Watershed Report for Biological Impairment of the Aberdeen Proving Ground in Harford County, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

DEPARTMENT OF THE ENVIRONMENT
1800 Washington Boulevard, Suite 540
Baltimore, Maryland 21230-1718

Submitted to:

Water Protection Division
U.S. Environmental Protection Agency, Region III
1650 Arch Street
Philadelphia, PA 19103-2029

January 2014

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
IR	Integrated Report
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
mg/L	Milligrams per liter
MS4	Municipal Separate Storm Sewer System
n	Number
NPDES	National Pollution Discharge Elimination System
PCB	Polychlorinated Biphenyls
PSU	Primary Sampling Unit
RESAC	Regional Earth Science Applications Center
SSA	Science Services Administration
SSO	Sanitary Sewage Overflow
TP	Total Phosphorous
TSS	Total Suspended Solids
TMDL	Total Maximum Daily Load
µeq/L	Micro equivalent per liter
µS/cm	Micro Siemens per centimeter
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
WWTP	Waste Water Treatment Plant

Executive Summary

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) 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. 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. 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 Water Quality Analysis (WQA) that water quality standards are being met.

The Aberdeen Proving Ground watershed (basin code 02130705), located in Harford County, MD, is associated with three assessment units in the Integrated Report (IR): non-tidal (8-digit basin) and two estuarine portions (Chesapeake Bay segment). The estuarine Chesapeake Bay segments related to the Aberdeen Proving Ground are the Northern Chesapeake Bay Tidal Fresh (CB1TF) and Northern Chesapeake Bay Oligohaline (CB2OH). Below is a table identifying the listings associated with this watershed (MDE 2012).

Table E1. 2012 Integrated Report Listings for the Aberdeen Proving Ground Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Aberdeen Proving Ground	02130705	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
Northern Chesapeake Bay Tidal Fresh	CB1TF - 02139996 02120201 02130609 02130705	Tidal	Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	TP	4a
					TN	
			Seasonal Shallow Water Submerged Aquatic Vegetation Subcategory	-	TSS	2
	CB1TF- 02130705		Aquatic Life and Wildlife	1996	Toxics	5
	CB1TF - 02139996 02120201 02130609 02130705			-	Impacts to Biological Communities	2
			Open-Water Fish and Shellfish	1996	TP	4a
					TN	
Northern Chesapeake Bay Oligohaline	CB2OH - 02139996 02139997 02130611 02130705 02130901		Seasonal Shallow Water Submerged Aquatic Vegetation Subcategory	-	TSS	2
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	TN	4a
					TP	
			Aquatic Life and Wildlife	-	Impacts to Biological Communities	2
			Open-Water Fish and Shellfish	1996	TN	4a
					TP	

In 2002, the State began listing biological impairments on the Integrated Report. The current MDE biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings in the Integrated Report are made, how TMDLs are developed, and how implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds with multiple impacted sites by measuring the percentage of stream miles that have an Index of Biotic Integrity (IBI) score of less than three, and calculating whether this is a significant deviation from reference condition watersheds (i.e., healthy stream, less than 10% stream miles degraded).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Aberdeen Proving Ground watershed's tributaries including Boone Creek (Edgewood Area), Delph Creek, Dipper Creek, Old Womans Creek, and Romney Creek are designated as Use I - *water contact recreation, and protection of nontidal*

warmwater aquatic life. Spesutie Narrows and Back Creek at Spesutie Island are designated as Use II - *support of estuarine and marine aquatic life and shellfish harvesting*. The headwaters of Mosquito Creek and Woodrest Creek are designated as Use I, as they approach the confluence with the Chesapeake Bay both streams become Use II (COMAR 2013a, b, c, d, e). The Aberdeen Proving Ground watershed is not attaining its designated use of protection of aquatic life because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, thus enabling the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact these stressors would have on the degraded sites in the watershed.

The BSID analysis uses data available from the statewide MDDNR MBSS. Once the BSID analysis is completed, a number of stressors (pollutants) may be identified as probable or unlikely causes of poor biological conditions within the Maryland 8-digit watershed study. BSID analysis results can be used as guidance to refine biological impairment listings in the Integrated Report by specifying the probable stressors and sources linked to biological degradation.

This Aberdeen Proving Ground watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and which may be reviewed in more detail in the report entitled “Maryland Biological Stressor Identification Process” (MDE 2009). Data suggest that the degradation of biological communities in the Aberdeen Proving Ground watershed is due to urban land use and its altered hydrology concomitant effects. Peer-reviewed scientific literature establishes a link between highly urbanized landscapes and degradation, e.g., urban runoff contamination (nutrients) of surface waters, in the aquatic health of non-tidal stream ecosystems.

The results of the BSID process, and the probable causes and sources of the biological impairments in the Aberdeen Proving Ground watershed can be summarized as follows:

- The BSID process did not identify sediment stressors in the non-tidal portion of the Aberdeen Proving Ground watershed.

- The BSID process has determined that biological communities in the Aberdeen Proving Ground watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization as pollution,

not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Aberdeen Proving Ground watershed based on channelization being present in approximately 67% of degraded stream miles.

- The BSID process has also determined that biological communities in the Aberdeen Proving Ground watershed are likely degraded due to nutrient related stressors. Specifically, anthropogenic impacts in the Coastal Plain physiographic region have resulted in subsequent elevated nutrients in the watershed, which are in turn the probable causes of impacts to biological communities. With identification of water chemistry stressors the BSID results confirm the tidal 1996 Category 4a listing for TP as an appropriate management action in the watershed, and links this pollutant to biological conditions in these waters and extends the impairment to the watershed's non-tidal waters. Therefore, the establishment of nutrient reductions through the 2010 Chesapeake Bay TMDL was an appropriate management action to begin addressing these stressors impact to the biological communities in the Aberdeen Proving Ground watershed.

1.0 Introduction

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) 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 Water Quality Analysis (WQA) that water quality standards are being met. In 2002, the State began listing biological impairments on the Integrated Report. Maryland Department of the Environment (MDE) has developed a biological assessment methodology to support the determination of proper category placement for 8-digit watershed listings.

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2009). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or blackwater streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, less than 10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary. A Category 5 listing can be amended to a Category 4a if a TMDL was established and approved by the USEPA.

The MDE biological stressor identification (BSID) analysis applies a case-control, risk-based approach that uses the principal dataset, with considerations for ancillary data, to identify potential causes of the biological impairment. Identification of stressors responsible for biological impairments was limited to rounds two and three of the Maryland Biological Stream Survey (MBSS) dataset (2000–2004; 2007-2009) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists. Once the BSID analysis is completed, one

or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

The remainder of this report provides a characterization of the Aberdeen Proving Ground watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Aberdeen Proving Ground Watershed Characterization

2.1 Location

The Aberdeen Proving Ground watershed is located entirely within Harford County, Maryland (see Figure 1). The watershed encompasses two peninsulas separated by the Bush River. Its northernmost point is near the mouth of the Susquehanna River, where the river enters the Chesapeake Bay, while on the south, it is bordered by the Gunpowder River. The northeastern section is known as the Aberdeen Area, which drains 20,525 acres and the southwestern section is the Edgewood Area, which drains 1,100 acres in the Gunpowder Neck Peninsula. The total drainage area of the Maryland 8-digit watershed is approximately 21,625 acres. The major tributaries include Boone Creek at the Edgewood Area, Back Creek on Spesutie Island, Delph Creek, Mosquito Creek, and Romney Creek. The watershed is located in the Coastal Plain region, one of three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005a) (see Figure 2).

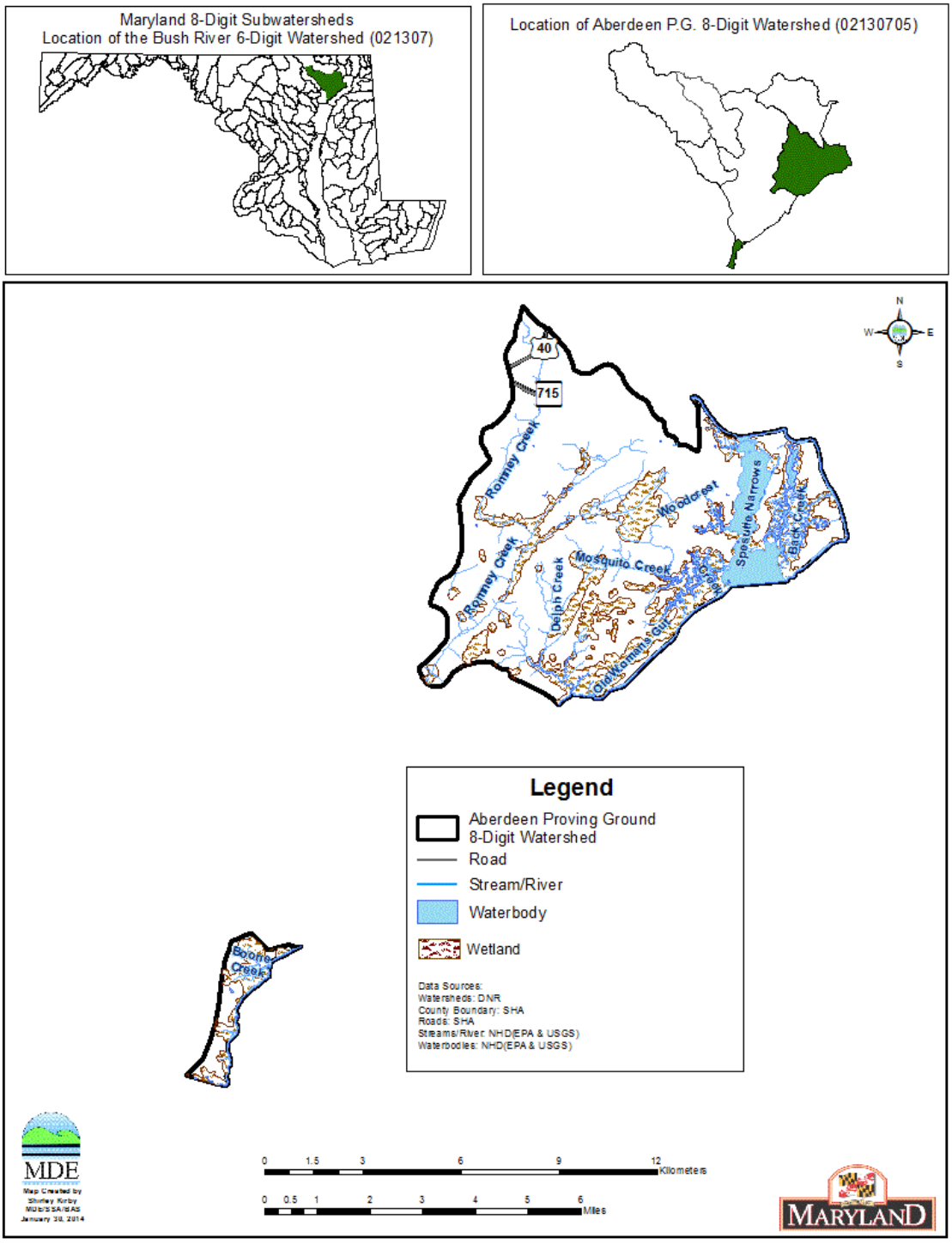

Figure 1. Location Map of the Aberdeen Proving Ground Watershed

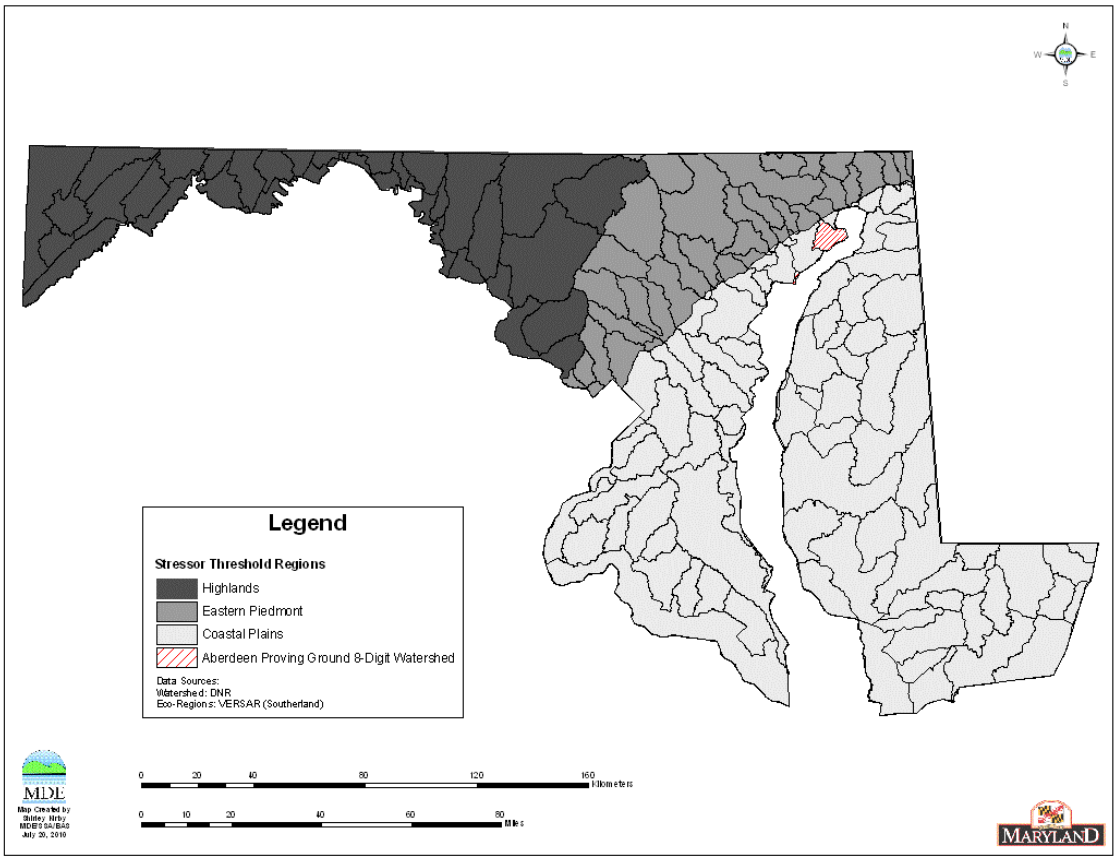

Figure 2. Eco-Region Location Map of the Aberdeen Proving Ground Watershed

2.2 Land Use

The Aberdeen Proving Ground watershed is primarily forest land use; urban land use is secondary (see Figure 3). The Aberdeen Proving Ground military facility includes an airfield, a golf course, and chemical, ordinance, and military training facilities. Aberdeen Proving Ground was the U.S. Army's primary chemical warfare research and development center, chemical manufacturing and munitions was concentrated in the area of the West Branch and East Branch Canal Creek in the Bush River watershed. Potentially contaminated materials were pushed out into Canal Creek wetland in the 1960s, and in 2006 all chemical weapons were destroyed (USGS 2002). State and county paved roads, such as US 40 and Route 715, and several minor roads interconnect points within the watershed. The land use distribution in the watershed is approximately 38% forest/herbaceous, 37% urban, 23% water, and 1% agriculture (see Figure 4). Urban impervious surface is 5% of the total land use in the watershed (USEPA 2010).

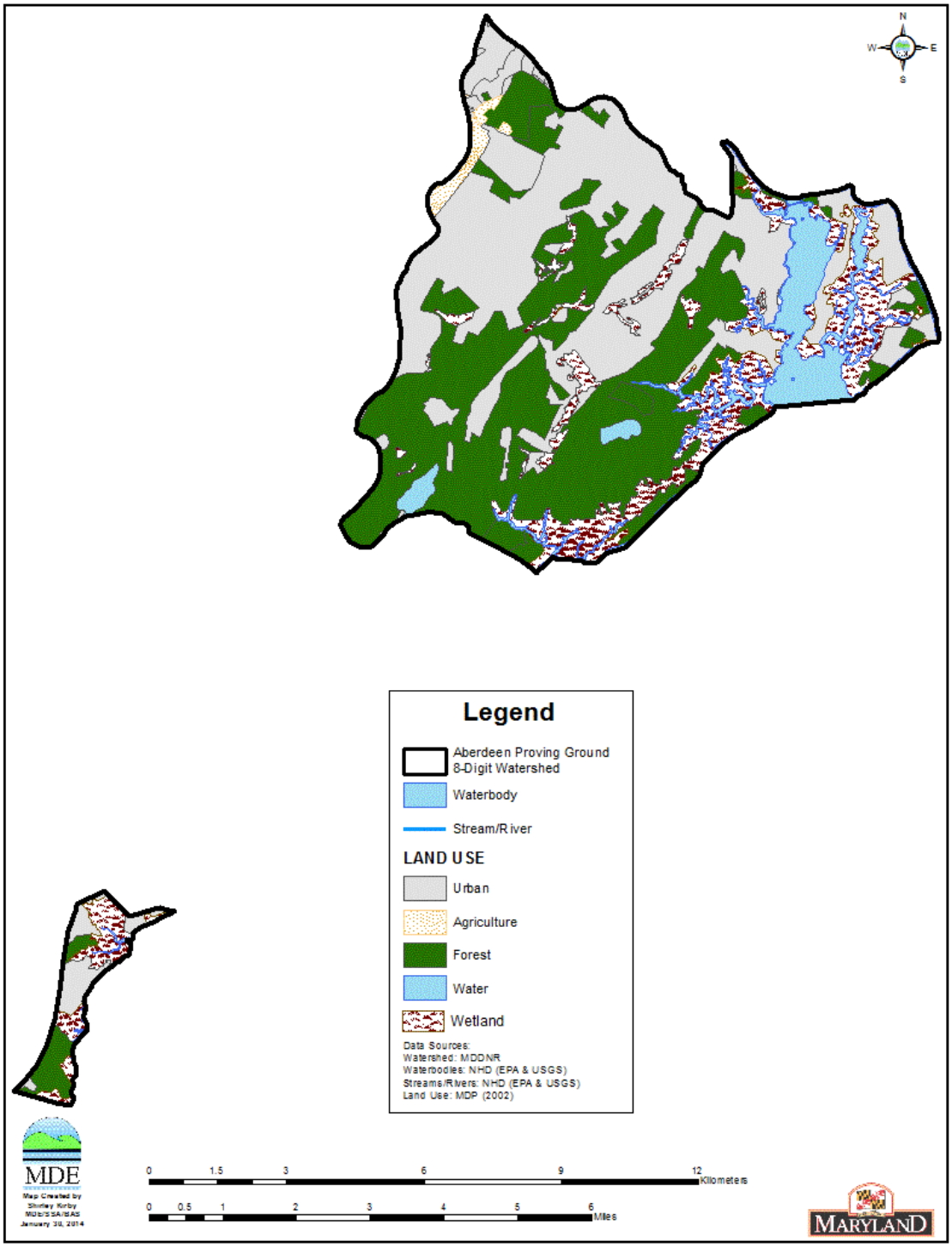

Figure 3. Land Use Map of the Aberdeen Proving Ground Watershed

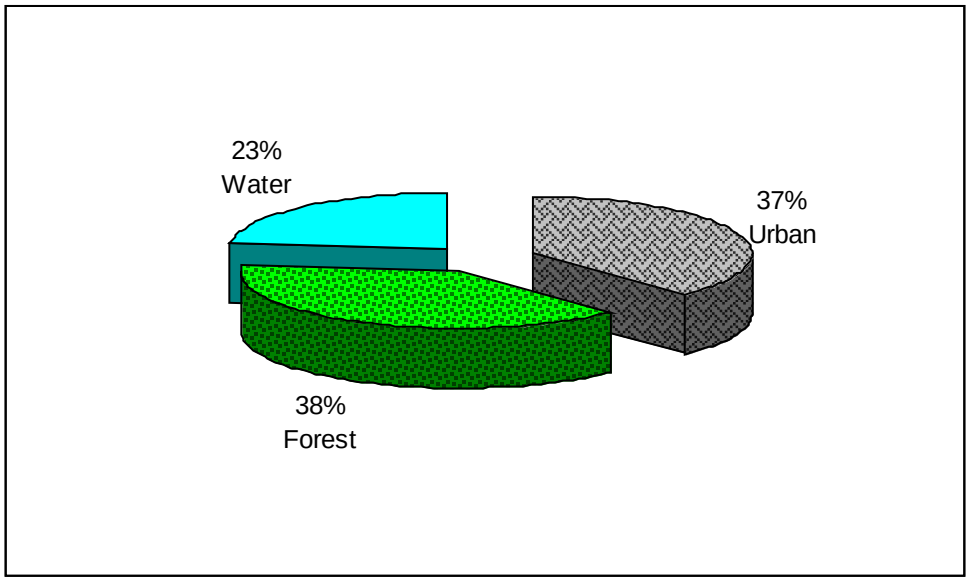

Figure 4. Proportions of Land Use in the Aberdeen Proving Ground Watershed

2.3 Soils/hydrology

The Aberdeen Proving Ground watershed lies within the Coastal Plain physiographic region, which is a wedge-shaped mass of primarily unconsolidated sediments of the Lower Cretaceous, Upper Cretaceous and Pleistocene Ages covered by sandy soils. The Coastal Plain Region is characterized by lower relief, and is drained by slowly meandering streams with shallow channels and gentle slopes (MGS 2007).

There are two soil series in the watershed, Beltsville and Othello, with Othello being dominant. These soils consist of unconsolidated deposits of gravel, sand, silt, and clay. The drainage capacity of the soils range from poor to moderate, and are strongly to extremely acidic. The soils have a low to moderate erosion potential; the hazard of erosion is severe if soil is regularly tilled. The topography ranges from sea level along the Chesapeake Bay to an elevation of about 90 feet near the town of Aberdeen (NRCS 1975).

3.0 Aberdeen Proving Ground Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment has identified the non-tidal areas of the Aberdeen Proving Ground watershed on the State's Integrated Report under Category 5 as impaired by evidence of biological impacts (2002 listings). The Aberdeen Proving Ground watershed (basin code 02130705), located in Harford County, MD, is associated

with three assessment units in the Integrated Report (IR): non-tidal (8-digit basin) and two estuarine portions (Chesapeake Bay segment). The estuarine Chesapeake Bay segments related to the Aberdeen Proving Ground are the Northern Chesapeake Bay Tidal Fresh (CB1TF) and Northern Chesapeake Bay Oligohaline (CB2OH). Below is a table identifying the listings associated with this watershed (MDE 2012).
Below is a table identifying the listings associated with this watershed (MDE 2012).

Table 1. 2012 Integrated Report Listings for the Aberdeen Proving Ground Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Aberdeen Proving Ground	02130705	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
Northern Chesapeake Bay Tidal Fresh	CB1TF - 02139996 02120201 02130609 02130705	Tidal	Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	TP	4a
					TN	
			Seasonal Shallow Water Submerged Aquatic Vegetation Subcategory	-	TSS	2
	CB1TF- 02130705		Aquatic Life and Wildlife	1996	Toxics	5
	CB1TF - 02139996 02120201 02130609 02130705			-	Impacts to Biological Communities	2
			Open-Water Fish and Shellfish	1996	TP	4a
					TN	
Northern Chesapeake Bay Oligohaline	CB2OH - 02139996 02139997 02130611 02130705 02130901		Seasonal Shallow Water Submerged Aquatic Vegetation Subcategory	-	TSS	2
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	TN	4a
					TP	
			Aquatic Life and Wildlife	-	Impacts to Biological Communities	2
			Open-Water Fish and Shellfish	1996	TN	4a
					TP	

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Aberdeen Proving Ground watershed's tributaries including Boone Creek (Edgewood Area), Delph Creek, Dipper Creek, Old Womans Creek, and Romney Creek are designated as Use I - *water contact recreation, and protection of nontidal warmwater aquatic life.* Spesutie Narrows and Back Creek at Spesutie Island are designated as Use II - *support of estuarine and marine aquatic life and shellfish harvesting*. The headwaters of Mosquito Creek and Woodrest Creek are designated as

Use I, as they approach the confluence with the Chesapeake Bay both streams become Use II (COMAR 2013a, b, c, d, e). Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Aberdeen Proving Ground watershed is listed under Category 5 of the 2012 IR as impaired for impacts to biological communities. Approximately 75% of the Aberdeen Proving Ground watershed is estimated as having fish and/or benthic indices of biological impairment in the poor to very poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include six stations. Five of the six stations have degraded benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, i.e. MBSS rounds two and three (2000-2009) contains seven sites; all seven having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Aberdeen Proving Ground watershed.

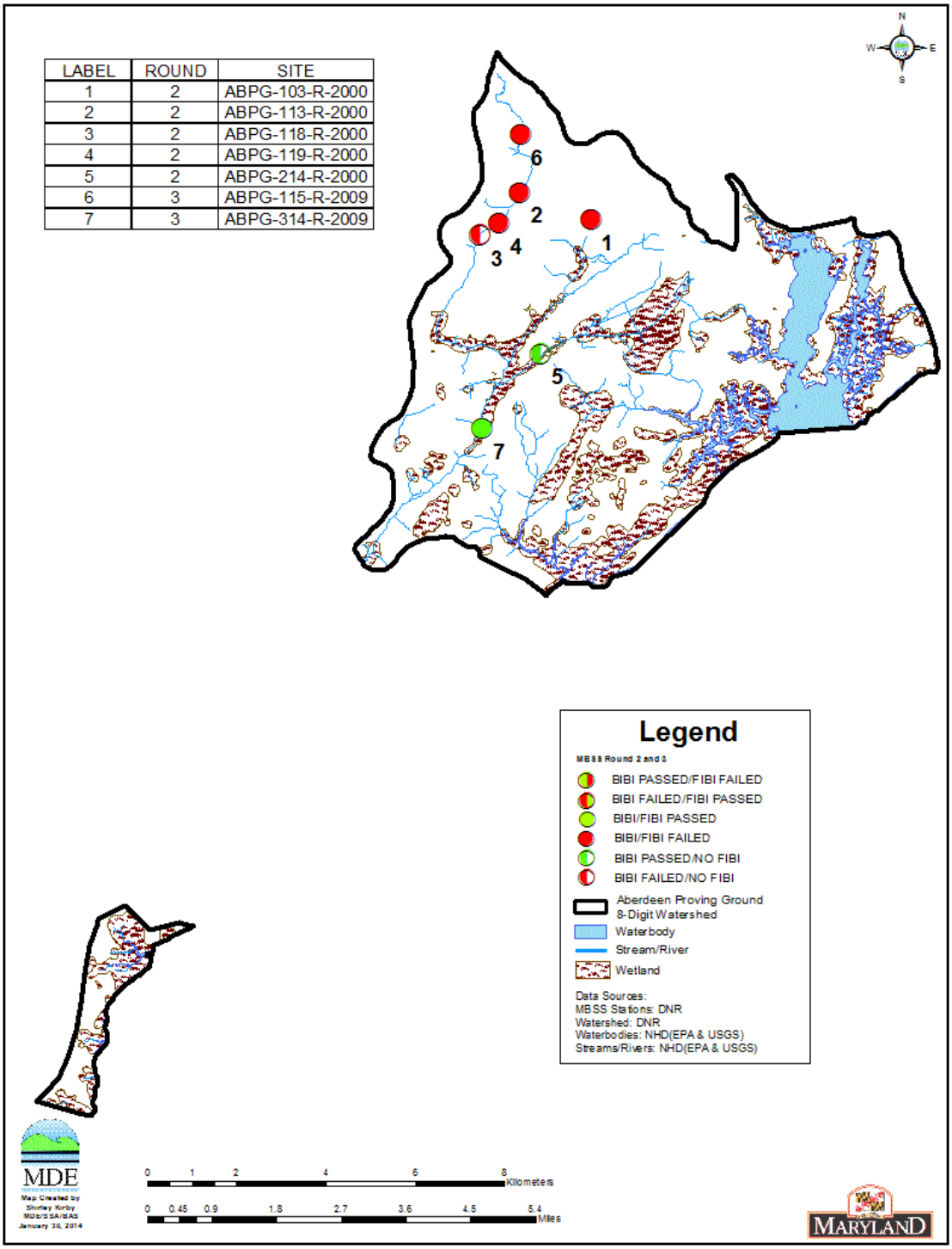

Figure 5. Principal Dataset Sites for the Aberdeen Proving Ground Watershed

4.0 Stressor Identification Results for the Aberdeen Proving Ground Watershed

The BSID process uses results from the BSID data analysis to evaluate each biologically impaired watershed and determines potential stressors and sources. Interpretation of the BSID data analysis results is based upon components of Hill's Postulates (Hill 1965), which propose a set of standards that could be used to judge when an association might be causal. The components applied are: 1) the strength of association, which is assessed using the odds ratio; 2) the specificity of the association for a specific stressor (risk among controls); 3) the presence of a biological gradient; 4) ecological plausibility, which is illustrated through final causal models; and 5) experimental evidence gathered through literature reviews to help support the causal linkage.

The BSID data analysis tests for the strength of association between stressors and degraded biological conditions by determining if there is an increased risk associated with the stressor being present. More specifically, the assessment compares the likelihood that a stressor is present, given that there is a degraded biological condition, by using the ratio of the incidence within the case group as compared to the incidence in the control group (odds ratio). The case group is defined as the sites within the assessment unit with BIBI/FIBI scores lower than 3.0 (i.e., poor to very poor). The controls are sites with similar physiographic characteristics (Highland, Eastern Piedmont, and Coastal region), and stream order for habitat parameters (two groups – 1st and 2nd-4th order), that have good biological conditions.

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenszel (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are poor to very poor biological conditions (cases) than when there are fair to good biological conditions (controls). This result suggests a statistically significant positive association between the stressor and poor to very poor biological conditions and is used to identify potential stressors.

Once potential stressors are identified (i.e., odds ratio significantly greater than one), the risk attributable to each stressor is quantified for all sites with poor to very poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with poor to very poor biological conditions that are associated with the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present.

Once the AR is calculated for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR calculation for each stressor, the AR calculation for a group of stressors is also summed over the case sites using the individual site

characteristics (i.e., stressors present at that site). The only difference is that the absolute risk for the controls at each site is estimated based on the stressor present at the site that has the lowest absolute risk among the controls.

After determining the AR for each stressor and the AR for groups of stressors, the AR for all potential stressors is calculated. This value represents the proportion of cases, sites in the watershed with poor to very poor biological conditions, which would be improved if the potential stressors were eliminated (Van Sickle and Paulsen 2008). The purpose of this metric is to determine if stressors have been identified for an acceptable proportion of cases (MDE 2009).

Through the BSID data analysis, MDE identified instream habitat, water chemistry, and potential sources significantly associated with degraded fish and/or benthic macroinvertebrate biological conditions. Parameters identified as representing possible sources are listed in Table 2 and include various urban land use types. A summary of combined AR values for each source group is shown in Table 3. As shown in Table 5 and Table 6, parameters from the instream habitat and water chemistry groups are identified as possible biological stressors in the Aberdeen Proving Ground watershed. A summary of combined AR values for each stressor group is shown in Table 6.

Table 2. Stressor Source Identification Analysis Results for the Aberdeen Proving Ground Watershed

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Sources - Acidity	Atmospheric deposition present	7	5	274	0%	37%	0.163	No	_
	Agricultural acid source present	7	5	274	0%	7%	1	No	_
	AMD acid source present	7	5	274	0%	0%	1	No	_
	Organic acid source present	7	5	275	0%	7%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	7	5	279	0%	3%	1	No	_
	High % of agriculture in 60m buffer	7	5	279	0%	4%	1	No	_
Sources - Anthropogenic	Low % of forest in watershed	7	5	279	20%	6%	0.294	No	_
	Low % of wetland in watershed	7	5	279	0%	11%	1	No	_
	Low % of forest in 60m buffer	7	5	279	0%	8%	1	No	_
	Low % of wetland in 60m buffer	7	5	279	0%	10%	1	No	_
Sources - Impervious	High % of impervious surface in watershed	7	5	279	60%	4%	0.001	Yes	56%
	High % of impervious surface in 60m buffer	7	5	279	80%	5%	0	Yes	75%
	High % of roads in watershed	7	5	279	20%	0%	0.018	Yes	20%
	High % of roads in 60m buffer	7	5	279	80%	5%	0	Yes	75%
Sources - Urban	High % of high-intensity developed in watershed	7	5	279	100%	8%	0	Yes	92%
	High % of low-intensity developed in watershed	7	5	279	80%	6%	0	Yes	74%
	High % of medium-intensity developed in watershed	7	5	279	20%	2%	0.118	No	_
	High % of early-stage residential in watershed	7	5	279	0%	5%	1	No	_
	High % of residential developed in watershed	7	5	279	80%	6%	0	Yes	74%

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
	High % of rural developed in watershed	7	5	279	0%	5%	1	No	_
	High % of high-intensity developed in 60m buffer	7	5	279	80%	6%	0	Yes	74%
	High % of low-intensity developed in 60m buffer	7	5	279	100%	5%	0	Yes	95%
	High % of medium-intensity developed in 60m buffer	7	5	279	40%	3%	0.013	Yes	37%
	High % of early-stage residential in 60m buffer	7	5	279	0%	7%	1	No	_
	High % of residential developed in 60m buffer	7	5	279	100%	5%	0	Yes	95%
	High % of rural developed in 60m buffer	7	5	279	0%	5%	1	No	_

Table 3. Summary of Combined Attributable Risk Values for Source Groups in the Aberdeen Proving Ground Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Impervious	96%
Sources - Urban	96%
All Sources	***97%***

4.1 Sources Identified by BSID Analysis

All the sources identified by the BSID analysis (Table 2) are the result of urban development in the watershed, which has significant association with degraded biological conditions in the Aberdeen Proving Ground watershed. The watershed is comprised of 37% urban land uses with 5% of this being impervious surface. The BSID analysis identified several stressor sources including impervious surface and roads in the watershed and 60-meter buffer zone, and a high percentage of urban development in the watershed and 60-meter buffer zone. Developed land occurs predominantly in the areas around Edgewood and Abingdon. The Aberdeen Proving Ground facility is a mixed-use industrial military development, which includes recreational land use, i.e. a golf course.

The BSID source analysis (Table 2) identifies various types of urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 97% suggesting that these stressors impact a substantial proportion of the degraded stream miles in the Aberdeen Proving Ground watershed (Table 3).

Table 4. Sediment Biological Stressor Identification Analysis Results for the Aberdeen Proving Ground Watershed

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Sediment	Extensive bar formation present	5	4	161	0%	21%	0.582	No	_
	Moderate bar formation present	5	4	160	25%	49%	0.621	No	_
	Bar formation present	5	4	160	50%	78%	0.23	No	_
	Channel alteration moderate to poor	3	3	131	100%	60%	0.277	No	_
	Channel alteration poor	3	3	131	0%	26%	0.571	No	_
	High embeddedness	5	4	160	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	5	4	160	25%	46%	0.626	No	_
	Epifaunal substrate poor	5	4	160	25%	13%	0.425	No	_
	Moderate to severe erosion present	5	4	160	25%	43%	0.639	No	_
	Severe erosion present	5	4	160	0%	13%	1	No	_
	Silt clay present	5	4	160	100%	99%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Aberdeen Proving Ground Watershed

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Instream Habitat	Channelization present	7	5	172	80%	13%	0.002	Yes	67%
	Concrete/gabion present	5	4	148	0%	1%	1	No	_
	Beaver pond present	5	4	159	0%	7%	1	No	_
	Instream habitat structure marginal to poor	5	4	160	25%	40%	1	No	_
	Instream habitat structure poor	5	4	160	25%	6%	0.245	No	_
	Pool/glide/eddy quality marginal to poor	5	4	160	75%	46%	0.342	No	_
	Pool/glide/eddy quality poor	5	4	160	25%	3%	0.14	No	_
	Riffle/run quality marginal to poor	5	4	160	100%	53%	0.124	No	_
	Riffle/run quality poor	5	4	160	50%	21%	0.2	No	_
	Velocity/depth diversity marginal to poor	5	4	160	100%	61%	0.299	No	_
	Velocity/depth diversity poor	5	4	160	25%	16%	0.502	No	_
Riparian Habitat	No riparian buffer	4	4	140	0%	15%	1	No	_
	Low shading	5	4	160	25%	3%	0.118	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Aberdeen Proving Ground Watershed

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Chemistry - Inorganic	High chlorides	7	5	279	20%	8%	0.359	No	_
	High conductivity	7	5	279	20%	6%	0.281	No	_
	High sulfates	7	5	279	0%	8%	1	No	_
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	5	4	261	75%	17%	0.02	Yes	58%
	Dissolved oxygen < 6mg/l	5	4	261	75%	25%	0.055	Yes	50%
	Low dissolved oxygen saturation	5	4	261	25%	6%	0.234	No	_
	High dissolved oxygen saturation	5	4	261	25%	3%	0.116	No	_
	Ammonia acute with salmonid present	7	5	279	0%	0%	1	No	_
	Ammonia acute with salmonid absent	7	5	279	0%	0%	1	No	_
	Ammonia chronic with early life stages present	7	5	279	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	7	5	279	0%	0%	1	No	_
	High nitrites	7	5	279	0%	3%	1	No	_
	High nitrates	7	5	279	0%	7%	1	No	_
	High total nitrogen	7	5	279	0%	6%	1	No	_
	High total phosphorus	7	5	279	0%	9%	1	No	_
	High orthophosphate	7	5	279	60%	5%	0.002	Yes	55%
Chemistry - pH	Acid neutralizing capacity below chronic level	7	5	279	0%	9%	1	No	_
	Acid neutralizing capacity below episodic level	7	5	279	0%	45%	0.068	No	_
	Low field pH	5	4	262	0%	40%	0.153	No	_
	High field pH	5	4	262	25%	1%	0.045	Yes	24%
	Low lab pH	7	5	279	0%	38%	0.161	No	_
	High lab pH	7	5	279	0%	0%	1	No	_

Table 7. Summary of Combined Attributable Risk Values for Stressor Groups in the Aberdeen Proving Ground Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Instream Habitat	67%
Chemistry - Nutrients	90%
Chemistry - pH	24%
All Chemistry	91%
All Stressors	***92%***

4.2 Stressors Identified by BSID Analysis

All five stressor parameters identified by the BSID analysis (Tables 5 and 6), are significantly associated with biological degradation in the Aberdeen Proving Ground watershed and are representative of impacts from urban developed landscapes.

Sediment Conditions

BSID analysis results for the Aberdeen Proving Ground watershed did not identify sediment parameters that have statistically significant associations with poor to very poor stream biological condition, i.e., removal of stressors would result in improved biological community (Table 4).

Instream Habitat Conditions

BSID analysis results for the Aberdeen Proving Ground watershed identified one habitat parameter that has a statistically significant association with poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *channelization present* (Table 5).

Channelization present was identified as significantly associated with degraded biological conditions and found to impact approximately 67% of the stream miles with poor to very poor biological conditions in the Aberdeen Proving Ground watershed. Channelized describes a condition determined by visual observation of the presence or absence of the channelization of the stream segment and the extent of the channelization. Channelization is the human alteration of the natural stream morphology by altering the stream banks, (i.e., concrete, rip rap, and ditching). Streams are channelized to increase the efficiency of the downstream flow of water. Channelization likely inhibits

heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities.

Significant channel and streambed alteration, and subsequent altered flow, i.e. flashiness, has been the result of stream channelization in the Aberdeen Proving Ground watershed. Channelization is detrimental for the "well being" of streams and rivers through the elimination of suitable habitat and the creation of excessive flows. Stream bottoms are made more uniform. Habitats of natural streams contain numerous bends, riffles, runs, pools and varied flows, and tend to support healthier and more diversified plant and animal communities than those in channelized streams. The natural structures impacting stream hydrology, which were removed for channelization, also provide critical habitat for stream species and impact nutrient availability in stream microhabitats (Bolton and Shellberg 2001). Channelized streams retain less leaf litter and support lower densities of detritivore invertebrates than natural streams. The refuge cavities removed by channelization not only provide concealment for fish, but also serve as traps for detritus, and are areas colonized by benthic macroinvertebrates. Although the BSID analysis results do not identify sediment deposition as a stressor, the scouring associated with increased flows leads to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed and decreasing habitat heterogeneity. Sediment transported downstream subsequently affects the tidal region of the watershed. Toxics can also bind to sediments, therefore affecting the downstream regions of the watershed.

The combination of the altered flow regime and stream morphology in the Aberdeen Proving Ground watershed has resulted in loss of available habitat and an unstable stream ecosystem, characterized by a continuous displacement of biological communities that require frequent re-colonization. Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the instream habitat stressor group is approximately 67% suggesting that this stressor group impacts a substantial proportion of the degraded stream miles in the Aberdeen Proving Ground (Table 7).

Riparian Habitat Conditions

BSID analysis results for the Aberdeen Proving Ground watershed did not identify riparian habitat parameters that have statistically significant associations with poor to very poor stream biological condition (Table 5).

Water Chemistry

BSID analysis results for the Aberdeen Proving Ground watershed identified four water chemistry parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved

biological community): *dissolved oxygen <5 mg/L, dissolved oxygen <6 mg/L, high orthophosphate, high field pH.* (Table 6).

Low (< 5mg/L and *< 6mg/L) dissolved oxygen* (DO) concentrations were identified as significantly associated with degraded biological conditions and found in 58% and 50%, respectively, of the stream miles with poor to very poor biological conditions in the Aberdeen Proving Ground watershed. Low DO concentrations may indicate organic pollution due to excessive oxygen demand and may stress aquatic organisms. The DO threshold value, at which concentrations below 5.0 mg/L may indicate biological degradation, is established by COMAR (2013f).

High orthophosphate (OP) concentration was identified as significantly associated with degraded biological conditions and found to impact approximately 55% of the stream miles with poor to very poor biological conditions in the Aberdeen Proving Ground watershed. OP is the most readily available form of phosphorus for uptake by aquatic organisms. For every form of life, phosphates play an essential role in all energy-transfer processes such as metabolism and photosynthesis. About three-quarters of the phosphates used in the United States goes into fertilizers. Other important uses are as builders for detergents and nutrient supplements for animal feeds. Phosphorus plays a crucial role in primary production. Elevated levels of phosphorus can lead to excessive growth of filamentous algae and aquatic plants. Excessive phosphorus input can also lead to increased primary production, which potentially results in species tolerance exceedances of dissolved oxygen and pH levels. Phosphates input to surface waters typically increases in watersheds where urban and agricultural land uses are predominant.

High field pH concentration was identified as significantly associated with degraded biological conditions and found to impact approximately 24% of the stream miles with poor to very poor biological conditions in the Aberdeen Proving Ground watershed. pH is a measure of the acid balance of a stream and uses a logarithmic scale range from 0 to 14, with 7 being neutral. Most stream organisms prefer a pH range of 6.5 to 8.5. Intermittent high pH (greater than 8.5) is often associated with eutrophication related to increased algal blooms. High stream pH results from agricultural and urban land uses. Exceedances of pH may allow concentrations of toxic elements (such as ammonia, nitrite, and aluminum) and high amounts of dissolved heavy metals (such as copper and zinc) to be mobilized for uptake by aquatic plants and animals.

There is one National Pollutant Discharge Elimination System (NPDES) permitted discharge facility in the Aberdeen Proving Ground watershed, the City of Aberdeen Wastewater Treatment Plant (NPDES MD0021237). The wastewater treatment plant discharges into Spesutie Narrows, which is not one of the streams represented in the principal dataset for the BSID analysis. Since the treatment plant is not a probable source, it is assumed that elevated nutrients, bacteria levels and toxic organic and metal compounds are to due to urban runoff, and munitions dumps and hazardous water in landfills on the Army property (MDDNR 1996). Therefore, urban land use and military legacy contaminants are the mostly likely source of the stressors significantly associated with poor biological conditions in the Aberdeen Proving Ground watershed.

In urban areas, excessive fertilization of lawns can be significant contributors of nutrients (Weibel 1969). The three major nutrients in fertilizers and manure are nitrogen, phosphorus, and potassium. The MDDNR MBSS notes that there is a golf course present at Aberdeen Proving Ground; this is a probable source of elevated orthophosphate in the watershed. Two of the seven sampling stations are located within the golf course; ABPG-113-R-2000 and ABPG-118-R-2000. The presence of elevated orthophosphate in the watershed can lead to intermittent algal blooms which in turn may lead to fluctuations in oxygen demand, i.e. low oxygen concentrations.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the water chemistry stressor group is approximately 90% suggesting this stressor impacts a substantial proportion of the degraded stream miles in the Aberdeen Proving Ground watershed (Table 7).

4.3 Discussion of BSID Results

Since 1917, the Aberdeen Proving Ground installation has been the primary chemical-warfare research and development center for the U.S. Army (USGS 2002). Due to this utilization there are legacy contaminants in the watershed. The BSID results identified urban land use sources (i.e., impervious surface, low and high urban intensity, and urban in 60m buffer) as having a statistically significant association with poor to very poor stream biological conditions in the Aberdeen Proving Ground watershed. Urban land use comprises 37% of the watershed; which causes an increase in contaminant loads from point and non-point sources (e.g., lawn fertilizers, failing septic systems, legacy toxic contaminants) by adding pollutants to surface waters. Urban land use is associated with the water chemistry stressors (high orthophosphate, high field pH, low dissolved oxygen) identified by the BSID analysis.

MDDNR MBSS does not sample for all possible constituents, therefore the biological community may be affected by other toxics, etc. The BSID analysis identified high field pH as significantly associated with degraded biological conditions in the Aberdeen Proving Ground watershed. High field pH may allow concentrations of toxic contaminants to be mobilized for uptake by the biological community of the watershed. There is an existing 1996 Category 5 toxics listing for the tidal portion of the watershed. In order to evaluate a TMDL for this toxics listing, USEPA contracted Tetra Tech to assess information and monitoring data completed by Aberdeen Proving Ground (Tetra Tech 2011). The USEPA provided funds to TetraTech in 2012 to monitor two tidal waterbodies within Aberdeen Proving Ground (Dipper Creek and Spesutie Narrows) for chemical contaminants that may be present due to historical and ongoing practices at the facility. TetraTech submitted the water quality data report in early 2013 to the USEPA and MDE SSA. MDE SSA plans to review this data report to refine the toxics listing for these waterbodies and determine if WQA or TMDL development is necessary to address the listing. In the future, if the USEPA provides additional funds, the remaining six tidal

waterbodies will also be monitored. MDE SSA will not be providing any data relevant to the non-tidal region to which this watershed study pertains. Remediation efforts within the 8-digit watershed should reduce toxics contamination levels in both the tidal and non-tidal portions of the watershed.

In watersheds already experiencing anthropogenic stress, hydrologic variability is exacerbated by urbanization, which increases the amount of impervious surface in a basin and causes higher overland flows to streams, especially during storm events (Southerland et al. 2005b). Urbanization, specifically channelization, exacerbates the overland flows during storm events carrying toxics and nutrients (i.e., orthophosphate). When flows recede and water velocity slows, it stagnates and there are resulting fluctuations in nutrients, dissolved oxygen and pH. During the spring and summer index sampling periods, the MDDNR MBSS reported issues related to the golf course at Aberdeen Proving Ground, including comments regarding channelization and sediment deposition, altered flow resulting in a dry streambed (impoundment, no and/or low flow, standing pools), and excessive instream plant growth. The Aberdeen Proving Ground watershed primary dataset contains four headwater (i.e., first-order) streams. These streams do not typically support biologically diverse and/or sustainable communities (Vannote 1980), making their biological communities more vulnerable to natural and anthropogenic land use alterations, and their associated stressors. The watershed is in the Coastal Plain physiographic region, which is naturally impacted by sediment deposition due to the region's soil and hydrology. Under normal conditions, the watershed receives low freshwater input and experiences very little flushing except from stormwater, therefore there are usually episodic pulses of nutrients and sediments. Sites were sampled in 2000, a year with high precipitation, suggesting that the lack of flow may be primarily attributable to altered hydrology and possibly small stream order. During this time, the fish and benthic macroinvertebrate communities experienced drastic changes in water quality, and a reduction in the quantity and quality of available physical habitat.

All of these impacts have resulted in the shift in the fish and benthic macroinvertebrate community structure in the Aberdeen Proving Ground watershed. The combined AR for all the stressors is approximately 92%, suggesting that altered hydrology, instream habitat and water chemistry stressors adequately account for the biological impairment in the Aberdeen Proving Ground watershed.

The BSID analysis evaluates numerous key stressors using the most comprehensive data sets available that meet the requirements outlined in the methodology report. It is important to recognize that stressors could act independently or act as part of a complex causal scenario (e.g., eutrophication, urbanization, habitat modification). Also, uncertainties in the analysis could arise from the absence of unknown key stressors and other limitations of the principal data set. The results are based on the best available data at the time of evaluation.

4.4 Final Causal Model

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr 1991; USEPA 2009). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final casual model for the Aberdeen Proving Ground watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

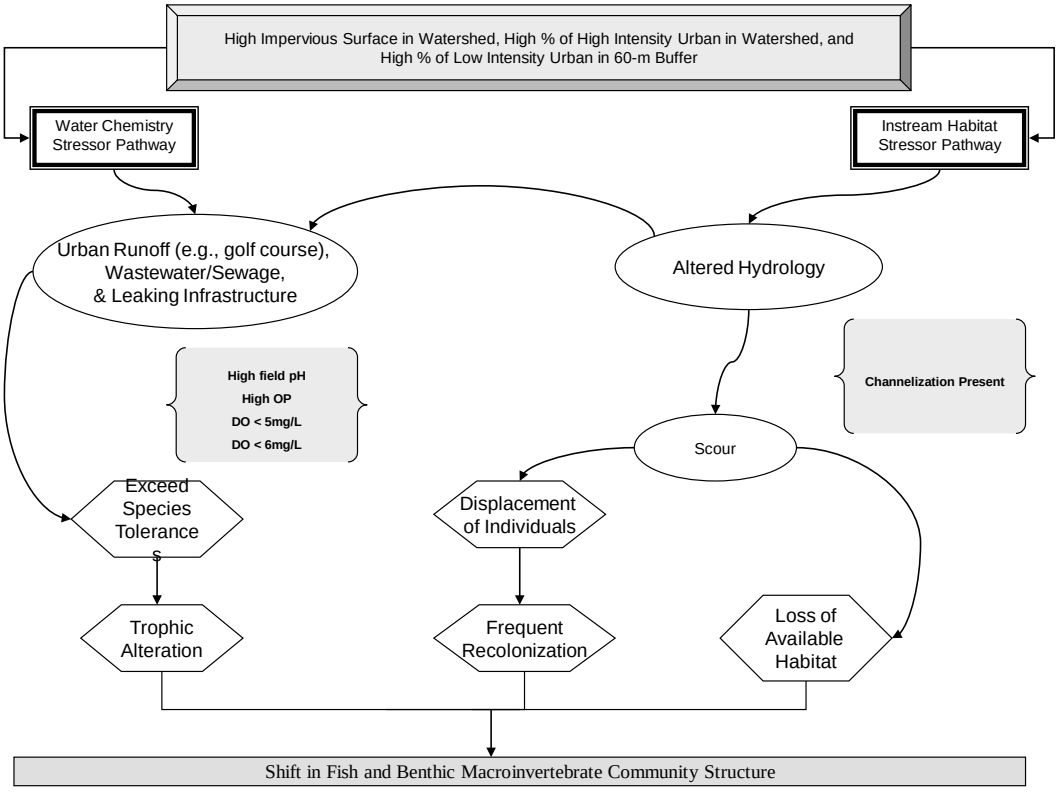

Figure 6. Final Causal Model for the Aberdeen Proving Ground Watershed

5.0 Conclusions

Data suggest that the Aberdeen Proving Ground watershed's biological communities are influenced by urban land use. Urban development has led to the channelization of streams and has altered hydrology which results in episodic pulses of nutrients and toxics entering the streams. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to urban landscapes, which often cause flashy hydrology in streams and increased contaminant loads (e.g., nutrients, toxics) from runoff. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the Aberdeen Proving Ground watershed are summarized as follows:

- The BSID process did not identify sediment stressors in the non-tidal portion of the Aberdeen Proving Ground watershed.

- The BSID process has determined that biological communities in the Aberdeen Proving Ground watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization as pollution, not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Aberdeen Proving Ground watershed based on channelization being present in approximately 67% of degraded stream miles.

- The BSID process has also determined that biological communities in the Aberdeen Proving Ground watershed are likely degraded due to nutrient related stressors. Specifically, anthropogenic impacts in the Coastal Plain physiographic region have resulted in subsequent elevated nutrients in the watershed, which are in turn the probable causes of impacts to biological communities. With identification of water chemistry stressors the BSID results confirm the tidal 1996 Category 4a listing for TP as an appropriate management action in the watershed, and links this pollutant to biological conditions in these waters and extends the impairment to the watershed's non-tidal waters. Therefore, the establishment of nutrient reductions through the 2010 Chesapeake Bay TMDL was an appropriate management action to begin addressing these stressors impact to the biological communities in the Aberdeen Proving Ground watershed.

References

Bolton, S., and J. Shellberg. 2001. *Ecological Issues in Floodplains and Riparian Corridors.* University of Washington, Center for Streamside Studies, Olympia, Washington. pp. 217-263.

COMAR (Code of Maryland Regulations). 2013a. *26.08.02.02.* http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.02.htm (Accessed June, 2013).

_____. 2013b. *26.08.02.08 (I), (1).* http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.08.htm (Accessed June, 2013).

_____. 2013c. *26.08.02.08 (I), (2), (a).* http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.08.htm (Accessed June, 2013).

_____. 2013d. *26.08.02.08 (I), (2), (b), (i).* http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.08.htm (Accessed June, 2013).

_____. 2013e. *26.08.02.08 (I), (2), (b), (ii).* http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.08.htm (Accessed June, 2013).

_____. 2013f. *26.08.02.03* http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.03.htm (Accessed June, 2013).

Hill, A. B. 1965. The Environment and Disease: Association or Causation? *Proceedings of the Royal Society of Medicine* 58: 295-300.

Karr, J. R. 1991. Biological integrity: A long-neglected aspect of water resource management. *Ecological Applications* 1: 66-84.

Mantel, N., and W. Haenszel. 1959. Statistical aspects of the analysis of data from retrospective studies of disease. *Journal of the National Cancer Institute* 22: 719-748.

MDDNR (Maryland Department of Natural Resources). 1996. 305(b) Report: Maryland Water Quality Inventory, 1993-1995. Annapolis, MD: Maryland Department of Natural Resources.

MDE (Maryland Department of the Environment). 2012. *Final Integrated Report of Surface Water Quality in Maryland*. Baltimore, MD: Maryland Department of the Environment. Also Available at http://www.mde.state.md.us/programs/Water/TMDL/Integrated303dReports/Pages/Final_approved_2012_ir.aspx (Accessed May, 2013).

_____. 2009. *2009 Maryland Biological Stressor Identification Process*. Baltimore, MD: Maryland Department of the Environment. Available at http://www.mde.state.md.us/assets/document/BSID_Methodology_Final_03-12-09.pdf (Accessed May, 2013).

MDP (Maryland Department of Planning). 2002. *Land Use/Land Cover Map Series*. Baltimore, MD: Maryland Department of Planning.

MGS (Maryland Geological Survey). 2007. *A Brief Description of the Geology of Maryland*. http://www.mgs.md.gov/esic/brochures/mdgeology.html (Accessed May, 2013).

NRCS (Natural Resources Conservation Service). 1975. *Soil Survey of Harford County, Maryland*. United States Department of Agriculture, Natural Resources Conservation Service (formerly Soil Conservation Service), in cooperation with Maryland Agricultural Experiment Station.

Southerland, M. T., G. M. Rogers, R. J. Kline, R. P. Morgan, D. M. Boward, P. F. Kazyak, R. J. Klauda and S. A. Stranko. 2005a. *New biological indicators to better assess the condition of Maryland Streams.* Columbia, MD: Versar, Inc. with Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Division. CBWP-MANTA-EA-05-13. Available at http://www.dnr.state.md.us/streams/pubs/ea-05-13_new_ibi.pdf

Southerland, M. T., L. Erb, G. M. Rogers, R. P. Morgan, K. Eshleman, M. Kline, K. Kline, S. A. Stranko, P. F. Kazyak, J. Kilian, J. Ladell, and J. Thompson. 2005b. *Maryland Biological Stream Survey 2000 – 2004 Volume XIV: Stressors Affecting Maryland Streams.* Columbia, MD: Versar, Inc. with Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Division. CBWP-MANTA-EA-05-11. Available at http://www.dnr.state.md.us/streams/pubs/ea05-11_stressors.pdf (Accessed March, 2013).

Tetra Tech, Inc. 2011. *Assessment of Toxic Impairments in Tidal Waters in Maryland Basin Code 02130705 at Aberdeen Proving Ground.* Fairfax, VA: Tetra Tech, Inc.

USEPA (United States Environmental Protection Agency). 2010. Chesapeake Bay Phase 5 Community Watershed Model. Annapolis MD:Chesapeake Bay Program Office.

In Preparation EPA XXX-X-XX-008 February 2010. http://www.chesapeakebay.net/model_phase5.aspx?menuitem=26169 (Accessed June, 2013)

_____. 2013. *The Causal Analysis/Diagnosis Decision Information System (CADDIS)*. Available at http://cfpub.epa.gov/caddis/ (Accessed June, 2013).

USGS (United States Geological Survey). 2002. *Changes in Ground-Water Quality in the Canal Creek Aquifer Between 1995 and 2000-2001, West Branch Canal Creek Area, Aberdeen Proving Ground, Maryland.* Water-Resources Investigations Report 02-4076. Baltimore, MD:United States Geological Survey.

Van Sickle, J., and S.G. Paulsen. 2008. Assessing the attributable risks, relative risks, and regional extents of aquatic stressors. *Journal of the North American Benthological Society* 27 (4): 920-931.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Science* 37: 130-137.

Weibel, S. R. 1969. Urban drainage as a factor in eutrophication. In *Eutrophication: causes, consequences, corrections.* Washington, DC: National Academy of Sciences.