Water Quality Analysis of Copper in the Bodkin Creek portion of the Patapsco River Mesohaline Chesapeake Bay Segment, Anne Arundel County, Maryland

FINAL

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List of Abbreviations

BIBI	Benthic Index of Biotic Integrity
CBL	Chesapeake Biological Laboratory
cm	Centimeter
COMAR	Code of Maryland Regulations
Cu	Copper
CWA	Clean Water Act
DOC	Dissolved Organic Carbon
EPA	US Environmental Protection Agency
FIBI	Fish Index of Biotic Integrity
g/L	Grams per Liter
HAC	Hardness Adjusted Criteria
km	kilometer
LSD	Least Significant Difference
MDE	Maryland Department of the Environment
mi	mile
mg	Milligram
mg/L	Milligrams per Liter
mg/day	Milligrams per Day
MMCS	Maryland Metals Contaminant Survey
PATMH	Patapsco River Mesohaline
Pb	Lead
ppt	Parts per Thousand
SCS	Soil Conservation Service
SD	Standard Deviation
TMDL	Total Maximum Daily Load
UM	University of Maryland
UMCES	University of Maryland Center for Environmental Sciences
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

EXECUTIVE SUMMARY

This document, upon approval by the U.S. Environmental Protection Agency (EPA), presents a Water Quality Analysis (WQA) of copper (Cu) in the Bodkin Creek (Maryland 8-Digit basin number: 02130902) portion of the Patapsco River Mesohaline (PATMH) Tidal Chesapeake Bay Segment (2010 *Integrated Report of Surface Water Quality in Maryland* Assessment Unit ID: MD-PATMH-Bodkin_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 Bodkin Creek portion 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 2010 Integrated Report as impaired by nutrients – nitrogen and phosphorus (1996), sediments – total suspended solids (1996), and impacts to biological communities (2004). The Bodkin Creek portion of the PATMH Tidal Chesapeake Bay Segment was individually identified on the 2010 Integrated Report as impaired by nutrients – nitrogen and phosphorus (1996), Cu (1996), lead (Pb) (1996), and zinc (Zn) (1996) (MDE 2010). The Integrated Report specifies that the Cu impairment in the Bodkin Creek portion of the PATMH Tidal Chesapeake Bay Segment does not support the protection of aquatic life designated use of the waterbody. From this point on in the Executive Summary to this report, the Bodkin Creek portion of the PATMH Tidal Chesapeake Bay Segment, also referred to as an embayment, will simply be referred to as Bodkin Creek, or the embayment.

The WQA presented herein by MDE will address the 1996 Cu listing for Bodkin Creek, for which a data solicitation was conducted, and all readily available data from the past five years have been considered. The nutrient listings for Bodkin Creek have been addressed through the Chesapeake Bay TMDL, which was approved by the EPA on December 29, 2010, and a WQA for Pb and Zn in Bodkin Creek was approved by the EPA on February 20, 2009. The sediment listing for the PATMH Tidal Chesapeake Bay Segment was also addressed via the Chesapeake Bay TMDL. The listing for impacts to biological communities in the PATMH Tidal Chesapeake Bay Segment will be addressed separately at a future date.

An analysis of recent monitoring data from Bodkin Creek demonstrates that the Cu water quality criterion for the protection of aquatic life is being met, thus indicating that the embayment is not impaired for Cu. In addition, an ambient sediment bioassay conducted by the University of Maryland (UM) Wye Research and Education Center (WREC), concluded that no toxicity is

present within the Bodkin Creek sediments as a result of Cu concentrations or any other toxic substance. This analysis supports the assertion that the original 1996 303(d) listing for the Cu impairment to aquatic life within the embayment is believed to have been made erroneously. The original 1996 303(d) assessment was based on water quality data that was believed to have been collected in the Bodkin Creek mainstem; however, the data had been collected in the Jones Falls, a nontidal tributary of the PATMH Tidal Chesapeake Bay Segment (Fisher and Katz 1984). Presumably, the data collected in the Jones Falls was applied in listing Bodkin Creek as impaired for Cu based on the assumption that elevated Cu levels in the Jones Falls would also be found in Bodkin Creek, since the two watersheds are characteristically similar (MDE 1996).

As stated above, the analysis presented in this report supports the conclusion that a TMDL for Cu is not necessary to achieve water quality standards in Bodkin Creek. Although the tidal waters of Bodkin Creek do not display signs of a Cu impairment, the State reserves the right to require future controls if evidence suggests that Cu from the watershed is contributing to downstream water quality problems. Barring the receipt of contradictory data, this report will be used to support a revision of the 2010 Integrated Report Cu listing for Bodkin 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 Cu related] water quality standards, but with insufficient data to assess all impairment") when MDE proposes revision of the Integrated Report.

1.0 INTRODUCTION

This document, upon approval by the U.S. Environmental Protection Agency (EPA), presents a Water Quality Analysis (WQA) of copper (Cu) in the Bodkin Creek (Maryland 8-Digit basin number: 02130902) portion of the Patapsco River Mesohaline (PATMH) Tidal Chesapeake Bay Segment (2010 *Integrated Report of Surface Water Quality in Maryland* Assessment Unit ID: MD-PATMH-Bodkin_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 copper in the Bodkin Creek portion of the Patapsco River Mesohaline Chesapeake Bay Segment (PATMH) incorporating the first and third scenarios described 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 Bodkin Creek portion 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 2010 Integrated Report as impaired by nutrients – nitrogen and phosphorus (1996), sediments – total suspended solids (1996), and impacts to biological communities (2004). The Bodkin Creek portion of the PATMH Tidal Chesapeake Bay Segment was individually identified on the 2010 Integrated Report as impaired by nutrients – nitrogen and phosphorus (1996), Cu (1996), lead (Pb) (1996), and zinc (Zn) (1996) (MDE 2010). The Integrated Report specifies that the Cu impairment in the Bodkin Creek portion of the PATMH Tidal Chesapeake Bay Segment does not support the protection of aquatic life designated use of the waterbody. From this point forward in the report, the Bodkin Creek portion of the PATMH Tidal Chesapeake Bay Segment, also referred to as an embayment, will simply be referred to as Bodkin Creek, or the embayment.

The WQA presented herein by MDE will address the 1996 Cu listing for Bodkin Creek, for which a data solicitation was conducted, and all readily available data from the past five years have been considered. The nutrient listings for Bodkin Creek have been addressed through the Chesapeake Bay TMDL, which was approved by the EPA on December 29, 2010, and a WQA for Pb and Zn in Bodkin Creek was approved by the EPA on February 20, 2009. The sediment listing for the PATMH Tidal Chesapeake Bay Segment was also addressed via the Chesapeake Bay TMDL. The listing for impacts to biological communities in the PATMH Tidal Chesapeake Bay Segment will be addressed separately at a future date.

The original 1996 303(d) listing for the Cu impairment to aquatic life was created based on an assessment of mean water column Cu concentrations that exceeded the EPA's chronic aquatic life Cu criterion. This assessment was based on water quality data that was believed to have been collected in the Bodkin Creek mainstem; however, the data had been collected in the Jones Falls, a nontidal tributary of the PATM Tidal Cheaspeake Bay Segment, as part of a 1984 Stormwater Runoff Study conducted by the United States Geological Survey (USGS) (Fisher and Katz 1984). The information from this study found that Cu concentrations in the Jones Falls exceeded EPA's chronic aquatic life criterion. Presumably, Bodkin Creek was then identified on the 1996 303(d) List as being impaired for Cu based on the assumption that Cu concentrations in Bodkin Creek would be similar to those in the Jones Falls, since the two watersheds are characteristically similar (MDE 1996).

This report provides an analysis of recent monitoring data that supports the removal of the Cu impairment listing for Bodkin Creek, when MDE proposes the revision of the State's Integrated Report. The remainder of this report lays out the general setting of the Bodkin Creek watershed, presents a discussion of the water quality characteristics within the embayment relative to the established water quality criteria for Cu, specific to the applicable designated uses of Bodkin Creek, and provides conclusions with regard to the characterization.

2.0 GENERAL SETTING

Location

The Bodkin Creek portion of the PATMH Tidal Chesapeake Bay Segment is located near the confluence of the Patapsco River and the mainstem Chesapeake Bay. The Bodkin Creek watershed (embayment plus drainage area) covers 6,579 acres (see Figure 1).

Bodkin Creek is located in Anne Arundel County and is bounded by the Baltimore Harbor watershed to the north and west and the mainstem of the Chesapeake Bay to the east (see Figure 1). The embayment consists of three small creeks: Back Creek, Main Creek, and Wharf Creek, and it comprises 90% of all surface water within the watershed (i.e., 90% of all surface waters in the watershed are tidally influenced). Only 2.5 stream miles within Main Creek's headwaters, out of a total 24 stream miles within the Bodkin Creek watershed, are designated as being nontidal (freshwater). The Bodkin Creek embayment is approximately 24 miles (mi) (39 kilometers (km)) long, from its tidal headwaters to its confluence with the Chesapeake Bay. The depth of the embayment ranges from about 6 inches in the tidal headwaters to greater than ten feet in the middle of the embayment. At the mouth of the embayment, the depths range from seven to nine feet. 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 embayment's watershed is approximately 18,710 (US Census Bureau 2000).

Geology/Soils

The Bodkin Creek watershed lies entirely within the Coastal Plain geologic province of Maryland. Broad upland areas with low slopes, gentle drainage, and deep sedimentary soil complexes that support broad meandering streams characterize the Coastal Plain geologic province (DNR 2012; MGS 2012). 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 (MGS 2012).

Soil type for the Bodkin Creek watershed is 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 Bodkin Creek watershed is comprised primarily of Group A soils (47%) and Group B soils (37%), with smaller amounts of Group C (10%) and Group D soils (6%) (USDA 2006).

Land-Use

According to the USGS 2006 land-cover data modified for the Chesapeake Bay watershed (USGS 2011), land-use in the Bodkin Creek watershed can be classified as predominately forested. Forest occupies approximately 54.9% (3,616 acres) of the watershed, while 20.4% (1,342 acres) is urban, 13.5% (888 acres) is covered by water (e.g., open waters of the embayment itself, streams, ponds, etc), and 11.2% (734 acres) is agricultural. The land use distribution is displayed and summarized in Figures 2 and 3.

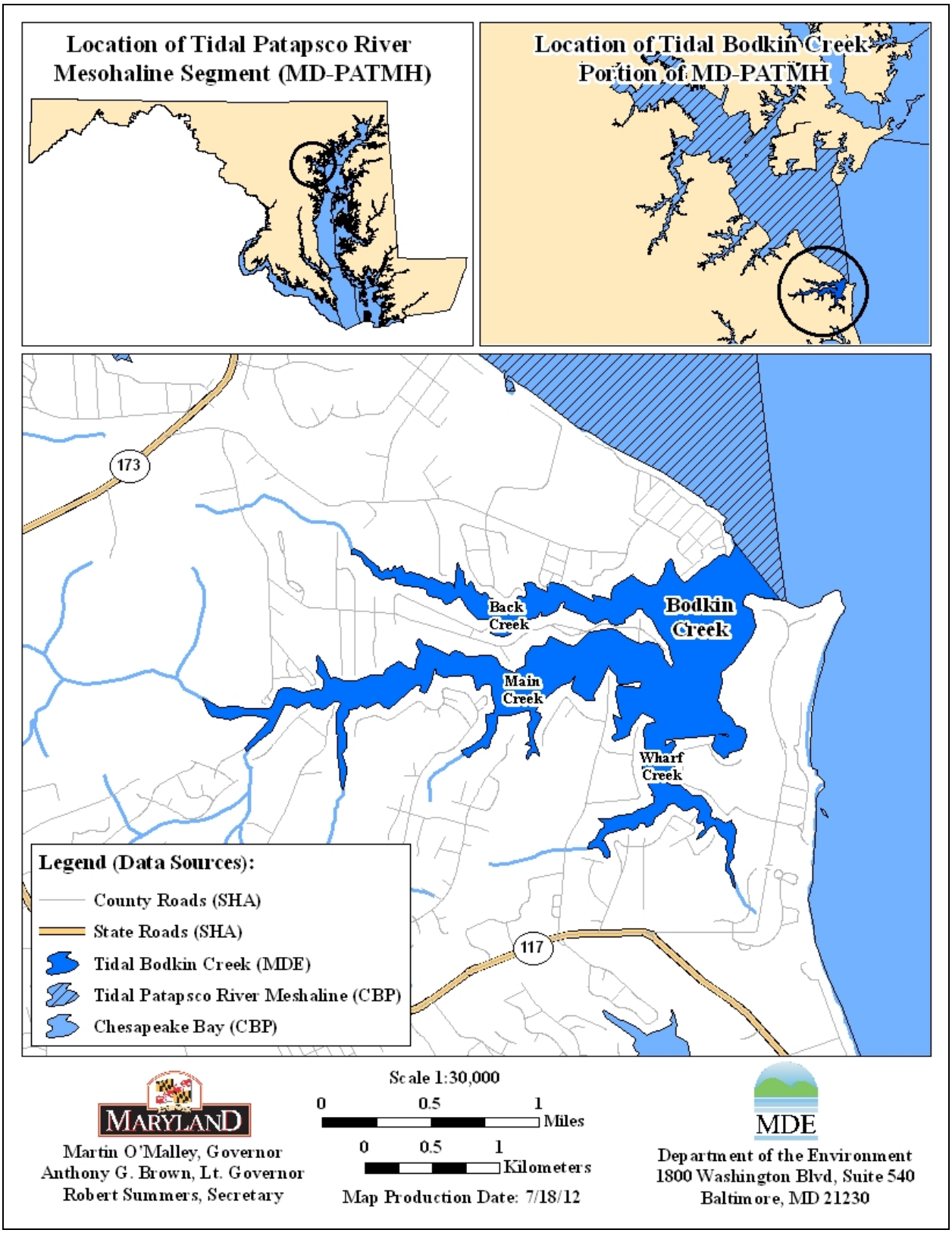

Figure 1: Location Map of Bodkin Creek

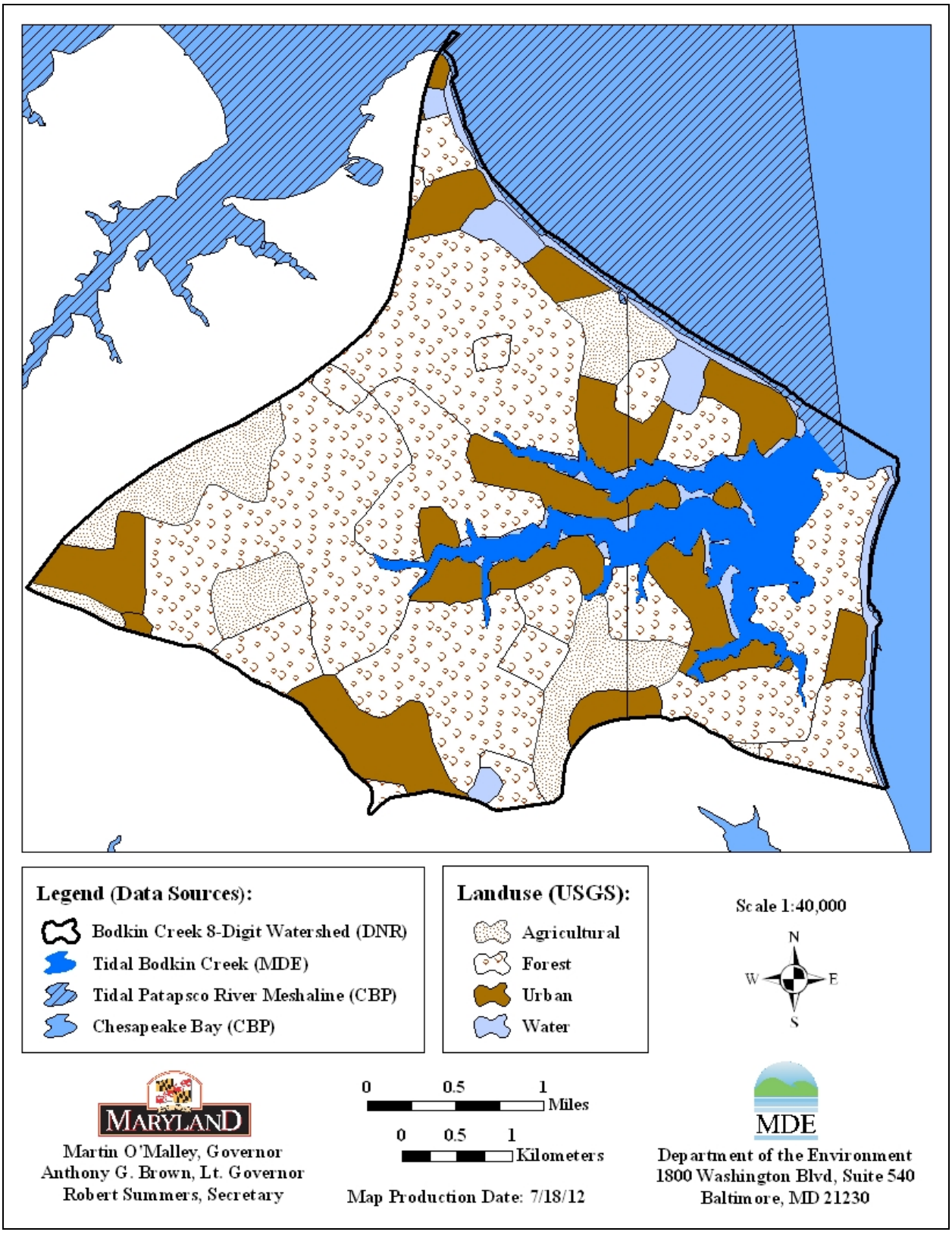

Figure 2: Land Use Map for the Bodkin Creek Watershed

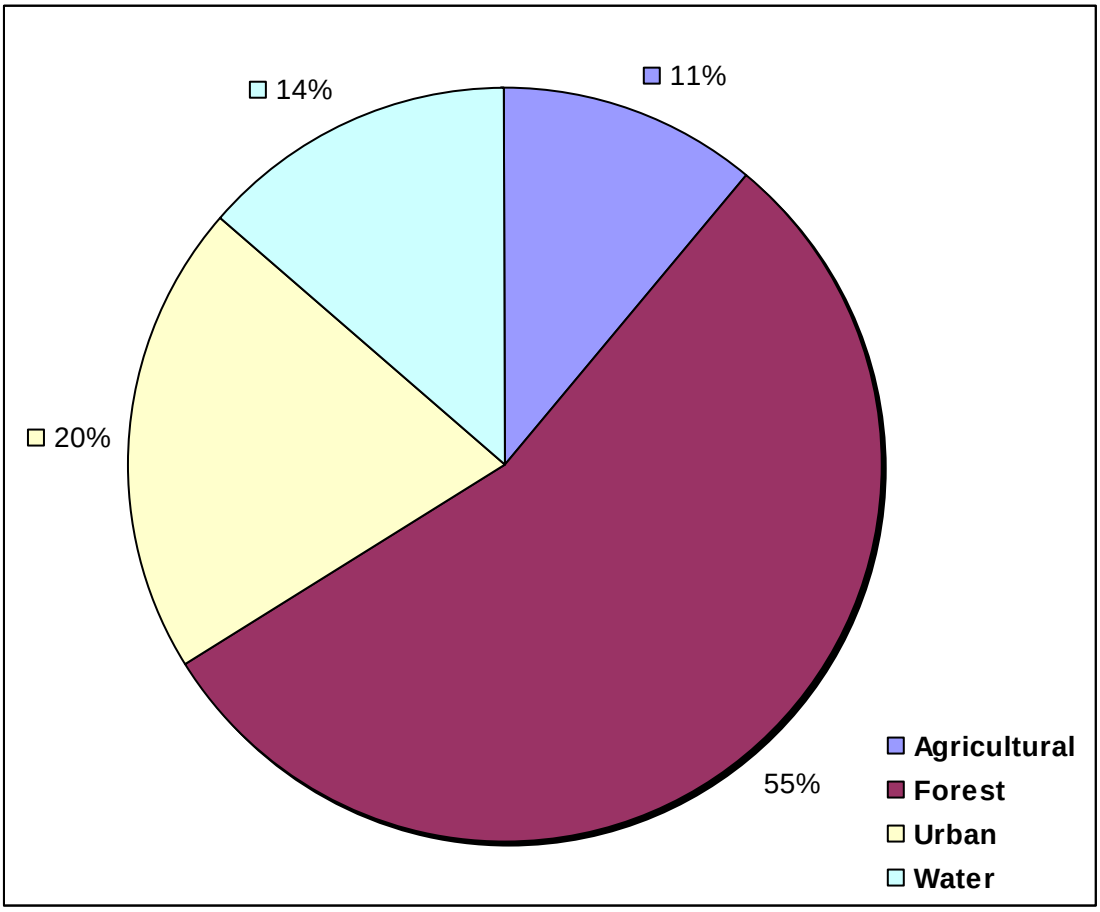

Figure 3: Land Use Distribution in the Bodkin Creek Watershed

3.0 WATER QUALITY CHARACTERIZATION

A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life, primary or secondary contact recreation, drinking water supply, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. Criteria may differ among waters with different designated uses.

Maryland's Surface Water Use Designations in 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 Bodkin Creek is Use II (*Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting*) (COMAR 2012b,c).

The 2010 Integrated Report specifies that the Cu impairment within Bodkin Creek does not support the protection of aquatic life designated use of the waterbody. The original 1996 303(d) listing for the Cu impairment to aquatic life was created based on an assessment of mean water column Cu concentrations that exceeded the EPA's chronic aquatic life Cu criterion. This assessment was based on water quality data that was believed to have been collected in the Bodkin Creek mainstem; however, the data had been collected in the Jones Falls, a nontidal tributary of the PATM Tidal Chesapeake Bay Segment, as part of a 1984 Stormwater Runoff Study conducted by the USGS (Fisher and Katz 1984). The information from this study found that Cu concentrations in the Jones Falls exceeded EPA's chronic aquatic life criterion. Presumably, Bodkin Creek was then identified on the 1996 303(d) List as being impaired for Cu based on the assumption that Cu concentrations in Bodkin Creek would be similar to those in the Jones Falls, since the two watersheds are characteristically similar (MDE 1996).

Maryland's current water quality standards include numeric criteria for metals and other toxic substances in the water column, which establish threshold concentrations that are protective of aquatic life, wildlife, and human health. Maryland's current water quality standards, however, do not include criteria for toxic substance and/or metals concentrations in sediments. Ambient sediment bioassays were conducted for this analysis to assess whether or not toxic contaminant/metals concentrations in Bodkin Creek sediments adversely impact aquatic life.

The applicable numeric water column Cu criteria is shown in Table 1 (COMAR 2012e). Maryland's water quality standards contain acute and chronic freshwater aquatic life Cu criteria, acute and chronic saltwater aquatic life Cu criteria, an acute estuarine aquatic life Cu criterion, and a human health Cu criterion. The exposure period for aquatic life being in contact with the water column are defined as one hour for an acute exposure and 96 hours, or 4 days, for a chronic exposure (US EPA 2002). For the purposes of this analysis, the chronic criteria were applied in order to assess whether or not Cu concentrations are impairing the Bodkin Creek aquatic life designated use, since it is the most conservative and thus protective of all conditions.

Table 1: Numeric Water Column Cu Criteria

Toxic/Metal	Water Column Criteria					
	Freshwater Aquatic Life Acute[1] (µg/L[2])	**Freshwater Aquatic Life Chronic**[1] (µg/L)	**Estuarine Aquatic Life Acute** (µg/L)	**Saltwater Aquatic Life Acute** (µg/L)	**Saltwater Aquatic Life Chronic** (µg/L)	**Human Health (Water + Organism)** (µg/L) (10-5 risk level)
Cu	13	9	6.1	4.8	3.1	1300

Notes: [1]Criterion based on a default hardness of 100 milligrams per Liter (mg/L).
[2]µg/L: micrograms per liter.

Maryland's Surface Water Use Designations in COMAR indicate that Bodkin Creek is an estuarine waterbody (COMAR 2012b). As per EPA guidance, water quality assessment in estuarine waters where salinity concentrations range between one and ten parts per thousand (ppt) should apply the more stringent threshold out of the applicable freshwater and saltwater criteria (US EPA 2002). Salinity concentrations in Bodkin Creek range between 2.7 and 9.1 ppt; therefore, MDE conducted a comparison of the applicable freshwater and saltwater chronic Cu criteria to determine which was the most conservative threshold and consequently should be applied in the analysis. The freshwater aquatic life chronic Cu criterion, amongst other chronic freshwater metals criteria, includes an adjustment for water column hardness, because the toxicity of many metals is a function of total hardness. Therefore, the hardness adjusted freshwater aquatic life chronic Cu criterion and saltwater aquatic life chronic Cu criterion will be compared, in order to determine which criterion is more conservative and thus should be applied within this analysis.

According to the EPA's National Recommended Water Quality Criteria (US EPA 2012), hardness concentrations must fall within the range of 25 - 400 mg/L. MDE uses an upper limit of 400 mg/L in calculating a freshwater aquatic life chronic hardness-adjusted criteria (HAC), when the measured hardness exceeds the threshold value of 400 mg/L. At elevated hardness above 400 mg/L, data indicates that hardness and related inorganic water quality characteristics do not have as pronounced of an effect on the toxicity of metals as they do at lower hardness. The EPA's Office of Research and Development does not recommend a lower limit for hardness concentrations when adjusting criterion (US EPA 2002). A lower limit may result in a criterion that is less protective of the water quality standard. In analyses where available hardness data indicate a concentration less than 25 mg/L, MDE may perform additional analyses to ensure that data quality objectives for the assessments were met. When data is of questionable quality, MDE will take additional samples to establish the validity of the initial assessment.

If data demonstrate that a violation of the freshwater aquatic life chronic Cu criterion is the result of an adjusted criteria based on a hardness concentration less than 25 mg/L, the State will perform a scientific review of the following conditions to determine if the violation is valid:

A. Presence/absence of sensitive species in the waterbody of concern.

B. Additional environmental conditions (e.g. high Dissolved Organic Carbon (DOC) concentrations), which may mitigate the toxicity of metals due to the competitive binding/complexation of metals.

This review is necessary because of the scientific uncertainty surrounding the hardness-toxicity relationship, when hardness concentrations are less than 25 mg/L, due to the limited toxicity test data that was used to define the relationship.

The freshwater aquatic life chronic Cu HAC equation is as follows (US EPA 2012):

$$\text{Freshwater Aquatic Life Chronic Cu HAC} = e^{(m[\ln(\text{Hardness(mg/L)})]+b)} * CF$$

Where,
HAC = Freshwater Aquatic Life Chronic Cu Hardness Adjusted Criteria (µg/L)
m = slope
b = y intercept
CF = Conversion Factor (conversion from total to dissolved numeric criteria)
Hardness = Observed hardness value (mg/L)

The freshwater aquatic life chronic Cu HAC parameters are presented in Table 2 (US EPA 2012).

Table 2: Fresh Water Aquatic Life Chronic Cu HAC Parameters

Toxic/Metal	Slope (m)	Y Intercept (b)	Conversion Factor (CF)
Cu	0.8545	-1.702	0.96

Hardness concentration data for Bodkin Creek was gathered from the Maryland Metals Contaminant Survey (MMCS) conducted by University of Maryland Center for Environmental Science (UMCES) Chesapeake Biological Laboratory (CBL) and University of Maryland (UM) Wye Research and Education Center (WREC) (Heyes et al. 2007). Hardness concentrations from this study ranged from 467.5 to 1,467 mg/L; therefore, an upper limit of 400 mg/L was applied in calculating the freshwater aquatic life chronic Cu HAC. Table 3 presents a comparison of the hardness adjusted freshwater and saltwater aquatic life chronic Cu criterion.

Table 3: Aquatic Life Chronic Cu Criteria

Toxic/Metal	Freshwater Aquatic Life (µg/L)[1]	Saltwater Aquatic Life (µg/L)
Cu	29.3	3.1

Note: [1]Hardness adjusted criterion based on Bodkin Creek hardness concentration data. Maximum concentration = 1,467 mg/L. Thus, concentration used in calculation set at upper limit of 400 mg/L.

Because the saltwater aquatic life chronic Cu criterion is more stringent/conservative than the freshwater aquatic life chronic Cu HAC, it will be applied within this analysis in order to assess whether or not ambient dissolved water column Cu concentrations in Bodkin Creek are attaining water quality standards and therefore are supportive of the Use II designation for the embayment.

Three water column surveys were conducted as part of the MMCS at ten monitoring stations throughout Bodkin Creek from 2005 to 2007. Water column samples were collected on 11/01/05, 6/14/06, and 4/30/07 to capture seasonal variations. These samples were analyzed by UMCES CBL for hardness (mg/L), salinity (grams/Liter (g/L)), and dissolved Cu (µg/L) concentrations. Sediment samples were also collected on 6/14/06 at five of the monitoring stations. These sediment samples were used in the ambient sediment bioassays conducted by UM WREC.

Monitoring station information including geographical coordinates and media sampled (sediment or water column) is presented in Table 4. A map of the monitoring station locations in Bodkin Creek is presented in Figure 4. An assessment of the water column and sediment Cu concentrations in Bodkin Creek is presented in sections 3.1 and 3.2, respectively.

Table 4: Bodkin Creek MMCS Monitoring Stations

Station ID	Latitude	Longitude	Sample Media	
			Water Column	Sediment
BKN-1	39.134983	-76.434633	✓	✓
BKN-2	39.132167	-76.447417	✓	
BKN-3	39.130900	-76.459267	✓	✓
BKN-4	39.133717	-76.469617	✓	
BKN-5	39.127117	-76.443200	✓	✓
BKN-6	39.128667	-76.449767	✓	
BKN-7	39.126217	-76.458483	✓	✓
BKN-8	39.126200	-76.469667	✓	
BKN-9	39.124250	-76.479033	✓	
BKN-10	39.119217	-76.445733	✓	✓

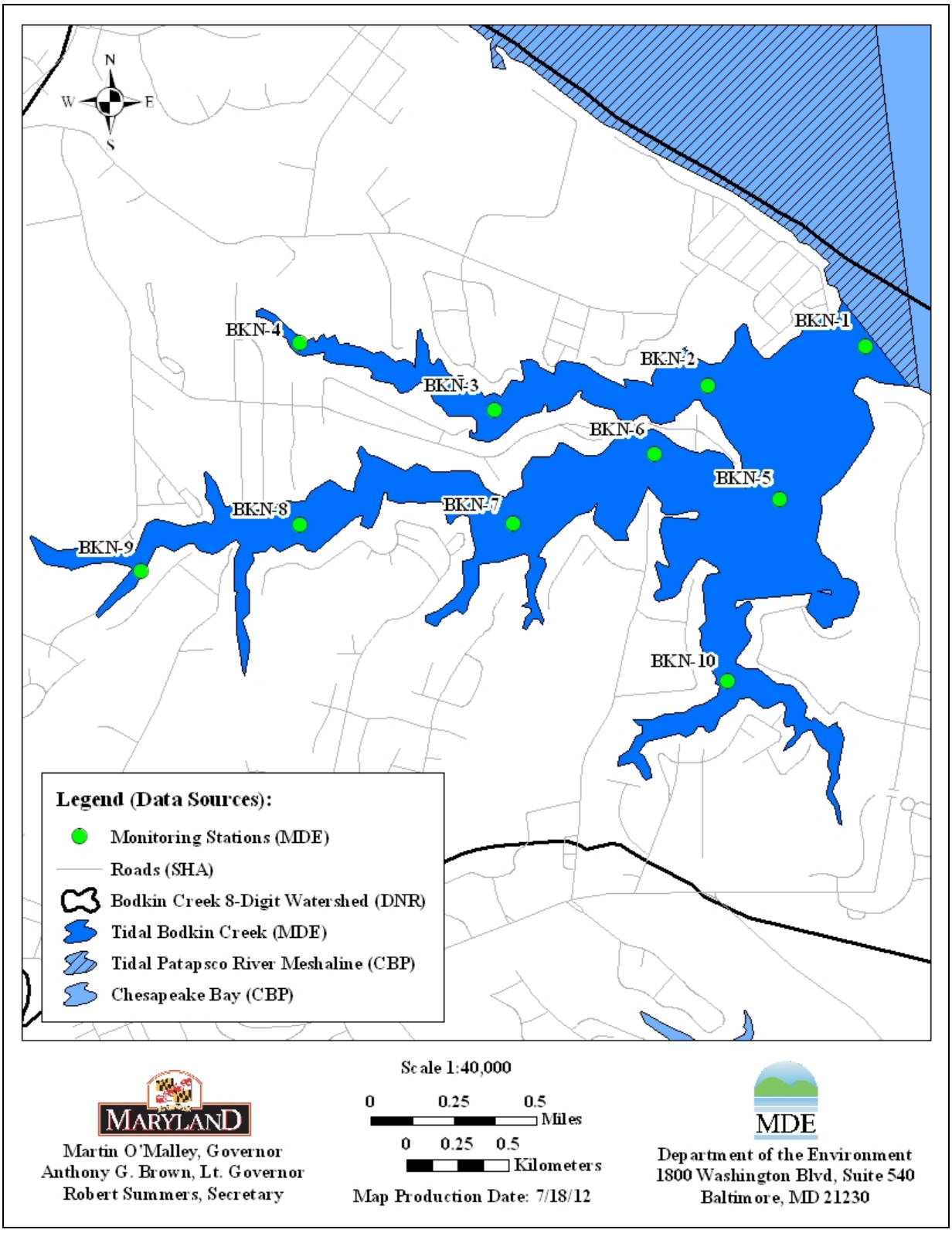

Figure 4: Bodkin Creek MMCS Monitoring Stations Location Map

3.1 WATER QUALITY EVALUATION

A data solicitation for information pertaining to the Cu impairment to aquatic life in Bodkin Creek, as identified in the 2010 Integrated Report, was conducted by MDE in 2012 and all readily available data from the past five years has been considered.

Within this analysis, the saltwater aquatic life chronic Cu criterion is compared to the dissolved water column Cu concentrations in Bodkin Creek to determine whether water quality standards are being met (i.e., whether or not Cu is impairing the aquatic life designated use of the embayment). EPA guidance for development of the 305(b) report (Maryland's Water Quality Inventory) states that, with a minimum of ten samples over a three-year period, the designated use is not supported if greater than ten percent of the samples exceed the appropriate benchmark (US EPA 1997). MDE has adopted EPA's guidance as the official Integrated Report assessment methodology for identifying whether or not waterbodies are impaired by toxic contaminants/metals (MDE 2012). Therefore a waterbody is not impaired for metals/toxics as long as less than or equal to ten percent of the sample data for the assessment does not exceed the applicable water quality criteria.

Water quality data gathered from the MMCS study including hardness (mg/L), salinity (mg/L), and dissolved water column Cu concentrations (µg/L) is displayed in Table 5 along with the applicable saltwater aquatic life chronic Cu criterion. A graph comparing the saltwater aquatic life chronic Cu criterion and the dissolved water column Cu concentration data in Bodkin Creek is presented in Figure 5. Hardness concentrations in Bodkin Creek ranged between 475.0 and 1,451 mg/L. Dissolved water column Cu concentrations ranged between 0.54 and 4.16 µg/L. Dissolved water column Cu concentrations were less than the saltwater aquatic life acute Cu criterion in all 30 water column samples and exceeded the saltwater aquatic life chronic Cu criterion in only three out of 30 water column samples. Thus, only 10% of the samples exceed the criterion, and consequently, based on MDE's official Integrated Report assessment methodology and water quality criteria for toxic contaminants/metals in the water column, Cu concentrations in the water column are not impairing the aquatic life designated use of Bodkin Creek.

Samples from the MMCS were collected discretely (grab samples), which means they are only considered to be representative of an acute exposure (duration time of one hour in the water column) instead of a chronic exposure (duaration time of 96 hours, during which the Cu concentrations could change significantly over this period depending on watershed flow and tidal flushing). The three samples that exceeded the saltwater aquatic life chronic Cu criterion ranging between 3.14 and 4.16 µg/L did not exceed the saltwater aquatic life acute Cu criterion of 4.8 µg/L. This additional information further demonstrates that water column Cu concentrations are not an impairing the aquatic life designated use of Bodkin Creek.

Table 5: Bodkin Creek MMCS Study Water Column Data

Station	Sample Date	Hardness (mg/L)	Salinity (g/L)	Dissolved Cu Concentration (µg/L) [1]	Saltwater Aquatic Life Chronic Criterion (µg/L)	Saltwater Aquatic Life Acute Criterion (µg/L)
BKN-1	11/01/05	1438	7.3	2.00	3.1	4.8
	06/14/06	1451	9.1	2.12	3.1	4.8
	04/30/07	542	3.1	1.24	3.1	4.8
BKN-2	11/01/05	1246	7.6	2.02	3.1	4.8
	06/14/06	1121	9.0	**3.14**	3.1	4.8
	04/30/07	524	2.7	1.60	3.1	4.8
BKN-3	11/01/05	1285	8.3	2.64	3.1	4.8
	06/14/06	1190	8.6	1.97	3.1	4.8
	04/30/07	561	3.0	1.71	3.1	4.8
BKN-4	11/01/05	1208	8.3	2.82	3.1	4.8
	06/14/06	1344	8.5	2.52	3.1	4.8
	04/30/07	486	2.8	1.81	3.1	4.8
BKN-5	11/01/05	1198	8.0	2.12	3.1	4.8
	06/14/06	1346	8.9	2.91	3.1	4.8
	04/30/07	561	2.8	2.29	3.1	4.8
BKN-6	11/01/05	1342	8.4	2.47	3.1	4.8
	06/14/06	1140	8.8	2.19	3.1	4.8
	04/30/07	512	3.0	1.58	3.1	4.8
BKN-7	11/01/05	1342	8.4	2.74	3.1	4.8
	06/14/06	1280	8.6	2.92	3.1	4.8
	04/30/07	542	3.2	1.83	3.1	4.8
BKN-8	11/01/05	1198	8.4	**4.16**	3.1	4.8
	06/14/06	1281	8.3	2.52	3.1	4.8
	04/30/07	561	3.4	2.20	3.1	4.8
BKN-9	11/01/05	1131	8.0	3.00	3.1	4.8
	06/14/06	1109	7.6	1.69	3.1	4.8
	04/30/07	475	3.2	1.64	3.1	4.8
BKN-10	11/01/05	2128	8.1	2.91	3.1	4.8
	06/14/06	1467	8.8	**3.76**	3.1	4.8
	04/30/07	468	3.0	0.54	3.1	4.8

Note: [1]Dissolved water column Cu concentrations that exceed the saltwater aquatic life chronic criterion are displayed in bold.

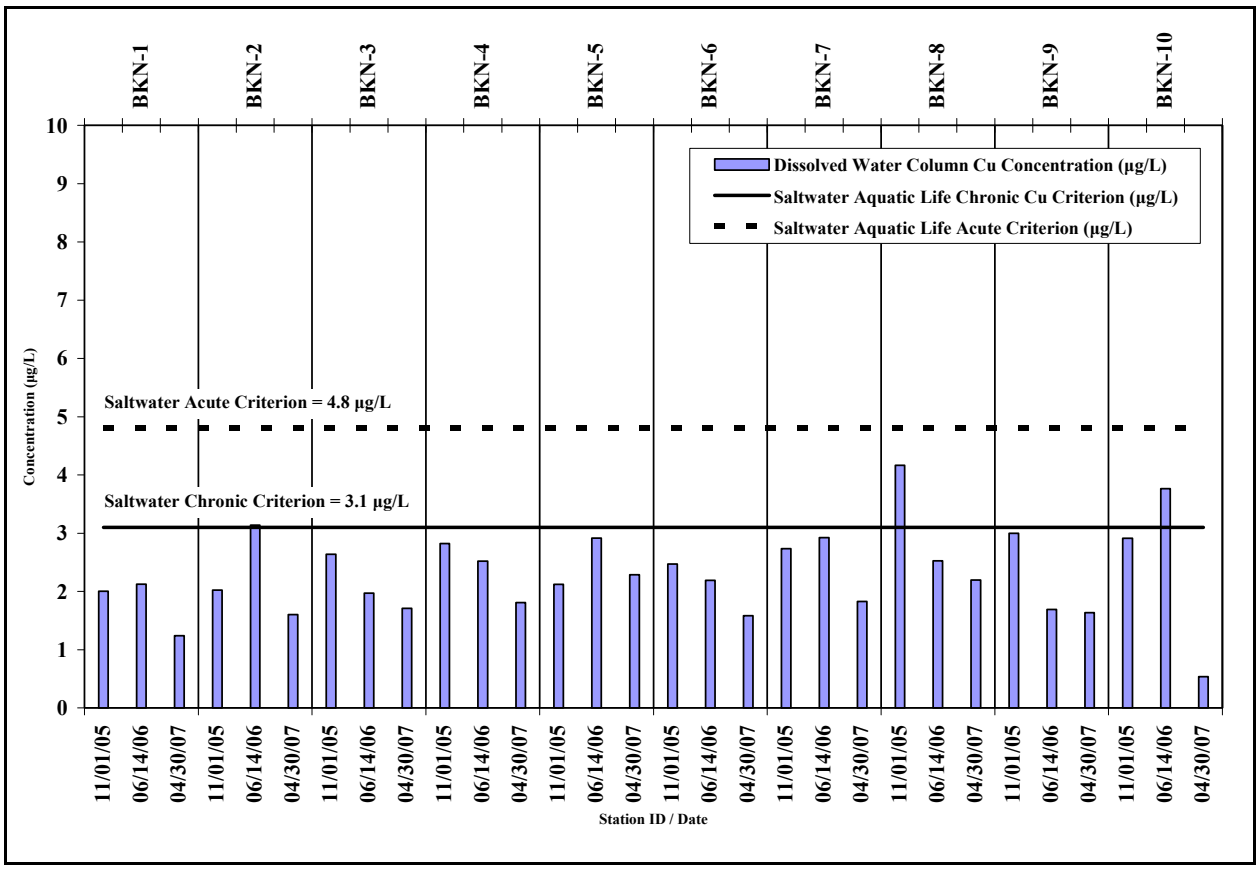

Figure 5: Comparison of Saltwater Aquatic Life Chronic Cu Criterion and Dissolved Water Column Cu Concentrations in Bodkin Creek

3.2 SEDIMENT QUALITY EVALUATION

Maryland's current water quality standards do not include criteria for toxic substance and/or metals concentrations in sediments. Ambient sediment bioassays were conducted for this analysis to assess whether or not toxic contaminant/metals in Bodkin Creek sediments adversely impact aquatic life.

Three ambient sediment bioassays to assess sediment toxicity within Bodkin Creek were conducted by UM WREC as part of the MMCS using sediments data collected from five stations in the embayment. The tests include a 10-day survival and growth test with the freshwater amphipod *Hyalella azteca*, a 10-day survival and growth test with the estuarine amphipod *Leptocheirus plumulosus*, and a 28-day survival, growth, and reproduction test with the estuarine amphipod *Leptocheirus plumulosus* (Heyes et al. 2007). These species were chosen because of their practical and ecological relevance and applicability in EPA recommended test methods for assessing the toxicity of freshwater and marine/estuarine sediments (US EPA 2000, 2001).

The bioassays were conducted for five surficial sediment samples collected on June 14th, 2006 using a petite ponar dredge sampling device (top 2-3 centimeters (cm)) in Bodkin Creek. Monitoring station locations where sediment data was collected are referenced in Table 4. Control site sediment data was collected from the Wye River, in a depositional area with low levels of toxic contaminants/metals. For each bioassay, test organisms (amphipods) were exposed to field sediments from the five monitoring stations sampled in Bodkin Creek and a control sediment for the designated time period (10-day or 28-day). Individual tests for each field and control sediment sample are referred to as treatments. For the 10-day freshwater and estuarine bioassays, each field and control treatment was replicated eight times. For the 28-day estuarine bioassay, each field and control treatment was replicated five times. Each control and field treatment for the 10-day and 28-day bioassays contained ten and twenty amphipod organisms, respectively.

A summary of the results from all three sediment bioassays is presented in Table 6. Detailed results from each sediment bioassay, 10-day freshwater amphipod, 10-day estuarine amphipod, and 28-day estuarine amphipod, are presented in Tables 7, 8, and 9, respectively.

Summary results for average survival, average growth or growth rate, and average reproduction are presented for each of the three sediment bioassays, when applicable, in Table 6. Table 7 presents the survival and growth results from the 10-day freshwater amphipod bioassay. Table 8 presents the survival and growth results from the 10-day estuarine amphipod bioassay. Table 9 presents the survival, growth rate, and reproduction results from the 10-day estuarine amphipod bioassay. In each table, the results are presented for all treatment replicates as well as the overall average of the treatments by Bodkin Creek monitoring station and control site.

Bioassay test performance criteria require a survival rate of 80 % in the control treatment, as well as measurable growth and reproduction of neonates (amphipod offspring) in order to validate field treatment results. The average survival of amphipods ranged between 93.8 and 98.8 % for the 10-day freshwater amphipod bioassay, 61.3 and 81.3 % for the 10-day estuarine amphipod bioassay, and 71.0 and 89.0 % for the 28-day estuarine amphipod bioassay. Average survival of amphipods in the control treatments was 98.8 %, 81.3 %, and 87 % for the 10-day freshwater

amphipod bioassay, 10-day estuarine amphipod bioassay, and 28-day estuarine amphipod bioassay, respectively. A statistical comparison was made between the control and field treatment amphipod survival percentages using Fisher's Least Significance Difference (LSD) test ($\sigma = 0.05$). Average survival for field treatments in all three bioassays were not significantly less than the average survival in the control treatment; therefore, Bodkin Creek sediments do not exhibit toxicity and toxic contaminants/metals in the sediments are not contributing to the mortality of the test organisms.

For each bioassay, the average growth (milligrams (mg)) or growth rate (milligrams per day (mg/day)) of amphipods ranged between 0.17 and 0.27 mg for the 10-day freshwater amphipod bioassay, 0.16 and 0.36 mg for the 10-day estuarine amphipod bioassay, and 0.044 and 0.076 mg/day for the 28-day estuarine amphipod bioassay. Average growth or growth rate of amphipods in the control treatments was 0.18 mg, 0.23 mg, and 0.064 mg/day, for the 10-day freshwater amphipod bioassay, 10-day estuarine amphipod bioassay, and 28-day estuarine amphipod bioassay, respectively. A statistical comparison was also made between the control and field treatment average amphipod growth or growth rate using Fisher's LSD test ($\sigma = 0.05$). Average growth or growth rate for field treatments in all three bioassays were not significantly less than the average growth or growth rate in the control treatment; therefore, Bodkin Creek sediments do not exhibit toxicity and toxic contaminants/metals in the sediments are not contributing to a reduction in growth or growth rate of the test organisms.

For the 28-day estuarine amphipod bioassay, average amphipod reproduction ranged between 3.1 and 11.8 neonates per amphipod. Average amphipod reproduction in the control treatment was 5.1 neonates per amphipod. A statistical comparison was also made between the control and field treatment average amphipod reproduction using Fisher's LSD test ($\sigma = 0.05$). Average amphipod reproduction for field treatments was not statistically significantly less than the average amphipod reproduction in the control treatment; therefore, Bodkin Creek sediments do not exhibit toxicity and toxic contaminants/metals in the sediments are not contributing to a reduction in the reproduction of test organisms.

Table 6: Bodkin Creek Sediment Bioassay Results Summary

	***H. azteca* 10-day**		***L. plumulosus* 10-day**		***L. plumulosus* 28-day**		
Monitoring Station	**Survival** (%)	**Average Growth** (mg)	**Average Survival** (%)	**Average Growth** (mg)	**Average Survival** (%)	**Average Growth Rate** (mg/day)	**Average Reproduction** (# neonates)
Control	98.8	0.18	81.3	0.23	87.0	0.064	5.1
BKN-1	95.0	0.27	71.3	0.19	89.0	0.045	3.1
BKN-3	93.8	0.18	81.3	0.36	77.0	0.071	7.3
BKN-5	97.5	0.17	67.5	0.16	71.0	0.044	5.1
BKN-7	98.8	0.19	80.0	0.24	84.0	0.076	11.8
BKN-10	93.8	0.19	61.3	0.27	82.0	0.074	9.4

Table 7: Bodkin Creek 10-day Freshwater Amphipod *Hyalella azteca* Sediment Bioassay Results

Monitoring Station/Treatment	Amphipod Survival (#)	Amphipod Growth (mg)	Average Amphipod Survival (% (SD[1]))	Average Amphipod Growth (mg (SD[1]))
Control A	10	0.18	98.8 (3.54)	0.18 (0.015)
Control B	9	0.2		
Control C	10	0.19		
Control D	10	0.18		
Control E	10	0.18		
Control F	10	0.15		
Control G	10	0.18		
Control H	10	0.19		
BKN-1 A	9	0.26	95.0 (7.56)	0.27 (0.013)
BKN-1 B	10	0.27		
BKN-1 C	9	0.28		
BKN-1 D	10	0.27		
BKN-1 E	8	0.27		
BKN-1 F	10	0.27		
BKN-1 G	10	0.24		
BKN-1 H	10	0.28		
BKN-3 A	9	0.16	93.8 (7.44)	0.18 (0.015)
BKN-3 B	10	0.18		
BKN-3 C	8	0.18		
BKN-3 D	10	0.19		
BKN-3 E	9	0.21		
BKN-3 F	10	0.19		
BKN-3 G	10	0.18		
BKN-3 H	9	0.17		

Note: [1]SD: Standard Deviation

Monitoring Station/Treatment	**Amphipod Survival** (#)	**Amphipod Growth** (mg)	**Average Amphipod Survival** (% (SD[1]))	**Average Amphipod Growth** (mg (SD[1]))
BKN-5 A	10	0.18	97.5 (4.63)	0.17 (0.006)
BKN-5 B	9	0.16		
BKN-5 C	10	0.17		
BKN-5 D	9	0.17		
BKN-5 E	10	0.17		
BKN-5 F	10	0.17		
BKN-5 G	10	0.17		
BKN-5 H	10	0.18		
BKN-7 A	9	0.21	98.8 (3.54)	0.19 (0.020)
BKN-7 B	10	0.19		
BKN-7 C	10	0.17		
BKN-7 D	10	0.2		
BKN-7 E	10	0.22		
BKN-7 F	10	0.17		
BKN-7 G	10	0.17		
BKN-7 H	10	0.18		
BKN-10 A	10	0.18	93.8 (7.44)	0.19 (0.011)
BKN-10 B	9	0.2		
BKN-10 C	10	0.2		
BKN-10 D	9	0.18		
BKN-10 E	10	0.2		
BKN-10 F	9	0.19		
BKN-10 G	10	0.17		
BKN-10 H	8	0.19		

Note: [1]SD: Standard Deviation

Table 8: Bodkin Creek 10-day Estuarine Amphipod *Leptocheirus plumulosus* Sediment Bioassay Results

Monitoring Station/Treatment	**Amphipod Survival** (#)	**Amphipod Growth** (mg)	**Average Amphipod Survival** (% (SD))	**Average Amphipod Growth Rate** (mg (SD))
Control A	7	0.21	81.3 (14.58)	0.23 (0.104)
Control B	8	0.33		
Control C	6	0.29		
Control D	10	0.27		
Control E	10	0.1		
Control F	9	0.16		
Control G	7	0.39		
Control H	8	0.12		
BKN-1 A	7	0.1	71.3 (18.85)	0.19 (0.097)
BKN-1 B	6	0.11		
BKN-1 C	9	0.13		
BKN-1 D	10	0.21		
BKN-1 E	7	0.34		
BKN-1 F	8	0.17		
BKN-1 G	4	0.34		
BKN-1 H	6	0.15		
BKN-3 A	8	0.4	81.3 (9.91)	0.36 (0.082)
BKN-3 B	9	0.37		
BKN-3 C	7	0.36		
BKN-3 D	7	0.39		
BKN-3 E	8	0.35		
BKN-3 F	8	0.18		
BKN-3 G	10	0.36		
BKN-3 H	8	0.47		

Monitoring Station/Treatment	**Amphipod Survival** (#)	**Amphipod Growth** (mg)	**Average Amphipod Survival** (% (SD))	**Average Amphipod Growth Rate** (mg (SD))
BKN-5 A	9	0.18	67.5 (12.82)	0.16 (0.064)
BKN-5 B	7	0.14		
BKN-5 C	7	0.18		
BKN-5 D	5	0.06		
BKN-5 E	5	0.09		
BKN-5 F	7	0.13		
BKN-5 G	7	0.22		
BKN-5 H	7	0.25		
BKN-7 A	7	0.28	80.0 (19.27)	0.24 (0.096)
BKN-7 B	8	0.38		
BKN-7 C	10	0.22		
BKN-7 D	10	0.11		
BKN-7 E	8	0.28		
BKN-7 F	5	0.09		
BKN-7 G	10	0.28		
BKN-7 H	6	0.27		
BKN-10 A	9	0.2	61.3 (21.00)	0.27 (0.111)
BKN-10 B	7	0.39		
BKN-10 C	6	0.34		
BKN-10 D	5	0.21		
BKN-10 E	5	0.41		
BKN-10 F	3	0.24		
BKN-10 G	9	0.31		
BKN-10 H	5	0.08		

Table 9: Bodkin Creek 28-day Estuarine Amphipod *Leptocheirus plumulosus* Sediment Bioassay Results

Monitoring Station/Treatment	Amphipod Survival (#)	Amphipod Growth Rate (mg/day)	Neonates (#)	Average Amphipod Survival (%)	Average Amphipod Growth Rate (mg/day)	Average Amphipod Reproduction (# neonates)
Control A	17	0.089	5.2	87	0.064	5.1
Control B	18	0.041	4.4			
Control C	17	0.067	7.2			
Control D	20	0.058	5.9			
Control E	15	0.064	2.9			
BKN-1 A	17	0.035	4.5	89	0.045	3.1
BKN-1 B	20	0.045	2.2			
BKN-1 C	20	0.052	2.9			
BKN-1 D	14	0.048	3.4			
BKN-1 E	18	0.043	2.4			
BKN-3 A	20	0.072	5.9	77	0.071	7.3
BKN-3 B	8	0.037	8.5			
BKN-3 C	17	0.079	7.7			
BKN-3 D	18	0.083	6.7			
BKN-3 E	15	0.084	8			
BKN-5 A	4	0.033	8.3	71	0.044	5.1
BKN-5 B	15	0.074	9			
BKN-5 C	19	0.045	4.2			
BKN-5 D	13	0.025	2.5			
BKN-5 E	20	0.041	1.8			
BKN-7 A	18	0.078	9.5	84	0.076	11.8
BKN-7 B	16	0.07	14			
BKN-7 C	19	0.076	12.8			
BKN-7 D	16	0.08	10			
BKN-7 E	15	0.076	12.6			
BKN-10 A	18	0.071	6.6	82	0.074	9.4
BKN-10 B	19	0.078	7.1			
BKN-10 C	17	0.08	11.4			
BKN-10 D	14	0.056	11.7			
BKN-10 E	14	0.087	10.2			

4.0 CONCLUSION

Based on the analysis presented in this report, it is concluded that the Cu water quality criterion for the protection of aquatic life designated use is being met within Bodkin Creek, thus indicating that the embayment is not impaired for Cu. The Bodkin Creek Cu impairment was evaluated via a comparison of dissolved water column Cu concentrations and the saltwater aquatic life chronic Cu criterion. This comparison demonstrated that dissolved water column Cu concentrations never exceeded the acute criterion in all 30 water column samples and exceeded the chronic criterion in only three out of 30 water column samples, which only equates to a 10% exceedance rate. MDE follows EPA's guidance for assessing water quality impairments for toxic substances/metals, which state that, using a minimum of ten samples, a waterbody is not impaired for metals/toxics as long as less than or equal to ten percent of the sample data for the assessment does not exceed the applicable water quality criteria.

The water column monitoring data applied in this analysis were collected as part of the MMCS. These samples were collected discretely (grab samples), meaning that they are only considered to be representative of an acute exposure (duration time of one hour in the water column) instead of a chronic exposure (duration time of 96 hours), during which the concentrations could change significantly depending on watershed flow and tidal flushing. The three water column samples that exceeded the saltwater aquatic life chronic Cu criterion, ranging between 3.14 and 4.16 µg/L, did not exceed the saltwater aquatic life acute Cu criterion of 4.8 µg/L. Also, exceedances did not occur more than once at any monitoring station.or at monitoring stations adjacent to one another within the embayment. This further demonstrates that dissolved water column Cu concentrations are not impairing the Bodkin Creek protection of aquatic life designated use.

Maryland's current water quality standards do not include criteria for toxic substance and/or metals concentrations in sediments. However, ambient sediment bioassays were conducted for this analysis to assess whether or not toxic contaminant/metals concentrations in Bodkin Creek sediments adversely impact aquatic life. Results of these tests found that Bodkin Creek sediments do not exhibit signs of toxicity, and thus the toxic contaminant/metal concentrations in the sediments are not contributing to a reduction in the survival, growth, or reproduction of test organisms.

Therefore, the results from both the water column and sediment assessments indicate that Cu concentrations in the water column and sediment do not adversely impact aquatic life in Bodkin Creek; therefore, the water quality standards are being met and the designated use protective of aquatic life is supported.

Barring the receipt of contradictory data, this report will be used to support the revision of the 2010 Integrated Report Cu listing for Bodkin 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 Cu 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 Bodkin Creek do not display signs of a Cu impairment to aquatic life in the water column or sediment, the State reserves the right to require future controls if evidence suggests that Cu from the watershed is contributing to downstream water quality problems.

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