Watershed Report for Biological Impairment of the Non-Tidal Nanticoke River Watershed, Dorchester and Wicomico Counties, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BMP	Best Management Practices
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
MD	Maryland
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
MH	Mantel-Haenzel
mg/L	Milligrams per liter
NMP	Nutrient Management Practices
PDA	Public Drainage Association
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
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*, 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 Nanticoke River watershed (basin code 02130305), located in Dorchester and Wicomico Counties, has four different assessment units: non-tidal (8-digit basin) and three estuarine portions (Chesapeake Bay segments) in the Integrated Report. The Chesapeake Bay segments related to the Nanticoke River watershed are the Upper Nanticoke River Tidal Fresh, Middle Nanticoke River Oligohaline, and Lower Nanticoke River Mesohaline segments. A TMDL was developed and approved by the USEPA for fecal coliform in 2008, and the Chesapeake Bay TMDL addresses all tidal total suspended solid and nutrient listings. Below, Table E1 identifies the listings associated with this watershed.

Table E1. 2012 Integrated Report Listings for the Nanticoke River Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Nanticoke River	02130305	Non-tidal	Aquatic Life and Wildlife	2004	Impacts to Biological Communities	5
Lower Nanticoke River Mesohaline	NANMH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory	-	TN	3
					TP	3
			Open Water Fish and Shellfish	-	TN	3
					TP	3
			Aquatic Life and Wildlife	-	Impacts to Biological Communities	2
			Water Contact Sports	-	Fecal Coliform (Cove Road Beach)	2
			Seasonal Shallow Water Submerged Aquatic Vegetation	2008	TSS	4a
			Shellfishing	1998	Fecal Coliform	4a
			Fishing	2008	PCBs (Fish Tissue)	5
				-	Mercury (Fish Tissue)	2
Middle Nanticoke River Oligohaline	NANOH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory	2012	TN	4a
				2012	TP	4a
			Aquatic Life and Wildlife	-	Impacts to Biological Communities	3
			Seasonal Shallow Water Submerged Aquatic Vegetation	1998	TSS	4a
			Open Water Fish and Shellfish	2008	TN	4a
				2008	TP	4a
Upper Nanticoke River Tidal Fresh	NANTF	Tidal Fresh	Seasonal Migratory fish spawning and nursery Subcategory	2012	TN	4a
				2012	TP	4a
			Aquatic Life and Wildlife	-	Impacts to Biological Communities	3
			Water Contact Sports	-	Enterococcus (Cherry Beach)	2
			Open Water Fish and Shellfish	2006	TN	4a
				2006	TP	4a

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 on 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 less than 3, and calculating whether this is significantly different from a reference condition watershed (i.e., healthy stream, <10% stream miles degraded).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Nanticoke River and all tributaries is Use I designation - *water contact recreation, and protection of nontidal warmwater aquatic life.* In addition the Upper Nanticoke River Tidal Fresh from the Maryland-Delaware state line to the confluence with Plum Creek, the Middle Nanticoke River Oligohaline, and the Lower Nanticoke River Mesohaline portions of the watershed is Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting.* (COMAR 2014 a, b). The Nanticoke River is not attaining its *nontidal warmwater aquatic life* use designation because of 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 biological stressor identification (BSID) analysis that uses a case-controlled, risk-based approach to systematically and objectively determine the predominant cause(s) of reduced biological conditions, which will enable the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact these stressors would have on the degraded sites in the watershed.

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

This Nanticoke River watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the Nanticoke River watershed’s biological communities are strongly influenced by agricultural land use, which alters the stream morphology resulting in loss of the quality and diversity of in-stream habitats. 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 increased contaminant loads from runoff.

The results of the BSID process, and the probable causes and sources of the biological impairments of the Nanticoke River watershed, can be summarized as follows:

- The BSID process has determined that biological communities in the Nanticoke River watershed are likely degraded due to sediment and in-stream habitat-related stressors. Specifically, natural sediment conditions exacerbated by anthropogenic sources in the Coastal Plain physiographic region have resulted in altered habitat heterogeneity and subsequent elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results support the identification of the non-tidal portion of this watershed in Category 5 of the Integrated Report as impaired by total suspended solids (TSS) to begin addressing the impacts of this stressor on the biological communities in the Nanticoke River watershed. The BSID results also confirm the tidal 2006 Category 5 listing for TSS as an appropriate management action in the watershed, and links this pollutant to biological conditions in these waters and extend the impairment to the watershed's non-tidal waters. Therefore, the establishment of a total suspended solids TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin addressing this stressor to the biological communities in the Nanticoke River watershed.

- The BSID process has also determined that biological communities in the Nanticoke 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 Nanticoke River watershed based on channelization being present in approximately 62% of degraded stream miles.

- No nutrient stressors were identified in the BSID analysis as having significant association with degraded biological conditions 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, and decomposition of organic matter. Nutrient reductions are mandated by the 2010 Chesapeake Bay TMDL and a 2007 nutrient TMDL for the tidal portions of the watershed; therefore, no other management actions requiring additional nutrient reductions are necessary.

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

2.0 Nanticoke River Watershed Characterization

2.1 Location

The Nanticoke River is a major tributary of the Chesapeake Bay draining approximately 800 square miles in Delaware and Maryland (CBF 1996). The headwaters of the Nanticoke River originate in wetlands located in western Sussex County, Delaware. From Delaware, the mainstem flows west into Maryland forming the boundary between Dorchester and Wicomico Counties. The river course proceeds southwest and it empties into Chesapeake Bay at Nanticoke, Maryland (see Figure 1). Its main tributaries are Marshyhope Creek on the north side and Gravelly Fork and Broad Creek on the south side. Marshyhope Creek forms in southwest Kent County, Delaware and flows through a section of Sussex County, Delaware and Caroline County, Maryland before joining the Nanticoke River in Dorchester County, MD (CBF 1996). The watershed is over 88 miles long and the total rise in elevation is only 19.8 feet, giving the river a very low gradient (Tiner et al. 2000). The river's main stem is navigable up to Seaford, Delaware. The river is tidal along the major channels up to dams on Broad Creek in Laurel, Delaware, and on Deep Creek in Concord, Delaware. Notable communities situated along the river include the towns of Nanticoke, Bivalve, Vienna, and Sharptown in Maryland; and the city of Seaford, Delaware.

The watershed is located in the Coastal Plain eco-region, one of three distinct eco-regions identified in the MBSS indices of biological integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

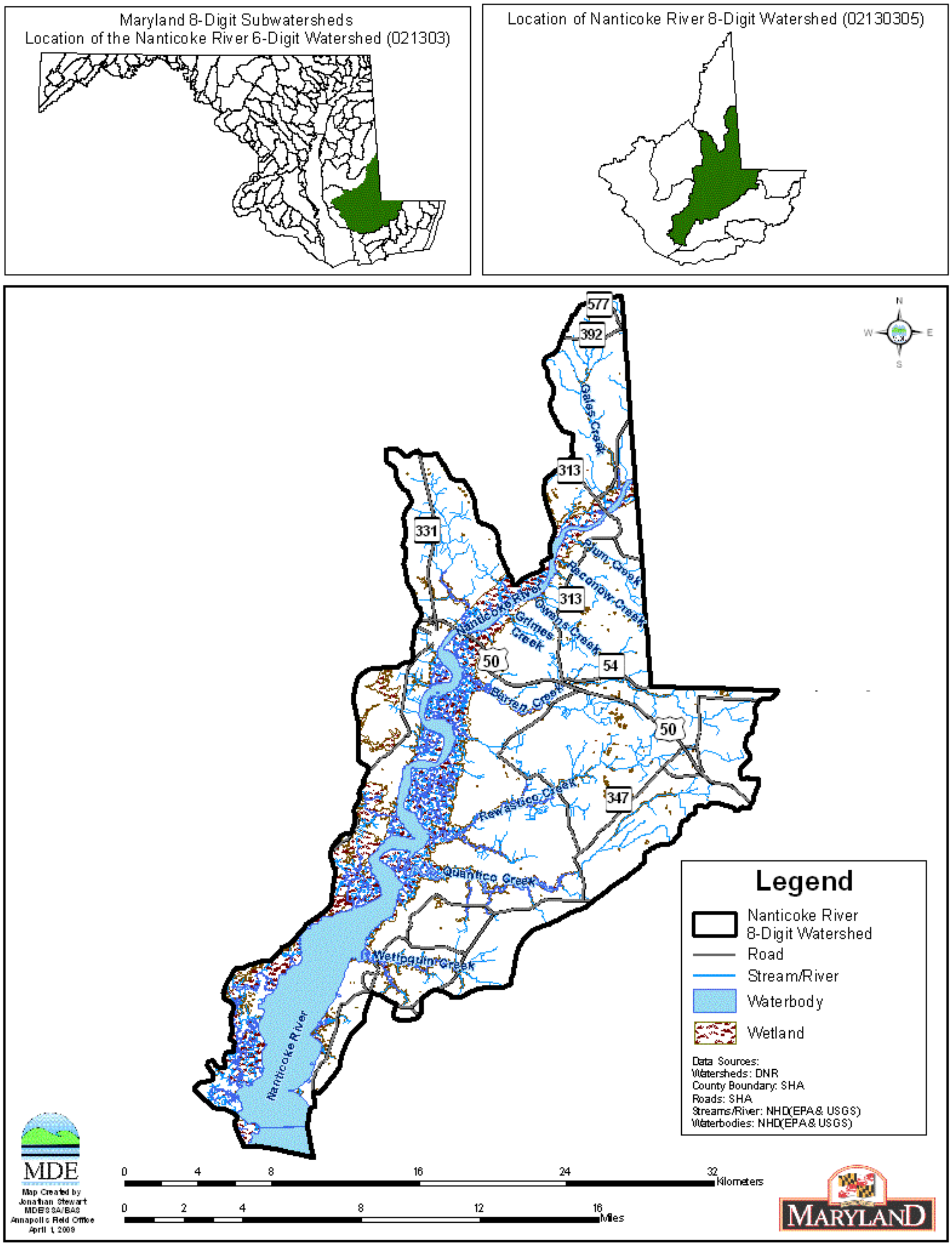

Figure 1. Location Map of the Nanticoke River Watershed

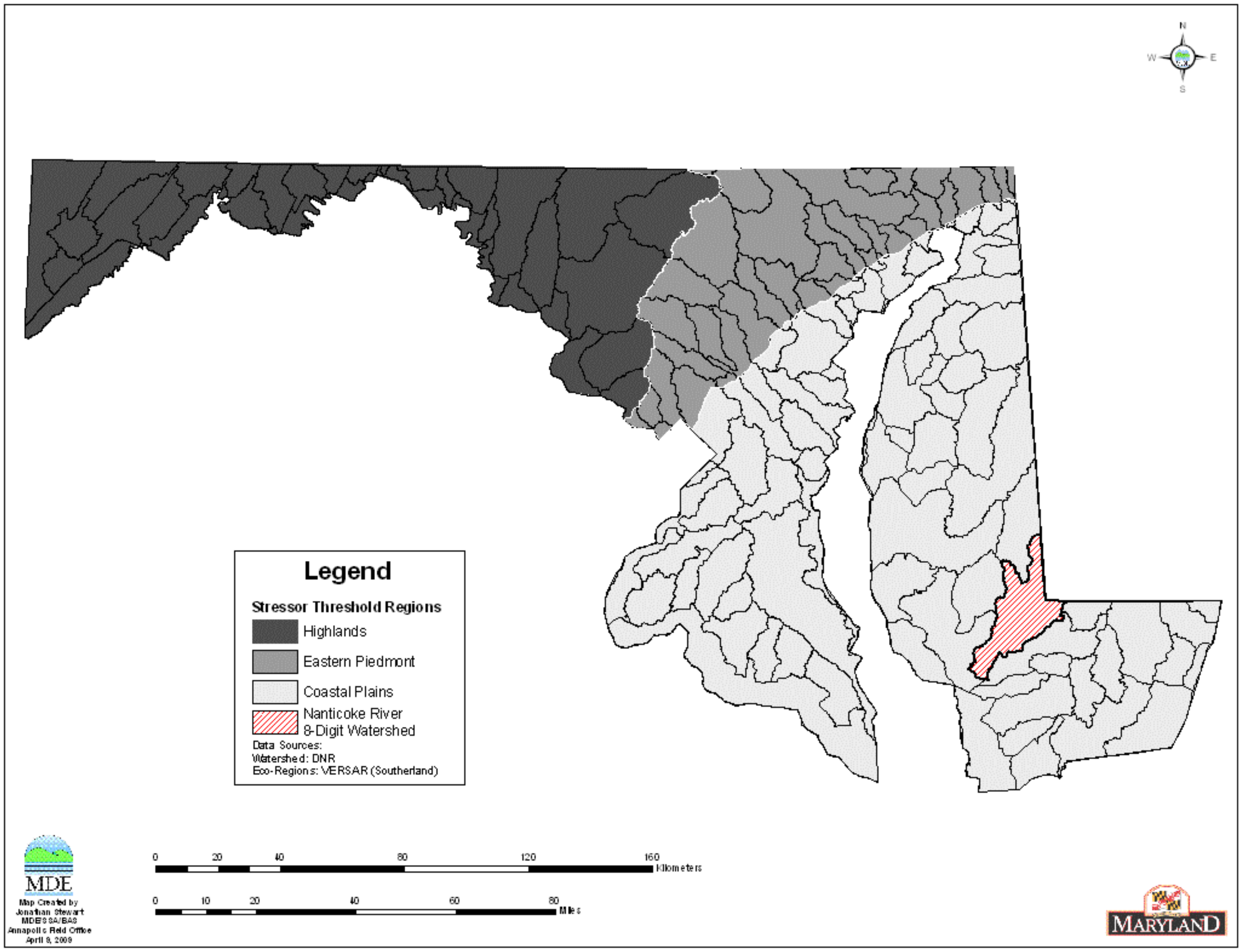

Figure 2. Eco-Region Location Map of the Nanticoke River Watershed

2.2 Land Use

Nanticoke River watershed comprises approximately 110,464 acres of drainage area in Dorchester and Wicomico Counties, Maryland. At the time of European settlement, the land was predominately forested, and has been estimated to have had as much as 95% old growth mixed species forest (Tiner and Bergquist 2003). Large blocks of forest remain, especially in the lower portion of the watershed. However, many of these forest stands have been converted from the original mix of hardwood species to extensive pine plantations. The Nanticoke River watershed was ideal for agriculture because of the flat topography and soils of unconsolidated sands and clays that contain little surface rock. With European settlement, forested land was cleared to grow tobacco as a cash crop and to grow other subsistence crops. In spite of the dry nature of the sandy soils found in the region, precipitation drained slowly and saturated soils were common. To facilitate agricultural production, drainage ditch networks were constructed, which over time became extensive. Since 1990, agriculture in the region has declined; this change may predispose the watershed to more intensive residential and urban development in the future. The primary agricultural industry in the Nanticoke River is the production of poultry including the raising of chickens and growing grain crops for feed. This generates substantial animal waste and subsequent waste disposal problems. The application of the animal waste as fertilizer to cropland has, in turn, produced water quality problems within the watershed (Tiner and Bergquist 2003).

After traditional agriculture, forestry is the next major extractive land use within the watershed. Large tracts of land have been used for the production of fiber from Loblolly pine (*Pinus taeda*). With the domestic paper market in decline, significant acreages of these managed pine plantations have transferred to public ownership within the past few years (Tiner and Bergquist 2003). According to the Chesapeake Bay Program's Phase 5.2 Model, the land use distribution in the watershed is approximately 61% forest/herbaceous, 30% agricultural, and 9% urban (USEPA 2010) (see Figure 3 and Figure 4).

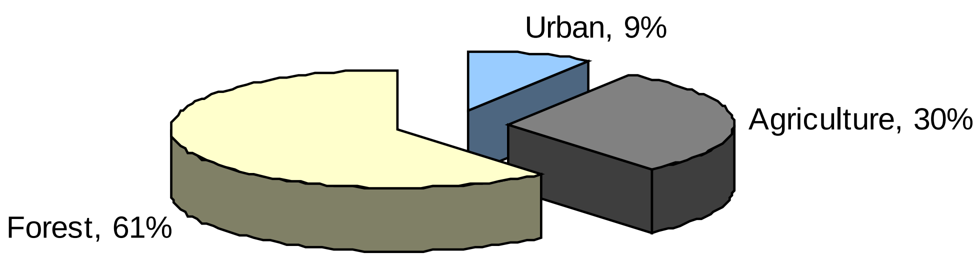

Figure 3. Proportions of Land Use in the Nanticoke River Watershed

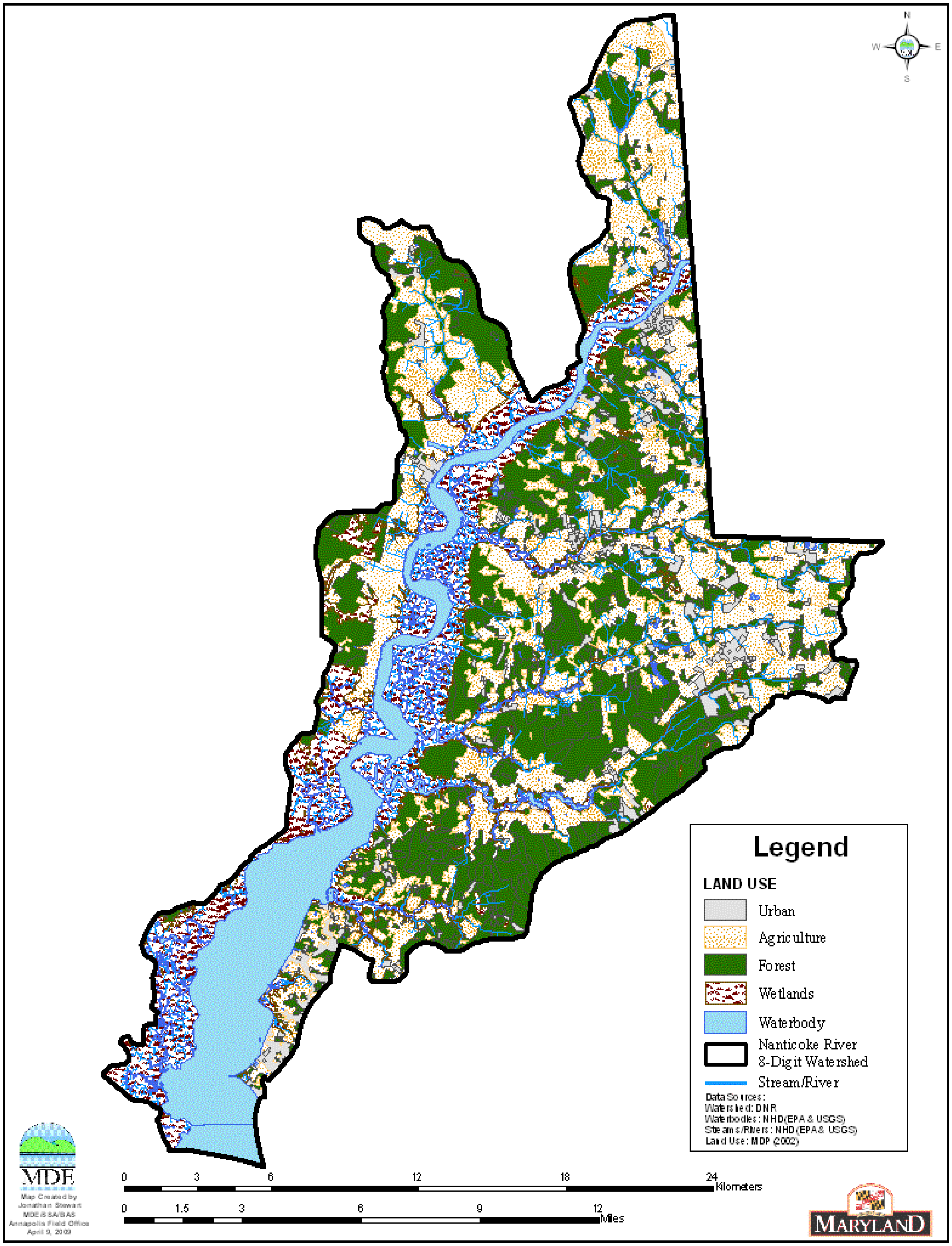

Figure 4. Land Use Map of the Nanticoke River Watershed

2.3 Soils/hydrology

The Nanticoke 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. The Coastal Plain region is characterized by lower relief, and is drained by slowly meandering streams with shallow channels and gentle slopes (MGS 2014).

The primary soils in the Nanticoke River Watershed are Evesboro-Rumsford and Fallingston-Sassafras-Woodstown soils that are characteristic of a coastal plain. These soils are typically light and sandy, well-drained, and highly permeable. These conditions encourage nutrient leaching into the groundwater, which expedites contamination if pollutants are present. In the Nanticoke River Watershed a link exists between groundwater and surface water pollution because of the high permeability (USDA NRCS 2007).

An abundance of wetlands were formed throughout Coastal Plains region because of the ideal geomorphic and hydrologic conditions. Tiner and Bergquist (2003) estimated that 45% of the land area in the Nanticoke River Watershed was wetland before European colonization. Most of the precipitation falling in the watershed enters these wetlands, where the water remains until it percolates through the soil into the ground water or is evapotranspired into the atmosphere again. The groundwater often moves laterally until it encounters a stream or ditch where it may re-emerge as baseflow to surface waters. The interaction of wetlands and ground water in the Nanticoke River basin is complex and dependent on the structure of local soils. The groundwater in the watershed is usually within 3 meters of the surface and the soils are generally poorly drained because of the combination of high water tables, low stream gradients, and low rates of stream incision (Phillips and Bachman 1996).

3.0 Nanticoke River Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Nanticoke River watershed (basin code 02130305), located in Caroline and Dorchester Counties, has four different assessment units: non-tidal (8-digit basin) and three estuarine portions (Chesapeake Bay segment) in the Integrated Report. The Chesapeake Bay segments related to the Nanticoke River watershed are the Upper Nanticoke River Tidal Fresh, Middle Nanticoke River Middle Oligohaline, and Lower Nanticoke River Mesohaline segments. A TMDL was developed and approved by the USEPA for fecal coliform in 2008, and the Chesapeake Bay TMDL addresses all tidal total suspended solids and nutrient listings. Below, Table 1 identifies the listings associated with this watershed.

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					TP	3
			Open Water Fish and Shellfish	-	TN	3
					TP	3
			Aquatic Life and Wildlife	-	Impacts to Biological Communities	2
			Water Contact Sports	-	Fecal Coliform (Cove Road Beach)	2
			Seasonal Shallow Water Submerged Aquatic Vegetation	2008	TSS	4a
			Shellfishing	1998	Fecal Coliform	4a
			Fishing	2008	PCBs (Fish Tissue)	5
				-	Mercury (Fish Tissue)	2
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				2012	TP	4a
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			Seasonal Shallow Water Submerged Aquatic Vegetation	1998	TSS	4a
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				2008	TP	4a
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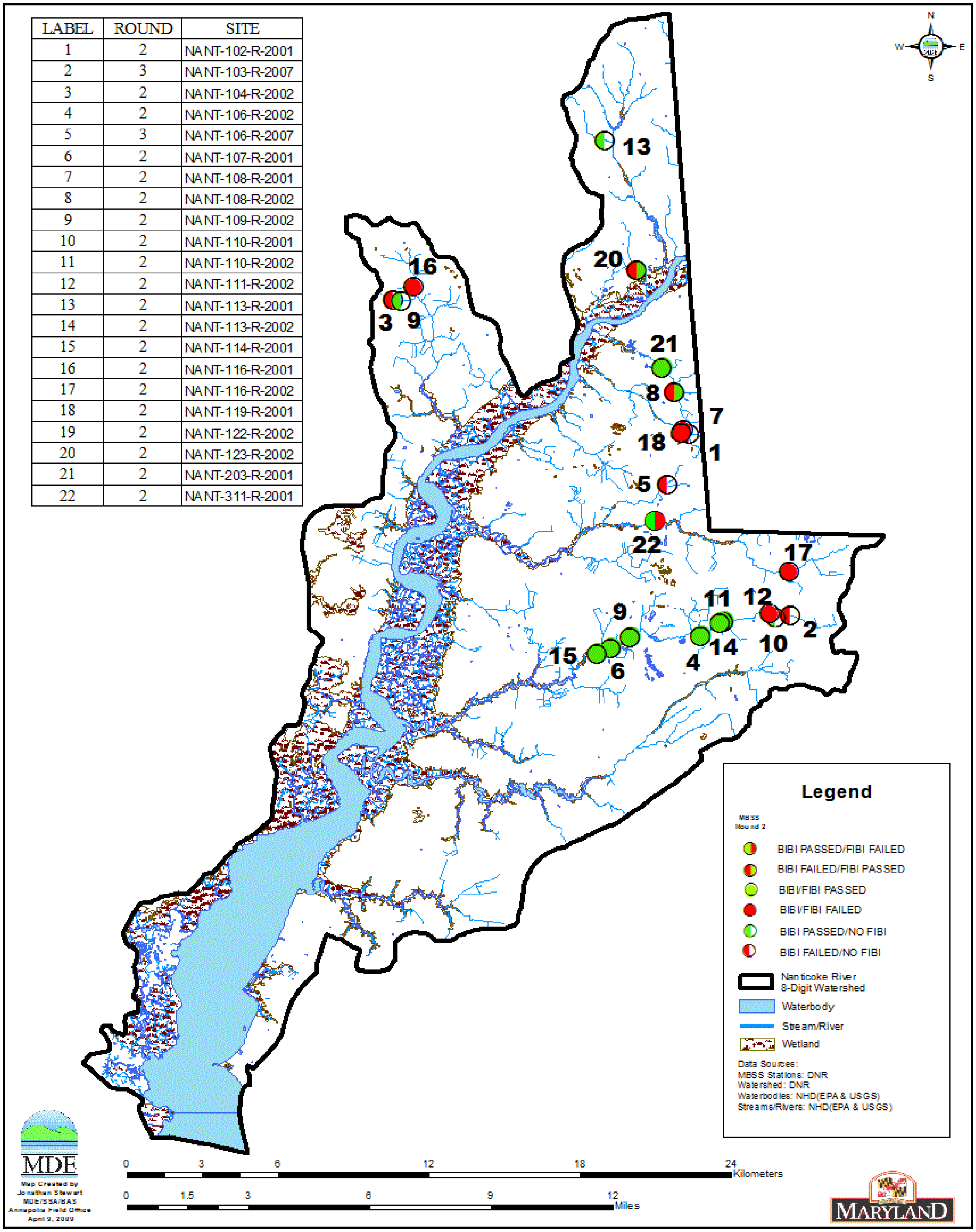
				2006	TP	4a

3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Nanticoke River and all tributaries is Use I designation - *water contact recreation, and protection of nontidal warmwater aquatic life.* In addition the Upper Naticoke River Tidal Fresh from the Maryland-Delaware state line to the confluence with Plum Creek, the Middle Nanticoke River Oligohaline, and the Lower Nanticoke River Mesohaline portions of the watershed is Use II designation - *support of estuarine and marine aquatic life and shellfish harvesting.* (COMAR 2014a, 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 Nanticoke River watershed is listed under Category 5 of the 2012 Integrated Report as impaired for impacts to biological communities. Approximately 40% of stream miles in the Nanticoke River basin are estimated as having fish and 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 twenty-three sites. Ten of the twenty-three sites have benthic and/or fish indices of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, i.e. MBSS round two and round three (2000-2009) contains twenty-two MBSS sites with twelve having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Nanticoke River watershed.



LABEL	ROUND	SITE
1	2	NANT-102-R-2001
2	3	NANT-103-R-2007
3	2	NANT-104-R-2002
4	2	NANT-106-R-2002
5	3	NANT-106-R-2007
6	2	NANT-107-R-2001
7	2	NANT-108-R-2001
8	2	NANT-108-R-2002
9	2	NANT-109-R-2002
10	2	NANT-110-R-2001
11	2	NANT-110-R-2002
12	2	NANT-111-R-2002
13	2	NANT-113-R-2001
14	2	NANT-113-R-2002
15	2	NANT-114-R-2001
16	2	NANT-116-R-2001
17	2	NANT-116-R-2002
18	2	NANT-119-R-2001
19	2	NANT-122-R-2002
20	2	NANT-123-R-2002
21	2	NANT-203-R-2001
22	2	NANT-311-R-2001

Figure 5. Principal Dataset Sites for the Nanticoke 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 – 1st and 2nd-4th 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 Nanticoke River watershed, MDE identified sources, sediments, in-stream habitat, and water chemistry stressors as having significant association with poor to very poor fish and/or benthic biological conditions. Parameters identified as representing possible sources are listed in Table 2 and include various agricultural land uses within the sixty meter riparian buffer. Table 3 shows the summary of combined AR values for the source groups in the Nanticoke River watershed. As shown in Table 4 through Table 6, numerous parameters from the sediments, in-stream habitat, and water chemistry groups were identified as possible biological stressors. Table 7 shows the summary of combined AR values for the stressor groups in the Nanticoke River watershed.

Table 2. Stressor Source Identification Analysis Results for the Nanticoke 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	20	10	274	20%	7%	0.151	No	_
	AMD acid source present	20	10	274	0%	0%	1	No	_
	Organic acid source present	20	10	275	0%	7%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	22	12	279	0%	3%	1	No	_
	High % of agriculture in 60m buffer	22	12	279	25%	4%	0.018	Yes	21%
Sources - Anthropogenic	Low % of forest in watershed	22	12	279	0%	6%	1	No	_
	Low % of wetland in watershed	22	12	279	0%	11%	0.62	No	_
	Low % of forest in 60m buffer	22	12	279	17%	8%	0.275	No	_
	Low % of wetland in 60m buffer	22	12	279	0%	10%	0.617	No	_
Sources - Impervious	High % of impervious surface in watershed	22	12	279	0%	4%	1	No	_
	High % of impervious surface in 60m buffer	22	12	279	17%	5%	0.15	No	_
	High % of roads in watershed	22	12	279	0%	0%	1	No	_
	High % of roads in 60m buffer	22	12	279	0%	5%	1	No	_
Sources - Urban	High % of high-intensity developed in watershed	22	12	279	0%	8%	1	No	_
	High % of low-intensity developed in watershed	22	12	279	8%	6%	0.562	No	_
	High % of medium-intensity developed in watershed	22	12	279	0%	2%	1	No	_
	High % of residential developed in watershed	22	12	279	0%	8%	0.608	No	_
	High % of rural developed in watershed	22	12	279	0%	5%	1	No	_
	High % of high-intensity developed in 60m buffer	22	12	279	0%	6%	1	No	_
	High % of low-intensity developed in 60m buffer	22	12	279	0%	5%	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 medium-intensity developed in 60m buffer	22	12	279	0%	3%	1	No	_
	High % of residential developed in 60m buffer	22	12	279	0%	8%	1	No	_
	High % of rural developed in 60m buffer	22	12	279	8%	5%	0.453	No	_

Table 3. Summary AR Values for Source Groups for Nanticoke River Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Agricultural	21%
All Sources	***21%***

4.1 Sources Identified by BSID Analysis

According to the Chesapeake Bay Program's Phase 5.2 Model, 30% of the Nanticoke River watershed is comprised of agricultural land uses. Agricultural land use in the sixty meter riparian buffer was the only land use source identified by the BSID analysis (Table 2). The combined AR for the source group is approximately 21%, suggesting this source only impacts a minimal portion of the degraded stream miles in the Nanticoke River watershed (Table 3).

The primary agricultural industry in the Nanticoke River is the production of poultry, including the raising of chickens and growing grain crops for feed. Poultry waste is often applied as fertilizer to the row crops in the watershed. After traditional agriculture, forestry is the next major extractive land use within the watershed. Large tracts of land have been used for the production of fiber from Loblolly pine.

BSID results identified agricultural land uses within the sixty meter riparian buffer zone as having significant association with degraded biological conditions. The high percentage of agriculture within the riparian buffer zone is indicative of crops that are cultivated all the way to the stream banks. Although nutrient and best management practices (NMPs and BMPs) are in place to control sediment and nutrient runoff in the watershed, the BSID analyses revealed that agricultural practices, especially in the riparian buffer zone, continue to create conditions in the watershed that are impacting biological resources.

Before European settlement, the Nanticoke River watershed consisted mostly of non-tidal freshwater wetlands and forests. The groundwater was very close to the surface, saturating soils much of the year. As the population in the region increased, much of the land was drained and cleared of its natural vegetation so that the land could be used for agriculture. This widespread drainage of land has led to significant changes that affect both the physical and biological conditions of an aquatic system. A typical sequence of events is channelization leading to immediate changes in physical aspects of the channel. These physical changes lead to longer-term biotic responses that extend over space and time (Simpson et al. 1982). The resulting stress, depending on the tolerance of the species and individual, may limit growth, abundance, reproduction and survival (Lynch, Corbett, and Hoopes 1977).

Typical anthropogenic alterations to a stream caused by agricultural development include channelization, substrate disturbance (dredging), nutrient eutrophication, hydrological changes, and riparian removal (Hynes 1970; Allan 1995). Some of the alterations have direct in-stream effects on structure, water chemistry (e.g., nutrient additions due to lack of riparian buffer), and some have geomorphological repercussions (e.g., channelization).

All the stressors identified in the BSID analysis for the Nanticoke River watershed can be linked to the typical consequences of agricultural development. The remainder of this section will discuss identified stressors and their link to degraded biological conditions in the watershed.

Table 4. Sediment Biological Stressor Identification Analysis Results for Nanticoke 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	18	9	154	0%	21%	0.21	No	_
	Moderate bar formation present	18	9	153	0%	49%	0.004	No	_
	Channel alteration moderate to poor	18	9	125	56%	59%	1	No	_
	Channel alteration poor	18	9	125	0%	25%	0.118	No	_
	High embeddedness	18	9	153	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	18	9	153	56%	45%	0.512	No	_
	Epifaunal substrate poor	18	9	153	33%	12%	0.086	Yes	22%
	Moderate to severe erosion present	18	9	153	0%	42%	0.012	No	_
	Severe erosion present	18	9	153	0%	12%	0.6	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Nanticoke 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	22	12	167	75%	13%	0	Yes	62%
	Concrete/gabion present	20	10	142	0%	1%	1	No	_
	Beaver pond present	18	9	152	0%	7%	1	No	_
	Instream habitat structure marginal to poor	18	9	153	56%	38%	0.305	No	_
	Instream habitat structure poor	18	9	153	33%	6%	0.018	Yes	28%
	Pool/glide/eddy quality marginal to poor	18	9	153	56%	44%	0.494	No	_
	Pool/glide/eddy quality poor	18	9	153	11%	3%	0.265	No	_
	Riffle/run quality marginal to poor	18	9	153	89%	51%	0.036	Yes	38%
	Riffle/run quality poor	18	9	153	67%	21%	0.005	Yes	46%
	Velocity/depth diversity marginal to poor	18	9	153	89%	59%	0.083	Yes	31%
	Velocity/depth diversity poor	18	9	153	56%	15%	0.006	Yes	41%
Riparian Habitat	No riparian buffer	20	10	134	30%	15%	0.178	No	_
	Low shading	18	9	153	0%	3%	1	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Nanticoke 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	22	12	279	0%	8%	0.608	No	_
	High conductivity	22	12	279	0%	6%	1	No	_
	High sulfates	22	12	279	8%	8%	1	No	_
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	18	9	261	44%	17%	0.06	Yes	27%
	Dissolved oxygen < 6mg/l	18	9	261	67%	25%	0.013	Yes	41%
	Low dissolved oxygen saturation	18	9	261	0%	6%	1	No	_
	High dissolved oxygen saturation	18	9	261	0%	3%	1	No	_
	Ammonia acute with salmonid present	22	12	279	0%	0%	1	No	_
	Ammonia acute with salmonid absent	22	12	279	0%	0%	1	No	_
	Ammonia chronic with early life stages present	22	12	279	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	22	12	279	0%	0%	1	No	_
	High nitrites	22	12	279	0%	3%	1	No	_
	High nitrates	22	12	279	17%	7%	0.211	No	_
	High total nitrogen	22	12	279	17%	6%	0.165	No	_
	High total phosphorus	22	12	279	25%	9%	0.106	No	_
	High orthophosphate	22	12	279	8%	5%	0.477	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	22	12	279	25%	9%	0.106	No	_
	Low field pH	18	9	262	56%	40%	0.494	No	_
	High field pH	18	9	262	0%	1%	1	No	_
	Low lab pH	22	12	279	75%	38%	0.014	Yes	37%
	High lab pH	22	12	279	0%	0%	1	No	_

Table 7. Summary AR Values for Stressor Groups for Nanticoke River Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	22%
Instream Habitat	80%
Chemistry - Nutrients	48%
Chemistry - pH	37%
All Chemistry	65%
All Stressors	***80%***

4.2 Stressors Identified by BSID Analysis

All ten stressor parameters identified by the BSID analysis (Table 4, 5, and 6), as being significantly associated with biological degradation in the Nanticoke River watershed are characteristic of agriculturally developed landscapes.

Sediment Conditions

BSID analysis results for the Nanticoke River watershed identified one sediment parameter that has a statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *epifuanal substrate (poor)* (Table 4).

Epifaunal Substrate (poor) was identified as significantly associated with degraded biological conditions in the Nanticoke River watershed, and found to impact approximately 22% of the stream miles with poor to very poor biological conditions. Epifaunal substrate is a visual observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. The varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates. Like embeddedness, epifaunal substrate is confounded by natural variability (i.e., streams will naturally have more or less available productive substrate). Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. Epifaunal substrate conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, where stable substrate is lacking, or particles are over 75%

surrounded by fine sediment and/or flocculent material; and 2) marginal, where large boulders and/or bedrock are prevalent and cobble, woody debris, or other preferred surfaces are uncommon.

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 Nanticoke River watershed in this analysis. The data review did, however, identify seventeen of the eighteen DNR MBSS round two sites (with habitat assessments) used in this analysis has 70% embeddedness or higher, with twelve having 100%. Embeddedness describes the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. In the Coastal Plains eco-region, the presence of high embeddness occurs equally in both non-degraded and degraded sites.

A poor rating for epifaunal substrate and the presence of high embeddedness is an indicator that stable substrate is lacking and stream bottom is covered with fine layer of sediment. Some of the impacts associated with sedimentation are smoothing of benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from embedding of stream bottom (Hoffman, Rattner, and Burton 2003). All of these processes result in an unstable stream ecosystem that impacts habitat heterogeneity and the dynamics (structure and abundance) of stream benthic organisms (Allan 2004).

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 sediment stressor group is approximately 22%, suggesting these stressors are one of the probable causes of biological impairments in the Nanticoke River.

In-stream Habitat Conditions

BSID analysis results for the Nanticoke River watershed identified six in-stream habitat parameters that have statistically significant association with poor to very poor stream biological condition: *channelization present, in-stream habitat structure (poor), riffle/run quality (marginal to poor & poor), velocity/depth diversity (marginal to poor & poor)* (Table 5).

Channelization present was identified as significantly associated with degraded biological conditions in the Nanticoke River watershed, and found to impact approximately 62% of the stream miles with poor to very poor biological conditions. This stressor measures the presence/absence of channelization in stream banks. It describes both the straightening of channels and their fortification with concrete or other hard materials. Natural channels have diverse habitats with varying water velocities as the morphology changes between riffles and pools. The diverse nature of natural channels provides slow water refugia during high flow and many resting areas. With less structural diversity, channelized systems have minimal resting areas and organisms are easily swept away during high flows. In low flow periods, natural channels have sufficient water depth to support fish and aquatic species during the dry season; where as, channelized streams often have insufficient depth to sustain diverse aquatic life (Bolton and Shellberg 2001).

In-stream habitat structure (poor) was identified as significantly associated with degraded biological conditions in the Nanticoke River watershed and found to impact approximately 28% (poor) of the stream miles with poor to very poor biological conditions. In-stream habitat is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. High in-stream habitat scores are evidence of the lack of sediment deposition. In-stream habitat structure is confounded by natural variability (i.e., some streams will naturally have more or less in-stream habitat). Low in-stream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats. In-stream habitat conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, which is defined as less than 10% stable habitat where lack of habitat is obvious; and 2) marginal to poor, where there is a 10-30% mix of stable habitat but habitat availability is less than desirable.

Riffle/run quality (marginal to poor & poor) was identified as significantly associated with degraded biological conditions in the Nanticoke River watershed, and found to impact approximately 38% (*marginal to poor* rating) and 46% (*poor* rating) 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.

Velocity/depth diversity (marginal to poor & poor) was identified as significantly associated with degraded biological conditions in the Nanticoke River watershed, and found to impact approximately 31% (*marginal to poor* rating) and 41% (*poor* rating) 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 two 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).

The presence of a well-developed riffle/run system, and velocity/depth diversity is indicative of different types of habitat, and is typically assumed to have a higher biodiversity of organisms (Richards, Host, and Arthur 1993). Often sedimentation and increased flooding can disrupt riffle/run/pool/glide/eddy sequences (Richards, Host, and Arthur 1993). The geomorphological characteristics described above are often strongly influenced by land use characteristics, e.g., agricultural development within the riparian buffer zone allowing for increased sedimentation and flow which alters natural in-stream habitat.

Sixty-two percent of degraded stream miles in the watershed are artificially straightened or channelized in some way. Historically many streams in the coastal plain were channelized to improve drainage of croplands. The water table in the basin before ditching was close to the surface and interfered with agricultural practices; subsequent ditching lowered the groundwater table (Maguire, Needelman, and Vadas 2009). The Delmarva Peninsula contains over 808 miles of Public Drainage Association (PDA) or tax ditches that drain over 143,311 acres of land (MDDNR 2002 and Bell and Favero 2000). The increased mechanization of agriculture has led to the use of larger and heavier farm equipment. Efficient soil drainage became a priority to avoid losing such machinery in poorly drained fields. In 1951, special tax levies were instituted to create and maintain larger ditches. Drainage was no longer confined to the removal of water from relative low spots in farm fields. Natural stream channels were straightened and deepened to remove water as rapidly as possible. As a result of these efforts, 87.2% of the streams were channelized (Tiner et al. 2000; Tiner 2005).

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 in-stream habitat stressor group is approximately 80%, suggesting these stressors are one of the probable causes of biological impairments in the Nanticoke River (See Table 7).

Riparian Habitat Conditions

BSID analysis results for the Nanticoke River watershed did not identify any riparian 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) (Table 5).

Water Chemistry

BSID analysis results for the Nanticoke River watershed identified three 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 < 5.0 mg/l and <6.0 mg/l,* and *low lab pH* (Table 6).

Low (< 5mg/L and *< 6mg/L) dissolved oxygen* (DO) concentrations were identified as significantly associated with degraded biological conditions in the Nanticoke River watershed and found in 27% and 41%, respectively, of the stream miles with poor to very poor biological conditions. Low DO concentrations may indicate organic pollution due to excessive oxygen demand and may stress aquatic organisms or lead to exceedences in species tolerances. The DO threshold value, at which concentrations below 5.0 mg/L may indicate biological degradation, is established by COMAR (2014c).

Usually low DO concentrations are associated with surface waters experiencing eutrophication; however, the BSID analysis did not identify nutrients has having significant association with degraded biological conditions in the Nanticoke River watershed. The total rise in elevation in the Nanticoke River Watershed is only 19.8 feet, giving the river a very low gradient (Tiner et al. 2000). Because of the low topographic relief of the watershed and the Coastal Plains physiographic ecoregion in general, streams tend to have very gentle slopes with few riffles to aerate the water. 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. Four of the six MBSS stations with low DO levels had recorded “field crew comments” referencing little flow, standing pools, and dry segments.

Low lab pH was identified as significantly associated with degraded biological conditions in the Nanticoke River watershed and found in 37% of the stream miles with poor to very poor biological conditions. pH is a measure of acidity that uses a logarithmic scale ranging 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. *Low pH* values (less than 6.5) can be damaging to aquatic life. The pH threshold values, at which levels below 6.5 and above 8.5 may indicate biological degradation, are established from state regulations (COMAR 2014c). Many biological processes, such as reproduction, cannot function in acidic waters. Acidic conditions also aggravate toxic contamination problems because sediments release toxicants (such as copper, zinc, nitrite and aluminum) in acidic waters. Common sources of acidity include mine drainage, atmospheric deposition, runoff from mine tailings, agricultural fertilizers, and natural organic sources. The BSID analysis identified agricultural land uses in the sixty meter riparian buffer as having significant association with degraded biological conditions. Fertilizers used in agricultural practices include the use of nitrogen fertilizers, which often contain high levels of strong acid anions, and other acidifying compounds, which are sources of acidification in surface waters.

The low pH stressor identified by the BSID is indicative of soils and geology with a limited buffering capacity to neutralize acidic compounds entering the stream. Acid from atmospheric deposition and agricultural runoff is deleterious for freshwater streams, rivers, and lakes. Non-tidal streams in the Nanticoke River watershed, a region in the Coastal Plains of Maryland with inherently poor buffering capacity in the primarily sandy soils, are more susceptible to acidification from these and other acid sources.

The Nanticoke River watershed has organic inputs causing acidity from natural sources. These acids are derived from the leaching of leaves and wood that fall into streams. Non-tidal wetland areas with slow moving and poorly-buffered soils, like those in the Nanticoke River watershed, are often naturally acidic. Their pH values can fall far below neutral (7.0). In streams where naturally acidic conditions have existed over evolutionary time aquatic communities consist of adaptive and specialized species that can tolerate mildly acidic conditions. However, when natural organic acidity is amplified by atmospheric sources of acidity, even these specialized aquatic communities can be detrimentally affected.

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 65%, suggesting these stressors are one of the probable causes of biological impairments in the Nanticoke River (Table 7).

4.3 Discussion of BSID Results

Approximately 30% of the Nanticoke River watershed is comprised of agricultural landscape consisting of row crops, poultry operations, and timber harvesting. Agricultural practices in the watershed include row crops that are commonly cultivated to the stream banks, disturbing riparian buffer zones; ditch maintenance; and poultry manure application to fields. Despite the NMPs and BMPs applied in the watershed, agricultural practices continue to impact the water quality.

Degraded biological communities in the Nanticoke River watershed are a result of agricultural land use practices that have altered the stream morphology (primarily through channelization and ditching). These practices have led to a homogeneous habitat unsuitable for full colonization of a healthy fish and macroinvertebrate community structure. Due to significant anthropogenic changes of natural stream channels within the watershed, health and diversity of biological communities are severely impacted.

Since the BSID analysis did not identify nutrients as having significant association with degraded biological conditions in the Nanticoke River watershed, eutrophication is not considered to be the primary cause for low DO values. Due to the low topographic relief of the Nanticoke River watershed, and extensive agricultural ditching, streams tend to have very gentle slopes, seasonal low flow conditions, and few riffles to aerate the water, most probably resulting in naturally low DO.

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 Nanticoke River 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 1991and USEPA 2014). 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 Nanticoke River watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

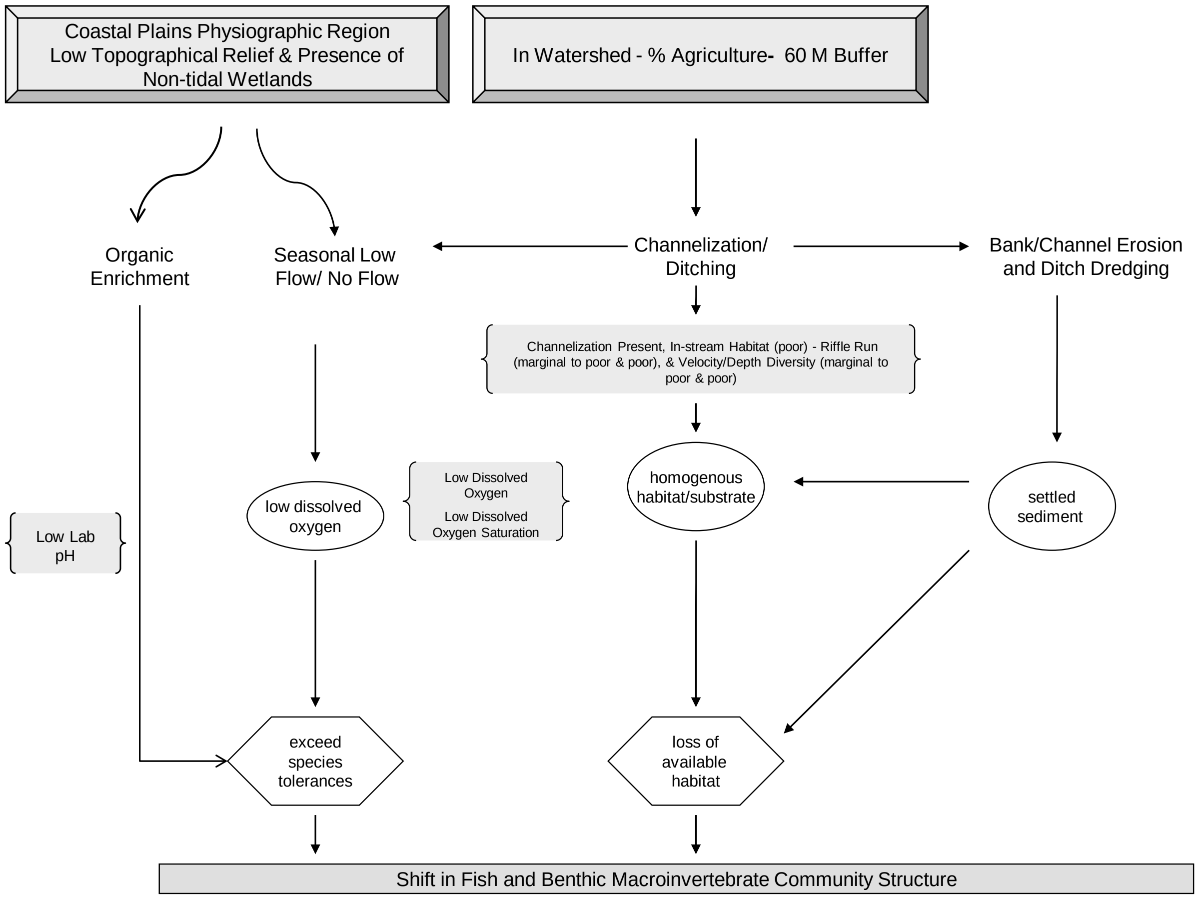


Figure 6. Final Causal Model for the Nanticoke River Watershed

5.0 Conclusion

Data suggest that the Nanticoke River watershed's biological communities are strongly influenced by agricultural land use, which alters the stream morphology resulting in increased erosion and sedimention. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to agricultural landscapes. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the Nanticoke River watershed are summarized as follows:

- The BSID process has determined that biological communities in the Nanticoke River watershed are likely degraded due to sediment and in-stream habitat-related stressors. Specifically, natural sediment conditions exacerbated by anthropogenic sources in the Coastal Plain physiographic region have resulted in altered habitat heterogeneity and subsequent elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results support the identification of the non-tidal portion of this watershed in Category 5 of the Integrated Report as impaired by total suspended solids (TSS) to begin addressing the impacts of this stressor on the biological communities in the Nanticoke River watershed. The BSID results also confirm the tidal 2006 Category 5 listing for TSS as an appropriate management action in the watershed, and links this pollutant to biological conditions in these waters and extend the impairment to the watershed's non-tidal waters. Therefore, the establishment of total suspended solids TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin addressing this stressor to the biological communities in the Nanticoke River watershed.

- The BSID process has also determined that biological communities in the Nanticoke 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 Nanticoke River watershed based on channelization being present in approximately 62% of degraded stream miles.

- No nutrient stressors were identified in the BSID analysis as having significant association with degraded biological conditions 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, and decomposition of organic matter. Nutrient reductions are mandated by the 2010 Chesapeake Bay TMDL and a 2007 nutrient TMDL for the tidal portions of the watershed, therefore, no other management actions requiring additional nutrient reductions are necessary.

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