to assist MDE in assessing the potential ecological impact of chromium in sediments. In addition to these studies provided by JHU CTFR, an ERA of DMT and an EPA Data Evaluation of Bear Creek sediments were recently completed investigating the potential ecological impact from chromium. The following sections present a summary of these five individual studies which establish that Cr is not a source of toxicity within the sediments of Northwest Branch and Bear Creek.

5.1 John's Hopkins University Studies Investigating Chromium Speciation and Benthic Toxicity in Baltimore Harbor Sediments

5.1.1 Bioassay Testing of Baltimore Harbor Sediments Spiked with Cr (VI)

JHU CTFR completed the study "Bioassay Testing of Baltimore Harbor Sediments Spiked with Cr (VI)" on February 12, 2008. Dr. Bouwer, director of the JHU CTFR, is a co-author of this study. The primary objective of this study was to determine if there is a relationship between toxicity and the exposure of chromium to benthic organisms inhabiting Baltimore Harbor sediments. Whole sediment bioassays were conducted using the amphipod *Leptocheirus Plumulosus* and exposing the test organism to sediments from the Baltimore Harbor spiked with increasing levels of Cr (VI). This amphipod was selected for testing as it is a resident species of the Baltimore Harbor, it is sensitive to chemical contaminants and has a tendency to burrow in and ingest sediment (Watlington *et al.* 2008).

Previous studies presented in this document established that Cr (III) is the predominant species in sediment due to elevated sulfide levels which maintain a reducing environment. Cr (III) exhibits low solubility and will partition from pore water to sediment primarily as insoluble oxide/hydroxide compounds. The previous WQA presented water quality data demonstrating that chromium concentrations in pore water were well below numeric criterion supportive of the protection of aquatic life designated use and pore water toxicity tests conducted under the TIE study found no toxicity due to metals. While this information indicated that chromium is not a source of toxicity in sediments, these studies only consider pore water as the primary route of exposure through respiration and dermal absorption and did not investigate whether sediment ingestion of chromium is also a contributing pathway for potential toxicity to benthic organisms (Watlington *et al.* 2008).

FINAL

In this study both acute (10-day) and chronic (28 day) whole sediment bioassays were conducted on the test organism. Test sediments were spiked at three different levels of Cr (VI) from five stations throughout the Baltimore Harbor. Two of these stations, BSM 68 and BSM 33, were located in Northwest Branch and Bear Creek, respectively. Sample sites were selected based on information from previous surveys conducted in the Baltimore Harbor (e.g., TIE Study) in which geochemical properties (TOC, grain size, etc...), chemical contaminant concentrations and toxicity were measured. A map displaying the monitoring stations locations are presented in Figure 5.1.1(a). Sediments from selected sites could not exhibit more than 50% mortality to test organisms in a baseline acute whole sediment bioassay so that potential changes in toxicity with increasing Cr (VI) spike concentrations would be observable (Watlinton *et al.* 2008).

Baseline Cr concentrations of the selected test sites were previously found to range between 200 and 850 mg/kg. The first spiking level (range of 383-677 mg/kg) was chosen to span the observed range of concentrations from the test sites to be representative of environmental conditions. The second and third spiking level, (1250-1810 mg/kg) and (2000-4180 mg/kg), respectively, were chosen to assess the level of Cr (VI) necessary to elicit an acute or chronic toxicological response to test organisms. These levels significantly exceed environmentally relevant levels of measured total Cr concentrations in Baltimore Harbor sediments. Sediment concentration data of total Cr for baseline and spiked treatments are presented in Table 5.1.1(a). (Watlinton *et al.* 2008).

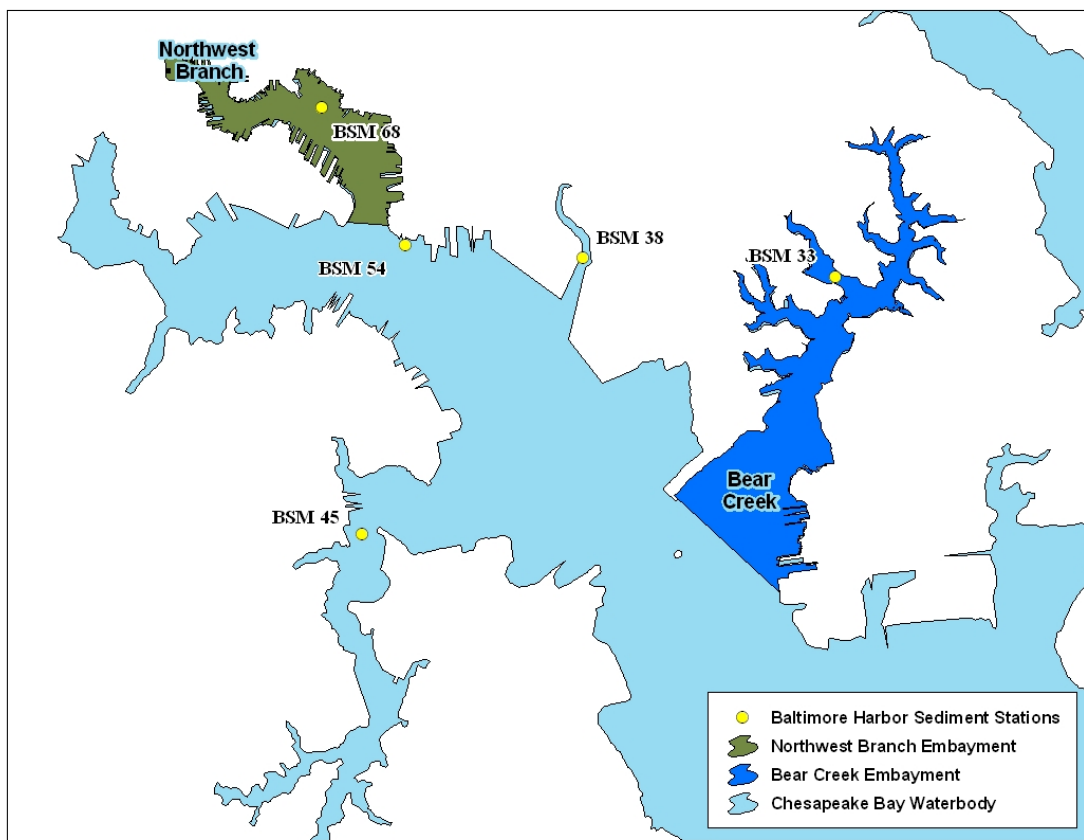


Figure 5.1.1(a): Baltimore Harbor Sediment Test Stations

Table 5.1.1(a): Total Chromium Sediment Concentration Data (Baseline & Spiked Levels)

Station	Total Cr (Baseline) (mg/kg)	Spike A (mg/kg)	Total Cr (post Spike A) (mg/kg)	Spike B (mg/kg)	Total Cr (post Spike B) (mg/kg)	Spike Cr (mg/kg)	Total Cr (post Spike C) (mg/kg)
BSM 33	823	677	1500	1650	2470	2000	2820
BSM 38	271	383	654	1310	1580	3090	3360
BSM 45	148	400	548	1670	1820	4180	4330
BSM 54	126	408	535	1250	1380	2920	3050
BSM 68	354	610	964	1810	2160	3210	3560

The results of both the acute and chronic whole sediment bioassays established that no spiked sediment treatment displayed elevated toxicity when compared with the baseline treatments, except for one station (BSM 68) where the highest spiking level of 3210 mg/kg resulted in significant mortality. Results of the chronic whole sediment toxicity tests for baseline and spiked treatments are presented in Table 5.1.1(b) and Figure 5.1.1(b) (Watlington *et al.* 2008).

Table 5.1.1(b): Whole Sediment Chronic Toxicity Test Results (Baseline & Spiked Levels)

Treatment	Matrix	Stations				
		BSM 33	BSM 38	BSM 45	BSM 54	BSM 68
Baseline	Total Cr (mg/kg)	823	271	148	126	354
	Survival (%)	32	37	86	76	56
Spike A	Total Cr (mg/kg)	1325	654	548	535	964
	Survival (%)	33	50	72	78	67
Spike B	Total Cr (mg/kg)	2466	1580	1820	1380	2160
	Survival (%)	47	53	88	73	57
Spike C	Total Cr (mg/kg)	2820	3360	4330	3050	3560
	Survival (%)	34	60	93	82	0

All baseline and spiked sediment samples used for toxicity assessment were also analyzed for Cr (VI) concentrations. This information is presented in Table 5.1.1(c). Concentrations of Cr (VI) in spiked sediments were within the same range as the baseline sediments with the exception of the high level spiking for BSM 68 of 9.57 mg/kg which contained Cr (VI) in sediment approximately 150 times the baseline concentration. Cr (VI) concentrations in sediment for baseline treatments were between 0.05 and 0.08 mg/kg while concentrations for spiking treatments excluding the high level spiking for BSM 68 ranged between zero and 1.37 mg/kg.

FINAL

While Cr (VI) was present in the third spiking treatment for BSM 68 it only accounted for 0.3 % of the total mass of chromium (Watlington *et al.* 2008).

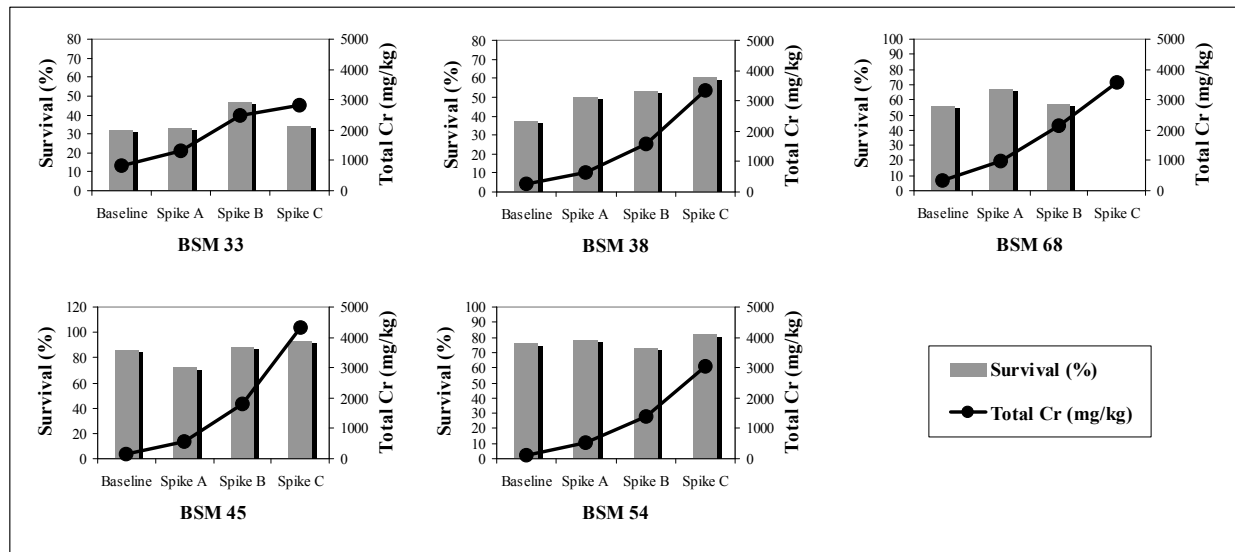


Figure 5.1.1(b): Whole Sediment Chronic Toxicity Test Results (Baseline & Spiked Levels)

The overlying water from the test beakers for each sediment treatment was also analyzed for total chromium and Cr (VI). This information is also presented in Table 5.1.1(c). No Cr (VI) was detected in any treatment except for the high level spiking for BSM 68 at a concentration of 1054.1 $\mu\text{g/L}$ which was well above the saltwater aquatic life Cr (VI) criterion of 50 $\mu\text{g/L}$. An additional spiking evaluation was conducted for station BSM-68 to determine the true lowest observed apparent effects level (LOAEL) for which toxicity would be observed between the no effects level of 1810 mg/kg and effects level of 3210 mg/kg from the previous analysis. The LOAEL threshold spiking concentration was determined to be approximately 2,250 mg/kg. This concentration was well above the range of environmentally relevant concentrations within Baltimore Harbor sediments as baseline concentrations did not exceed 823 mg/kg (Watlington *et al.* 2008).

Cr (VI) concentrations in sediment were not detected in all spiking treatments except for the high level spiking at BSM 68, therefore the existing reducing capacity within the sediments is sufficient to facilitate the complete conversion of Cr (VI) additions to Cr (III). To further demonstrate this, an AVS-SEM analysis was conducted on sediments for all spiking treatments. The molar ratio of Cr (VI) additions to AVS for each spiking treatment is presented in Table 5.1.1(d).

Table 5.1.1(c): Total Chromium and Cr (VI) Concentration Data (Baseline & Spiked Levels)

Treatment	Matrix	Analyte	Station				
			BSM 33	BSM 38	BSM 45	BSM 54	BSM 68
Baseline	Sediment (mg/kg)	Total Cr	823	271	148	126	354
		Cr (VI)	0.05	0.05	0.05	0.08	0.06
	Overlying Water (µg/L)	Total Cr	0.05	13.4	0.1	0.5	0.8
		Cr (VI)	ND	ND	ND	ND	ND
Spike A	Sediment (mg/kg)	Total Cr	1325	654	548	535	964
		Cr (VI)	0.00	0.01	0.01	1.37	0.36
	Overlying Water (µg/L)	Total Cr	ND	ND	0.3	ND	1.7
		Cr (VI)	ND	ND	ND	ND	ND
Spike B	Sediment (mg/kg)	Total Cr	2466	1580	1820	1380	2160
		Cr (VI)	0.00	0.01	0.00	0.27	1.10
	Overlying Water (µg/L)	Total Cr	ND	1.6	1.5	2.7	3.1
		Cr (VI)	ND	ND	ND	ND	ND
Spike C	Sediment (mg/kg)	Total Cr	2820	3360	4330	3050	3560
		Cr (VI)	0.02	0.03	0.02	0.80	9.57
	Overlying Water (µg/L)	Total Cr	ND	1.6	1.3	9.2	1455.9
		Cr (VI)	ND	ND	ND	ND	1054.1

Table 5.1.1(d): Cr (VI)/AVS Molar Ratios (Spiked Levels)

Treatment	Molar Ratio	Station				
		BSM 33	BSM 38	BSM 45	BSM 54	BSM 68
Spike A	Cr (VI) addition /AVS	0.03	0.08	0.08	0.17	0.32
Spike B		0.06	0.28	0.33	0.51	0.96
Spike C		0.11	0.67	0.83	1.19	1.71

FINAL

A ratio below one indicates that AVS is present at levels providing sufficient capacity to reduce all Cr (VI) to Cr (III). All ratios were below one except for the high level spiking at BSM 54 and BSM 68. This analysis found that the LOAEL for the high level spiking at BSM 68 occurred when the molar ratio exceeded one. In this treatment, Cr (VI) was no longer completely reduced to Cr (III) and therefore remained in the dissolved phase of the overlying water and pore water during the bioassay resulting in the death of all test organisms (Watlington *et al.* 2008). While the molar ratio for BSM 54 exceeded one, no toxicity was observed in the spiking treatment. This indicated that reductants other than AVS were present in the sediment, such as Fe (II) or TOC, which provided sufficient reducing capacity to convert all Cr (VI) in the spiking addition when AVS was no longer available (Watlington *et al.* 2008).

The bioassay testing of Baltimore Harbor sediments concluded that, with the exception of the high level spiking treatment for BSM 68, toxicity values did not vary from those observed for the baseline treatments. No correlation was observed between sediment toxicity and total chromium concentrations. The baseline treatments for some stations exhibited pre-existing chronic toxicity while levels of mortality in subsequent spiked treatments were not elevated with respect to the baseline treatments, excluding the high level spiking treatment for BSM-68. The addition of Cr (VI) to sediments at concentrations at or exceeding environmentally relevant concentrations caused no increases in observed toxicity, with the exception of the high level spiking treatment for BSM 68. This finding indicated that pre-existing chromium in the baseline sediment treatments did not contribute to any observed toxicity. If chromium already present in the baseline sediment was responsible for toxicity, an increase in mortality would have occurred with minimal addition of chromium. These findings indicated that chromium is not responsible for observed toxicity in Baltimore Harbor sediments evaluated in this study. As a result of the toxicity observed in Station BSM-68 and the AVS-SEM analysis, it can be concluded that AVS constituents are the major contributor to Cr (VI) reduction in anoxic sediments. A geochemical condition in sediment where Cr (VI) exceeds AVS is an indicator of potential toxicity (Watlington *et al.* 2008).

5.1.2 The Sediment Ingestion Pathway as a Source of Toxicity in the Baltimore Harbor

JHU CTFR submitted the literature review “The Sediment Ingestion Pathway as a Source of Toxicity in the Baltimore Harbor” to MDE on January 4, 2007. Dr. Bouwer, director of the JHU CTFR, is a co-author of this study. This document provides additional information on previous studies that investigated sediment ingestion of Cr (III) as a pathway for toxicity to benthic organisms (Watlington *et al.* 2007).

Berry *et al.* (2002) conducted several studies using marine sediments and the amphipod *Ampelisca abdita* to demonstrate that sediment containing levels of Cr (III) well above the ERM of 370 mg/kg for total chromium is not acutely toxic to the test organism. A whole sediment acute bioassay was conducted on sediments with Cr (III) concentrations ranging from less than 50 mg/kg to levels greater than 3,000 mg/kg. There was no observed relationship demonstrating changes in toxicity with increasing Cr (III) concentrations. No acute toxicity was observed even

FINAL

at levels of Cr (III) of more than an order of magnitude greater than the ERM (Watlington *et al.* 2007).

Berry *et al.* (2002) also conducted a water only toxicity test using the amphipod *A. abdita*. A test solution with a maximum Cr (III) concentration of 100,000 µg/L was introduced while adjusting pH to maintain conditions similar to natural seawater. As Cr (III) exhibits low solubility, a precipitate was formed at the base of the test chamber. Amphipods were placed in the chamber and resided on the pure Cr (III) precipitate for a test duration of 10 days. The amphipods lived in the precipitate for the entire 10-day period and utilized the precipitate in building tubes for burrowing as is typically done by the organism within sediment. No toxicity was observed while the amphipods lived within the pure Cr (III) precipitate for the duration of the test (Watlington *et al.* 2007).

Oshida *et al.* (1981) conducted a multigenerational toxicity test with Cr (III) on the marine polychaete, *Neanthes arenaceodentata*. The report states that the polychaete has been shown to be one of the more sensitive benthic macroinvertebrates when tested with chromium. A test solution with a Cr (III) concentration of 50,400 µg/L was prepared, forming a pure Chromium precipitate at the bottom of the test chamber. The study evaluated reproduction of this organism by introducing pairs of male and female *N. arenaceodentata* to the test chambers for a 23 day period to allow birth and development of offspring. The offspring once fully developed were removed and introduced as pairs of male and female *N. arenaceodentata* to test chambers in the same manner as the previous generation. The study found that no biological effects were observed in the polychaetes exposed to Cr (III) and that the Cr (III) precipitate in the long term study did not impact mortality rate, maturation time required for spawning, or the number of offspring per brood. These organisms will not only survive, but reproduce normally, while inhabiting sediment composed of pure Cr (III) precipitate (Watlington *et al.* 2007).

These studies established that Cr (III) is not a source of toxicity to benthic organisms inhabiting the sediment of marine environments. No acute toxicity was observed in marine amphipods when exposed to levels of Cr (III) up to 3000 mg/kg. In addition, marine amphipods and polychaetes did not exhibit a toxicological response when inhabiting pure Cr (III) precipitate for the duration of these tests. These findings are indicative of the inert biological nature of Cr (III) on sediment dwelling organisms. Finally, the data strongly suggests that levels of Cr (III) greater than those found in the Baltimore Harbor sediments are not a source of toxicity to benthic organisms (Watlington *et al.* 2007).

5.1.3 Geochemical Influences on Chromium Speciation and Fate in Estuarine Sediments

The dissertation “Geochemical Influences on Chromium Speciation and Fate in Estuarine Sediments; Importance of Redox Interactions with Manganese Sulfide Minerals” was completed by Amar Wadhawan of the JHU CTFR under the direction of Dr. Bouwer in April 2012. This study investigated chromium speciation and fate in Baltimore Harbor sediments under oxygenation to replicate conditions of sediment resuspension that may occur due to dredging, bioturbation, and flood events. These conditions have the potential to alter biogeochemical conditions (e.g., reducing capacity) in sediments resulting in Cr (III) oxidation and Cr (VI)

FINAL

reoccurrence in sediments that may provide an environment toxic to sediment dwelling organisms (Wadhawan 2012).

Under existing conditions, sediment samples collected from ten stations throughout the Baltimore Harbor were found to be chemically reducing and devoid of oxygen and Cr (VI), as well as contain a mixture of trace metals of which iron (Fe) and manganese (Mn) were most abundant. A map displaying the sediment stations locations is presented in Figure 5.1.3(a). Sediment concentration data for trace metals and iron are presented in Figures 5.1.3(b) and 5.1.3(c), respectively. Sediment concentrations of iron were generally three orders of magnitude greater than all trace metals. Manganese is typically found in two oxidation states; divalent (Mn (II)) and trivalent/tetravalent (Mn(III/IV)) as a (hydr)oxide compound. Mn (III/IV) (hydr)oxides are the only known naturally occurring oxidant for facilitating the conversion of Cr (III) to Cr (VI). Of the two species, Mn (II) is predominantly found in Baltimore Harbor sediments due to the presence of Mn-reducing microbial organisms. Total chromium sediment concentrations from all stations exceeded the effects range low (ERL) criteria of 81 mg/kg and from four stations exceeded the ERM of 370 mg/kg (Wadhawan 2012).

In all sediment samples, AVS levels exceeded the SEM concentration for total metals, indicating a reducing environment, where Cr (III), the relatively non-toxic species at levels typically found within the environment, is the predominant form of chromium found in sediments. Therefore, any toxicity present in the existing sediments is not due to chromium. AVS/SEM concentrations for total metals are presented in Figure 5.1.3(d) (Wadhawan 2012).

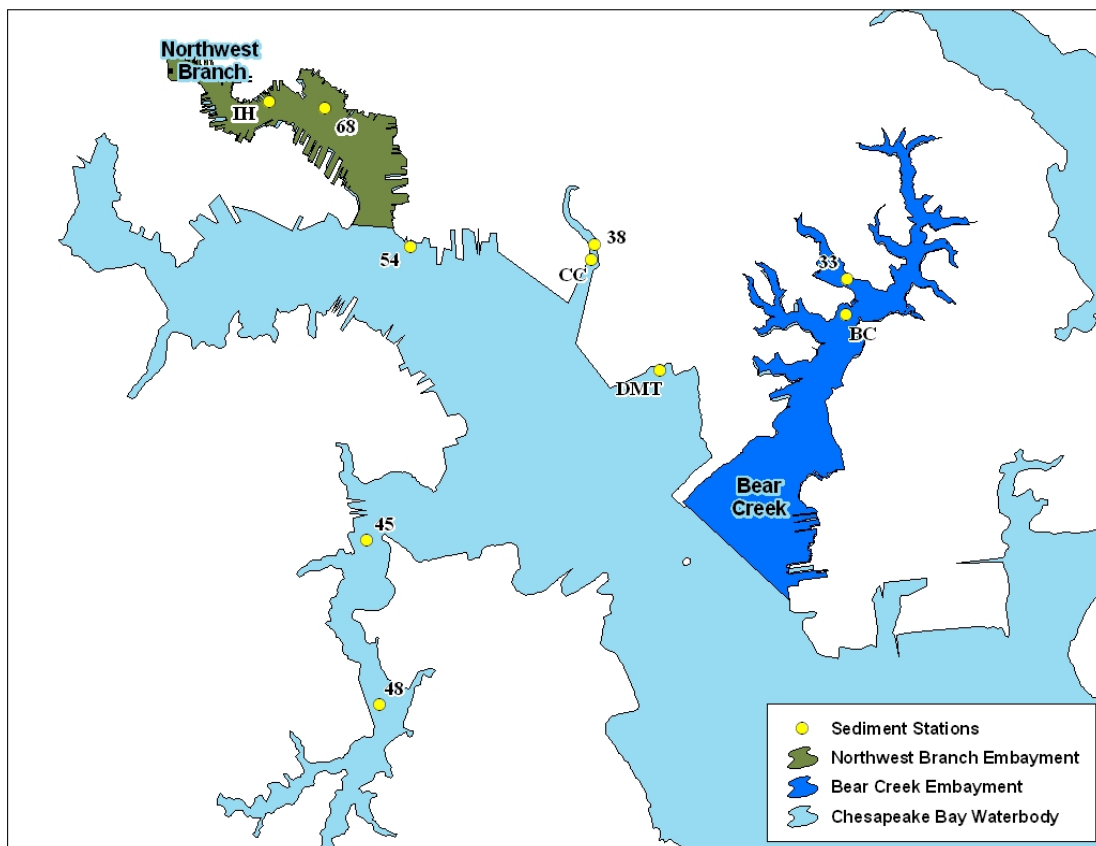
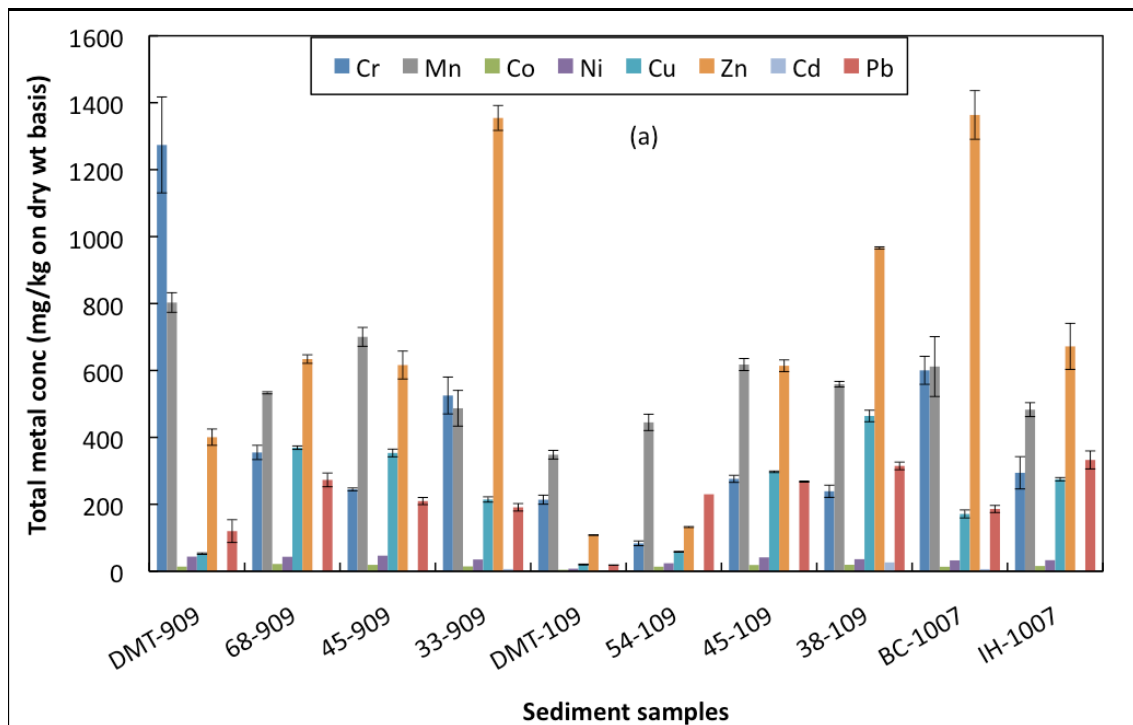


Figure 5.1.3(a): Baltimore Harbor Sediment Stations

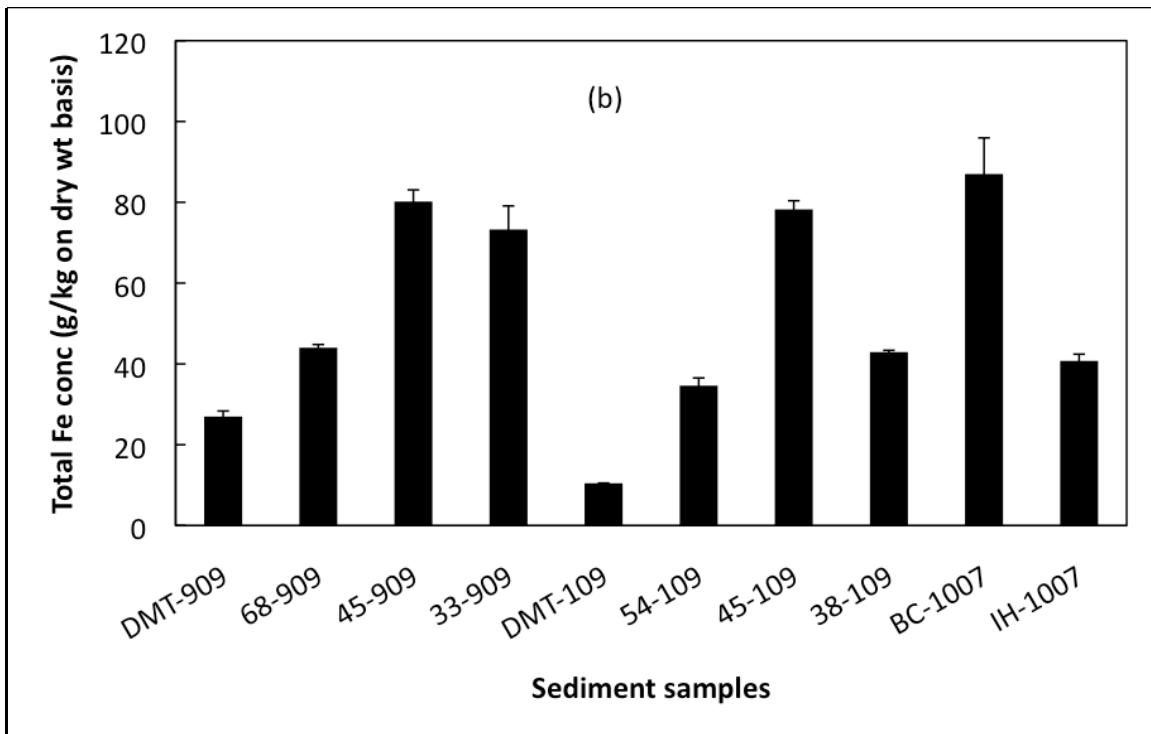
The objective of this study was to determine if Cr (VI) reduction to Cr (III) is the dominant and ongoing process in Baltimore Harbor sediments and whether the presence of oxygen will alter biogeochemical conditions facilitating the oxidation of Cr (III). Suspensions of sediments collected from stations throughout the Baltimore Harbor were employed in batch reaction experiments under anaerobic and aerobic conditions with additions of chromium to evaluate Cr (III) oxidation and Cr (VI) reoccurrence (Wadhawan 2012).

For an evaluation of Cr (III) oxidation, under anaerobic conditions, which is the predominant state of in-situ sediments, additions of Cr (III) to sediment suspensions resulted in no formation of Cr (VI) in multiple batch experiments. Under aerobic conditions, in which the sediment suspension was then oxygenated, Cr (VI) formation occurred in several sediment suspensions. Oxidation of Cr (III) additions ranged between 0.2 and 3 % in all sediment suspensions except for station DMT in which 70 % of available Cr (III) was oxidized. Cr (VI) concentrations over the duration of the batch experiments are presented in Figure 5.1.3(e) (Wadhawan 2012).



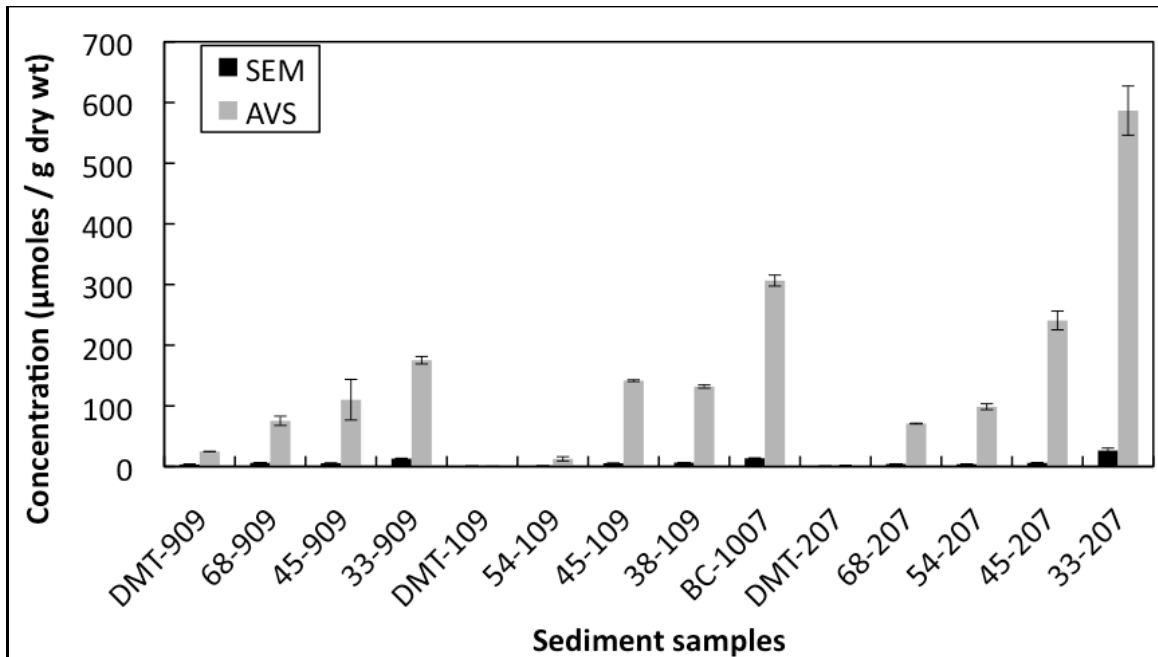
*Bars represent maximum and minimum concentrations

Figure 5.1.3(b): Sediment Concentration Data (Trace Metals)



*Bars represent maximum and minimum concentrations

Figure 5.1.3(c): Sediment Concentration Data (Fe)



*Bars represent maximum and minimum concentrations

Figure 5.1.3(d): AVS/SEM Sediment Concentrations

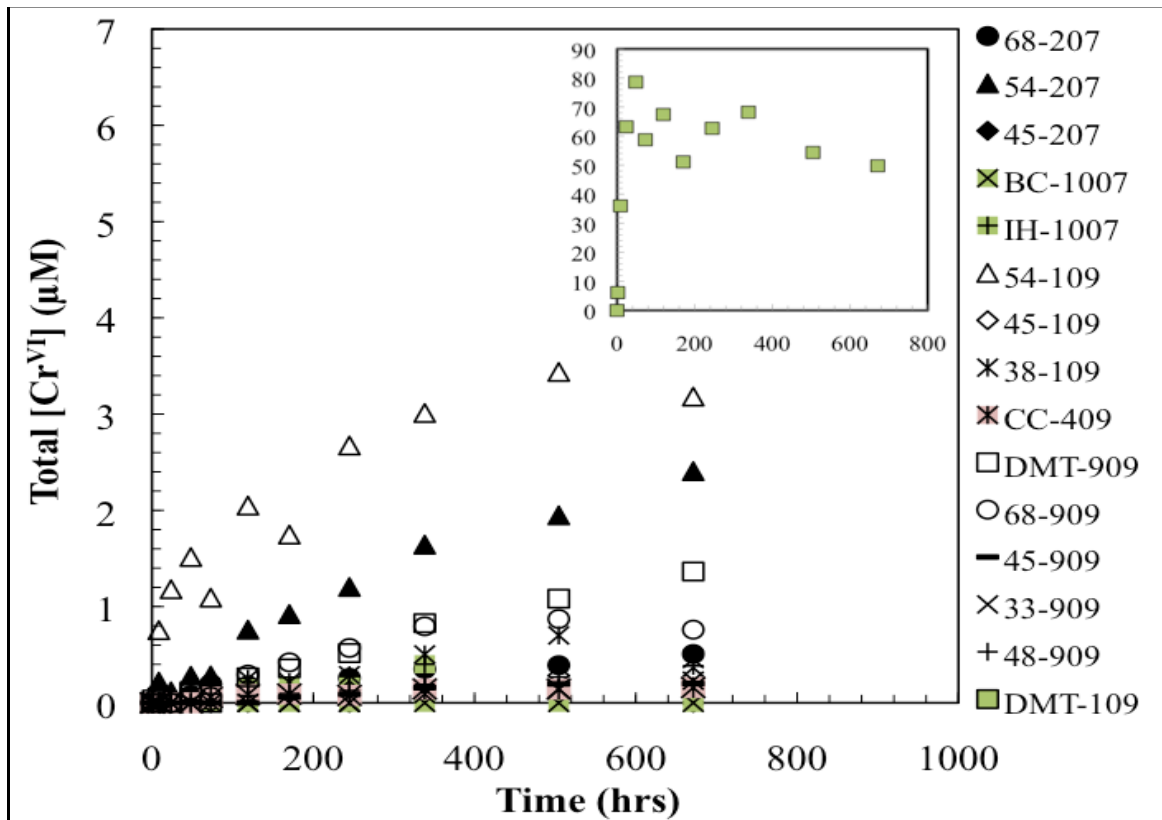


Figure 5.1.3(e): Cr (VI) Concentration vs. Time (Cr (III) suspension under Aerobic conditions)

Batch experiments run under aerobic conditions without chromium additions found oxidation of background Cr (III) to be insignificant as Cr (VI) formation did not occur, indicating that Cr (VI) was only formed from the oxidation of the Cr (III) additions. Formation of Cr (VI) occurred due to the oxygenation of the sediment suspensions which reduced concentrations of AVS and Fe (II), thus lowering the overall reducing capacity and facilitated the formation of Mn (III/IV) (hydr)oxide compounds necessary for oxidation of Cr (III) (Wadhawan 2012).

For an evaluation of Cr (VI) recurrence, sediment suspensions were dosed with Cr (VI) under anaerobic conditions allowing complete reduction of Cr (VI) to Cr (III) followed by aeration of the suspension to evaluate the secondary formation of Cr (VI) in multiple batch experiments. Cr (VI) formation or recurrence occurred in all batch experiments with concentrations ranging between 1 and 15 % of the original Cr (VI) addition. Cr (VI) concentrations over the duration of the batch experiments are presented in Figure 5.1.3(f). Cr (VI) formation reached a maximum concentration well below the available amount of oxidizable Cr (III) and either maintained a plateau or declined. The reaction may have ceased due to limited availability of Mn (III/IV) (hydr)oxides. The effect of “aging” on Cr (III) oxidation was investigated in these experiments by increasing the time interval between aeration of the sediment suspension following complete reduction of Cr (VI) additions to Cr (III). Cr (VI) concentrations over the duration of the experiments following aging (4.5 hours, 1 day and 5 days) are presented in Figure 5.1.3(g). Cr (VI) formation was delayed as aging time was increased and the rate of Cr (VI) formation and Cr

FINAL

(VI) concentrations decreased significantly. Aging of Cr (III) lowers its reactivity upon oxygenation due to aggregation and crystallization over time of Cr (III) precipitate and the adsorption of organic matter and metal ions present in the sediment which limit accessibility for oxidation by Mn (III/IV) (hydr)oxides, thus Cr (III) reactivity will decrease over time as long as reducing conditions remain in sediments (Wadhawan 2012).

While oxidation of Cr (III) to Cr (VI) may occur from oxygenation during sediment resuspension due to dredging, flood events, and bioturbation, the potential for Cr (VI) formation is dependent on the reactivity of existing Cr (III) in the sediments and its long-term persistence is governed by sediment reducing capacity. Cr (III) present in Baltimore Harbor sediments will remain relatively inert as oxidation reactivity is minimized due to prolonged anoxia supporting a sulfide rich environment. Any Cr (VI) formed during periods of resuspension will not persist as the excess reductant capacity in the form of sulfide and Fe (II) will facilitate the complete conversion of Cr (VI) to Cr (III) (Wadhawan 2012). Considering all these factors, it is understandable that no significant Cr (VI) was detected in the 'in-situ' Baltimore Harbor sediments and that this will remain so in the future as these conditions persist (Wadhawan 2012).

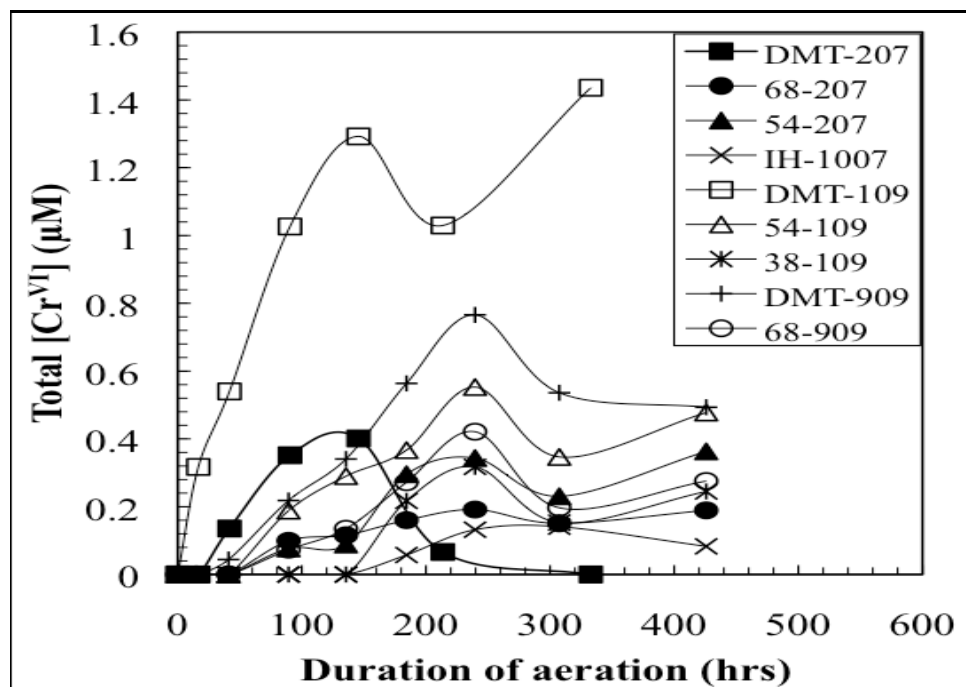


Figure 5.1.3(f): Cr (VI) Concentration vs. Time (Complete Reduction of Cr (VI) suspension to Cr (III) followed by aeration)

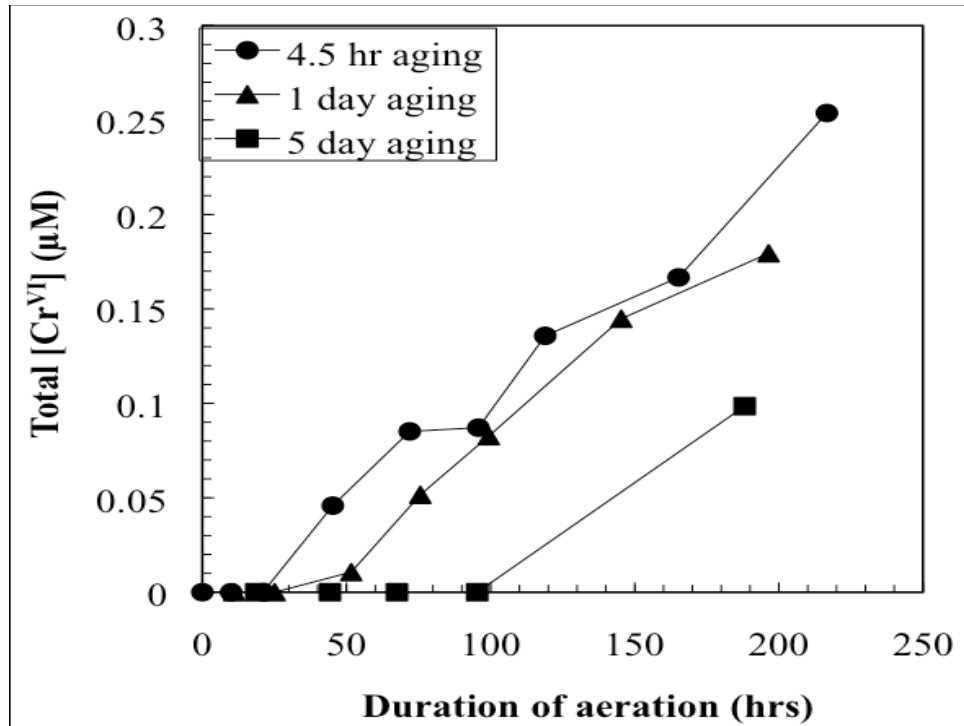


Figure 5.1.3(g): Cr (VI) Concentration vs. Time (Complete Reduction of Cr (VI) suspension to Cr (III) followed by aging (4.5 hr, 1 day, and 5 day) and subsequent aeration)

5.2 Data Evaluation and Screening Level Human Health and Ecological Risk Assessment for Bear Creek Sediments

EPA completed a “Data Evaluation and Screening Level Human Health and Ecological Risk Assessment for Bear Creek Sediment” study in October 2011. Surficial sediment samples were collected at ten stations throughout Bear Creek in 2009 by the Chesapeake Bay Foundation (CBF). This information was provided to EPA and MDE for assessment purposes. The samples were analyzed for select inorganics and PAHs including total chromium and Cr (VI). A map displaying the sediment station locations is presented in Figure 5.2.1. The map also displays historical station locations sampled in 1996 under the “Spatial Mapping of Sedimentary Contaminants in the Baltimore/Patapsco River/Back River System (BSM)” study conducted by Baker *et al.* Information from this historical study was applied in this data evaluation (EPA 2011).

Total chromium sediment concentrations for all samples ranged between 27.7 mg/kg and 705.0 mg/kg with an average of 225.6 mg/kg. No Cr (VI) was detected in any sediment sample with an average method detection level of 1.39 mg/kg. A comparison of total chromium sediment concentrations and the SQG Probable Effects Level (PEL) of 160 mg/kg for Total Cr, developed by MacDonald *et al.* (1996) resulted in four exceedances. No SQG has been established for Cr (VI). Sediment concentration data for total chromium and Cr (VI) and the PEL is presented in Table 5.2.1 (EPA 2011).

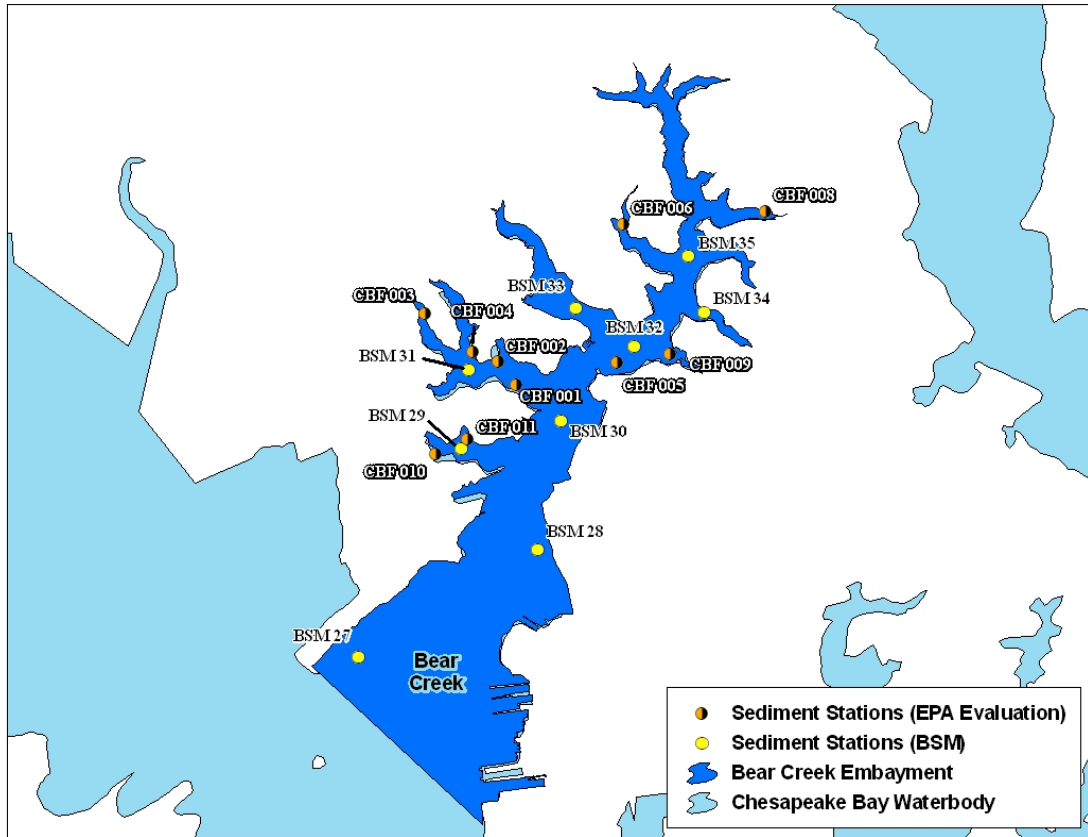


Figure 5.2.1: Bear Creek Sediment Stations (EPA Data Evaluation and BSM)

Table 5.2.1: Total Cr and Cr (VI) Sediment Concentration Data (EPA Data Evaluation)

Station	Total Cr (mg/kg)	Cr (VI) (mg/kg)	PEL (mg/kg)
CBF 001	705.0*	ND (2.8)**	160
CBF 002	27.7	ND (0.8)	160
CBF 003	181.0	ND (1.7)	160
CBF 004	25.6	ND (0.8)	160
CBF 005	30.7	ND (0.6)	160
CBF 006	265.0	ND (2.2)	160
CBF 008	81.9	ND(1.2)	160
CBF 009	175.0	ND (1.0)	160
CBF 010	128.0	ND (1.1)	160
CBF 011	636.0	ND (1.7)	160
Average	225.6	ND	-

*Sediment concentrations which exceed the PEL are presented in bold

**Method detection limit for Cr (VI) is presented in parentheses

FINAL

While four sediment concentrations for total chromium exceeded the PEL, no Cr (VI) was detected in any sediment sample. These findings indicated that reducing conditions persist within the sediment where Cr (III), the relatively non-toxic species at levels typically found within the environment, will be the predominant form of chromium. Also as Cr (VI) was not detected in sediment concentrations, it would not be expected for Cr (VI) to be elevated in pore water. The previous studies summarized in this report establish that Cr (VI) is not present in pore water at levels that exceed criterion supporting the aquatic life designated use. Therefore any toxicity found within the sediments of Bear Creek is not due to the presence of chromium (EPA 2011).

A comparison of current sediment concentrations for total chromium collected under this study and sediments collected from Bear Creek in 1996 under the BSM study found that the average total chromium sediment concentrations has declined by 77%. The average total chromium sediment concentrations for samples collected in 1996 and 2009, were 986.1 mg/kg and 225.6, respectively. The sediment concentration data for all monitoring stations from the BSM study is presented in Table 5.2.2. The locations of the monitoring stations were presented previously in Figure 5.2.1. Sediment concentrations for total chromium in Bear Creek have declined significantly since 1996 and should continue to do so over time as freshly deposited sediments bury historically contaminated sediments (EPA 2011).

Table 5.2.2: 1996 Total Chromium Sediment Concentration Data (BSM)

Station	Total Chromium (mg/kg)
BSM 27	51.9
BSM 28	1831.1
BSM 29	1536.4
BSM 30	1046.7
BSM 31	1141.7
BSM 32	1027.5
BSM 33	719.4
BSM 34	678.5
BSM 35	841.3
Average	986.1

5.3 Ecological Risk Assessment for Dundalk Marine Terminal

An Ecological Risk Assessment (ERA) of Dundalk Marine Terminal (DMT) located within the Baltimore Harbor was completed in September 2009 in compliance with a Consent Decree between the Maryland Port Administration (MPA), MDE, and Honeywell International Inc. DMT is a significant source of chromium to adjacent waters in the Baltimore Harbor as it was constructed over a land mass containing a large amount of chromium ore processing residue (COPR) fill material. The objective of the ERA was to determine whether sources of chromium from DMT pose an unacceptable risk to the ecological health of the system. While DMT is not located within Northwest Branch or Bear Creek, the site is representative of environmental conditions found throughout the Baltimore Harbor and provides supporting evidence that chromium is not a source of toxicity within these sediments. The location of DMT within the Baltimore Harbor is displayed in Figure 5.3.1 (CH2M HILL 2009).

As stated previously within the document, reducing conditions within sediment facilitate the conversion of Cr (VI) to Cr (III) in anoxic estuarine environments. Sediments with elevated levels of sulfides and Fe (II) provide a reducing environment where Cr (III) is the predominant species of chromium. Under this ERA, the toxicity of Cr was evaluated based on a comparison of Cr (VI) and total chromium concentrations in pore water and surface water to USEPA Nationally Recommended Water Quality Criteria (NRWQC), Maryland's adopted numeric criterion (CH2M HILL 2009).

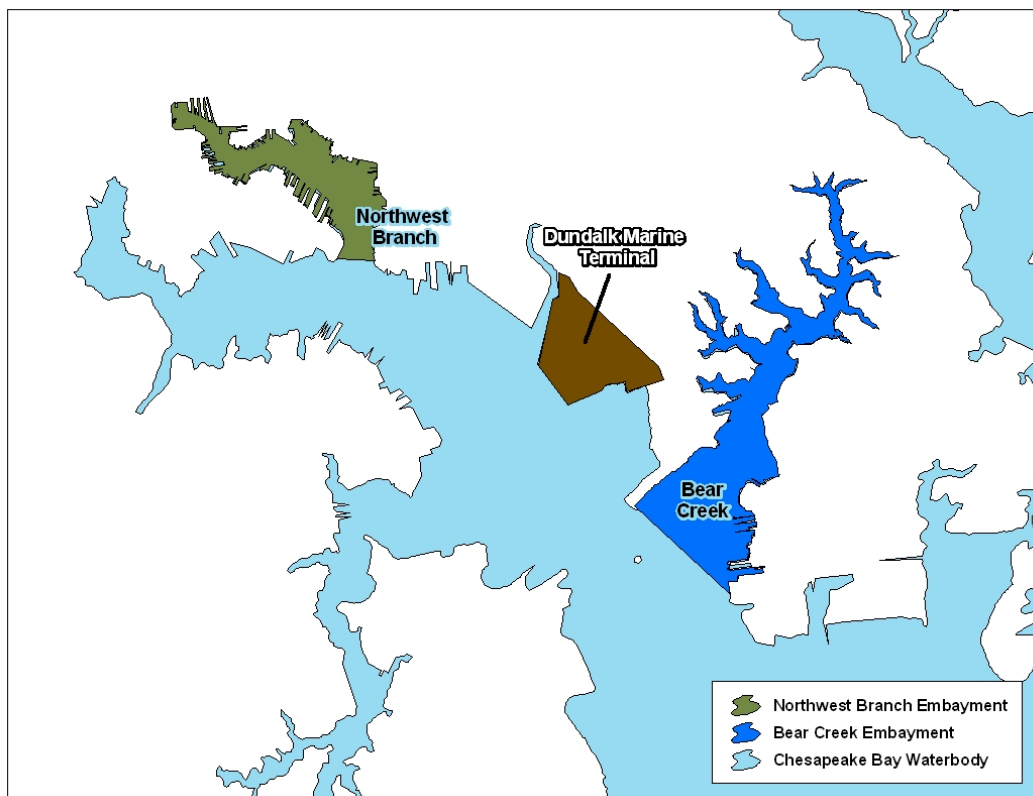


Figure 5.3.1: Location of Dundalk Marine Terminal

FINAL

The field survey was conducted over four quarterly sampling events in May, August, and December 2007 and February 2008. A map displaying the monitoring station locations is presented in Figure 5.3.2. Cr (VI) and total chromium were analyzed in all pore water and surface water samples. Only total chromium was analyzed in sediment samples, as Cr (VI), if present, will predominantly partition to pore water, as it is highly soluble. Therefore, pore water analysis is the most appropriate method for quantifying Cr (VI) associated with sediments (CH2M HILL 2009).



Figure 5.3.2: Dundalk Marine Terminal Water Quality Stations

Total chromium concentrations in pore water ranged from a detection level of 2.3 $\mu\text{g/L}$ to 16.2 $\mu\text{g/L}$. Cr (VI) was not detected in pore water in any sample taken from DMT. The detection level was 5 $\mu\text{g/L}$. Total chromium and Cr (VI) concentrations in pore water were well below the saltwater aquatic life chronic criterion of 50 $\mu\text{g/L}$. Total chromium and Cr (VI) concentrations in surface water ranged from a detection level of 2.3 $\mu\text{g/L}$ to 37.6 $\mu\text{g/L}$ and a detection level of 5 $\mu\text{g/L}$ to 34.9 $\mu\text{g/L}$, respectively. Cr (VI) was not detected in 97 percent of surface water samples analyzed, and for those samples that were detected; concentrations were well below the saltwater aquatic life chronic criterion. Surface water and pore water concentrations of total chromium and Cr (VI) are displayed in Table A-1 and Table A-2 of Appendix A, respectively (CH2M HILL 2009).

FINAL

Total chromium concentrations in sediments ranged from 33 to 2,360 mg/kg with a mean concentration of 394 mg/kg. Sediment concentrations of total chromium are displayed in Table A-3 of Appendix A. While sediment concentrations of total chromium exceeded the ERM of 370 mg/kg, this is not an indication of toxicity if the predominant form of chromium in sediment is Cr (III), the relatively non-toxic species at levels typically found within the environment. Geochemical parameters were analyzed to determine whether conditions within the sediment provide a reducing environment supporting the conversion of Cr (VI) to Cr (III). These include Fe (II), divalent manganese (Mn (II)), TOC, sulfide, and AVS/SEM. Concentrations of geochemical parameters and AVS/SEM are presented in Table A-3 and A-4 of Appendix A, respectively. Levels of these geochemical parameters establish that conditions are favorable for the presence of Cr (III) over Cr (VI). Molar concentrations of AVS and Fe were greater than the SEM molar concentrations for total metals in all analyses giving further indication that Cr (III) is the predominant species. Cr (III) in sediments is unlikely to oxidize to Cr (VI) in the future as geochemical conditions for this process are not supported (CH2M HILL 2009).

As all measured concentrations of total chromium and Cr (VI) in pore water and surface water were below criteria, and reducing conditions within the sediment support the conversion of Cr (VI) to Cr (III), chromium does not pose a risk to aquatic life and is therefore not a source of toxicity in the water column or sediment (CH2M HILL 2009).

FINAL

6.0 CONCLUSION

Based on the evaluation presented in this report, it has been determined that chromium is not a source of toxicity to aquatic life in the water column or sediments of the Northwest Branch and Bear Creek tidal segments. Therefore, the protection of the aquatic life designated use is not impaired by chromium.

MDE originally completed a WQA in 2004 in order to remove the chromium impairment listings in sediments for the Northwest Branch and Bear Creek portions of the Baltimore Harbor from Maryland's Integrated Report. The WQA established that the sediments are composed primarily of Cr (III), the relatively non-toxic species, at levels typically found within the environment. This indicates that any existing toxicity within the sediments is not due to the presence of chromium. While the listings are for sediment only, chromium contamination within the sediment has the potential to transport into the water column through resuspension and diffusion across the sediment-water interface. An analysis of chromium in the water column found that concentrations of Cr (III) and Cr (VI) were all well below the criterion. Therefore the water column and sediments are not impaired for chromium and the protection of aquatic life designated use is supported within the water column and sediments.

Following review of the chromium WQA, EPA stated that they supported the findings of the original study but chose to defer a delisting decision contingent upon the results of a TIE study underway at the time which could potentially identify a chemical contaminant responsible for impairing the benthic community in the Baltimore Harbor. The results of the TIE study were inconclusive regarding the toxicity of metals in Baltimore Harbor sediments; therefore, EPA did not approve the delisting decision supported by the original chromium WQA.

In order to assist MDE in addressing the chromium impairment listings, JHU CTFR conducted several studies investigating the relationship between toxicity and the exposure of chromium to benthic organisms, sediment ingestion as a pathway of toxicity, and the stability of Cr (III) under oxygenation in the sediments of Baltimore Harbor.

The sediment toxicity study established that chromium is not responsible for observed toxicity in Baltimore Harbor sediments at environmentally relevant levels. The findings of the sediment ingestion study demonstrated that Cr (III) is biologically unavailable to sediment dwelling organisms and levels of Cr (III) much greater than those found in Baltimore Harbor sediments are not toxic to benthic life. The sediment oxygenation study demonstrated that there is very little potential for oxidation of Cr (III) to occur in Baltimore Harbor sediments and if Cr (VI) does form it will not persist due to excess reducing capacity within the sediments

In addition to the studies conducted by JHU CTFR, an ERA of DMT and EPA Data Evaluation of Bear Creek sediments provided additional support that chromium is not a source of toxicity within Baltimore Harbor sediments. Sediment concentrations of total chromium in Bear Creek have also reduced by 77% between 1996 and 2009 indicating that sources of chromium within the Baltimore Harbor watershed are declining.

Based on the cumulative findings of all studies presented in this document, including the original WQA submitted in 2004, chromium is not a source of toxicity in the water column and

FINAL

sediments of Northwest Branch and Bear Creek. Therefore, the protection of the aquatic life designated use is not impaired by chromium.

Barring the receipt of contradictory data, this report will be used to support the revision of the 2012 Integrated Report Chromium listings for Northwest Branch and Bear Creek from Category 5 (“waterbody is impaired, does not attain the water quality standard, and a TMDL is required”) to Category 2 (“waterbody is meeting some [in this case chromium related] water quality standards, but with insufficient data to assess all impairment”) when MDE proposes the revision of Maryland’s Integrated Report. Although the tidal waters of Northwest Branch and Bear Creek do not display signs of chromium impairment to aquatic life in the water column or sediment, the State reserves the right to require future controls if evidence suggests that chromium from the watershed is contributing to downstream water quality problems.

7.0 REFERENCES

- Baker, J., Mason, R., Cornwell, J., and Ashley, J. 1997. *Spatial Mapping of Sedimentary Contaminants in the Baltimore Harbor/Patapsco River/Back River System*. Solomon's, MD: University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory.
- Berry, W.J., Boothman, W.S., Serbst, J.R., and Edwards, P.A. 2002. *Effects of Chromium in Sediment: Toxicity Tests with Saltwater Field Sediments*. Narragansett, RI: U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division.
- CFR (Code of Federal Regulations). 2012. *40 CFR 130.7*.
<http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=%2Findex.tpl> (Accessed August, 2012).
- CH2M HILL and ENVIRON. 2009. *Ecological Risk Assessment: Dundalk Marine Terminal*. Baltimore, MD.
- COMAR (Code of Maryland Regulations). 2012a. *26.08.02.07(A)*.
<http://www.dsd.state.md.us/comar/getfile.aspx?file=26.08.02.07.htm> (Accessed August, 2012).
- _____. 2012b. *26.08.02.08(K)(2)(b)*.
<http://www.dsd.state.md.us/comar/getfile.aspx?file=26.08.02.08.htm> (Accessed August, 2012).
- _____. 2012c. *26.08.02.02(B)(2)*.
<http://www.dsd.state.md.us/comar/getfile.aspx?file=26.08.02.02.htm>. (Accessed August, 2012)
- _____. 2012d. *26.08.02.04*.
<http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.04.htm> (Accessed August, 2012).
- DNR (Maryland Department of Natural Resources). 2012. *Physiography of Maryland*.
<http://www.dnr.state.md.us/forests/healthreport/mdmap.html> (Accessed May, 2012).
- Honeywell International Inc. 2007. *Baltimore Chromium Residue Cleanup – History*. Also Available at:
<http://baltimorechromiumresiduecleanup.com/history/> (Accessed August, 2012)
- Klousterhaus, S., Baker, J., Zeigler, G., and Fisher, D. 2007. *Toxicity Identification and Evaluation and Long-Term Contaminant Trends in the Baltimore Harbor*. Solomons, MD: University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory.

FINAL

MacDonald, D.R., Carr, R.S., Calder, F.D., Long, E.R., and Ingersoll, C.G. 1996. *Development and Evaluation of Sediment Quality Guidelines for Florida Coastal Waters*. *Ecotoxicology*, 5:253-278.

MDE (Maryland Department of the Environment). 2004. *Water Quality Analyses of Chromium in the Inner Harbor/Northwest Branch and Bear Creek Portions of Baltimore Harbor in Baltimore City and Baltimore County, Maryland*. Baltimore, MD: Maryland Department of the Environment. Also Available at:
http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Documents/www.mde.state.md.us/assets/document/Harbor_Cr_WQA_FA.pdf

_____. 2011. *Maryland Tier II Dataset*. Baltimore, MD: Maryland Department of the Environment.

_____. 2012a. *Methodology for Determining Impaired Waters by Chemical Contaminants for Maryland's Integrated Report of Surface Water Quality*. Baltimore, MD: Maryland Department of the Environment. Also Available at:
http://www.mde.state.md.us/programs/Water/TMDL/Integrated303dReports/Documents/Assessment_Methodologies/Toxics_AM_2012.pdf.

_____. 2012b. *The 2012 Integrated Report of Surface Water Quality in Maryland*. Baltimore, MD: Maryland Department of the Environment. Also Available at:
http://www.mde.maryland.gov/programs/water/tmdl/integrated303dreports/pages/2012_ir.aspx (Accessed July, 2013).

MGS (Maryland Geological Survey). 2012. *A Brief Description of the Geology of Maryland*. <http://www.mgs.md.gov/esic/brochures/mdgeology.html> (Accessed May, 2012).

Oshida, P.S., Word, L.S., and Mearns, A.J. 1981. *Effects of Hexavalent and Trivalent Chromium on the Reproduction of *Neanthes arenaceodetata* (Polychaeta)*. *Mar. Env. Res.* 5:41-49

US Census Bureau. 2010. *2010 Census*. Washington, DC: US Census Bureau.

USDA (United States Department of Agriculture). 2013. U.S. General Soil Map (STATSGO2). Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service. Also available online at <http://soildatamart.nrcs.usda.gov>. Accessed (July, 2013).

US EPA (U.S. Environmental Protection Agency). 2005. *U.S. EPA Decision Rationale for "Water Quality Analyses of Chromium in the Inner Harbor/Northwest Branch and Bear Creek Portions of Baltimore Harbor in Baltimore City and Baltimore County, Maryland."*. Philadelphia, PA: US Environmental Protection Agency, Region III. Also Available at:
<http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Documents/www.mde.state.md.us/assets/document/chromium-inner%20harbor.pdf>

FINAL

- _____. 2011. *Data Evaluation and Screening Level Human Health and Ecological Risk Assessment for Bear Creek Sediment*. Philadelphia, PA: US Environmental Protection Agency, Land and Chemicals Division, Region III.
- USGS (United States Geological Survey). 2011. *2006 National Land Cover Dataset Chesapeake Bay Area, Modified Version 1.0*. Annapolis, MD: United States Geological Survey, Chesapeake Bay Program Office.
- Wadhawan, A. 2012. *Geochemical Influences on Chromium Speciation and Fate in Estuarine Sediments; Importance of Redox Interactions with Manganese Sulfide Minerals*. Baltimore, MD: Johns Hopkins University.
- Watlington, K., Graham, A., and Bouwer, E. 2007. *The Sediment Ingestion Pathway as a Source of Toxicity in the Baltimore Harbor*. Baltimore, MD: Johns Hopkins University, Department of Geography and Environmental Engineering.
- Watlington, K., Graham, A., Bouwer, E., Goodfellow, W., and Baummer, J. 2008. *Bioassay Testing of Baltimore Harbor Sediments Spiked with Cr (VI)*. Baltimore, MD: Johns Hopkins University, Department of Geography and Environmental Engineering.

Appendix A: Tables for Ecological Risk Assessment for Dundalk Marine Terminal

Table A-1: Total Cr and Cr (VI) Surface Water Concentration Data (ERA DMT)

Station	Quarter	Date	Surface water Concentration (µg/L)		Station	Quarter	Date	Surface water Concentration (µg/L)	
			Total Cr	Cr (VI)				Total Cr	Cr (VI)
A1	Q1	May-07	2.3	5	E2	Q4-Dup	Feb-08	2.3	5
A1	Q2	Aug-07	2.3	5	E2	Q4	Feb-08	2.7	5
A1	Q3	Dec-07	5.6	5	E2	Q4	Feb-08	2.3	5
A1	Q4	Feb-08	2.3	5	E3	Q1	May-07	2.3	5
A1	Q4	Feb-08	2.3	5	E3	Q1	May-07	2.3	5
A2	Q1	May-07	2.3	5	E3	Q1	May-07	2.3	5
A2	Q1-Dup	May-07	2.5	5	E3	Q2	Aug-07	2.3	5
A2	Q2	Aug-07	2.3	5	E3	Q2	Aug-07	3.1	5
A2	Q2	Aug-07	2.3	5	E3	Q2	Aug-07	2.3	5
A2	Q3	Dec-07	2.3	5	E4	Q1	May-07	3.3	5
A2	Q4	Feb-08	2.4	5	E4	Q1	May-07	3.2	5
A3	Q1	May-07	2.3	5	E4	Q1	May-07	2.3	5
A3	Q2	Aug-07	2.3	5	E4	Q2	Aug-07	2.3	5
A3	Q3	Dec-07	2.3	5	E4	Q2	Aug-07	2.4	5
A3	Q4	Feb-08	2.3	5	E4	Q2	Aug-07	2.3	5
A3	Q4-Dup	Feb-08	2.3	5	E4	Q3	Dec-07	2.3	5
A4	Q1	May-07	2.3	5	E4	Q3	Dec-07	3.6	5
A4	Q2	Aug-07	2.3	5	E4	Q3	Dec-07	2.3	5
A4	Q2	Aug-07	2.3	5	E4	Q4	Feb-08	2.3	5
A4	Q3	Dec-07	2.3	5	E4	Q4	Feb-08	2.3	5
A4	Q4	Feb-08	2.3	5	E4	Q4	Feb-08	2.8	5
B1	Q1	May-07	2.3	5	F1	Q1	May-07	2.3	5
B1	Q2	Aug-07	3.8	5	F1	Q1	May-07	2.3	5
B1	Q2	Aug-07	5.2	5	F1	Q1	May-07	2.3	5
B1	Q3	Dec-07	2.3	5	F1	Q2	Aug-07	2.3	5
B1	Q3	Dec-07	-	-	F1	Q2	Aug-07	2.3	5
B1	Q3-Dup	Dec-07	-	-	F1	Q2	Aug-07	2.3	5
B1	Q3	Dec-07	2.3	5	F1	Q2-Dup	Aug-07	2.3	5
B1	Q4	Feb-08	2.3	5	F2	Q1	May-07	2.3	5
B1	Q4	Feb-08	4.2	5	F2	Q1	May-07	2.3	5
B2	Q1	May-07	2.3	5	F2	Q1	May-07	2.3	5
B2	Q1	May-07	2.3	5	F2	Q2	Aug-07	2.3	5

FINAL

Station	Quarter	Date	Surface water Concentration (µg/L)		Station	Quarter	Date	Surface water Concentration (µg/L)	
			Total Cr	Cr (VI)				Total Cr	Cr (VI)
B2	Q2	Aug-07	5.7	5	F2	Q2	Aug-07	2.3	5
B2	Q2	Aug-07	7.3	5	F2	Q2	Aug-07	2.3	5
B2	Q3	Dec-07	2.3	5	F2	Q3	Dec-07	2.3	5
B2	Q3	Dec-07	-	-	F2	Q3	Dec-07	2.3	5
B2	Q3	Dec-07	3.3	5	F2	Q3	Dec-07	2.3	5
B2	Q4	Feb-08	2.3	5	F2	Q4	Feb-08	2.3	5
B2	Q4	Feb-08	2.3	5	F2	Q4	Feb-08	2.3	5
B3	Q1	May-07	2.3	5	F2	Q4	Feb-08	2.3	5
B3	Q1	May-07	2.3	5	F3	Q1	May-07	2.3	5
B3	Q2	Aug-07	6.1	6	F3	Q1	May-07	2.3	5
B3	Q2	Aug-07	6	5	F3	Q1	May-07	2.3	5
B3	Q3	Dec-07	2.3	5	F3	Q2	Aug-07	2.3	5
B3	Q3	Dec-07	2.3	5	F3	Q2	Aug-07	2.3	5
B3	Q3	Dec-07	2.3	5	F3	Q2	Aug-07	2.3	5
B3	Q4	Feb-08	2.3	5	F4	Q1	May-07	2.3	5
B3	Q4	Feb-08	2.3	5	F4	Q1	May-07	2.3	5
B4	Q1	May-07	2.3	5	F4	Q1-Dup	May-07	2.3	5
B4	Q1	May-07	2.3	5	F4	Q1	May-07	2.3	5
B4	Q1-Dup	May-07	2.3	5	F4	Q2	Aug-07	2.3	5
B4	Q2	Aug-07	29.7	34.9	F4	Q2	Aug-07	2.3	5
B4	Q2	Aug-07	26	32.9	F4	Q2	Aug-07	2.3	5
B4	Q2-Dup	Aug-07	30.8	32	F4	Q3	Dec-07	2.3	5
B4	Q3	Dec-07	2.3	5	F4	Q3	Dec-07	2.3	5
B4	Q3	Dec-07	3.1	5	F4	Q3	Dec-07	2.3	5
B4	Q3	Dec-07	2.3	5	F4	Q4	Feb-08	2.3	5
B4	Q4	Feb-08	2.3	5	F4	Q4	Feb-08	2.3	5
B4	Q4	Feb-08	2.3	5	F4	Q4	Feb-08	2.3	5
B4	Q4	Feb-08	2.3	5	G1	Q1	May-07	2.3	5
B5	Q4	Feb-08	2.3	5	G1	Q1	May-07	2.3	5
B5	Q4	Feb-08	2.3	5	G1	Q1	May-07	2.3	5
C1	Q1	May-07	2.3	5	G1	Q2	Aug-07	2.3	5
C1	Q2	Aug-07	7.6	5	G1	Q2	Aug-07	2.3	5
C1	Q2	Aug-07	8.4	5	G1	Q2	Aug-07	2.3	5
C1	Q2-Dup	Aug-07	7.9	5	G2	Q1	May-07	2.3	5
C1	Q3	Dec-07	6.6	7	G2	Q1	May-07	2.3	5
C1	Q3-Dup	Dec-07	9.4	6.9	G2	Q1	May-07	2.3	5
C1	Q4	Feb-08	2.3	5	G2	Q2	Aug-07	2.3	5

FINAL

Station	Quarter	Date	Surface water Concentration (µg/L)		Station	Quarter	Date	Surface water Concentration (µg/L)	
			Total Cr	Cr (VI)				Total Cr	Cr (VI)
C2	Q1	May-07	2.3	5	G2	Q2	Aug-07	2.3	5
C2	Q1	May-07	2.3	5	G2	Q2	Aug-07	2.3	5
C2	Q2	Aug-07	4.2	5	G2	Q3	Dec-07	2.3	5
C2	Q2	Aug-07	5.6	5	G2	Q3	Dec-07	2.3	5
C2	Q3	Dec-07	2.3	5	G2	Q3	Dec-07	2.3	5
C2	Q3	Dec-07	-	-	G2	Q4	Feb-08	2.3	5
C2	Q3	Dec-07	2.3	5	G2	Q4	Feb-08	2.3	5
C2	Q4	Feb-08	2.3	5	G2	Q4	Feb-08	2.6	5
C3	Q1	May-07	2.3	5	G3	Q1	May-07	2.3	5
C3	Q1	May-07	2.3	5	G3	Q1	May-07	2.3	5
C3	Q2	Aug-07	5.6	5	G3	Q1	May-07	2.3	5
C3	Q2	Aug-07	4.5	5	G3	Q2	Aug-07	2.3	5
C3	Q2	Aug-07	5.8	5	G3	Q2	Aug-07	2.3	5
C3	Q3	Dec-07	2.9	5	G3	Q2	Aug-07	2.3	5
C3	Q3	Dec-07	2.3	5	G4	Q1	May-07	2.3	5
C3	Q4	Feb-08	2.3	5	G4	Q1	May-07	2.3	5
C3	Q4	Feb-08	2.3	5	G4	Q1	May-07	2.3	5
C4	Q1	May-07	2.3	5	G4	Q2	Aug-07	2.3	5
C4	Q1	May-07	2.3	5	G4	Q2	Aug-07	2.3	5
C4	Q2	Aug-07	5.5	5	G4	Q2	Aug-07	2.3	5
C4	Q2	Aug-07	6.2	5	G4	Q3	Dec-07	2.3	5
C4	Q2	Aug-07	2.6	5	G4	Q3	Dec-07	2.3	5
C4	Q3	Dec-07	2.3	5	G4	Q3	Dec-07	2.3	5
C4	Q3-Dup	Dec-07	2.3	5	G4	Q4	Feb-08	2.3	5
C4	Q3	Dec-07	2.3	5	G4	Q4	Feb-08	2.3	5
C4	Q4	Feb-08	2.3	5	G4	Q4	Feb-08	2.3	5
C4	Q4	Feb-08	2.3	5	H1	Q1	May-07	2.3	5
D1	Q1	May-07	2.3	5	H1	Q1	May-07	2.3	5
D1	Q1	May-07	2.3	5	H1	Q1	May-07	2.3	5
D1	Q1	May-07	2.3	5	H1	Q2	Aug-07	2.3	5
D1	Q2	Aug-07	2.3	5	H1	Q2	Aug-07	2.3	5
D1	Q2	Aug-07	2.3	5	H1	Q2	Aug-07	2.3	5
D1	Q2	Aug-07	2.3	5	H1	Q3	Dec-07	3.6	5
D1	Q3	Dec-07	6.5	5	H1	Q3	Dec-07	2.7	5
D1	Q3	Dec-07	4.8	5	H1	Q3-Dup	Dec-07	2.6	5
D1	Q3	Dec-07	2.5	5	H1	Q3	Dec-07	2.3	5
D1	Q4	Feb-08	17.3	10.5	H1	Q4	Feb-08	2.3	5

FINAL

Station	Quarter	Date	Surface water Concentration (µg/L)		Station	Quarter	Date	Surface water Concentration (µg/L)	
			Total Cr	Cr (VI)				Total Cr	Cr (VI)
D1	Q4	Feb-08	2.3	5	H1	Q4	Feb-08	2.3	5
D1	Q4	Feb-08	2.7	5	H1	Q4	Feb-08	2.3	5
D2	Q1	May-07	2.3	5	H2	Q1	May-07	2.3	5
D2	Q1	May-07	2.3	5	H2	Q1	May-07	2.3	5
D2	Q1	May-07	2.3	5	H2	Q1	May-07	2.3	5
D2	Q2	Aug-07	2.3	5	H2	Q2	Aug-07	2.3	5
D2	Q2	Aug-07	2.3	5	H2	Q2	Aug-07	2.3	5
D2	Q2	Aug-07	2.3	5	H2	Q2	Aug-07	2.3	5
D2	Q3	Dec-07	2.3	5	H3	Q1	May-07	2.3	5
D2	Q3	Dec-07	2.3	5	H3	Q1	May-07	2.3	5
D2	Q3	Dec-07	2.5	5	H3	Q1	May-07	2.3	5
D2	Q4	Feb-08	2.8	5	H3	Q2	Aug-07	2.3	5
D2	Q4	Feb-08	2.3	5	H3	Q2	Aug-07	2.3	5
D2	Q4	Feb-08	2.3	5	H3	Q2	Aug-07	2.3	5
D3	Q1	May-07	2.3	5	H4	Q1	May-07	2.3	5
D3	Q1	May-07	2.3	5	H4	Q1	May-07	2.3	5
D3	Q1	May-07	2.3	5	H4	Q1	May-07	2.3	5
D3	Q2	Aug-07	2.3	5	H4	Q2	Aug-07	2.3	5
D3	Q2	Aug-07	3.2	5	H4	Q2	Aug-07	2.3	5
D3	Q2	Aug-07	2.3	5	H4	Q2	Aug-07	2.3	5
D3	Q3	Dec-07	2.3	5	H4	Q3	Dec-07	2.3	5
D3	Q3	Dec-07	2.3	5	H4	Q3	Dec-07	2.3	5
D3	Q3	Dec-07	2.3	5	H4	Q3	Dec-07	2.3	5
D3	Q4	Feb-08	9.4	6.3	H4	Q4	Feb-08	2.3	5
D3	Q4-Dup	Feb-08	8.9	6.7	H4	Q4	Feb-08	2.3	5
D3	Q4	Feb-08	2.3	5	H4	Q4	Feb-08	2.3	5
D3	Q4	Feb-08	2.3	5	I1	Q1	May-07	2.3	5
D4	Q1	May-07	2.3	5	I1	Q2	Aug-07	2.3	5
D4	Q1	May-07	2.3	5	I1	Q2	Aug-07	2.3	5
D4	Q1-Dup	May-07	2.3	5	I1	Q3	Dec-07	2.3	5
D4	Q1	May-07	2.3	5	I1	Q4	Feb-08	2.3	5
D4	Q2	Aug-07	2.3	5	I1	Q4-Dup	Feb-08	2.3	5
D4	Q2	Aug-07	2.3	5	I2	Q1	May-07	2.3	5
D4	Q2	Aug-07	2.3	5	I2	Q1	May-07	2.3	5
D4	Q3	Dec-07	2.7	5	I2	Q2	Aug-07	2.3	5
D4	Q3	Dec-07	4.5	5	I2	Q2	Aug-07	2.3	5
D4	Q3-Dup	Dec-07	2.9	5	I2	Q2	Aug-07	2.3	5

FINAL

Station	Quarter	Date	Surface water Concentration (µg/L)		Station	Quarter	Date	Surface water Concentration (µg/L)	
			Total Cr	Cr (VI)				Total Cr	Cr (VI)
D4	Q4	Feb-08	2.3	5	I2	Q3	Dec-07	2.9	5
D4	Q4	Feb-08	2.3	5	I2	Q3	Dec-07	2.3	5
D4	Q4	Feb-08	2.3	5	I2	Q4	Feb-08	2.3	5
E1	Q1	May-07	2.3	5	I2	Q4	Feb-08	2.3	5
E1	Q1	May-07	2.3	5	I3	Q1	May-07	2.3	5
E1	Q1	May-07	2.3	5	I3	Q1	May-07	2.3	5
E1	Q1-Dup	May-07	2.3	5	I3	Q1	May-07	2.3	5
E1	Q2	Aug-07	2.3	5	I3	Q2	Aug-07	2.3	5
E1	Q2	Aug-07	21.3	25.7	I3	Q2	Aug-07	2.3	5
E1	Q2	Aug-07	2.3	5	I3	Q2	Aug-07	2.3	5
E1	Q3	Dec-07	37.6	30.4	I3	Q3	Dec-07	2.3	5
E1	Q3	Dec-07	5.5	5	I3	Q3	Dec-07	2.3	5
E1	Q3	Dec-07	2.7	5	I3	Q4	Feb-08	2.3	5
E1	Q4	Feb-08	6.1	8.1	I3	Q4	Feb-08	2.3	5
E1	Q4	Feb-08	2.4	5	I4	Q1	May-07	2.3	5
E1	Q4	Feb-08	2.3	5	I4	Q1	May-07	2.3	5
E2	Q1	May-07	2.3	5	I4	Q2	Aug-07	2.3	5
E2	Q1	May-07	2.3	5	I4	Q2	Aug-07	2.3	5
E2	Q1	May-07	2.3	5	I4	Q2	Aug-07	2.3	5
E2	Q2	Aug-07	2.3	5	I4	Q3	Dec-07	2.3	5
E2	Q2	Aug-07	2.3	5	I4	Q3	Dec-07	2.3	5
E2	Q2	Aug-07	2.3	5	I4	Q4	Feb-08	2.3	5
E2	Q3	Dec-07	10.2	11	I4	Q4	Feb-08	2.3	5
E2	Q3	Dec-07	3	5	J1	Q4	Feb-08	2.3	5
E2	Q3	Dec-07	2.3	5	J2	Q4	Feb-08	2.3	5
E2	Q4	Feb-08	2.3	5	J3	Q4	Feb-08	2.3	5
					J4	Q4	Feb-08	2.3	5

FINAL

Table A-2: Total Cr and Cr (VI) Pore Water Concentration Data (ERA DMT)

Station	Quarter	Date	Pore water Concentration (µg/L)		Station	Quarter	Date	Pore water Concentration (µg/L)	
			Total Cr	Cr (VI)				Total Cr	Cr (VI)
A1	Q1	May-07	2.3	5	E1	Q2	Aug-07	6.5	5
A1	Q2	Aug-07	2.3	5	E1	Q3	Dec-07	4	5
A1	Q3	Dec-07	2.3	5	E1	Q4	Feb-08	2.3	5
A1	Q4	Feb-08	2.3	5	E2	Q1	May-07	2.3	5
A2	Q1	May-07	2.3	5	E2	Q2	Aug-07	12.2	5
A2	Q2	Aug-07	-	-	E2	Q3	Dec-07	8.1	5
A2	Q3	Dec-07	4.3	5	E2	Q4	Feb-08	5.7	5
A2	Q4	Feb-08	2.3	5	E3	Q1	May-07	3.2	5
A3	Q1	May-07	2.3	5	E3	Q2	Aug-07	13.5	5
A3	Q2	Aug-07	-	-	E4	Q1	May-07	2.3	5
A3	Q3	Dec-07	3.1	5	E4	Q2	Aug-07	2.3	5
A3	Q4	Feb-08	2.9	5	E4	Q3	Dec-07	2.3	5
A4	Q1	May-07	-	-	E4	Q4	Feb-08	2.3	5
A4	Q2	Aug-07	-	-	F1	Q1	May-07	3	5
A4	Q3	Dec-07	3.2	5	F1	Q2	Aug-07	7.4	5
A4	Q4	Feb-08	2.3	5	F2	Q1	May-07	2.3	5
B1	Q1	May-07	2.3	5	F2	Q2	Aug-07	3.2	5
B1	Q2	Aug-07	3.5	5	F2	Q3	Dec-07	3.5	5
B1	Q3	Dec-07	2.3	5	F2	Q4	Feb-08	6.2	5
B1	Q4	Feb-08	2.3	5	F3	Q1	May-07	4.7	5
B2	Q1	May-07	2.3	5	F3	Q2	Aug-07	10.1	5
B2	Q2	Aug-07	2.3	5	F3	Q2-Dup	Aug-07	9.1	5
B2	Q3	Dec-07	2.3	5	F4	Q1	May-07	3.2	5
B2	Q4	Feb-08	2.3	5	F4	Q2	Aug-07	8.2	5
B3	Q1	May-07	2.3	5	F4	Q3	Dec-07	2.3	5
B3	Q2	Aug-07	2.3	5	F4	Q4	Feb-08	5.7	5
B3	Q3	Dec-07	2.3	5	G1	Q1	May-07	2.3	5
B3	Q4	Feb-08	2.3	5	G1	Q2	Aug-07	2.3	5
B4	Q1	May-07	2.3	5	G2	Q1	May-07	2.3	5
B4	Q1	May-07	5	5	G2	Q2	Aug-07	11.7	5
B4	Q2	Aug-07	2.3	5	G2	Q3	Dec-07	10.2	5
B4	Q3	Dec-07	2.3	5	G2	Q4	Feb-08	5	5
B4	Q4	Feb-08	2.3	5	G3	Q1	May-07	2.6	5
B5	Q4	Feb-08	2.3	5	G3	Q2	Aug-07	10.1	5

FINAL

Station	Quarter	Date	Pore water Concentration (µg/L)		Station	Quarter	Date	Pore water Concentration (µg/L)	
			Total Cr	Cr (VI)				Total Cr	Cr (VI)
C1	Q1	May-07	2.3	5	G4	Q1	May-07	4.2	5
C1	Q2	Aug-07	2.3	5	G4	Q2	Aug-07	13.4	5
C1	Q3	Dec-07	2.3	5	G4	Q3	Dec-07	8.1	5
C1	Q4	Feb-08	2.3	5	G4	Q4	Feb-08	3.2	5
C2	Q1	May-07	2.3	5	H1	Q1	May-07	2.8	5
C2	Q2	Aug-07	2.3	5	H1	Q2	Aug-07	4.4	5
C2	Q3	Dec-07	2.3	5	H1	Q3	Dec-07	11	5
C2	Q4	Feb-08	2.4	5	H1	Q3-Dup	Dec-07	11	5
C3	Q1	May-07	2.3	5	H1	Q4	Feb-08	5.1	5
C3	Q2	Aug-07	2.3	5	H2	Q1	May-07	4.3	5
C3	Q3	Dec-07	3.4	5	H2	Q2	Aug-07	3.5	5
C3	Q4	Feb-08	2.3	5	H3	Q1	Dec-07	5.5	5
C4	Q1	May-07	2.3	5	H3	Q2	Feb-08	3.2	5
C4	Q2	Aug-07	2.3	5	H4	Q1	May-07	3.1	5
C4	Q2-Dup	Aug-07	2.3	5	H4	Q2	Aug-07	4.8	5
C4	Q3	Dec-07	3.8	5	H4	Q3	Dec-07	12.2	5
C4	Q4	Feb-08	2.3	5	H4	Q4	Feb-08	6.5	5
D1	Q1	May-07	3.3	5	H4	Q4-Dup	Feb-08	10.2	5
D1	Q2	Aug-07	11	5	I1	Q1	May-07	2.3	5
D1	Q3	Dec-07	11.7	5	I1	Q2	Aug-07	2.3	5
D1	Q4	Feb-08	4.3	5	I1	Q3	Dec-07	3.1	5
D1	Q4-Dup	Feb-08	2.3	5	I1	Q4	Feb-08	2.3	5
D2	Q1	May-07	3.3	5	I2	Q1	May-07	2.6	5
D2	Q2	Aug-07	16.2	5	I2	Q2	Aug-07	2.3	5
D2	Q3	Dec-07	9	5	I2	Q3	Dec-07	3.1	5
D2	Q4	Feb-08	4.4	5	I2	Q4	Feb-08	2.3	5
D3	Q1	May-07	8.5	5	I3	Q1	May-07	2.3	5
D3	Q2	Aug-07	12.4	5	I3	Q2	Aug-07	2.7	5
D3	Q3	Dec-07	6.6	5	I3	Q3	Dec-07	4.7	5
D3	Q4	Feb-08	3.7	5	I3	Q4	Feb-08	2.3	5
D4	Q1	May-07	2.3	5	I4	Q1	May-07	2.7	5
D4	Q2	Aug-07	3.1	5	I4	Q2	Aug-07	5.8	5
D4	Q3	Dec-07	2.3	5	I4	Q3	Dec-07	6.7	5
D4	Q3-Dup	Dec-07	2.3	5	I4	Q4	Feb-08	2.3	5
D4	Q4	Feb-08	2.3	5	J1	Q4	Feb-08	2.3	5
E1	Q1	May-07	4.8	5	J2	Q4	Feb-08	2.3	5
E1	Q1-Dup	May-07	4.8	5	J3	Q4	Feb-08	2.3	5

Table A-3: Total Cr & Geochemical Parameter Sediment Concentration Data (ERA DMT)

Station	Quarter	Date	Sediment Concentration (mg/kg)				
			Total Cr	Fe (II)	TOC	Mn (II)	Sulfides
A1	Q1	May-07	698	600	17,000	0.5	33.2
A1	Q2	Aug-07	1,200	5,140	480	2.237	328
A1	Q2	Aug-07	1,330	4,130	4,900	1.464	603
A1	Q2	Aug-07	17	85.8	260	1.478	23.4
A2	Q1	May-07	363	85.1	390	0.5	25.6
A2	Q2	Aug-07	347	500	270	2.181	45.3
A2	Q2	Aug-07	315	-	-	-	-
A2	Q2	Aug-07	78.3	-	-	-	-
A3	Q1	May-07	96.6	334	710	0.5	41.3
A3	Q2	Aug-07	110	250	270	2.144	200
A3	Q2	Aug-07	2.91	-	-	-	-
A3	Q2	Aug-07	3.94	-	-	-	-
A4	Q1	May-07	89.6	103	200	0.5	25.7
A4	Q2	Aug-07	97.4	129	260	2.194	386
A4	Q2	Aug-07	12.8	-	-	-	-
A4	Q2	Aug-07	34.1	-	-	-	-
B1	Q1	May-07	640	NA	15,000	0.5	33.8
B1	Q2	Aug-07	595	4,280	11,000	2.252	77.3
B1	Q2	Aug-07	80.9	1,990	6,800	1.612	67.3
B1	Q2	Aug-07	29.4	655	490	4.793	24.9
B2	Q1	May-07	369	802	12,000	0.5	401
B2	Q2	Aug-07	236	2,220	6,600	2.224	92
B2	Q2	Aug-07	22.7	-	-	-	-
B2	Q2	Aug-07	1.97	-	-	-	-
B3	Q1	May-07	683	731	18,000	2.55	65
B3	Q2	Aug-07	637	2,030	24,000	2.211	1,420
B3	Q2	Aug-07	94	-	-	-	-
B3	Q2	Aug-07	1.15	-	-	-	-
B4	Q1	May-07	424	29.2	14,000	0.5	142
B4	Q1-Dup	May-07	355	657	10000	0.823	145
B4	Q2	Aug-07	404	1,850	11,000	2.345	528
B4	Q2	Aug-07	2,290	-	-	-	-
B4	Q2	Aug-07	690	-	-	-	-
B5	Q4	Feb-08	54.3	410	838	-	-
B5	Q4-Dup	Feb-08	58.2	238	614	-	-

FINAL

Station	Quarter	Date	Sediment Concentration (mg/kg)				
			Total Cr	Fe (II)	TOC	Mn (II)	Sulfides
B5	Q4	Feb-08	43.6	589	672	-	-
B5	Q4	Feb-08	37.9	221	670	-	-
C1	Q1	May-07	1,160	5,840	17,000	0.5	1,090
C1	Q2	Aug-07	1,310	10,600	25,000	2.298	1,780
C1	Q2	Aug-07	2,090	24,400	24,000	1.544	1,300
C1	Q2	Aug-07	-	21300	-	-	-
C1	Q2	Aug-07	1440	21,300	9,800	1.485	1,910
C1	Q2-Dup	Aug-07	1,800	-	2500	-	-
C2	Q1	May-07	1,080	4,670	25,000	0.5	73.5
C2	Q2	Aug-07	1,070	5,570	20,000	2.267	509
C2	Q2	Aug-07	91.5	-	-	-	-
C2	Q2	Aug-07	3.62	-	-	-	-
C3	Q1	May-07	582	3,430	9,500	0.5	96.4
C3	Q2	Aug-07	618	6,470	18,000	2.272	313
C3	Q2	Aug-07	250	-	-	-	-
C3	Q2	Aug-07	78.3	-	-	-	-
C4	Q1	May-07	357	3,150	9,700	0.5	33.8
C4	Q2	Aug-07	315	6,500	14,000	2.346	54.4
C4	Q2-Dup	Aug-07	328	6370	14,000	2.313	158
C4	Q2	Aug-07	57	-	-	-	-
C4	Q2	Aug-07	2.32	-	-	-	-
D1	Q1	May-07	304	9,770	25,000	5.924	1,880
D1	Q2	Aug-07	310	14,400	29,000	19.578	2,040
D1	Q2	Aug-07	372	16,400	51,000	10.285	2,330
D1	Q2	Aug-07	251	10,500	32,000	2.496	418
D2	Q1	May-07	239	13,000	29,000	7.75	2,020
D2	Q2	Aug-07	258	8,830	34,000	10.47	2,760
D2	Q2	Aug-07	237	-	-	-	-
D2	Q2	Aug-07	66.1	-	-	-	-
D3	Q1	May-07	306	1,290	25,000	2.678	476
D3	Q2	Aug-07	253	5,870	28,000	34.002	2,090
D3	Q2	Aug-07	218	-	-	-	-
D3	Q2	Aug-07	95.8	-	-	-	-
D4	Q1	May-07	198	5,120	13,000	0.5	36.5
D4	Q2	Aug-07	214	3,060	15,000	2.318	261
D4	Q2	Aug-07	78.1	-	-	-	-
D4	Q2	Aug-07	60.2	-	-	-	-

FINAL

Station	Quarter	Date	Sediment Concentration (mg/kg)				
			Total Cr	Fe (II)	TOC	Mn (II)	Sulfides
E1	Q1	May-07	223	83	30,000	2.785	658
E1	Q1-Dup	May-07	200	41	20,000	0.5	305
E1	Q2	Aug-07	253	10,700	23,000	2.449	1,680
E1	Q2	Aug-07	217	11,200	41,000	2.494	1,210
E1	Q2	Aug-07	68.2	4,700	30,000	2.244	125
E2	Q1	May-07	67	5,320	19,000	4.848	708
E2	Q2	Aug-07	65	5,910	25,000	7.304	1,900
E2	Q2	Aug-07	61	-	-	-	-
E2	Q2	Aug-07	62.1	-	-	-	-
E3	Q1	May-07	238	13,600	18,000	8.539	1,320
E3	Q2	Aug-07	197	11,200	21,000	10.258	2,120
E3	Q2	Aug-07	262	-	-	-	-
E3	Q2	Aug-07	259	-	-	-	-
E4	Q1	May-07	61.2	1,010	7,300	0.5	28.5
E4	Q2	Aug-07	114	1,150	16,000	2.18	361
E4	Q2	Aug-07	52.1	-	-	-	-
E4	Q2	Aug-07	125	-	-	-	-
F1	Q1	May-07	97.9	5,810	15,000	3.225	570
F1	Q2	Aug-07	117	4,840	20,000	2.372	1,160
F1	Q2	Aug-07	76.7	8,810	15,000	2.807	1,050
F1	Q2	Aug-07	159	15,200	30,000	1.651	2,380
F2	Q1	May-07	65.8	3,640	20,000	1.483	38
F2	Q2	Aug-07	33.1	808	3,000	2.219	224
F2	Q2	Aug-07	49.3	-	-	-	-
F2	Q2	Aug-07	36.9	-	-	-	-
F3	Q1	May-07	152	13,400	25,000	0.5	1,720
F3	Q2	Aug-07	211	8890	24000	2.418	1050
F3	Q2-Dup	Aug-07	261	11,500	25,000	4.005	2,350
F3	Q2	Aug-07	56	-	-	-	-
F3	Q2	Aug-07	56.2	-	-	-	-
F4	Q1	May-07	211	7,580	26,000	0.778	555
F4	Q2	Aug-07	190	11,300	20,000	2.431	2,000
F4	Q2	Aug-07	120	-	-	-	-
F4	Q2-Dup	Aug-07	159	-	-	-	-
F4	Q2	Aug-07	55.1	-	-	-	-
F4	Q2-Dup	Aug-07	54	-	-	-	-
G1	Q1	May-07	67	1,250	5,900	1	152

FINAL

Station	Quarter	Date	Sediment Concentration (mg/kg)				
			Total Cr	Fe (II)	TOC	Mn (II)	Sulfides
G1	Q2	Aug-07	67	4,340	7,200	1.521	1,170
G1	Q2	Aug-07	33	3,700	22,000	1.526	102
G1	Q2	Aug-07	28.8	5,170	9,700	1.505	128
G2	Q1	May-07	123	6,210	14,000	2	896
G2	Q2	Aug-07	153	6,410	28,000	2.458	1,500
G2	Q2	Aug-07	144	-	-	-	-
G2	Q2	Aug-07	50	-	-	-	-
G3	Q1	May-07	148	28	17,000	4.083	449
G3	Q2	Aug-07	164	8,510	13,000	2.421	1,900
G3	Q2	Aug-07	29.8	-	-	-	-
G3	Q2	Aug-07	29.6	-	-	-	-
G4	Q1	May-07	121	15	17,000	13.992	1,430
G4	Q2	Aug-07	140	4,170	9,100	2.371	1,650
G4	Q2	Aug-07	182	-	-	-	-
G4	Q2	Aug-07	197	-	-	-	-
H1	Q1	May-07	114	11,100	25,000	10.439	2,630
H1	Q2	Aug-07	89.5	7,410	21,000	2.404	2,690
H1	Q2	Aug-07	182	9,980	35,000	2.342	2,400
H1	Q2	Aug-07	29.2	493	860	1.441	35.1
H2	Q1	May-07	47.1	1,900	8,700	1	203
H2	Q2	Aug-07	134	2,180	29,000	2.403	1,040
H2	Q2	Aug-07	43.2	-	-	-	-
H2	Q2	Aug-07	88.4	-	-	-	-
H3	Q1	May-07	49.3	8,330	12,000	1	1,480
H3	Q2	Aug-07	71.8	6,100	9,800	9.836	1,870
H3	Q2	Aug-07	71.7	-	-	-	-
H3	Q2	Aug-07	101	-	-	-	-
H4	Q1	May-07	107	12,800	20,000	3.842	732
H4	Q2	Aug-07	207	13,200	48,000	13.377	3,470
H4	Q2	Aug-07	80.7	-	-	-	-
H4	Q2	Aug-07	28	-	-	-	-
I1	Q1	May-07	316	6,600	20,000	1	311
I1	Q2	Aug-07	700	4,490	14,000	2	1,240
I1	Q2	Aug-07	17	5,270	3,100	1.453	815
I1	Q2	Aug-07	22	6,100	11,000	1.498	1,060
I2	Q1	May-07	254	2,410	40,000	1	292
I2	Q2	Aug-07	315	5,580	34,000	2	1,600

FINAL

Station	Quarter	Date	Sediment Concentration (mg/kg)				
			Total Cr	Fe (II)	TOC	Mn (II)	Sulfides
I2	Q2	Aug-07	308	-	-	-	-
I2	Q2	Aug-07	575	-	-	-	-
I3	Q1	May-07	357	3,630	36,000	0.582	1,140
I3	Q2	Aug-07	425	5,960	39,000	5.431	2,070
I3	Q2	Aug-07	327	-	-	-	-
I3	Q2	Aug-07	332	-	-	-	-
I4	Q1	May-07	374	8,210	33,000	0.5	1,000
I4	Q2	Aug-07	542	4,570	39,000	1.836	1,690
I4	Q2	Aug-07	1,390	-	-	-	-
I4	Q2	Aug-07	508	-	-	-	-
J1	Q4	Feb-08	1,830	2,690	21,500	-	-
J1	Q4	Feb-08	1,620	6,340	10,900	-	-
J1	Q4	Feb-08	2,730	11,900	18,000	-	-
J2	Q4	Feb-08	1,840	2,050	9,640	-	-
J2	Q4	Feb-08	605	1,060	10,900	-	-
J2	Q4	Feb-08	303	701	679	-	-
J3	Q4	Feb-08	1,260	4,910	13,600	-	-
J3	Q4	Feb-08	28.2	144	769	-	-
J3	Q4	Feb-08	567	176	9,590	-	-
J4	Q4	Feb-08	2,360	818	9,670	-	-
J4	Q4	Feb-08	8,140	1,550	762	-	-
J4	Q4	Feb-08	114	22	572	-	-

FINAL

Table A-4: AVS/SEM Sediment Concentration Data (ERA DMT)

Station	Date	AVS/SEM Concentration (µmole/g)										
		AVS	Cd	Cu	Pb	Ni	Hg	Zn	Fe	Total Metals	Excess AVS	Excess Fe
A1	May-07	0.44	0.0045	0.27	0.09	0.59	2.80E-05	1.86	92.80	2.81	-2.37	92.36
A1	Aug-07	12.10	0.0019	0.06	0.09	0.18	-	1.79	71.90	2.12	9.98	59.80
A1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
A1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
A2	May-07	0.39	0.0007	0.05	0.03	0.11	2.60E-05	0.47	20.00	0.66	-0.27	19.61
A2	Aug-07	0.57	0.0001	0.06	0.04	0.13	-	0.55	25.40	0.77	-0.20	24.83
A2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
A2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
A3	May-07	0.52	0.0005	0.04	0.02	0.03	7.70E-06	0.29	17.50	0.37	0.15	16.98
A3	Aug-07	0.99	0.0001	0.12	0.02	0.63	-	0.22	20.10	0.99	0.00	19.11
A3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
A3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
A4	May-07	0.39	0.0007	0.05	0.02	0.11	7.60E-06	0.31	29.20	0.49	-0.10	28.81
A4	Aug-07	1.40	0.0001	0.03	0.02	0.02	-	0.28	17.20	0.36	1.04	15.80
A4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
A4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
B1	May-07	0.44	0.0016	0.30	0.08	0.57	1.40E-05	1.40	82.00	2.35	-1.91	81.56
B1	Aug-07	10.40	0.0027	0.11	0.07	0.48	-	1.22	73.70	1.88	8.52	63.30
B1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
B1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
B2	May-07	0.53	0.0015	0.28	0.06	0.50	2.90E-05	0.97	74.40	1.82	-1.29	73.87
B2	Aug-07	3.20	0.0016	0.16	0.06	0.06	-	0.91	52.10	1.19	2.01	48.90
B2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
B2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
B3	May-07	7.70	0.0037	0.16	0.12	0.43	7.70E-06	1.47	102.00	2.18	5.52	94.30
B3	Aug-07	11.60	0.0039	0.34	0.13	0.69	-	1.62	107.00	2.78	8.82	95.40
B3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
B3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
B4	May-07	3.40	0.0006	0.40	0.14	0.09	7.50E-06	1.70	125.00	2.32	1.08	121.60
B4	May-07	4.30	0.0004	0.40	0.12	0.40	7.80E-06	1.54	122.00	2.46	1.84	117.70
B4	Aug-07	3.80	0.0046	0.46	0.15	0.40	-	1.93	121.00	2.94	0.86	117.20
B4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
B4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
B5	Feb-08	0.63	0.0009	0.10	0.03	0.04	-	0.51	39.40	0.68	-0.05	38.77
B5	Feb-08	0.74	0.0008	0.09	0.03	0.04	-	0.48	35.70	0.64	0.10	34.96

FINAL

Station	Date	AVS/SEM Concentration (µmole/g)										
		AVS	Cd	Cu	Pb	Ni	Hg	Zn	Fe	Total Metals	Excess AVS	Excess Fe
B5	Feb-08	0.63	0.0004	0.07	0.02	0.04	-	0.21	45.20	0.35	0.28	44.57
B5	Feb-08	0.63	0.0001	0.02	0.00	0.03	-	0.03	25.30	0.08	0.55	24.67
C1	May-07	12.60	0.0017	0.14	0.13	0.37	7.50E-06	1.60	136.00	2.25	10.35	123.40
C1	Aug-07	14.30	0.0057	0.22	0.18	0.68	-	1.85	109.00	2.93	11.37	94.70
C1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
C1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
C1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
C1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
C2	May-07	13.10	0.0053	0.14	0.17	0.25	7.80E-06	1.74	92.60	2.30	10.80	79.50
C2	Aug-07	16.00	0.0043	0.15	0.17	0.21	-	1.68	98.60	2.21	13.79	82.60
C2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
C2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
C3	May-07	9.80	0.0048	0.19	0.13	0.43	7.70E-06	1.88	101.00	2.62	7.18	91.20
C3	Aug-07	6.50	0.0047	0.29	0.12	0.11	-	1.96	84.00	2.49	4.01	77.50
C3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
C3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
C4	May-07	4.90	0.0051	0.40	0.13	0.18	7.50E-06	1.86	125.00	2.58	2.32	120.10
C4	Aug-07	3.30	0.0044	0.35	0.13	0.28	-	1.81	107.00	2.57	0.73	103.70
C4	Aug-07	7.10	0.0044	0.36	0.13	0.08	-	1.84	92.00	2.42	4.68	84.90
C4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
C4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
D1	May-07	28.80	0.0010	0.05	0.09	0.16	7.50E-06	1.17	103.00	1.46	27.34	74.20
D1	Aug-07	18.70	0.0024	0.13	0.08	0.16	-	1.02	74.70	1.39	17.31	56.00
D1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
D1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
D2	May-07	16.60	0.0010	0.20	0.09	0.06	7.60E-06	1.04	82.50	1.38	15.22	65.90
D2	Aug-07	32.70	0.0027	0.03	0.08	0.09	-	0.99	87.90	1.19	31.51	55.20
D2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
D2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
D3	May-07	15.30	0.0010	0.13	0.09	0.12	7.60E-06	0.99	80.40	1.32	13.98	65.10
D3	Aug-07	11.40	0.0032	0.15	0.10	0.36	-	1.20	86.70	1.82	9.58	75.30
D3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
D3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
D4	May-07	13.20	0.0018	0.25	0.09	0.37	7.60E-06	1.10	170.00	1.82	11.38	156.80
D4	Aug-07	10.30	0.0041	0.38	0.15	0.59	-	1.74	162.00	2.86	7.44	151.70
D4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
D4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
E1	May-07	22.90	0.0008	0.0604*	0.08	0.06	7.80E-06	0.89	75.10	1.03	21.87	52.20
E1	May-07	12.10	0.0008	0.10	0.04	0.13	7.60E-06	0.80	47.90	1.08	11.02	35.80

FINAL

Station	Date	AVS/SEM Concentration (µmole/g)										
		AVS	Cd	Cu	Pb	Ni	Hg	Zn	Fe	Total Metals	Excess AVS	Excess Fe
E1	Aug-07	19.00	0.0025	0.05	0.07	0.06	-	0.95	68.50	1.13	17.87	49.50
E1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
E1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
E2	May-07	6.80	0.0020	0.14	0.04	0.25	7.60E-06	0.56	139.00	0.99	5.81	132.20
E2	Aug-07	20.10	0.0039	0.09	0.06	0.56	-	0.68	77.60	1.40	18.70	57.50
E2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
E2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
E3	May-07	27.50	0.0035	0.20	0.08	0.43	7.60E-06	1.08	105.00	1.79	25.71	77.50
E3	Aug-07	25.10	0.0029	0.05	0.09	0.34	-	1.03	97.40	1.50	23.60	72.30
E3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
E3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
E4	May-07	0.93	0.0011	0.18	0.09	0.04	9.90E-06	0.49	60.40	0.79	0.14	59.47
E4	Aug-07	7.60	0.0018	0.21	0.09	0.28	-	0.72	61.00	1.29	6.31	53.40
E4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
E4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
F1	May-07	12.90	0.0005	0.13	0.05	0.05	7.80E-06	0.64	69.40	0.87	12.03	56.50
F1	Aug-07	19.90	0.0025	0.19	0.07	1.00	-	0.92	91.60	2.18	17.72	71.70
F1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
F1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
F2	May-07	9.50	0.0005	0.17	0.05	0.05	7.80E-06	0.62	80.60	0.89	8.61	71.10
F2	Aug-07	4.20	0.0008	0.15	0.03	0.50	-	0.16	109.00	0.84	3.36	104.80
F2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
F2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
F3	May-07	22.00	0.0038	0.29	0.15	0.07	7.60E-06	1.33	172.00	1.84	20.16	150.00
F3	Aug-07	41.50	0.0037	0.17	0.11	0.08	-	1.13	110.00	1.49	40.01	68.50
F3	Aug-07	21.50	0.0028	0.11	0.08	0.16	-	0.85	94.20	1.20	20.30	72.70
F3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
F3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
F4	May-07	20.60	0.0029	0.27	0.10	0.12	7.60E-06	1.15	107.00	1.64	18.96	86.40
F4	Aug-07	8.40	0.0026	0.06	0.08	0.04	-	0.90	75.10	1.08	7.32	66.70
F4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
F4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
F4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
F4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
G1	May-07	6.80	0.0001	0.07	0.02	0.17	7.60E-06	0.26	48.70	0.52	6.28	41.90
G1	Aug-07	21.20	0.0024	0.10	0.05	0.65	-	0.57	68.70	1.38	19.82	47.50
G1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
G1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
G2	May-07	29.10	0.0012	0.09	0.07	0.06	7.80E-06	0.84	80.70	1.06	28.04	51.60

FINAL

Station	Date	AVS/SEM Concentration (µmole/g)										
		AVS	Cd	Cu	Pb	Ni	Hg	Zn	Fe	Total Metals	Excess AVS	Excess Fe
G2	Aug-07	17.10	0.0029	0.20	0.07	0.16	-	0.86	68.40	1.29	15.81	51.30
G2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
G2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
G3	May-07	23.90	0.0016	0.14	0.08	0.29	7.80E-06	0.85	74.30	1.35	22.55	50.40
G3	Aug-07	25.60	0.0036	0.15	0.08	0.44	-	0.97	81.90	1.65	23.95	56.30
G3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
G3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
G4	May-07	22.20	0.0015	0.13	0.09	0.29	7.80E-06	1.02	100.00	1.53	20.67	77.80
G4	Aug-07	10.20	0.0030	0.09	0.08	0.06	-	0.91	72.20	1.13	9.07	62.00
G4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
G4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
H1	May-07	51.20	0.0363	0.43	0.18	0.50	7.80E-06	1.86	71.00	3.01	48.19	19.80
H1	Aug-07	16.90	0.0070	0.01	0.07	0.04	-	0.80	61.00	0.94	15.96	44.10
H1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
H1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
H2	May-07	20.80	0.0149	0.23	0.10	0.04	7.70E-06	0.98	48.70	1.36	19.44	27.90
H2	Aug-07	32.20	0.0109	0.02	0.10	0.27	-	0.95	57.90	1.34	30.86	25.70
H2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
H2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
H3	May-07	36.50	0.0095	0.14	0.09	0.05	7.60E-06	0.95	60.70	1.25	35.25	24.20
H3	Aug-07	16.40	0.0114	0.02	0.08	0.31	-	0.72	36.20	1.14	15.26	19.80
H3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
H3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
H4	May-07	24.50	0.0044	0.23	0.07	0.34	7.50E-06	0.82	82.60	1.46	23.04	58.10
H4	Aug-07	38.30	0.0294	0.09	0.15	0.25	-	1.49	58.90	2.01	36.29	20.60
H4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
H4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
I1	May-07	3.20	0.1420	1.02	0.39	0.31	7.60E-06	4.69	63.40	6.55	-3.35	60.20
I1	Aug-07	26.50	0.0746	0.00	0.23	0.48	-	3.19	78.10	3.97	22.53	51.60
I1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
I1	Aug-07	-	-	-	-	-	-	-	-	-	-	-
I2	May-07	10.60	0.0880	0.53	0.35	0.63	7.70E-06	3.14	59.90	4.74	5.86	49.30
I2	Aug-07	23.80	0.0856	0.01	0.23	0.74	-	3.01	57.80	4.08	19.72	34.00
I2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
I2	Aug-07	-	-	-	-	-	-	-	-	-	-	-
I3	May-07	24.40	0.1210	0.12	0.54	0.55	7.50E-06	3.60	55.50	4.93	19.47	31.10
I3	Aug-07	21.50	0.1690	0.00	0.49	0.04	-	5.56	32.70	6.26	15.24	11.20
I3	Aug-07	-	-	-	-	-	-	-	-	-	-	-
I3	Aug-07	-	-	-	-	-	-	-	-	-	-	-

FINAL

Station	Date	AVS/SEM Concentration (µmole/g)										
		AVS	Cd	Cu	Pb	Ni	Hg	Zn	Fe	Total Metals	Excess AVS	Excess Fe
I4	May-07	42.70	0.1920	0.09	0.63	0.54	7.70E-06	4.99	74.40	6.44	36.26	31.70
I4	Aug-07	11.90	0.0759	0.00	0.32	0.29	-	3.16	40.80	3.86	8.04	28.90
I4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
I4	Aug-07	-	-	-	-	-	-	-	-	-	-	-
J1	Feb-08	5.00	0.0091	0.30	0.21	0.30	-	2.53	162.00	3.34	1.66	157.00
J1	Feb-08	7.10	0.0085	0.66	0.56	0.31	-	1.60	104.00	3.13	3.97	96.90
J1	Feb-08	10.00	0.0048	0.23	0.12	0.18	-	1.39	79.80	1.92	8.08	69.80
J2	Feb-08	16.80	0.0057	0.15	0.06	0.41	-	1.20	127.00	1.84	14.96	110.20
J2	Feb-08	4.80	0.0055	0.35	0.13	0.16	-	2.29	104.00	2.93	1.87	99.20
J2	Feb-08	5.00	0.0115	0.24	0.19	0.18	-	3.12	45.80	3.73	1.27	40.80
J3	Feb-08	0.63	0.0014	0.15	0.05	0.22	-	0.95	89.40	1.37	-0.74	88.77
J3	Feb-08	6.60	0.0026	0.19	0.07	0.08	-	1.16	63.80	1.51	5.09	57.20
J3	Feb-08	0.63	0.0001	0.03	0.00	0.00	-	0.01	12.10	0.05	0.58	11.47
J4	Feb-08	2.40	0.0072	0.19	0.08	0.35	-	2.57	121.00	3.19	-0.79	118.60
J4	Feb-08	0.63	0.0019	0.26	0.15	0.69	-	4.24	192.00	5.34	-4.71	191.37
J4	Feb-08	0.63	0.0001	0.01	0.00	0.00	-	0.01	1.11	0.02	0.61	0.48