Watershed Report for Biological Impairment of the Non-Tidal Lower Pocomoke River Watershed, Somerset and Worcester Counties, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

MARYLAND
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 2016

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
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
IDNR	Iowa Department of Natural Resources
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
mg/L	Milligrams per liter
n	Number
NADP	National Atmospheric Deposition Program
NPDES	National Pollution Discharge Elimination System
POCOH	Lower Pocomoke River Oligohaline
POCMH	Lower Pocomoke River Mesohaline
PSU	Primary Sampling Unit
SSA	Science Services Administration
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 Lower Pocomoke River watershed is located in Worcester and Somerset Counties, MD. It is associated with three assessment units, the non-tidal 8-digit basin (basin code 02130202), and the Middle Pocomoke River Oligohaline (POCOH) and Upper Pocomoke River Tidal Fresh (POCTF), in the Integrated Report. Below is a table identifying the listings associated with this watershed (MDE 2014).

Table E1. 2014 Integrated Report Listings for the Lower Pocomoke Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Lower Pocomoke River	02130202	Non-tidal	Aquatic Life and Wildlife	2004	Impacts to Biological Communities	5
		Middle Pocomoke River Oligohaline (POCOH)	Fishing	2008	PCB Fish Tissue	5
				-	Mercury in Fish Tissue	2
			Shellfishing	1996	Fecal Coliform	4a
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	TN	4a
					TP	
					BIBI	3
		Upper Pocomoke River Tidal Fresh (POCTF)	Open-Water Fish and Shellfish Subcategory	1996	TN	4a
					TP	
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2008	TSS	4a
				2012	TN	4a
					TP	
				-	Benthic IBI	3

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 Lower Pocomoke River are Use Class I - *water contact recreation, and protection of nontidal warmwater aquatic life* and Use Class II - *Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting* for the tidal portion (COMAR 2015a, b). The Lower Pocomoke River watershed is not attaining its designated use of protection of aquatic life because of biological impairments. 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 Lower Pocomoke River watershed is not attaining its designated use of protection of aquatic life because of impairments to biological communities. 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 degraded 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 either 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 Lower Pocomoke River 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 2015). Data suggest that the degradation of biological communities in the Lower Pocomoke River watershed is due to naturally occurring conditions, agricultural use and its concomitant altered hydrology effects, and inorganics. The development of landscapes creates broad and interrelated forms of degradation (i.e., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between highly urbanized landscapes and degradation, e.g., urban runoff contamination 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 Lower Pocomoke River watershed, can be summarized as follows:

- The BSID process has determined that the biological communities in the Lower Pocomoke River watershed are likely degraded due to inorganics (i.e., sulfates, and conductivity). Sulfates and conductivity levels are significantly associated with degraded biological conditions and found, respectively, in approximately

75% and 27% of the stream miles with poor to very poor biological conditions in the Lower Pocomoke River watershed. The BSID results thus support an inorganic/sulfate Category 5 listing of Lower Pocomoke River for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Lower Pocomoke River watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID process has also determined that biological communities in the Lower Pocomoke River 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 Lower Pocomoke River watershed based on channelization being present in approximately 70% of degraded stream miles.

- The BSID process has also determined that biological communities in the Lower Pocomoke River watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones 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. MDE recommends a Category 4c listing for the Lower Pocomoke River watershed based on inadequate riparian buffer zones in approximately 45% of degraded stream miles.

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 2012). 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 dataset 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 the level of precision is acceptable and the watershed is only meeting some of the water quality standards the status of the watershed is listed as Category 2. If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). Watersheds that are impaired but have a TMDL that has been completed or submitted to EPA are listed as Category 4a. If the state can demonstrate that a watershed impairment is a result of pollution, but not a pollutant the watershed is listed under Category 4c. If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL may be necessary.

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 Lower Pocomoke River watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Lower Pocomoke River Watershed Characterization

2.1 Location

The Lower Pocomoke River watershed is located in Somerset and Worcester Counties, MD, and drains to the Lower Pocomoke River (see Figure 1). The Lower Pocomoke River watershed encompasses approximately 99,250 acres, and includes Snow Hill, Princess Anne, and Pocomoke City. The Pocomoke River Wildlife Management Area and a southeastern portion of the Pocomoke State Forest are located in the watershed. The watershed is located in the Coastal Plain region, which is one of three distinct eco-regions identified in the MBSS indices of biological integrity (IBI) metrics (Southerland et al. 2005a) (see Figure 2).

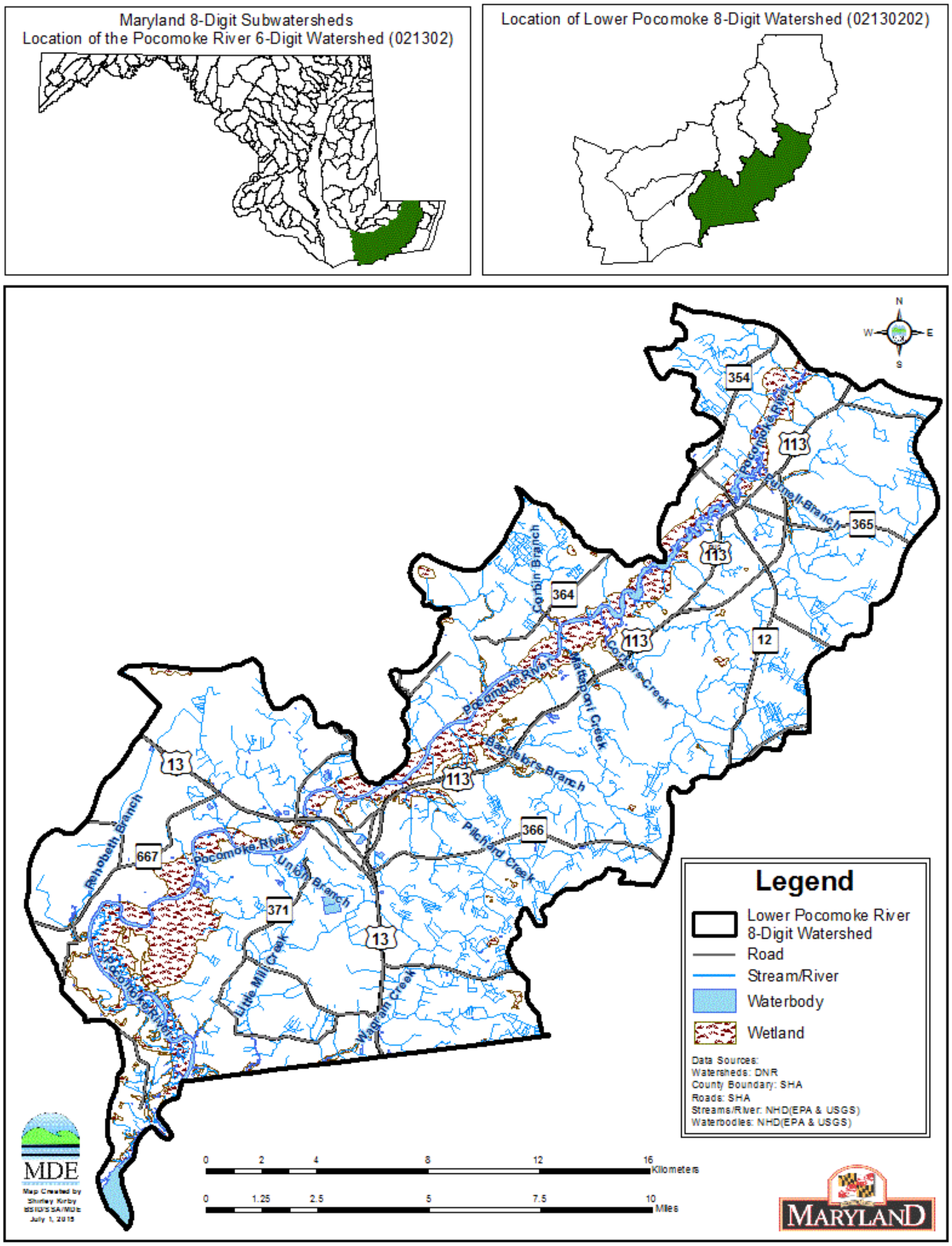


Figure 1. Location Map of the Lower Pocomoke River Watershed

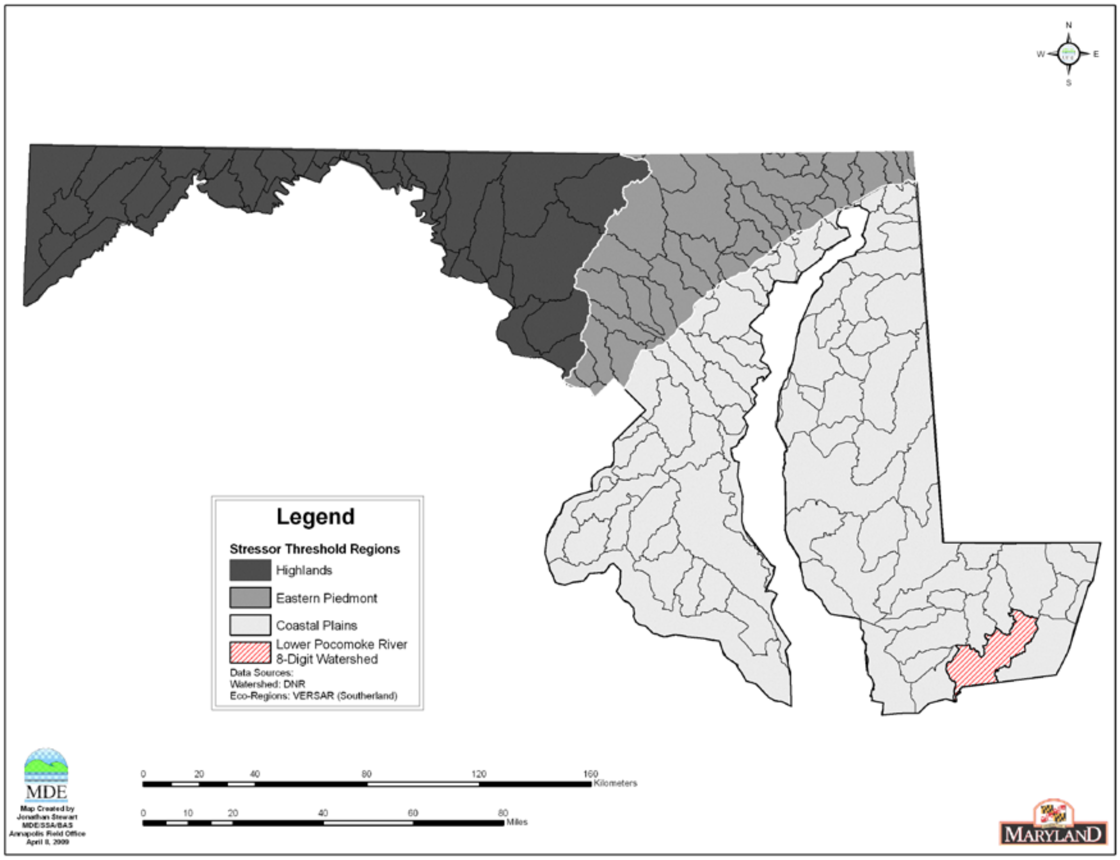


Figure 2. Eco-Region Map of the Lower Pocomoke River Watershed

2.2 Land Use

The drainage area of the Lower Pocomoke River watershed is approximately 99,250 acres. The Lower Pocomoke River watershed contains urban, agricultural, and forested land uses (see Figure 3). The predominant land use in the Maryland 8-digit watershed is forest. The Phase 5.2 Chesapeake Bay Watershed Model reports the land use distribution in the Lower Pocomoke watershed as forest (60%), agricultural (32%), urban pervious (6%), and urban impervious (2%) (see Figure 4) (USEPA 2010).

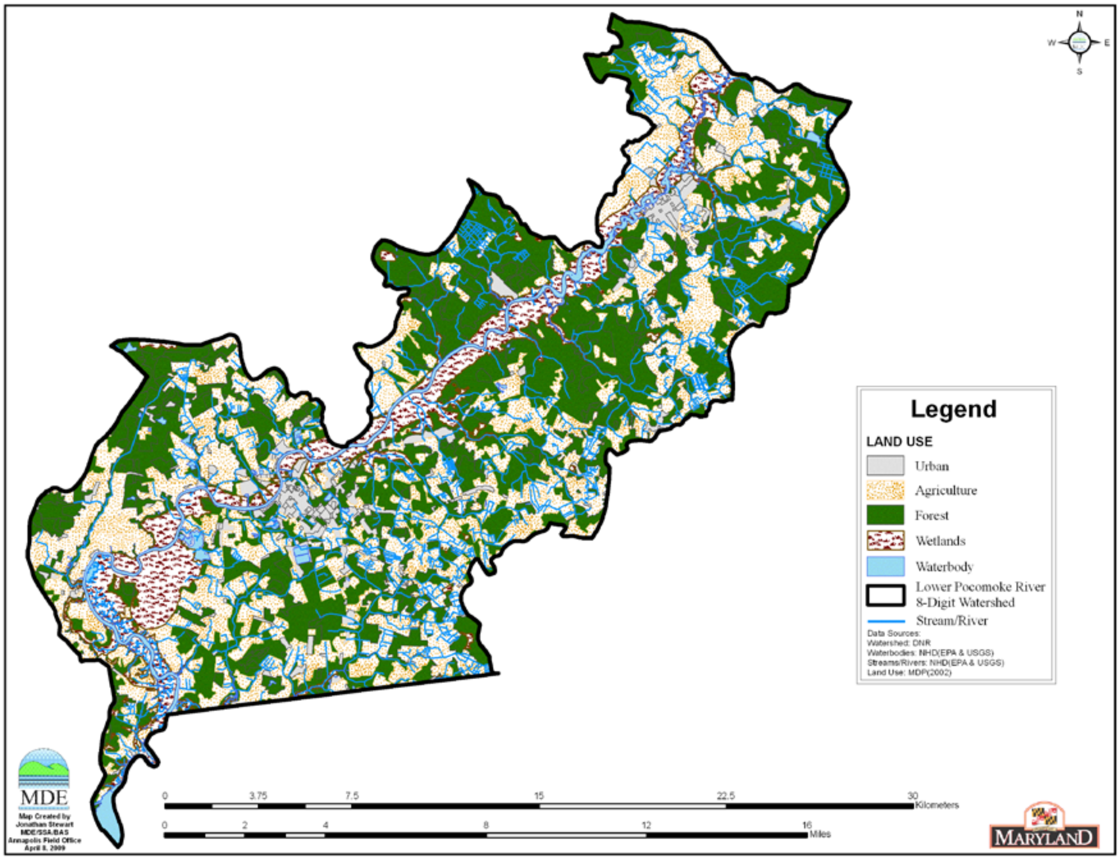


Figure 3. Land Use Map of the Lower Pocomoke River Watershed

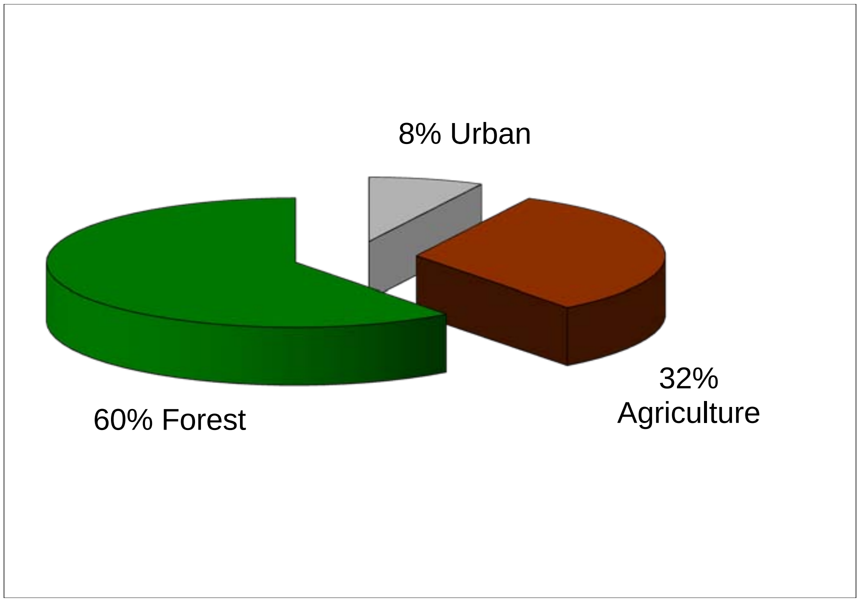


Figure 4. Proportions of Land Use in the Lower Pocomoke River Watershed

2.3 Soils/hydrology

The Lower Pocomoke River lies in the Coastal Plain physiographic province. The Coastal Plain region is characterized by flat or gently rolling topography and elevations rising from sea level to about 100 feet. The Coastal Plain Province is underlain by a wedge of unconsolidated sediments including gravel, sand, silt, and clay (MGS 2007). The province has poorly drained and highly erodible soils with a shallow aquifer system.

3.0 Lower Pocomoke River Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment has identified the non-tidal areas of the Lower Pocomoke River watershed under Category 5 of the State's Integrated Report as impaired for impacts to biological communities (2004 listing). The watershed is associated with three assessment units, the non-tidal 8-digit basin (basin code 02130202), and the Middle Pocomoke River Oligohaline (POCOH) and Upper Pocomoke River Tidal Fresh (POCTF), in the Integrated Report. Below is a table identifying the listings associated with this watershed (MDE 2014).

Table 1. 2014 Integrated Report Listings for the Lower Pocomoke Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Lower Pocomoke River	02130202	Non-tidal	Aquatic Life and Wildlife	2004	Impacts to Biological Communities	5
		Middle Pocomoke River Oligohaline (POCOH)	Fishing	2008	PCB Fish Tissue	5
				-	Mercury in Fish Tissue	2
			Shellfishing	1996	Fecal Coliform	4a
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	TN	4a
					TP	
					BIBI	3
		Upper Pocomoke River Tidal Fresh (POCTF)	Open-Water Fish and Shellfish Subcategory	1996	TN	4a
					TP	
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2008	TSS	4a
				2012	TN	4a
					TP	
				-	Benthic IBI	3

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Lower Pocomoke River are Use Class I - *water contact recreation, and protection of nontidal warmwater aquatic life* and Use Class II - *Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting* for the tidal portion (COMAR 2015a, b). 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 Lower Pocomoke River watershed is listed under Category 5 of the 2012 Integrated Report as impaired for impacts to biological communities. Approximately 78% of the Lower Pocomoke River 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 eight stations. Six of the eight stations have degraded benthic and/or fish indices of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal BSID dataset, i.e. MBSS rounds two and three (2000-2009), contains seven sites with six of the seven having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Marsh Run watershed.

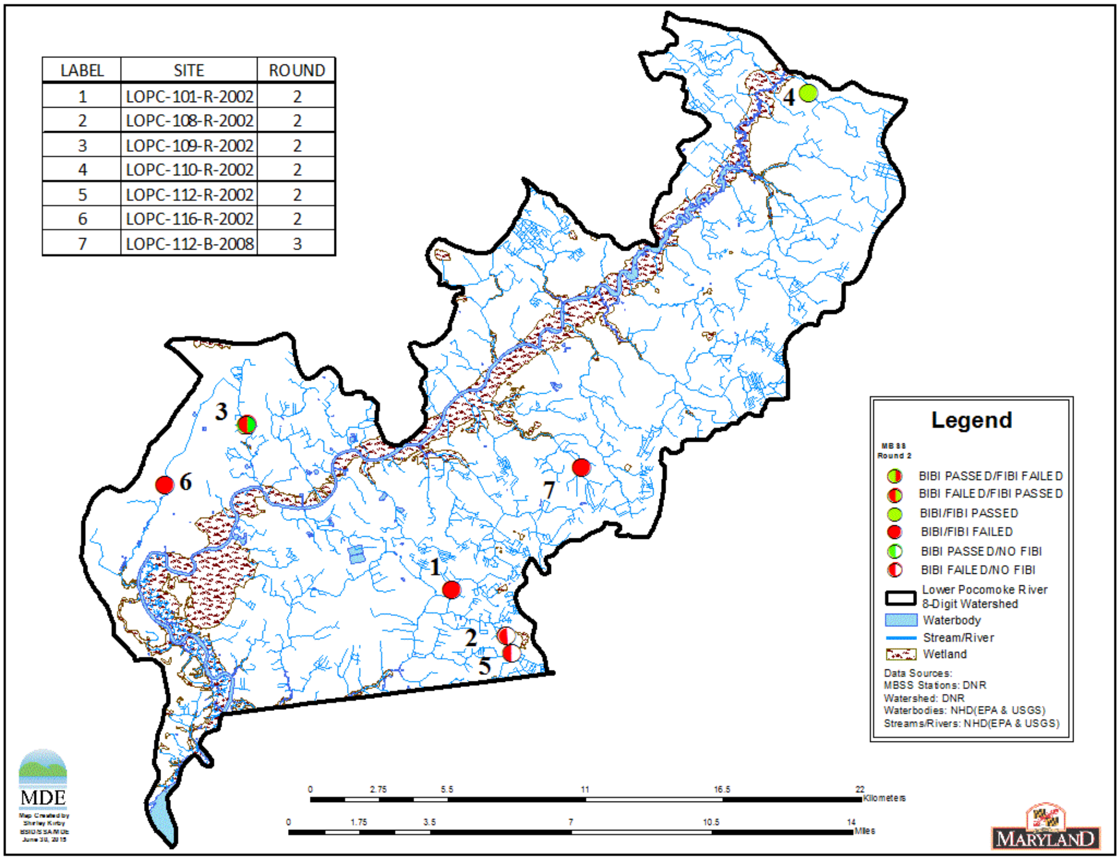


Figure 5. Principle Dataset Sites for the Lower Pocomoke River Watershed

4.0 Stressor Identification Results

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 – 1^{st} and 2^{nd}-4^{th} 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 2015).

Through the BSID data analysis, MDE identified instream and riparian 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 agriculture 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, riparian habitat, and water chemistry groups are identified as possible biological stressors in the Lower Pocomoke River watershed. A summary of combined AR values for each stressor group is shown in Table 7.

Table 2. Stressor Source Identification Analysis Results for the Lower Pocomoke River 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	Agricultural acid source present	7	6	274	17%	7%	0.347	No	_
	AMD acid source present	7	6	274	0%	0%	1	No	_
	Organic acid source present	7	6	274	0%	7%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	7	6	279	0%	3%	1	No	_
	High % of agriculture in 60m buffer	7	6	279	67%	4%	0	Yes	62%
Sources - Anthropogenic	Low % of forest in watershed	7	6	279	50%	6%	0.006	Yes	44%
	Low % of wetland in watershed	7	6	279	0%	11%	1	No	_
	Low % of forest in 60m buffer	7	6	279	50%	8%	0.011	Yes	42%
	Low % of wetland in 60m buffer	7	6	279	0%	10%	1	No	_
Sources - Impervious	High % of impervious surface in watershed	7	6	279	0%	4%	1	No	_
	High % of impervious surface in 60m buffer	7	6	279	0%	5%	1	No	_
	High % of roads in watershed	7	6	279	0%	0%	1	No	_
	High % of roads in 60m buffer	7	6	279	0%	5%	1	No	_
Sources - Urban	High % of high-intensity developed in watershed	7	6	279	0%	8%	1	No	_
	High % of low-intensity developed in watershed	7	6	279	0%	6%	1	No	_
	High % of medium-intensity developed in watershed	7	6	279	0%	2%	1	No	_
	High % of residential developed in watershed	7	6	279	0%	8%	1	No	_
	High % of rural developed in watershed	7	6	279	0%	5%	1	No	_
	High % of high-intensity developed in 60m buffer	7	6	279	0%	6%	1	No	_

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 low-intensity developed in 60m buffer	7	6	279	0%	5%	1	No	_
	High % of medium-intensity developed in 60m buffer	7	6	279	0%	3%	1	No	_
	High % of residential developed in 60m buffer	7	6	279	0%	8%	1	No	_
	High % of rural developed in 60m buffer	7	6	279	0%	5%	1	No	_

Table 3. Summary of Combined Attributable Risk Values for Source Groups in the Lower Pocomoke River Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Agricultural	62%
Sources - Anthropogenic	44%
All Sources	***62%***

4.1 Sources Identified by BSID Analysis

The sources identified by the BSID analysis (Table 2) are the result of natural conditions and agricultural development in the watershed, which has significant association with degraded biological conditions in the Lower Pocomoke River watershed. The watershed is comprised of 32% agriculture land use. The BSID analysis identified several stressor sources including agriculture in the 60-meter buffer zone, and low forest in the watershed and in the 60-meter buffer zone. Numerous studies have identified row crop agriculture as being the most significantly detrimental type of agriculture within a watershed regardless of whether the entire watershed, catchment, riparian zone, or different riparian widths are considered (McCollum 2004). The proportion of row crop agriculture is more significantly important than the proportion of all agriculture in regards to the effects of habitat quality, water quality, and biotic integrity (Richards et al. 1997, Johnson et al. 1997).

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 62% suggesting that these stressors are a probable cause of the biological impairments in the Lower Pocomoke River watershed (Table 3).

Table 4. Sediment Biological Stressor Identification Analysis Results for the Lower Pocomoke River 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	6	5	160	0%	21%	1	No	_
	Moderate bar formation present	6	5	160	60%	49%	0.494	No	_
	Channel alteration moderate to poor	5	4	131	100%	60%	0.132	No	_
	Channel alteration poor	5	4	131	0%	26%	1	No	_
	High embeddedness	6	5	160	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	6	5	160	80%	46%	0.151	No	_
	Epifaunal substrate poor	6	5	160	40%	13%	0.132	No	_
	Moderate to severe erosion present	6	5	160	0%	43%	1	No	_
	Severe erosion present	6	5	160	0%	13%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Lower Pocomoke River 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	6	172	83%	13%	0	Yes	70%
	Concrete/gabion present	7	6	148	0%	1%	1	No	_
	Beaver pond present	6	5	159	0%	7%	1	No	_
	Instream habitat structure marginal to poor	6	5	160	40%	40%	0.666	No	_
	Instream habitat structure poor	6	5	160	20%	6%	0.295	No	_
	Pool/glide/eddy quality marginal to poor	6	5	160	60%	46%	0.437	No	_
	Pool/glide/eddy quality poor	6	5	160	0%	3%	1	No	_
	Riffle/run quality marginal to poor	6	5	160	80%	53%	0.228	No	_
	Riffle/run quality poor	6	5	160	80%	21%	0.009	Yes	59%
	Velocity/depth diversity marginal to poor	6	5	160	100%	61%	0.087	Yes	39%
	Velocity/depth diversity poor	6	5	160	60%	16%	0.035	Yes	44%
Riparian Habitat	No riparian buffer	7	6	172	50%	5%	0.004	Yes	45%
	Low shading	6	5	160	0%	3%	1	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Lower Pocomoke River 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	6	279	0%	8%	1	No	_
	High conductivity	7	6	279	33%	6%	0.054	Yes	27%
	High sulfates	7	6	279	83%	8%	0	Yes	75%
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	6	5	261	60%	17%	0.042	Yes	43%
	Dissolved oxygen < 6mg/l	6	5	261	80%	25%	0.018	Yes	55%
	Low dissolved oxygen saturation	6	5	261	20%	6%	0.283	No	_
	High dissolved oxygen saturation	6	5	261	0%	3%	1	No	_
	Ammonia acute with salmonid present	7	6	279	0%	0%	1	No	_
	Ammonia acute with salmonid absent	7	6	279	0%	0%	1	No	_
	Ammonia chronic with early life stages present	7	6	279	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	7	6	279	0%	0%	1	No	_
	High nitrites	7	6	279	0%	3%	1	No	_
	High nitrates	7	6	279	17%	7%	0.356	No	_
	High total nitrogen	7	6	279	0%	6%	1	No	_
	High total phosphorus	7	6	279	33%	9%	0.109	No	_
	High orthophosphate	7	6	279	0%	5%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	7	6	279	33%	9%	0.109	No	_
	Low field pH	6	5	262	60%	40%	0.331	No	_
	High field pH	6	5	262	0%	1%	1	No	_
	Low lab pH	7	6	279	100%	38%	0.003	Yes	62%
	High lab pH	7	6	279	0%	0%	1	No	_

Table 7. Summary AR Values for Stressor Groups for the Lower Pocomoke River Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Instream Habitat	85%
Riparian Habitat	45%
Chemistry - Inorganic	76%
Chemistry - Nutrients	61%
Chemistry - pH	62%
All Chemistry	91%
All Stressors	***92%***

4.2 Stressors Identified by BSID Analysis

All ten stressor parameters identified by the BSID analysis (Tables 5 and 6) are significantly associated with biological degradation in the Lower Pocomoke River watershed and are representative of impacts from agricultural landscapes.

Sediment Conditions

BSID analysis results for the Lower Pocomoke River watershed did not identify any sediment parameters that have statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community).

Instream Habitat Conditions

BSID analysis results for the Lower Pocomoke River watershed identified four instream habitat parameters that have a statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *channelization present, riffle/run quality poor, velocity/depth diversity marginal to poor, and velocity/depth diversity poor*.

Channelization present was identified as significantly associated with degraded biological conditions and found to impact approximately 70% of the stream miles with poor to very poor biological conditions in the Lower Pocomoke River watershed. Channelization 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 (Petersen et al. 1987).

Riffle/run quality (poor) was identified as significantly associated with degraded biological conditions and found to impact approximately 59% of the stream miles with poor to very poor biological conditions in the Lower Pocomoke River watershed. Riffle/Run Quality is a visual observation and quantitative measurement based on the depth, complexity, and functional importance of riffle/run habitat within the stream segment (Roth et al. 2005). An increase of heterogeneity of riffle/run habitat within the stream segment likely increases the abundance and diversity of fish species, while a decrease in heterogeneity likely decreases abundance and diversity.

Velocity/depth diversity (marginal to poor and poor) were identified as significantly associated with degraded biological conditions and found to impact approximately 39% and 44% respectively of the stream miles with poor to very poor biological conditions in the Lower Pocomoke River watershed. Velocity/depth diversity is a visual observation including quantitative measurements based on the variety of velocity/depth regimes present at a site (i.e., slow-shallow, slow-deep, fast-shallow, and fast-deep; Roth et al. 2005). Like *riffle/run quality*, an increase in the number of different velocity/depth regimes likely increases the abundance and diversity of fish species within the stream segment. The decrease in the number of different velocity/depth regimes likely decreases the abundance and diversity of fish species within the stream segment. The *marginal* or *poor* diversity categories could identify the absence of available habitat to sustain a diverse aquatic community. This measure may reflect natural conditions (e.g., bedrock), anthropogenic conditions (e.g., widened channels, dams, channel dredging, etc.), or excessive erosional conditions.

The MDDNR MBSS noted extensive channelization, and shallow pools and standing water. The instream habitat stressors identified are intricately linked with habitat heterogeneity. 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 altered streams. Stream morphology complexity directly increases the diversity and abundance of fish species found within the stream segment. The increase in heterogeneous habitat such as a variety in depths of pools, slow moving water, and complex covers likely provide valuable habitat for fish species; conversely, a lack of heterogeneity within the pool/glide/eddy habitat decreases valuable habitat for fish species. A lack of varying velocities and depth may reflect a combination of natural conditions, anthropogenic conditions, or excessive erosional conditions.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the instream habitat stressor group is approximately 85%, suggesting that these stressors are probable cause of the biological impairments in the Lower Pocomoke River watershed (Table 7).

Riparian Habitat Conditions

BSID analysis results for the Lower Pocomoke River watershed identified one riparian habitat parameter that has a statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community). This parameter is *no riparian buffer*.

No riparian buffer was identified as significantly associated with degraded biological conditions and found to impact approximately 45% of the stream miles with poor to very poor biological conditions in the Lower Pocomoke River watershed. Riparian buffer width represents the minimum width of vegetated buffer in meters, considering both sides of the stream. Riparian buffer width is measured from 0 m to 50 m, with 0 m having no buffer and 50 m having a full buffer (Mercurio, Chaillou, and Roth 1999). Riparian buffers serve a number of critical ecological functions. They control erosion and sedimentation, modulate stream temperature, provide organic matter, and maintain benthic macroinvertebrate communities and fish assemblages (Lee, Smyth, and Boutin 2004).

The Lower Pocomoke River watershed contains a considerable proportion (32%) of agricultural land use, and to a lesser extent (8%) urban land use. Stream channel shading is reduced or eliminated as forests and other riparian vegetation are replaced with urban development (Allan 2004; Kline, Hilderbrand, and Hairston-Strang 2005; Southerland et al. 2005b). Local riparian vegetation is a secondary predictor of stream integrity; the extent of riparian vegetation may affect the volume of pollutants in runoff (Kline, Hilderbrand, and Hairston-Strang 2005; Roth et al. 2005). Anthropogenic replacement of mature riparian vegetation by successional species or crops decreases shading and eliminates the buffer between terrestrial and aquatic components of a drainage basin, resulting in increased inputs of sediments and nutrients (Delong and Brusven 1994).

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the riparian habitat stressor group is approximately 45% suggesting that these stressors are probable cause of the biological impairments in the Lower Pocomoke River watershed (Table 7).

Water Chemistry

BSID analysis results for the Lower Pocomoke River watershed identified five water chemistry parameters that have a statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *high conductivity, high sulfates, dissovlved oxygen < 5mg/l, dissolved oxygen < 6mg/l, and low lab pH.*

High conductivity was identified as significantly associated with degraded biological conditions and found in 27% of the stream miles with very poor to poor biological conditions in the Lower Pocomoke River watershed. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Urban runoff, road salts, fertilizers, and leaking wastewater infrastructure are typical sources of inorganic compounds. Conductivity levels typically increase in watersheds where urban land uses are predominant. Conductivity, chlorides and sulfates are closely related. Streams with elevated levels of chlorides and sulfates typically display high conductivity.

High sulfates was identified as significantly associated with degraded biological conditions and found in 75% of the stream miles with very poor to poor biological conditions in the Lower Pocomoke River watershed. Sulfate in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities.

Dissolved oxygen (< 5mg/l and < 6mg/l) were identified as significantly associated with degraded biological conditions and found in 43% and 55% respectively, of the stream miles with very poor to poor biological conditions in the Lower Pocomoke River watershed. Dissolved Oxygen (DO) is a measure of the amount of oxygen dissolved in the water as a function of variables such as water temperature, atmospheric pressure, physical aeration, and chemical/biological oxygen demand. DO is generally reported as a concentration (mg/L). MDDNR MBSS measures DO in situ once during the summer. Low DO concentrations may indicate organic pollution due to heterotrophic oxygen consumption and may stress aquatic organisms. Low DO concentrations are considered to demonstrate excessive oxygen demand, primarily from decomposition of organic material (Allan and Castillo 2007). Sources are agricultural, forested, and urban land uses.

The COMAR criterion for Use Class I waters is that the DO concentration may not be less than 5.0 mg/L at any time. The criterion for Use III waters (Nontidal Cold Water) is that the DO concentration may not be less than 5.0 mg/L at any time, with a minimum daily average of not less than 6.0 mg/L (COMAR 2015c).

Low lab pH was identified as significantly associated with degraded biological conditions and found in 62% of the stream miles with very poor to poor biological conditions in the Lower Pocomoke River 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. MDDNR MBSS collects pH samples once during the spring, which are analyzed in the laboratory (*pH lab*), and measured once in situ during the summer (*pH field*). Most stream organisms prefer a pH range of 6.5 to 8.5. Values of less than 6.5 for pH are considered to demonstrate acidity, which can be damaging to aquatic life. Intermittent high pH (greater than 8.5) is often associated with eutrophication related to increased algal blooms (Smith, Alexander and Wolman 1999). 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 (Playle 1989).

The Coastal Plain region has a legacy of high sulfate concentrations due to natural conditions (e.g., wetlands), atmospheric deposition, and agricultural practices (MAPSS 2006). When these local soils are excavated too deeply, they can give rise to severe active acid sulfate soil problems if the underlying un-oxidized zone of the soil-geologic column that still contains sulfide minerals is exposed (MAPSS 2006). Sulfate in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities. There are several National Pollutant Discharge Elimination System (NPDES) permitted discharge facilities including the Pocomoke City Wastewater Treatment Plant (WWTP) in the Lower Pocomoke River watershed. NPDES permitting enforcement does not require sulfate testing; therefore data was not available to verify/identify sulfate as a specific pollutant in this watershed.

The National Atmospheric Deposition Program (NADP) monitors sulfate deposition in the United States. Figure 6 illustrates sulfate deposition at the Wye, Queen Anne County monitoring location (MD13) (NADP 2015). This trend line emulates a decreasing trend in sulfate deposition in the continental United States. Although sulfate deposition is generally decreasing, sulfates are still present in the sediment and can be released by natural and anthropogenic conditions. Due to the anoxic conditions caused by the 2002 drought, sulfates were probably released from the depositional sediments, and/or aeration of previously submerged wetland soils, which caused re-oxidation of stored sulfides to sulfate in the watershed (Eimers and Dillon 2002). The soils of the Lower Pocomoke River watershed are strongly to extremely acidic, the intermittent release of depositional sulfates exacerbates this naturally occurring condition. During baseflow conditions an acid neutralizing capacity (ANC) of 50-200 µeq/L indicates that a stream is vulnerable to episodic acidification; four of the seven stations of the dataset have an ANC of less than 200 µeq/L and two of those stations are negative numbers.

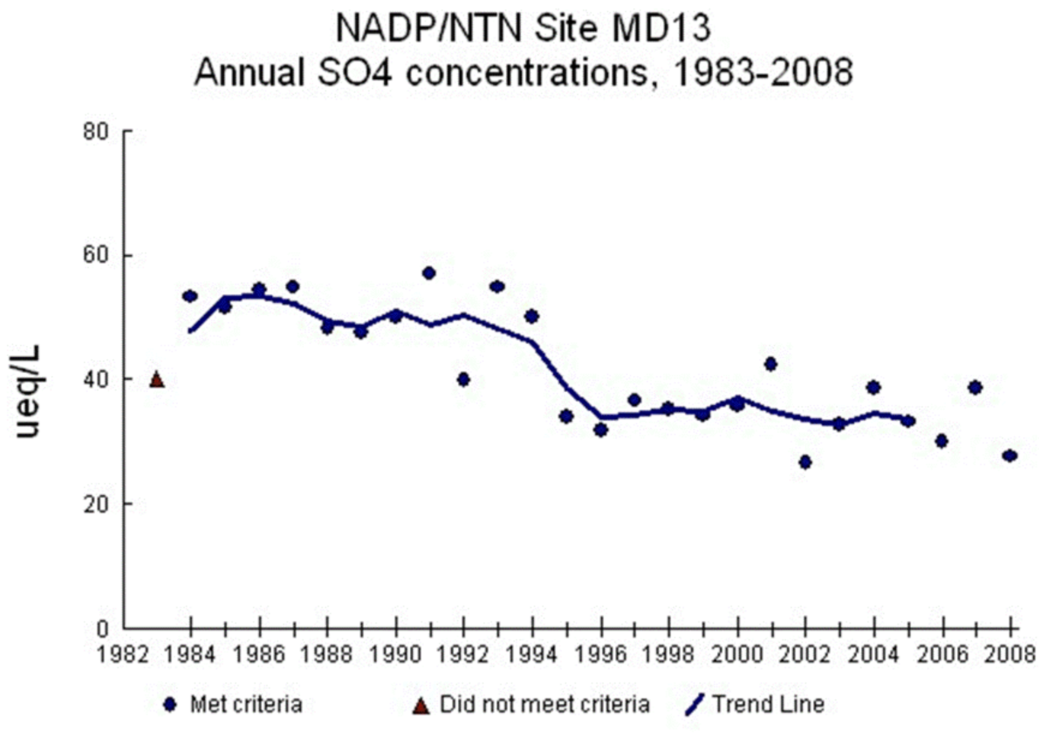


Figure 6. 1983-2008 Sulfate Deposition Trend at Wye, Queen Anne County, Maryland (MD13).

Application of road salts in the watershed is also a likely source of high conductivity levels. These salts remain in solution and are not subject to any significant natural removal mechanisms; road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality (Wegner and Yaggi 2001). According to Forman and Deblinger (2000), there is a "road-effect zone" over which significant ecological effects extend outward from a road; these effects extend 100 to 1,000 m (average of 300 m) on each side of four-lane roads. Sanitary sewage overflows are also likely a source of elevated concentrations of conductivity.

Currently in Maryland there are no specific numeric criteria that quantify the impact of conductivity and sulfates on the aquatic health of non-tidal stream systems. Since the exact sources and extent of inorganic pollutant loadings are not known, MDE determined that current data are not sufficient to enable identification of the specific pollutant(s) causing degraded biological communities from the array of potential inorganic pollutants loading from urban development.

As noted previously, the soils of the Lower Pocomoke River watershed are acidic. There is also acidic deposition in the Lower Pocomoke River watershed. Three of the 2002 stations with low pH values (pH 4.0, 5.4, 5.0) are flagged in the dataset for atmospheric deposition, and the 2008 station (pH 6.2) is flagged as an agriculture acidity source.

All of the stations in the BSID primary dataset are headwater (i.e., first-order) streams. Headwater 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 Lower Pocomoke River watershed is located in the Coastal Plain physiographic region. Under normal conditions, the watershed receives low freshwater input and experiences very little flushing except from storm events. Although low DO is usually associated with surface waters experiencing eutrophication as the result of excessive nutrient loading, the BSID analysis has not identified nutrients as a stressor in the watershed. Natural and anthropogenic changes to an aquatic environment can affect the availability of DO. The normal diurnal fluctuations of a system can be altered resulting in large fluctuations in DO levels which can occur throughout the day. The low DO concentration may be associated with the impacts of low precipitation, low gradient streams, and the decomposition of leaf litter. The failing stations with low dissolved oxygen saturation are first order streams; many first order streams on the Maryland lower eastern shore tend to have very little or no flow during long stretches of the year. Low DO values are not uncommon in small low gradient streams with low or stagnant flows.

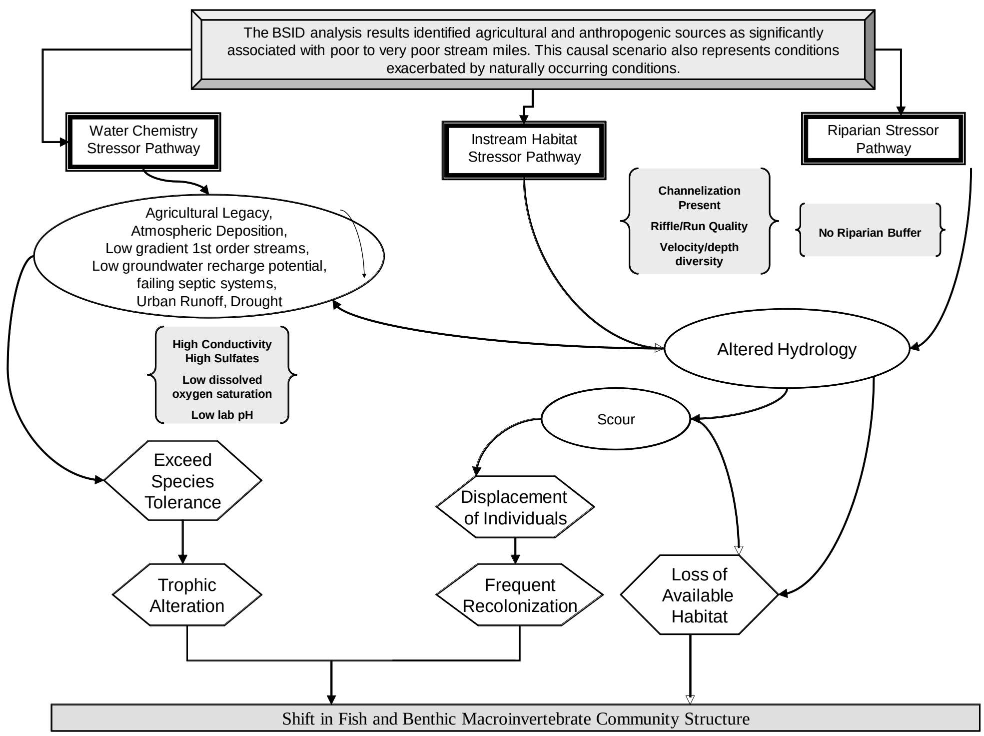
The Lower Potomac River watershed was sampled in 2002 (six stations) and 2008 (1 station) by MDDNR MBSS; three of the sampling sites had DO concentrations less than 6 mg/L and two with DO values below the COMAR water quality standard of 5.0 mg/L (DO 3.6 and 1.6 mg/L). There was a severe drought in 2002 (Kilian and Stranko 2003); during drought conditions there is less freshwater input, therefore less DO in a system. Even though 2008 (round 3) had above normal precipitation for the Salisbury, MD area (NOAA 2015), the one station sampled had a DO of 1.6 mg/L.

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 chemistry stressors is approximately 92%, suggesting that the stressors identified in the BSID analysis would account for a substantial portion of the degraded stream miles within the Lower Pocomoke River watershed (Table 7).

4.3 Discussion of BSID Results

The BSID analysis results suggest that degraded biological communities in the Lower Pocomoke River watershed are a result of increased agricultural land uses, which cause alterations to hydrology and riparian habitat. Increased agricultural land uses exacerbate the naturally occurring conditions in the Lower Pocomoke River watershed, which result in an unstable stream ecosystem that eliminates optimal habitat. The high proportions of these land uses also typically result in increased contaminant (e.g., sulfates) loads to surface waters. Decreased riparian buffer areas are potentially contributing to increased stream temperatures, and reduced amounts of large wood debris and allochthonous material in the stream. Altered flow regimes (e.g., channelization) create a less stable stream channel, leading to excessive bank erosion, loss of pool habitat and instream cover, and excessive streambed scour (Wang et al. 2001). In urbanized areas lawns are frequently and severely mowed, as a result soils can be more easily eroded and transported to streams. Alterations to the hydrologic regime, physical habitat, and water chemistry, have all combined to degrade the Lower Pocomoke River watershed, leading to a loss of diversity in the biological community.

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.


The BSID analysis results identified agricultural and anthropogenic sources as significantly associated with poor to very poor stream miles. This causal scenario also represents conditions exacerbated by naturally occurring conditions.
Water Chemistry Stressor Pathway
Instream Habitat Stressor Pathway
Riparian Stressor Pathway
Agricultural Legacy, Atmospheric Deposition, Low gradient 1st order streams, Low groundwater recharge potential, failing septic systems, Urban Runoff, Drought
Channelization Present
Riffle/Run Quality
Velocity/depth diversity
No Riparian Buffer
High Conductivity
High Sulfates
Low dissolved oxygen saturation
Low lab pH
Altered Hydrology
Scour
Exceed Species Tolerance
Displacement of Individuals
Trophic Alteration
Frequent Recolonization
Loss of Available Habitat
Shift in Fish and Benthic Macroinvertebrate Community Structure

5.0 Conclusion

Data suggest that the Lower Pocomoke River watershed's biological communities are strongly influenced by naturally occurring conditions and agricultural land use, which alters the hydrologic regime resulting in increased pollutant loading. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to agricultural landscapes, which often cause flashy hydrology in streams and increased contaminant loads from runoff. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the Lower Pocomoke River watershed are summarized as follows:

- The BSID process has determined that the biological communities in the Lower Pocomoke River watershed are likely degraded due to inorganics (i.e., sulfates, and conductivity). Sulfates and conductivity levels are significantly associated with degraded biological conditions and found, respectively, in approximately 75% and 27% of the stream miles with poor to very poor biological conditions in the Lower Pocomoke River watershed. The BSID results thus support an inorganic/sulfate Category 5 listing of Lower Pocomoke River for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Lower Pocomoke River watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID process has also determined that biological communities in the Lower Pocomoke River 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 Lower Pocomoke River watershed based on channelization being present in approximately 70% of degraded stream miles.

- The BSID process has also determined that biological communities in the Lower Pocomoke River watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones 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. MDE recommends a Category 4c listing for the Lower Pocomoke River watershed based on inadequate riparian buffer zones in approximately 45% of degraded stream miles.

References

Allan, J. D. 2004. Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems. *Annual Review Ecology, Evolution, and Systematics* 35: 257–84.

Allan, J. D., and M. M. Castillo. 2007. *Stream Ecology: Structure and function of running waters*. Norwell, MA: Kluwer Academic Publishers.

COMAR (Code of Maryland Regulations). 2015a. 26.08.02.02. http://www.dsd.state.md.us/comar/26/26.08.02.02.htm (Accessed August, 2015).

______________. 2015b. *26.08.02.08 (D), (2), (b), (a).* http://www.dsd.state.md.us/comar/26/26.08.02.08.htm (Accessed August, 2015).

_______________. 2015c. *26.08.02.03-3*. http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.03-3.htm (Accessed August, 2015).

Delong, M. D., and M. A. Brusven. 1994. Allochthonous Input of Organic Matter from Different Riparian Habitats of an Agriculturally Impacted Stream. *Environmental Management* 18 (1): 59-71.

Eimers, C. M., and P. J. Dillion. 2002. Climate effects on sulphate flux from forested catchments in south-central Ontario. *Biogeochemistry* 61: 337-355.

Forman, R. T. T., and R. D. Deblinger. 2000. The Ecological Road-Effect Zone of a Massachusetts (U.S.A) Suburban Highway. *Conservation Biology* 14(1): 36-46

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

IDNR (Iowa Department of Natural Resources). 2009. *Iowa's Water Quality Standard Review –Total Dissolved Solids (TDS).* http://www.iowadnr.gov/portals/idnr/uploads/water/standards/ws_review.pdf (Accessed August, 2015).

Johnson, L. B., C. Richards, G. E. Host, and J. W. Arthur. 1997. *Landscape influences on water chemistry in Midwestern stream ecosystems*. Freshwater Biology 37:193-208.

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

Kilian, J., and S. Stranko. 2003. Temporal changes in the ecological condition of non-tidal streams in Back River, Jones Falls, and South River Watersheds. Maryland Department of Natural Resources. Annapolis, MD: Maryland Department of Natural Resources. Available at http://www.dnr.state.md.us/irc/docs/00015730.pdf (Accessed August, 2015).

Kline, M., R. Hilderbrand, and A. Hairston-Strang. 2005. *Maryland Biological Stream Survey 2000-2004 Volume X: Riparian Zone Conditions.* University of Maryland Appalachian Laboratory with Maryland Department of Natural Resources, Forest Service. CBWP-MANTA-EA-05-07. Annapolis, MD: Maryland Department of Natural Resources. Also Available at http://www.dnr.state.md.us/streams/pubs/ea05-7_riparian.pdf (Accessed August, 2015).

Lee, P., C. Smyth and S. Boutin. 2004. *Quantative review of riparian buffer guidelines from Canada and the United States*. Journal of Environmental Management. 70:165-180.

Lewis, W. M. Jr. and D. P. Morris. 1986. Toxicity of Nitrate to Fish: A Review. *Transactions of the American Fisheries Society* 115: 183-195.

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.

MAPSS (Mid-Atlantic Association of Professional Soil Scientists. 2006. Pedologue Newsletter Spring 2006. Available at http://sawgal.umd.edu/mapss/ (Accessed August, 2015).

MDE **(**Maryland Department of the Environment). 2014. *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/Documents/Integrated_Report_Section_PDFs/IR_2014/MD_Final_2014_IR_Part_A-E.pdf (Accessed October, 2015).

_________. 2015. *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 August, 2015).

MGS (Maryland Geological Survey). 2007. *A Brief Description of the Geology of Maryland*. http://www.mgs.md.gov/esic/brochures/mdgeology.html (Accessed August, 2015).

_________. 2006. *Lower Pocomoke River Watershed Characterization*. Baltimore, MD: Maryland Department of the Environment. Available at http://www.dnr.state.md.us/irc/docs/00012411.pdf (Accessed August, 2015).

_________. 1999. *Total Maximum Daily Loads of Nitrogen and Phosphorous for the Lower Pocomoke River Watershed.* Baltimore, MD: Maryland Department of the Environment. Available at http://www.mde.maryland.gov/assets/document/tmdl/porttobacco/pt_tmdl_fin.PDF (Accessed August, 2015).

McCollum, Donna S. 2004. *Landscapes and local influences on the biotic integrity of fish communities in Ohio headwater streams.* Miami, FL: Miami University – Department of Zoology.

Mercurio, G., J. C. Chaillou, and N. E. Roth. 1999. *Guide to using 1995-1997 Maryland Biological Stream Survey Data.* Columbia, MD: Prepared for Maryland Department of Natural Resources by Versar, Inc. Available at: http://www.dnr.state.md.us/streams/pdfs/R1dataguide.pdf (Accessed August, 2015).

NADP (National Atmospheric Deposition Program [NRSP-3]). 2015. NADP Program Office, Illinois State Water Survey, 2204 Griffith Dr., Champaign, IL 61820. Available at http://nadp.sws.uiuc.edu/ (Accessed August, 2015).

NRC (National Research Council). 2008. *Urban Stormwater Management in the United States*. Committee on Reducing Stormwater Discharge Contributions to Water Pollution. Water Science and Technology Board. Division on Earth and Life Studies. National Research Council of the National Academies. Washington, D.C. Available at http://www.epa.gov/npdes/pubs/nrc_stormwaterreport.pdf (Accessed August, 2015).

NOAA (National Weather Service Forecast Office). 2015. *Salisbury Daily Records and Normals.* Wakefield Weather Forecast Office, 10009 General Mahone Hwy Wakefield, VA 23888. Available at http://w2.weather.gov/climate/local_data.php?wfo=akq (Accessed August, 2015).

Petersen, R. C., B. L. Madsen, M.W. Wilzbach, C.H. Magadza, A. Paarlberg, A. Kullberg, and K.W. Cummins. 1987. Stream Management: Emerging Global Similarities. *Ambio* 16 (4): 166-179.

Playle, R. C., G. G. Goss, and C. M. Wood. 1989. Physiological Disturbances in Rainbow Trout (*Salmo gairdneri*) During Acid and Aluminum Exposures in Soft Water of Two Calcium Concentrations. *Canadian Journal of Zoology* 67 (2): 314-324.

Richards C, Haro RJ, Johnson LB, and Host GE. 1997. *Catchment- and reach-scale properties as indicators of macroinvertebrate species traits*. Freshwater Biology 37:219–30.

Roth, N. E., J. H. Vølstad, L. Erb, E. Weber, P. F. Kazyak, S. A. Stranko, and D. M. Boward. 2005. *Maryland Biological Stream Survey 2000-2004 Volume 5: Laboratory, Field, and Analytical Methods.* Annapolis, MD: Maryland Department of Natural Resources.

Roth, N. E., M. T. Southerland, G. Mercurio, J. C. Chaillou, P. F. Kazyak, S. A. Stranko, A.P. Prochaska, D.G. Heimbuch, and J. C. Seibel. 1999. *State of the streams: 1995-1997 Maryland Biological Stream Survey Results*. Annapolis, MD: Prepared for Maryland Department of Natural Resources. Available at: http://www.dnr.state.md.us/streams/pdfs/ea-99-6.pdf (Accessed August, 2015).

Smith, R. A., R. B. Alexander, and M. G. Wolman. 1987. *Water Quality Trends in the Nation's Rivers*. Science. 235:1607-1615.

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. http://www.dnr.state.md.us/streams/pubs/ea-05-13_new_ibi.pdf (Accessed August, 2015).

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. http://www.dnr.state.md.us/streams/pubs/ea05-11_stressors.pdf (Accessed August, 2015).

USEPA (United States Environmental Protection Agency). 2015. *The Causal Analysis/Diagnosis Decision Information System.* http://www.epa.gov/caddis (Accessed August, 2015).

_________. 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 August, 2015).

Van Sickle, J., and Paulson, S.G. 2008. *Assessing the attributable risks, relative risks, and regional extents of aqautic stressors*. Journal of the North American Benthological Society 27: 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.

Wang, L., J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of Urbanization on Stream Habitat and Across Multiple Spatial Scales. *Environmental Management* 28(2): 255-266.

Wegner, W., and M. Yaggi. 2001. *Environmental Impacts of Road Salt and Alternatives in the New York City Watershed.* Stormwater: The Journal for Surface Water Quality Professionals. Available at http://www.newyorkwater.org/downloadedArticles/ENVIRONMENTANIMPACT.cfm (Accessed August, 2015).