FINAL

Watershed Report for Biological Impairment of the Lower Wicomico River Watershed in Wicomico and Somerset Counties, Maryland
Biological Stressor Identification Analysis Results and Interpretation

FINAL

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

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Water Protection Division
U.S. Environmental Protection Agency, Region III
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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BMPs	Best Management Practices
BOD	Biological Oxygen Demand
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
IR	Integrated Report
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MH	Mantel-Haenzel
mg/L	Milligrams per liter
µS/cm	Micro Siemens per centimeter
PCBs	Polychlorinated Biphenyls
P/G/E	Pool/Glide/Eddy
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

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 Wicomico River watershed (basin code 02130301), located in Wicomico and Somerset Counties, is associated with three assessment units in the Maryland Integrated Report (IR): non-tidal (8-digit basin) and two estuary portions, the Lower Wicomico River, and Lower Wicomico River Mesohaline Chesapeake Bay segment (MDE 2012). Below is a table identifying the listings associated with this watershed.

Table E1. 2012 Integrated Report Listings for the Lower Wicomico River Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Lower Wicomico River	02130301	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
		Impoundment Tony Tank Lake	Aquatic Life and Wildlife	1998	TP	4a
					TSS	4a
		Impoundment Schumaker Pond Beach	Water Contact Sport	-	Enterococcus	3
			Fishing	-	Mercury in Fish Tissue	2
Lower Wicomico River Mesohaline	WICMH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory	2012	TN	4a
				2012	TP	4a
			Aquatic Life and Wildlife	-	Impacts to Estuarine Biological Communities	2
			Open Water Fish and Shellfish	1996	TN	4a
				1996	TP	4a
			Seasonal Shallow Water Submerged Aquatic Vegetation	-	TSS	2
Lower Wicomico River Mesohaline	WICMH	Tidal	Shellfishing	1996	Fecal Coliform	4a
	WICMH-2	Tidal	Shellfishing	2012	Fecal Coliform	5
Lower Wicomico River	WICMH	Tidal	Fishing	-	Mercury in Fish Tissue	2
				2008	PCBs in Fish Tissue	5

In 2002, the State began listing biological impairments on the Integrated Report. The current Maryland Department of the Environment (MDE) biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings on the Integrated Report are made, TMDLs are developed, and implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds by measuring the percentage of stream miles that have poor to very poor biological conditions, and calculating whether this is significantly different from a reference condition watershed (i.e., healthy stream, <10% stream miles with poor to very poor biological condition).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Lower Wicomico River and all tributaries is Use I designation - w*ater contact recreation, and protection of nontidal warmwater aquatic life.* In addition, most of the mainstem of the Lower Wicomico River and some tributaries are Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, b, c). The Lower Wicomico River watershed is not attaining its nontidal warmwater aquatic life use designations due to impacts 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 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 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 Lower Wicomico 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 2009). Data suggest that the Lower Wicomico River watershed's biological communities are influenced by elevated nutrients, resulting in low dissolved oxygen levels that exceed species tolerances. Based upon the results of the BSID analysis, the probable causes and sources of the impacts to biological communities in the Lower Wicomico River watershed are summarized as follows:

- No nutrient stressors were identified in the BSID analysis has having significant association with degraded biological conditions in the watershed; however, water quality assessments conducted by a number of agencies over the years have demonstrated that nutrient over enrichment had been occurring in the watershed. In 1996, MDE listed the Lower Wicomico River watershed on the Integrated Report as being impaired by nutrients. A TMDL was developed for nutrients and BOD and was accepted by the USEPA in 2001. The low dissolved oxygen levels observed in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, decomposition of organic matter, and elevated nutrient loading. With identification of low dissolved oxygen levels, the BSID results confirm the tidal 1996 Category 4a listing for TN and 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 2001 Lower Wicomico River Nutrient TMDL and the 2010 Chesapeake Bay TMDL were appropriate management action to begin addressing these stressors to the biological communities in the Lower Wicomico River 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 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 black water 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, <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 the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is still considered impaired but has a TMDL that has been completed or submitted to EPA it will be listed as Category 4a. If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is 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 the round two and three Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) dataset (2000–2009) 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 Wicomico River watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Lower Wicomico River Watershed Characterization

2.1 Location

The Wicomico River is located in Wicomico and Somerset Counties, Maryland (Figure 1). The river is approximately 19 miles in length, from its headwaters to the confluence with the Monie Bay. It drains an area of low marshlands and farming country in the middle Delmarva Peninsula. The river contains four 8-digit watersheds: Wicomico River Head, Wicomico Creek, Lower Wicomico River, and Monie Bay. The headwaters of the Lower Wicomico River contain all of the South Prong and its tributaries, and the North Prong which begins at the outlet of Johnson Pond. The watershed contains the mainstem of the Wicomico River as well as all the tributaries except Wicomico Creek, which is its own 8-digit watershed. The watershed ends where the Wicomico River confluences with Monie Bay and Tangier Sound. The watershed is entirely located within the Coastal Plains physiographic region. There are three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

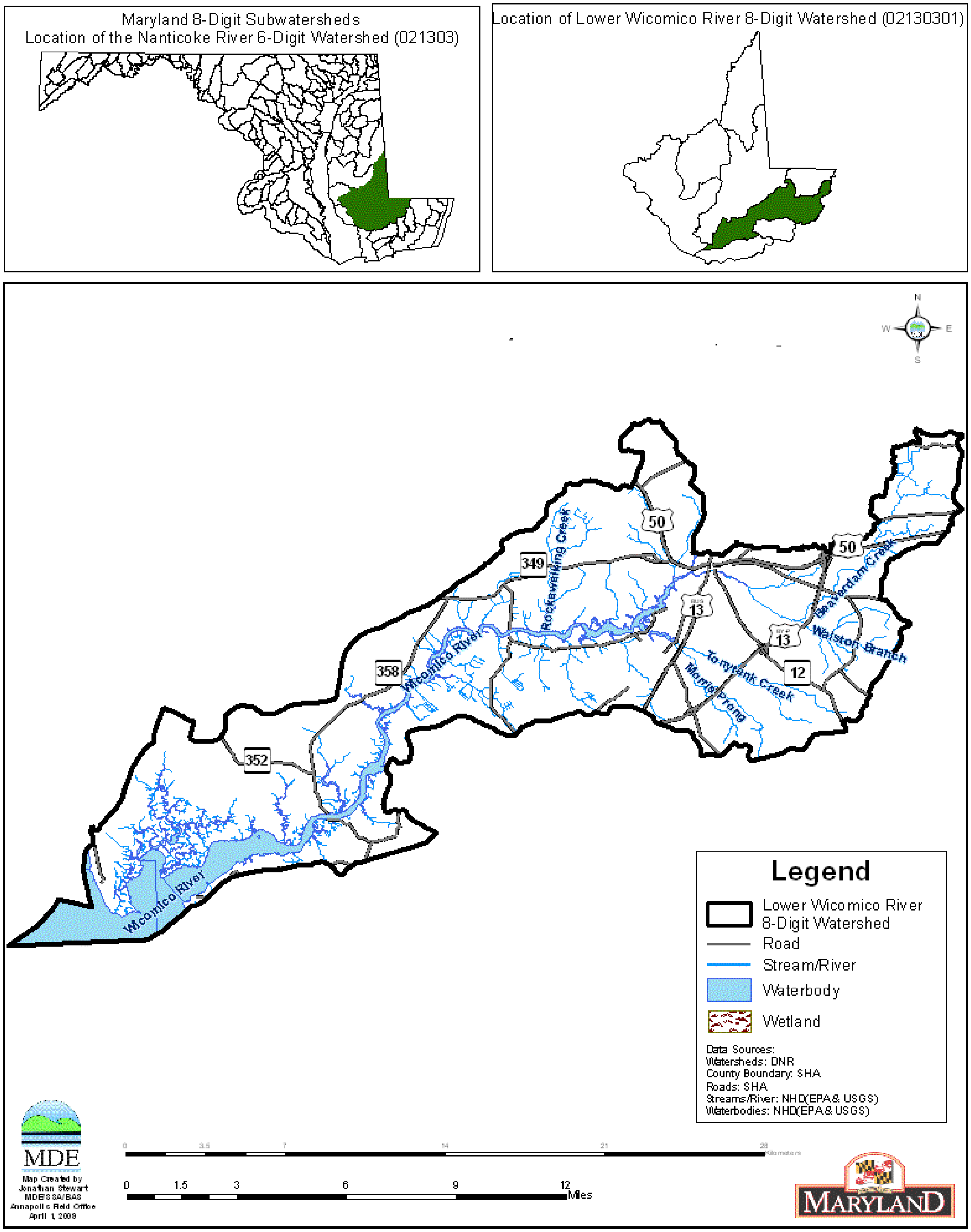

Figure 1. Location Map of the Lower Wicomico River Watershed

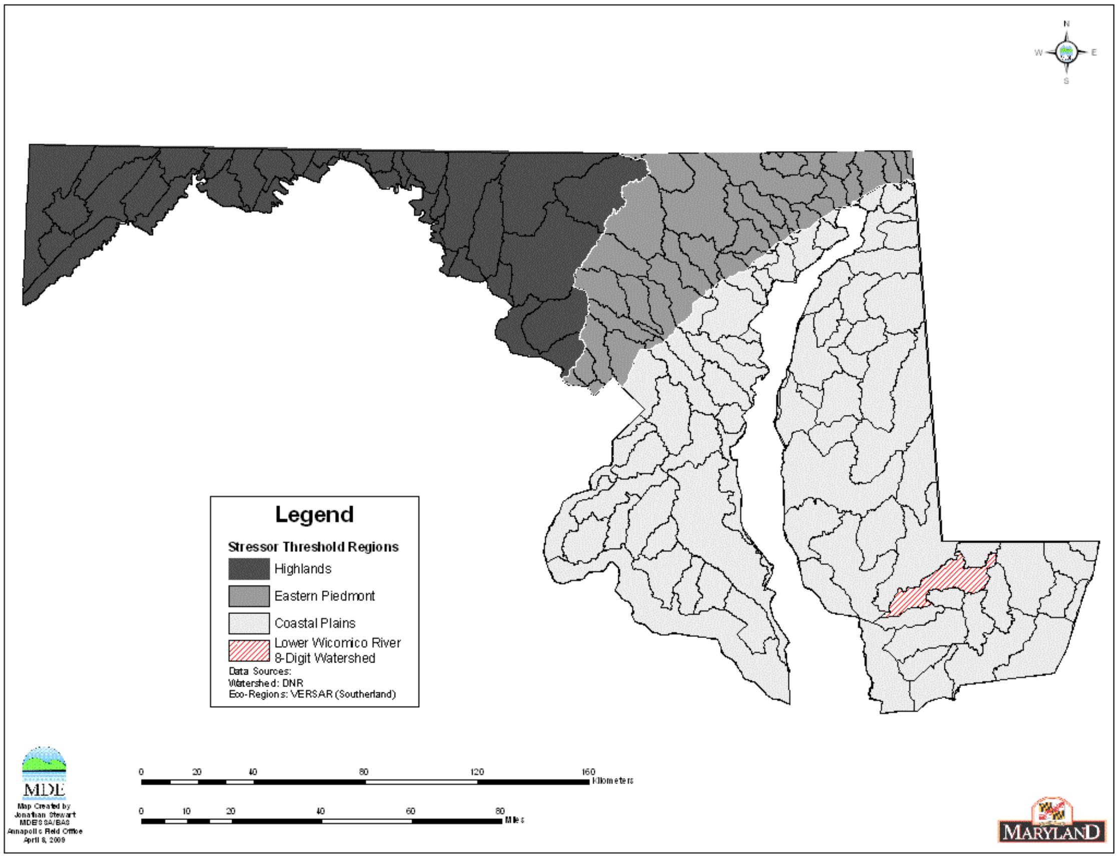

Figure 2. Eco-Region Location Map of the Lower Wicomico River Watershed

2.2 Land Use

The drainage area of the Lower Wicomico River watershed is approximately 73,000 acres. The watershed contains urban, agricultural, and forested land uses. Within the last twenty-six years there have been two different patterns of development in Wicomico County. From 1980 to 1989, almost half of the observed development was at the expense of forests and wetlands. Most new development occurred along the county's waterfront and urban areas. From 1989 to 1995, development was chiefly at the expense of agricultural land and was much larger and scattered in distribution (MDDNR 2007). There are two large urban areas in the watershed, Fruitland and Salisbury. These areas have been in a period of accelerated transition for the past ten years. Essentially, the urban areas are progressively expanding, with subdivisions replacing former cropland, forests, and wetlands.

According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the Lower Wicomico River watershed consists of approximately 49% forested, 31% urban (with 7% impervious surfaces), and 20% agricultural land uses (USEPA 2010) (see Figure 3 and Figure 4).

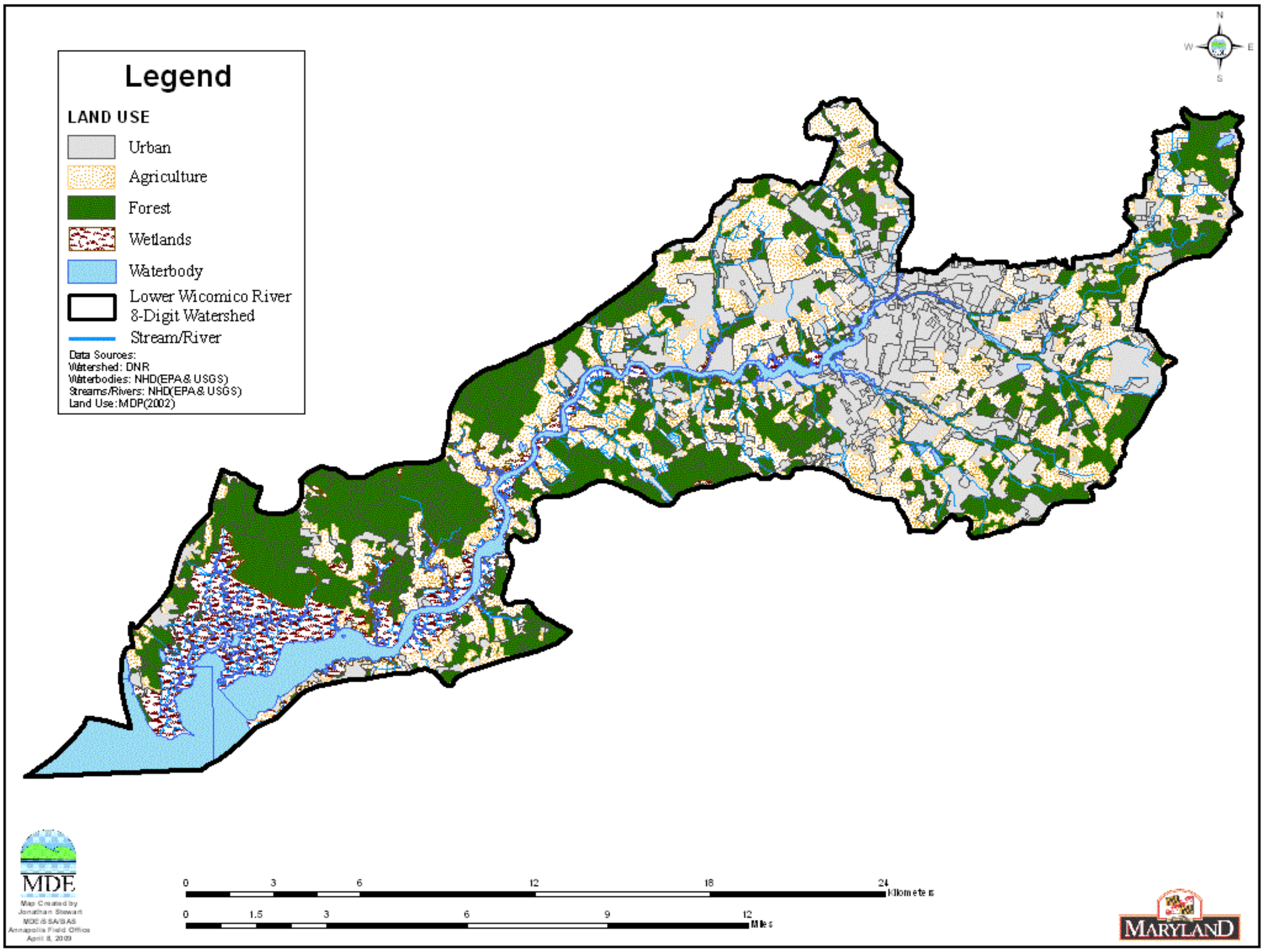

Figure 3. Land Use Map of the Lower Wicomico River Watershed

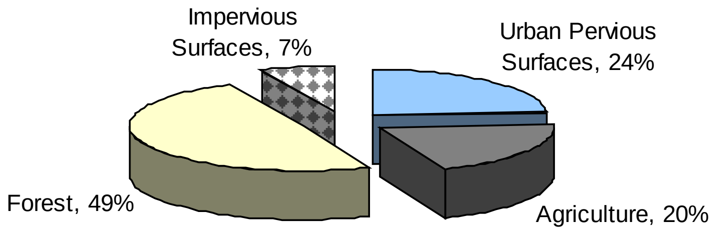

Figure 4. Proportions of Land Use in the Lower Wicomico River Watershed

2.3 Soils/hydrology

The Lower Wicomico River 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. In some areas of the Lower Coastal Plain, soils may be so sand-rich that they are economically valuable as sources of sand. These deep sand soils are very permeable and do not retain moisture well. Where organic material is available, the Coastal Plain's sandy soils become loams, may be highly acidic, and retain more moisture. In some shallow or exposed areas, soils may have silts or clays that further enhance their ability to retain moisture, host more diverse plant life, and support agriculture. Wetlands are found where silt, clay and/or very fine sand create wet, acidic soils; these soils have been ditched and drained in many areas to support agricultural farm fields. Tidal marsh and swamp soils are found along shorelines in the Coastal Plain region and can be rich in organic material, including peat (MDP 1973). The Coastal Plain Region is characterized by lower relief, and is drained by slowly meandering streams with shallow channels and gentle slopes (MGS 2007).

3.0 Lower Wicomico River Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Lower Wicomico River watershed (basin code 02130301), located in Wicomico and Somerset Counties, is associated with three assessment units in the Integrated Report

(IR): non-tidal (8-digit basin) and two estuary portions, the Lower Wicomico River, and Lower Wicomico River Mesohaline Chesapeake Bay segment (MDE 2012). Below is a table identifying the listings associated with this watershed.

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3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Lower Wicomico River and all tributaries is Use I designation - w*ater contact recreation, and protection of nontidal warmwater aquatic life.* In addition, most of the mainstem of the Lower Wicomico River and some tributaries are Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, b, c). A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life; primary or secondary contact recreation, drinking water supply, and trout waters. 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 Wicomico River watershed is listed under Category 5 of the 2012 Integrated Report for impacts to biological communities. Approximately 60% of stream miles in the Lower Wicomico River watershed are estimated as having benthic and/or fish indices of biological integrity 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 seven stations. Five of the seven stations have 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, MBSS round two and round three (2000-2009) contains five MBSS sites; with three having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Lower Wicomico River watershed.

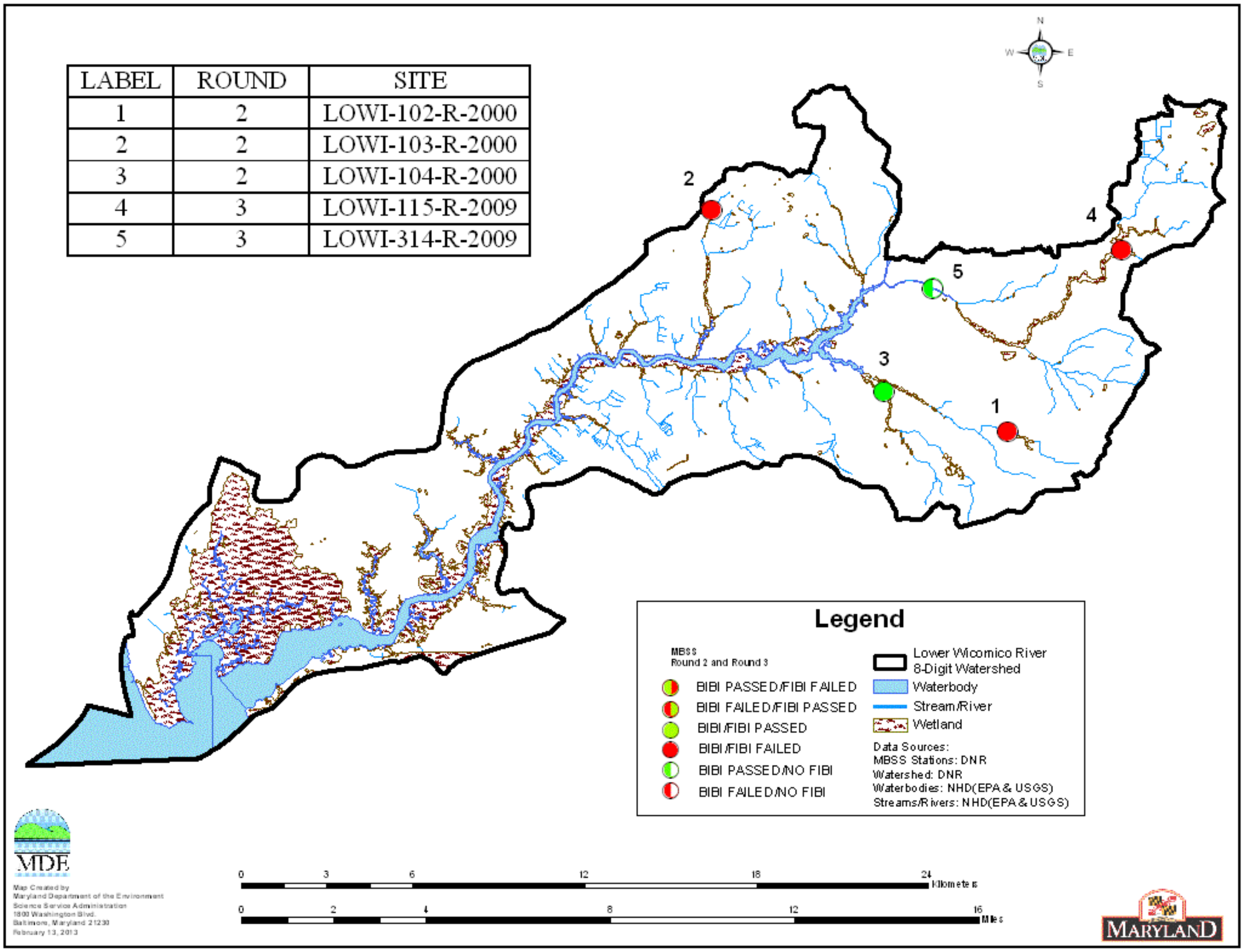

Figure 5. Principal Dataset Sites for the Lower Wicomico River Watershed

4.0 Stressor Identification Results

The BSID process uses results from the BSID data analysis to evaluate each biologically impaired watershed and determine 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 fair to 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-Haenzel (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).

The parameters used in the BSID analysis are segregated into five groups: land use sources, and stressors representing sediment, in-stream habitat, riparian habitat, and water chemistry conditions. Through the BSID data analysis of the Lower Wicomico River watershed, MDE identified habitat and water chemistry stressors as having significant association with poor to very poor fish and/or benthic biological conditions. Parameters representing possible sources in the watershed are listed in Table 2 and Table 3 shows the summary of combined AR values for the source groups in the Lower Wicomico River watershed. As shown in Table 4 through Table 6, a number of parameters from the habitat and water chemistry group were identified as possible biological stressors. Table 7 shows the summary of combined AR values for the stressor groups in the Lower Wicomico River watershed.

Table 2. Stressor Source Identification Analysis Results for the Lower Wicomico 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	Atmospheric deposition present	4	3	272	33%	37%	1	No	_
	Agricultural acid source present	4	3	272	0%	7%	1	No	_
	AMD acid source present	4	3	272	0%	0%	1	No	_
	Organic acid source present	4	3	273	0%	7%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	5	3	277	0%	3%	1	No	_
	High % of agriculture in 60m buffer	5	3	277	0%	4%	1	No	_
Sources - Anthropogenic	Low % of forest in watershed	5	3	277	0%	6%	1	No	_
	Low % of wetland in watershed	5	3	277	0%	11%	1	No	_
	Low % of forest in 60m buffer	5	3	277	0%	8%	1	No	_
	Low % of wetland in 60m buffer	5	3	277	0%	10%	1	No	_
Sources - Impervious	High % of impervious surface in watershed	5	3	277	0%	4%	1	No	_
	High % of impervious surface in 60m buffer	5	3	277	0%	5%	1	No	_
	High % of roads in watershed	5	3	277	0%	0%	1	No	_
	High % of roads in 60m buffer	5	3	277	0%	4%	1	No	_
Sources - Urban	High % of high-intensity developed in watershed	5	3	277	0%	7%	1	No	_
	High % of low-intensity developed in watershed	5	3	277	0%	6%	1	No	_
	High % of medium-intensity developed in watershed	5	3	277	0%	2%	1	No	_
	High % of early-stage residential in watershed	5	3	277	33%	5%	0.143	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 residential developed in watershed	5	3	277	0%	6%	1	No	_
	High % of rural developed in watershed	5	3	277	0%	5%	1	No	_
	High % of high-intensity developed in 60m buffer	5	3	277	0%	6%	1	No	_
	High % of low-intensity developed in 60m buffer	5	3	277	0%	4%	1	No	_
	High % of medium-intensity developed in 60m buffer	5	3	277	0%	3%	1	No	_
	High % of early-stage residential in 60m buffer	5	3	277	0%	7%	1	No	_
	High % of residential developed in 60m buffer	5	3	277	0%	4%	1	No	_
	High % of rural developed in 60m buffer	5	3	277	33%	5%	0.143	No	_

Table 3. Summary of Combined Attributable Risk Values of the Source Group in the Lower Wicomico River Watershed

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

4.1 Sources Identified by BSID Analysis

The BSID source analysis (Table 2) did not identify any potential sources of stressors that may cause negative biological impacts. Even though no potential sources were identified, the Wicomico River watershed has one of the fastest population growth rates on the Delmarva Peninsula and is growing at a faster rate than the state of Maryland (MDDNR 2007). According to the Chesapeake Bay Program's Phase 5.2 Model, 31% of the watershed is comprised of urban land uses with 7% consisting of impervious surfaces (USEPA 2010). The Lower Wicomico River watershed contains large areas of urban and impervious surfaces, which alters the hydrologic regime, leading to increased runoff and decreased infiltration. Many areas within the Lower Wicomico River watershed were developed before regulatory requirements were in place to treat the runoff to remove some of the pollutants or to reduce the flows and volumes running off the hard surfaces into nearby streams.

The remainder of this section will discuss stressors identified by the BSID analysis (Table 4, 5, and 6) and their link to degraded biological conditions in the watershed.

4.2 Stressors Identified by BSID Analysis

Table 4. Sediment Biological Stressor Identification Analysis Results for the Lower Wicomico 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	4	3	141	0%	20%	1	No	_
	Moderate bar formation present	4	3	140	0%	49%	0.25	No	_
	Bar formation present	4	3	140	0%	77%	0.014	No	_
	Channel alteration moderate to poor	3	2	131	50%	59%	1	No	_
	Channel alteration poor	3	2	131	0%	26%	1	No	_
	High embeddedness	4	3	140	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	4	3	140	33%	41%	1	No	_
	Epifaunal substrate poor	4	3	140	33%	10%	0.266	No	_
	Moderate to severe erosion present	4	3	140	33%	42%	1	No	_
	Severe erosion present	4	3	140	0%	11%	1	No	_
	Silt clay present	4	3	140	100%	99%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Lower Wicomico 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	5	3	150	33%	14%	0.363	No	_
	Concrete/gabion present	3	2	148	0%	1%	1	No	_
	Beaver pond present	4	3	138	0%	7%	1	No	_
	Instream habitat structure marginal to poor	4	3	140	33%	34%	1	No	_
	Instream habitat structure poor	4	3	140	0%	5%	1	No	_
	Pool/glide/eddy quality marginal to poor	4	3	140	100%	38%	0.028	Yes	65%
	Pool/glide/eddy quality poor	4	3	140	0%	3%	1	No	_
	Riffle/run quality marginal to poor	4	3	140	100%	49%	0.103	No	_
	Riffle/run quality poor	4	3	140	100%	21%	0.01	Yes	79%
	Velocity/depth diversity marginal to poor	4	3	140	100%	55%	0.231	No	_
	Velocity/depth diversity poor	4	3	140	67%	13%	0.036	Yes	55%
Riparian Habitat	No riparian buffer	3	2	140	50%	15%	0.287	No	_
	Low shading	4	3	140	0%	3%	1	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Lower Wicomico 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	5	3	277	33%	8%	0.227	No	_
	High conductivity	5	3	277	0%	6%	1	No	_
	High sulfates	5	3	277	0%	8%	1	No	_
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	4	3	261	67%	17%	0.083	Yes	49%
	Dissolved oxygen < 6mg/l	4	3	261	100%	25%	0.017	Yes	75%
	Low dissolved oxygen saturation	4	3	261	33%	6%	0.182	No	_
	High dissolved oxygen saturation	4	3	261	0%	3%	1	No	_
	Ammonia acute with salmonid present	5	3	277	0%	0%	1	No	_
	Ammonia acute with salmonid absent	5	3	277	0%	0%	1	No	_
	Ammonia chronic with early life stages present	5	3	277	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	5	3	277	0%	0%	1	No	_
	High total nitrogen	5	3	277	0%	6%	1	No	_
	High total phosphorus	5	3	277	0%	9%	1	No	_
	High orthophosphate	5	3	277	33%	5%	0.153	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	5	3	277	0%	9%	1	No	_
	Acid neutralizing capacity below episodic level	5	3	277	33%	45%	1	No	_
	Low field pH	4	3	262	33%	40%	1	No	_
	High field pH	4	3	262	0%	1%	1	No	_
	Low lab pH	5	3	277	67%	38%	0.56	No	_
	High lab pH	5	3	277	0%	0%	1	No	_

Table 7. Summary of Combined Attributable Risk Values of the Stressor Group in the Lower Wicomico River Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
In-stream Habitat	87%
Chemistry - Nutrients	80%
All Chemistry	80%
All Stressors	***88%***

Sediment Conditions

BSID analysis results for the Lower Wicomico River did not identify any sediment related stressor parameters that have a statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community) (Table 4).

In-stream Habitat Conditions

BSID analysis results for Lower Wicomico River identified only three in-stream habitat 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). These parameters are *pool/glide/eddy quality (marginal to poor), riffle/run quality (poor),* and *velocity/depth diversity (poor)* (Table 5).

Pool/glide/eddy quality (marginal to poor) was identified as significantly associated with degraded biological conditions in the Lower Wicomico River watershed, and found to impact approximately 65% of the stream miles with poor to very poor biological conditions. Pool/glide/eddy (P/G/E) quality is a visual observation and quantitative measurement of the variety and spatial complexity of slow or still water habitat and cover within a stream segment referred to as P/G/E. 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. P/G/E quality conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, defined as minimal heterogeneous habitat with a max depth of <0.2 meters or being absent completely; and 2) marginal, defined as <10% heterogeneous habitat with shallow areas (<0.2 meters) prevalent and slow moving water areas with little cover.

Riffle/run quality (poor) was identified as significantly associated with degraded biological conditions in the Lower Wicomico River watershed and found to impact approximately 79% of the stream miles with poor to very poor biological conditions. 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. An increase in the 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. Riffle/run quality conditions indicating biological degradation are set at two levels: 1) poor, defined as riffle/run depths < 1 cm or riffle/run substrates concreted; and 2) marginal to poor, defined as riffle/run depths generally 1 – 5 cm with a primarily single current velocity.
The presence of a well-developed riffle/run system is indicative of different types of habitat within a stream reach, and thereby an assumed higher biodiversity of organisms (Richards, Host, and Arthur 1993). Because stream organisms are highly specialized in many cases, a diverse array of habitat typically leads to a diverse array of macroinvertebrates (Karr 1997).

Velocity/depth diversity (poor) was identified as significantly associated with degraded biological conditions in the Lower Wicomico River watershed, and found to impact approximately 55% of the stream miles with poor to very poor biological conditions. Velocity/depth diversity is a visual observation and quantitative measurement based on the variety of velocity/depth regimes present at a site (i.e., slow-shallow, slow-deep, fast-shallow, and fast-deep). Like riffle/run quality, the 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 poor velocity/depth/diversity category 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 (e.g., bar formation, entrenchment, etc.). Poor velocity/depth diversity conditions are defined as the stream segment being dominated by one velocity/depth regime. Velocity is one of the critical variables that controls the presence and number of species (Gore 1978). Many invertebrates depend on certain velocity ranges for either feeding or breathing (Brookes 1988).

All the in-stream habitat parameters identified by the BSID analysis are intricately linked with habitat heterogeneity, the presence of these stressors indicates a lower diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. Substrate is an essential component of in-stream habitat to macroinvertebrates for several reasons. First, many organisms are adapted to living on or obtaining food from specific types of substrate, such as cobble or sand. The group of organisms known as scrapers, for instance, cannot easily live in a stream with no large substrate because there is nothing from which to scrape algae and biofilm. Hence substrate diversity is strongly correlated with macroinvertebrate assemblage composition (Cole, Russel, and Mabee 2003). Second, obstructions in the stream such as cobble or boulders slow the movement of coarse particulate organic matter, allowing it to break down and feed numerous insects in its vicinity (Hoover, Richardson, and Yonesmitsu 2006).

Urban and agricultural land use in watersheds often results in alterations of stream geomorphic structure. Such disturbances lead to increased fine sediment input to the stream along with direct changes in channel structure. Embeddedness and siltation often eliminate natural riffle-pool complexes and loss of stable diverse substrates. Loss of quality in-stream habitats, riffle/pool/glides, and velocity/depth diversities are serious habitat related problems in the Lower Wicomico River, since the naturally low topography of the watershed already limits habitat diversity. As the variety and abundance of substrates decreases, diversity decreases, and potential for recovery following disturbances decreases. As the physical habitat changes, increased stress is placed on aquatic organisms. These stresses, depending on the tolerance of the species and individuals, may limit growth, abundance, reproduction and survival (Lynch, Corbett, and Hoopes 1977).

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 in-stream habitat stressor group is approximately 87%, suggesting these stressors are the probable causes of biological impairments in the Lower Wicomico River watershed (Table 5).

Riparian Habitat Conditions

BSID analysis results for the Lower Wicomico River did not identify any riparian habitat parameters that have a statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community) (Table 5).

Water Chemistry Conditions

BSID analysis results for Lower Wicomico River identified only two 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). These parameters are *low dissolved oxygen < 6mg/l*, and *low dissolved oxygen < 5mg/l* (Table 6).

Low dissolved oxygen (DO) *< 5mg/L and < 6mg/L* concentrations were identified as significantly associated with degraded biological conditions and found to impact approximately 49% (*< 5mg/L)* and 75% (*< 6mg/L)* of the stream miles with poor to very poor biological conditions in the Lower Wicomico River 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 (2013d).

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 elevated nutrient loadings, low precipitation, low gradient streams, and the decomposition of leaf litter.

Although low DO concentrations are usually associated with surface waters experiencing eutrophication as the result of excessive nutrient loading, this might not be the only cause in the Lower Wicomico River watershed. One major difference between the Coastal Plain and the other physiographic provinces in Maryland is the response of streams to organic enrichment. Because of the lower gradient and naturally limited capacity to mechanically aerate the water and replace oxygen lost via biochemical oxygen demand (BOD), streams in the Coastal Plain more often tend to become more over-enriched than elsewhere in the State. Many first order streams on the Maryland 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 Maryland Department of Natural Resources (DNR) released a Wicomico River Water Quality Assessment newsletter in 2006. The newsletter reported that water quality was impacted by high nutrient inputs contributing to poor water clarity, tidally-influenced algal blooms, and a lack of underwater grasses. These findings were based on a review of data from DNR's shallow water monitoring program, which consists of two main components: automated continuous monitoring and water quality mapping. In 2006, the Wicomico River had both the highest average nitrogen concentration and the fourth highest average phosphorus concentration among the surrounding lower eastern shore tributaries to the Chesapeake Bay (MDDNR 2007).

The TMDL for nitrogen, phosphorus and BOD for the Lower Wicomico River was approved by USEPA in 2001. Since 2002, Wicomico Creekwatchers have been monitoring water quality at twenty-one sites throughout the Wicomico River system from March until November, collecting samples bi-weekly. From 2010 through 2012, water quality was collected from the following sites: Wicomico Creek, the East Prong, Shiles Creek, Rockawalkin Creek, Coulbourne Mill Pond, Johnson Pond, Parker Pond, Schumaker Pond, Tony Tank and Allen Pond. The sampling sites are divided into four functional groups: Ponds, Upper Wicomico, Lower Wicomico, and Wicomico Creek (WCW 2010, 2011, 2012).

In 2010, Wicomico Creekwatchers reported that water quality improved slightly compared with the previous multi-year averages in most Wicomico River sections. Total Nitrogen (TN) and Total Phosphorus (TP) improved in the upstream impoundments and in the Lower Wicomico River. However, TN averages for the year remained in the unhealthy range, while TP levels were "acceptable" (WCW 2010). In 2011 and 2012 the Wicomico Creekwatchers reported that the Wicomico River's water quality improved overall, with most annual averages considerably better compared with last year and with the previous multi-year average (WCW 2011). TN continued on a positive trend, lower than in previous years in all groups, and reaching or nearing the healthy threshold in Wicomico Creek and the Lower Wicomico River. In 2012 for the first time all individual site averages were below the high-level threshold (WCW 2012). TP also declined substantially in the Ponds, reaching the healthy threshold, and it also improved in the Lower Wicomico (WCW 2012).

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 80% suggesting these stressors are the probable causes of biological impairments in the Lower Wicomico River watershed (Table 7).

4.3 Discussion

The BSID analysis applies a threshold of 100% for embeddedness in the Coastal Plains since the eco-region is naturally embedded. Consequently, embeddedness was not identified as significantly associated with degraded biological conditions in the Lower Wicomico River watershed in this analysis. The data review did, however, identify all DNR MBSS round two and three sites used in this analysis were 100% embedded. Embeddedness describes the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. The BSID results also did not identify epi-faunal substrate quality as a stressor; however, all sites were either below or just slightly higher than marginal rating. Epifaunal substrate is a visual observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. Watersheds in the Coastal Plain physiographic region are naturally impacted by sediment deposition due to the region's soil types and hydrology. Streams with a lack of diverse substrates, typically the case with streams in this region, have little habitat heterogeneity because of high embeddedness, marginal epi-faunal quality, low gradients, and low flow/velocities. Historical loss of forest cover in the watershed and its replacement with urban and agricultural land uses have exacerbated loss of habitat heterogeneity and lower aquatic species diversity. After analysis of current MBSS data, sedimentation in the Lower Wicomico River watershed is predominately associated with natural conditions of the Coastal Plains eco-region. Land use changes in the watershed have exacerbated sedimentation rates, but not to the extent that these stressors are driving the biological impairments. Hopefully with continued efforts in implementing and enforcing the 2010 Chesapeake Bay TMDL by State and local agencies, sediment loads in the Lower Wicomico River watershed will decrease and stream's habitat will improve.

No nutrient stressors were identified in the BSID analysis has having significant association with degraded biological conditions in the watershed; however, water quality assessments conducted over many years have demonstrated that nutrient over enrichment had been occurring in the watershed. The low dissolved oxygen levels observed in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, decomposition of organic matter, and elevated nutrient loading.

All the MDDNR MBSS sampling in the Lower Wicomico River was conducted in 2000 and 2009. Due to the naturally low gradients and lack of aeration in streams of the Coastal Plains region, they tend to become more over enriched than elsewhere in the State; therefore, ensuring minimal nutrient loads is crucial to support diverse aquatic life. Hopefully with continued efforts in implementing and enforcing nutrient TMDLs by State and local agencies downward trends in nutrient loadings will continue in the Lower Wicomico River watershed, as well as occurrences of low DO levels.

The combined AR for all the stressors is approximately 88%, suggesting that the water chemistry stressors identified in the BSID analysis would account for almost all of the degraded stream miles within the Lower Wicomico River watershed (Table 7).

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 for the Patuxent River Middle Watershed

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 2013). 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 causal model for the Lower Wicomico River watershed, with pathways to show the watershed's probable stressors as indicated by the BSID analysis.

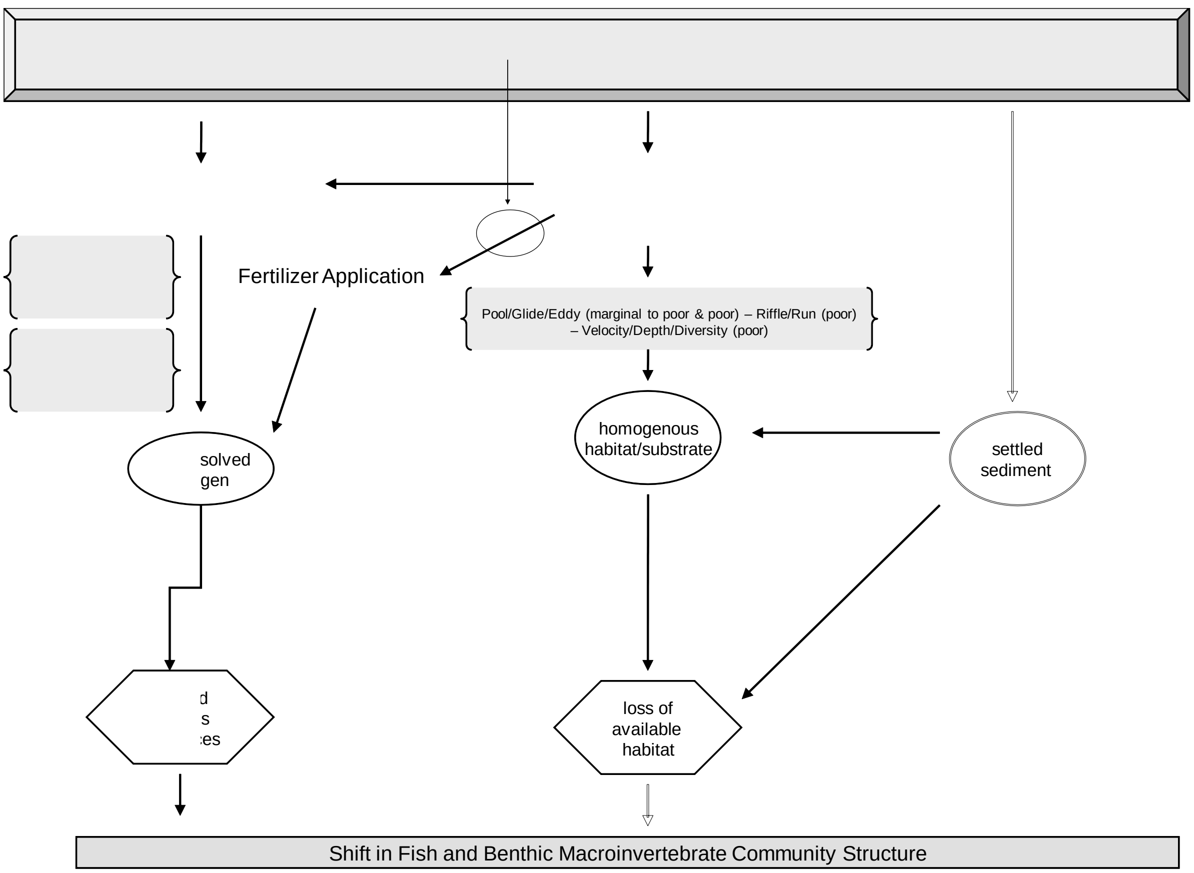

Figure 6. Final Causal Model for the Lower Wicomico River Watershed

5.0 Conclusions

Data suggest that the Lower Wicomico River watershed's biological communities are influenced by elevated nutrients, resulting in low dissolved oxygen levels that exceed species tolerances. Based upon the results of the BSID analysis, the probable causes and sources of the impacts to biological communities in the Lower Wicomico River watershed are summarized as follows:

- No nutrient stressors were identified in the BSID analysis has having significant association with degraded biological conditions in the watershed; however, water quality assessments conducted by a number of agencies over the years have demonstrated that nutrient over enrichment had been occurring in the watershed. In 1996, MDE listed the Lower Wicomico River watershed on the Maryland Integrated Report as being impaired by nutrients. A TMDL was developed for nutrients and BOD and was accepted by the USEPA in 2001. The low dissolved oxygen levels observed in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, decomposition of organic matter, and elevated nutrient loading. With identification of low dissolved oxygen levels, the BSID results confirm the tidal 1996 Category 4a listing for TN and 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 2001 Lower Wicomico River Nutrient TMDL and the 2010 Chesapeake Bay TMDL were appropriate management action to begin addressing these stressors to the biological communities in the Lower Wicomico River watershed.

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