FINAL

Watershed Report for Biological Impairment of Middle Chester River Watershed in Kent and Queen Anne's Counties, Maryland

FINAL

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Submitted to:

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
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
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
mg/L	Milligrams per liter
MH	Mantel-Haenzel
NO_2	Nitrites
NPDES	National Pollution Discharge Elimination System
OP	Orthophosphate
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TP	Total Phosphorous
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 Middle Chester River watershed (basin code 02130509), located in Kent and Queen Anne's Counties, is associated with three assessment units in the Maryland Integrated Report (IR): non-tidal (8-digit basin) and two estuary portions, the Middle Chester River and the Middle Chester River Oligohaline Chesapeake Bay segment (MDE 2012). Below is a table identifying the listings associated with this watershed.

Table E1. 2012 Integrated Report Listings for the Middle Chester River Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Middle Chester River	02130509	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
		Impoundment Urieville Lake	Aquatic Life and Wildlife	1996	TP	4a
				1996	TSS	4a
Middle Chester River Oligohaline	CHSOH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory	1996	TN	4a
				1996	TP	4a
			Aquatic Life and Wildlife	-	Impacts to Estuarine Biological Communities	3
			Open Water Fish and Shellfish	1996	TN	4a
				1996	TP	4a
			Seasonal Shallow Water Submerged Aquatic Vegetation	2010	TSS	4a
Middle Chester River	02130509	Tidal	Shellfishing	1996	Fecal Coliform	4a
Middle Chester River	02130509	Tidal	Fishing	-	PCBs in Fish Tissue	3

In 2002, the State began listing biological impairments on the Integrated Report. The current MDE biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings 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 significant from a reference condition watershed (i.e., healthy stream, <10% stream miles with poor to very poor biological condition).

The Maryland Surface Water Use Designations in the Code of Maryland Regulations (COMAR) for Middle Chester River and its tributaries are Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life) and Use II (Migratory Spawning and Nursery Use: February 1 to May 31, inclusive Shallow Water Submerged Aquatic Vegetation Use: April 1 to October 30, inclusive Application Depth: 0.5 meters, Open Water Fish and Shellfish Use: January 1 to December 31, inclusive Shellfish Harvest). All nontidal areas are Use I. Above U.S. Route 213 the Chester River and all tributaries are Use II except for the subcategory of shellfish harvest. (COMAR 2013a, b, c). The Middle Chester River watershed is not attaining its designated use of protection of aquatic life because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, thus enabling the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact these stressors 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 Middle Chester 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 Middle Chester River watershed's biological communities are strongly influenced by agricultural land use resulting in increased nutrient pollutant loading. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to agricultural landscapes, particularly when those land uses are present within the riparian buffer zone, which often results in even larger contaminant loads from runoff. The results of the BSID process, and the probable causes and sources of the biological impairments of Middle Chester River can be summarized as follows:

- The BSID process has determined that the biological communities in the Middle Chester River watershed are likely degraded due to water chemistry related stressors. Specifically, agricultural land use practices have resulted in the potential elevation of nitrites and phosphorus inputs throughout the watershed, which are in turn the probable causes of impacts to biological communities. In addition, the BSID process identified low dissolved oxygen below <6.0 mg/l as significantly associated with degraded biological conditions. Low dissolved oxygen levels in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, and elevated nutrient concentrations. Thus, the BSID results confirm that the establishment of nitrogen and phosphorus TMDL in 2006 for the Middle and Upper Chester River, as well as, 2010 Chesapeake Bay TMDL were appropriate management action to begin addressing this stressor to the biological communities in the Middle Chester River watershed. The BSID results also confirms the 1996 Category 4a listing for phosphorus as an appropriate management action in the Middle Chester River watershed, and links this pollutant to biological conditions in these waters, and extend the impairment to the watershed's non-tidal waters.

- Although there is presently a Category 4a listing for total suspended sediments (Urieville Lake) in Maryland's 2012 Integrated Report, the BSID analysis did not identify any sediment stressors present showing a significant association with degraded biological conditions.

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

2.0 Middle Chester River Watershed Characterization

2.1 Location

The Middle Chester River watershed is located within the Chester River watershed in Kent and Queen Anne's Counties, Maryland (see Figure 1). The Middle Chester River watershed encompasses about 37,400 acres of land and over 2,000 acres of open water of the Chester River, which separate the two counties creating hydrologically distinct drainage areas on either side of the River. Middle Chester River is approximately 9.5 miles in length and drains the Upper Chester River watershed. The Upper Chester River extends from the headwaters in Delaware downstream to the confluence with Foreman Branch, and the Middle Chester extends from that point downstream to the confluence with Southeast Creek. Most of the Middle Chester River watershed consists of Morgan Creek and is the largest tidally- influenced tributary of the Chester River. The free-flowing section of Morgan Creek is upstream of the USGS gauging station on Wallis Brothers Road, just east of Urieville Community Lake.
The watershed area is located in the Coastal region of three distinct eco-regions identified in the MBSS IBI metrics (Southerland et al. 2005) (see Figure 2).

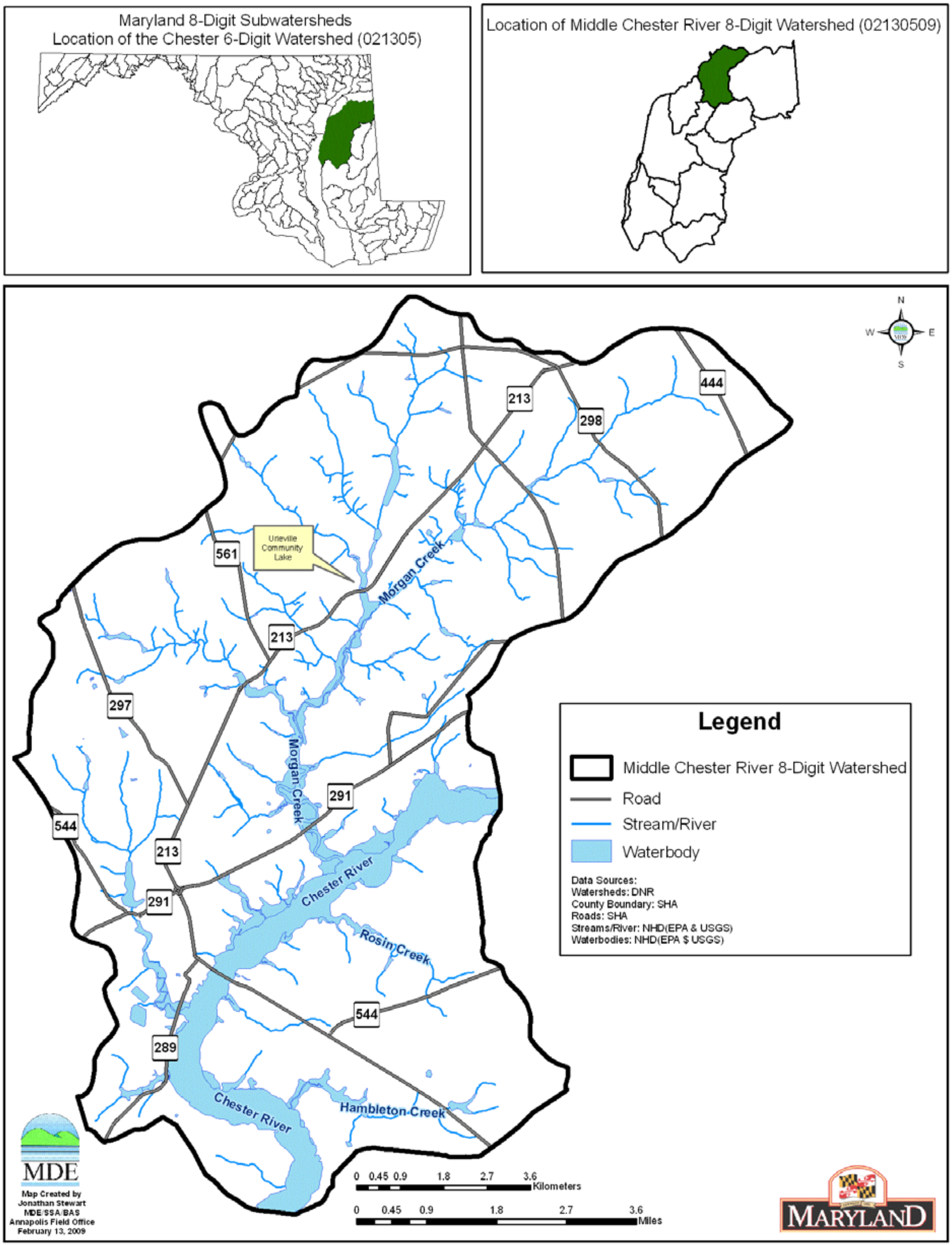

Figure 1. Location Map of the Middle Chester River Watershed

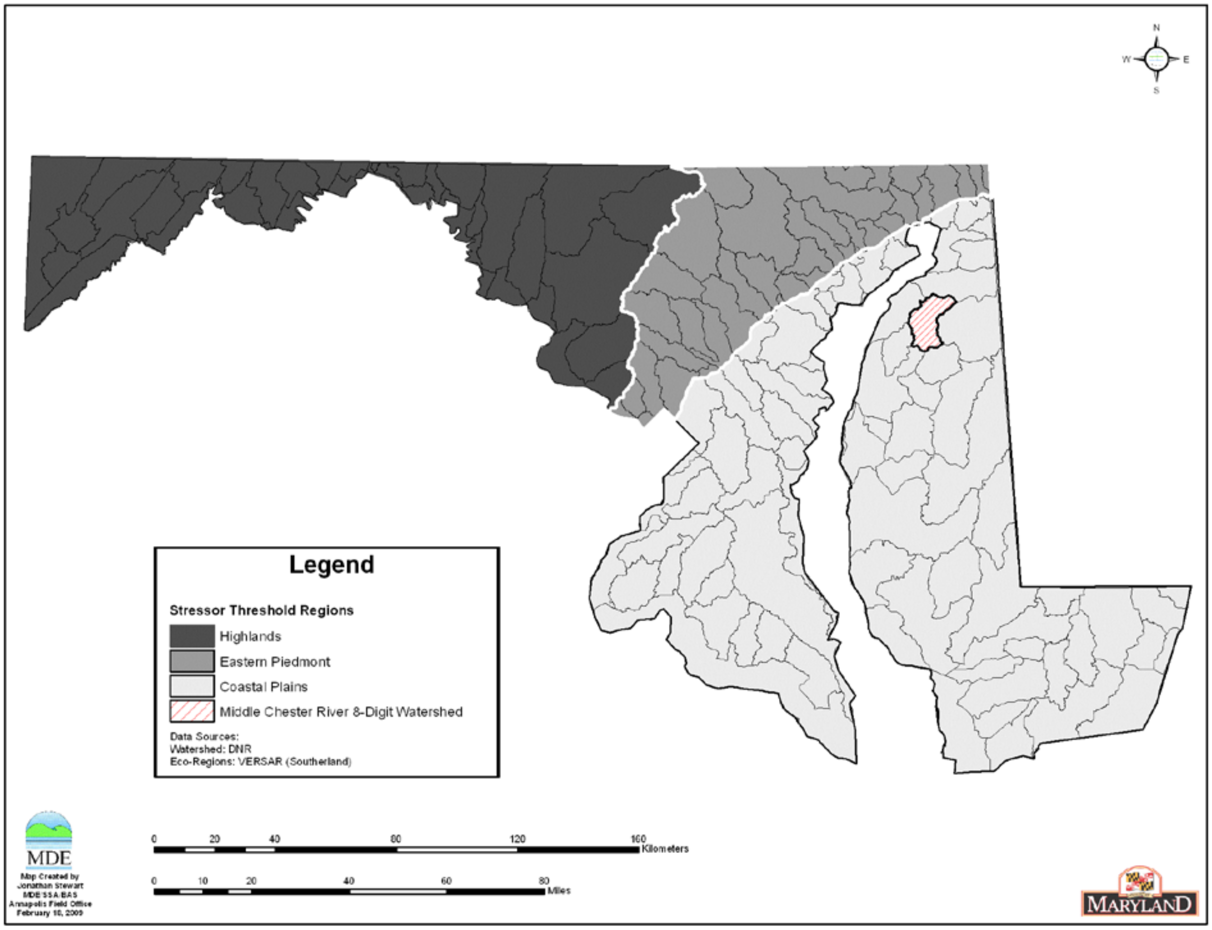

Figure 2. Eco-Region Location Map of Middle Chester River

2.2 Land Use

The Middle Chester River watershed is agriculturally diverse with considerable crop production of corn, wheat and soybean. The Middle Chester is among those Maryland watersheds with the least impervious surface, lowest population density, the least amount of wetland loss and the highest soil erodibility (MDDNR 2001a). The largest urban center within the watershed is the town of Chestertown. According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the Middle Chester watershed consists of approximately 69% agriculture, 17% forest, and 14% urban land uses (see Figure 3 and Figure 4) (USEPA 2010).

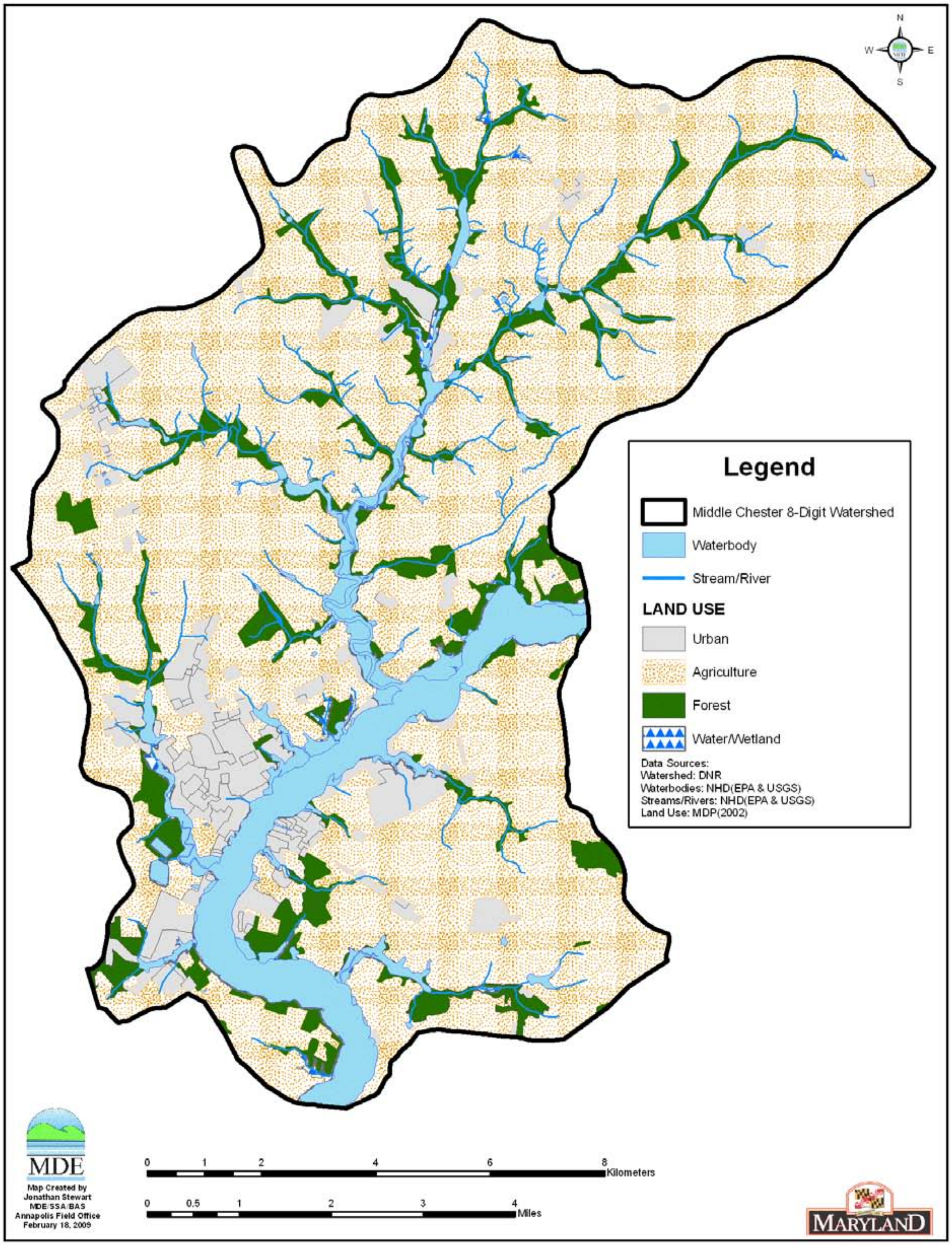

Figure 3. Land Use Map of the Middle Chester River Watershed

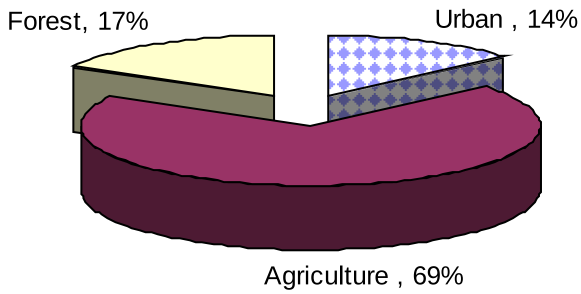

Figure 4. Proportions of Land Use in the Middle Chester River Watershed

2.3 Soils/hydrology

The Middle Chester River watershed lies within the Delmarva Peninsula Region of the Coastal Province physiographic region of Maryland. The Delmarva Peninsula Province encompasses the landmass between Chesapeake Bay and Delaware Bay. Wetlands are abundant in the Coastal Plain due to the low topographical relief and high groundwater characteristics of the region. Over seventy-five percent of the Middle Chester River watershed is prime farmland with moderately to well-drained soils and moderate to high erodibility. The remaining areas contain soils with wetness conditions that limit their agricultural or development potential. These soils are concentrated along the Middle Chester River and its tributaries Morgan Creek and Radcliffe Creek (USDA 1966 and 1982).

3.0 Middle Chester River Water Quality Characterization

3.1 Integrated Report Listings

The Middle Chester River watershed (basin code 02130509), located in Kent and Queen Anne's Counties, is associated with three assessment units in the Maryland Integrated Report (IR): non-tidal (8-digit basin) and two estuary portions, the Middle Chester River and the Middle Chester River Oligohaline Chesapeake Bay segment (MDE 2012). Below is a table identifying the listings associated with this watershed.

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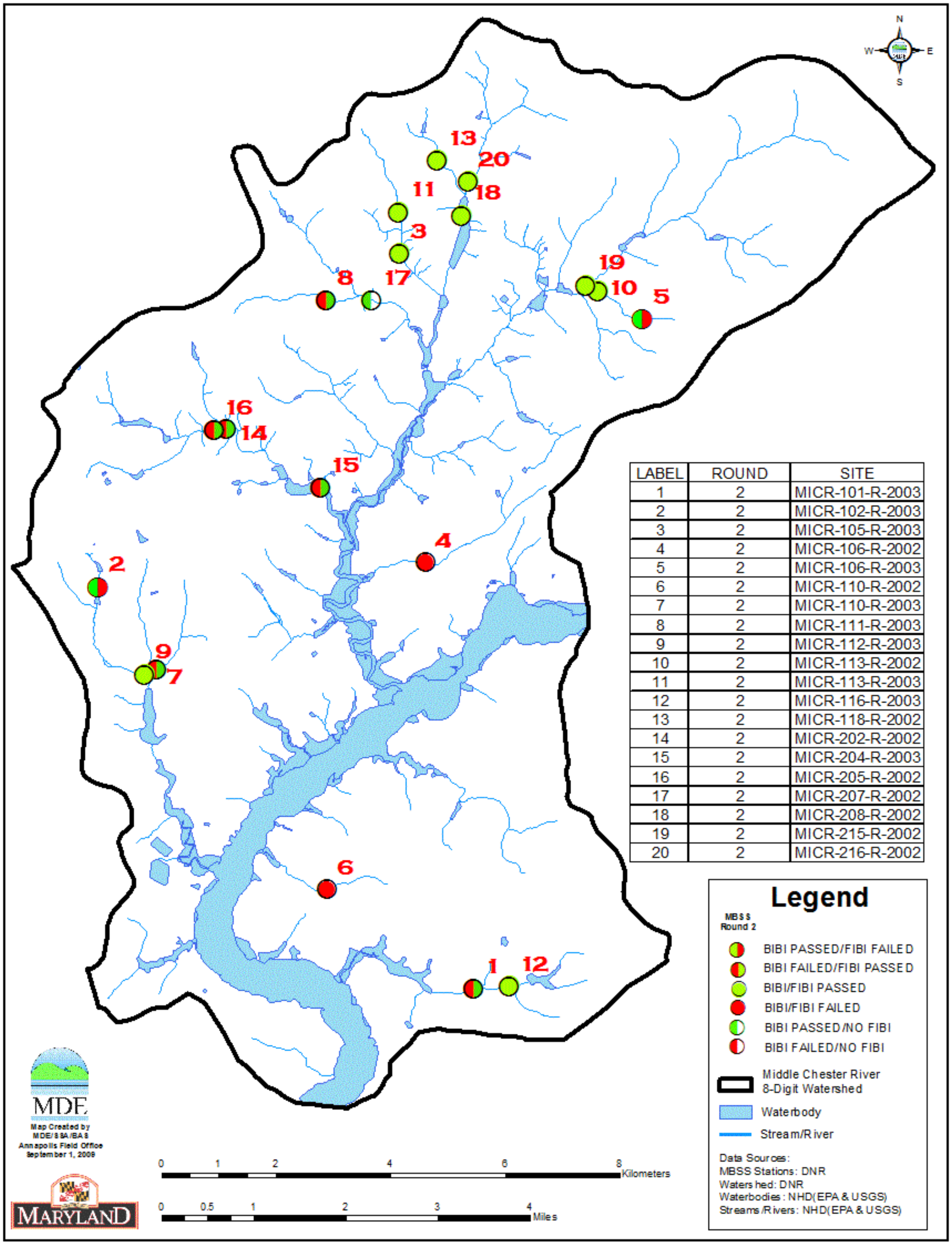
</table>

3.2 Biological Impairment

The Maryland Surface Water Use Designations in the Code of Maryland Regulations (COMAR) for Middle Chester River and its tributaries are Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life) and Use II (Migratory Spawning and Nursery Use: February 1 to May 31, inclusive Shallow Water Submerged Aquatic Vegetation Use: April 1 to October 30, inclusive Application Depth: 0.5 meters, Open Water Fish and Shellfish Use: January 1 to December 31, inclusive Shellfish Harvest). All nontidal areas are Use I. Above U.S. Route 213 the Chester River and all tributaries are Use II except for the subcategory of shellfish harvest. (COMAR 2013 a, b, c)

The Middle Chester River watershed is listed under Category 5 of the 2012 Integrated Report as impaired for evidence of biological impacts. Approximately 36% of stream miles in the Middle Chester River watershed 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-two sites. Eleven of the twenty-two sites have benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., very poor to poor). The principal dataset, MBSS round two and round three (2000-2009) contains twenty-three sites with eleven having BIBI and/or FIBI scores lower than 3.0.

For the Middle Chester River watershed, MDE chose to include only MBSS round two data in the BSID analysis, which contains twenty MBSS sites with ten having BIBI and/or FIBI scores lower than 3.0. The reason for this management decision was MBSS round three only added three sites, with one having degraded biology. The one degraded site did not have any nutrient stressor concentrations over the BSID thresholds values. This one site caused the AR values for water chemistry stressors to fall below the level at which MDE would consider them a significant cause of degraded biological conditions. If water chemistry stressors are not considered significantly associated with degraded biological conditions, then no IR Category 5 listings for nutrients would be required. MDE has analyzed data (1998-2007) from the Middle Chester River watershed and considers nutrients inputs to have significant impact on water quality. As a precautionary measure, MDE chose to include only MBSS round two data in the BSID analysis resulting in nutrient stressors having significant association with degraded biological conditions, preferring to be conservative and protective of the environment. Figure 5 illustrates the principal dataset site locations for the Middle Chester River watershed.



LABEL	ROUND	SITE
1	2	MICR-101-R-2003
2	2	MICR-102-R-2003
3	2	MICR-105-R-2003
4	2	MICR-106-R-2002
5	2	MICR-106-R-2003
6	2	MICR-110-R-2002
7	2	MICR-110-R-2003
8	2	MICR-111-R-2003
9	2	MICR-112-R-2003
10	2	MICR-113-R-2002
11	2	MICR-113-R-2003
12	2	MICR-116-R-2003
13	2	MICR-118-R-2002
14	2	MICR-202-R-2002
15	2	MICR-204-R-2003
16	2	MICR-205-R-2002
17	2	MICR-207-R-2002
18	2	MICR-208-R-2002
19	2	MICR-215-R-2002
20	2	MICR-216-R-2002

Figure 5. Round Two Dataset Sites for the Middle Chester 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 for each stressor, the AR for a group of stressors is also calculated from individual sites' characteristics (stressors present at that site). The only difference is that the group AR calculations combine each site's lowest relative stressor risk among the controls. The same process is run for all land use sources.

After determining the AR for each stressor/sources and the AR for groups of stressors/sources, the AR for all potential stressors/sources 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/sources were eliminated (Van Sickle and Paulsen 2008). The purpose of this metric is to determine if stressors/sources 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 Middle Chester River watershed, MDE identified 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 Middle Chester River watershed. As shown in Table 4 through Table 6, a number of parameters from the water chemistry group were identified as possible biological stressors. Table 7 shows the summary of combined AR values for the stressor groups in the Middle Chester River watershed.

Table 2. Stressor Source Identification Analysis Results for Middle Chester River

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	20	10	218	0%	39%	0.015	No	_
	Agricultural acid source present	20	10	218	10%	6%	0.501	No	_
	AMD acid source present	20	10	218	0%	0%	1	No	_
	Organic acid source present	20	10	219	0%	5%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	20	10	218	20%	3%	0.053	Yes	17%
	High % of agriculture in 60m buffer	20	10	218	30%	4%	0.011	Yes	26%
Sources - Anthropogenic	Low % of forest in watershed	20	10	218	70%	6%	0	Yes	64%
	Low % of wetland in watershed	20	10	218	0%	12%	0.612	No	_
	Low % of forest in 60m buffer	20	10	218	50%	8%	0.001	Yes	42%
	Low % of wetland in 60m buffer	20	10	218	0%	12%	0.609	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)
Sources - Impervious	High % of impervious surface in watershed	20	10	218	0%	4%	1	No	_
	High % of impervious surface in 60m buffer	20	10	218	10%	5%	0.424	No	_
	High % of roads in watershed	20	10	218	0%	0%	1	No	_
	High % of roads in 60m buffer	20	10	218	10%	5%	0.396	No	_
Sources - Urban	High % of high-intensity developed in watershed	20	10	218	0%	7%	1	No	_
	High % of low-intensity developed in watershed	20	10	218	0%	7%	1	No	_
	High % of medium-intensity developed in watershed	20	10	218	0%	3%	1	No	_
	High % of early-stage residential in watershed	20	10	218	10%	5%	0.396	No	_
	High % of residential developed in watershed	20	10	218	0%	7%	1	No	_
	High % of rural developed in watershed	20	10	218	0%	6%	1	No	_
	High % of high-intensity developed in 60m buffer	20	10	218	0%	6%	1	No	_
	High % of low-intensity developed in 60m buffer	20	10	218	0%	5%	1	No	_
	High % of medium-intensity developed in 60m buffer	20	10	218	0%	4%	1	No	_
	High % of early-stage residential in 60m buffer	20	10	218	0%	6%	1	No	_
	High % of residential developed in 60m buffer	20	10	218	0%	5%	1	No	_
	High % of rural developed in 60m buffer	20	10	218	20%	5%	0.104	No	_

Table 3. Summary Combined AR Values for Stressor Groups for Middle Chester River Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Agricultural	37%
Sources - Anthropogenic	74%
All Sources	***85%***

4.1 Sources Identified by BSID Analysis

All seven stressor parameters, identified in Tables 4-6, that are significantly associated with biological degradation in the Middle Chester River watershed BSID analysis are representative of impacts from agricultural development of natural landscapes. The watershed and riparian buffer zones of Middle Chester River contains a significant amount of agricultural land uses, which consist mostly of cropland. Numerous studies have documented declines in water quality, habitat, and biological assemblages as the extent of agricultural land increases within catchments (Roth, Allan, and Erickson 1996; Wang et al. 1997). Researchers commonly report that streams draining agricultural lands support fewer species of sensitive insect and fish taxa than streams draining forested catchments (Wang et al. 1997). Large-scale and long-term agricultural disturbances in a watershed can limit the recovery of stream diversity for many decades (Harding et al. 1998). Macroinvertebrate community richness usually does not vary by more than three families in streams affected by intensive agriculture (Delong and Brusven 1998).

Agricultural land use is an important source of pollution when rainfall carries fertilizers, manure, and pesticides into streams. The three major nutrients in fertilizers are nitrogen, phosphorus, and potassium. High concentrations of nutrients in agricultural streams were correlated with nitrogen and phosphorus inputs from fertilizers and manure used for crops and from livestock wastes (USGS 1999). Agriculture within the riparian buffer often exacerbates the increased inputs of nutrients to surface waters. Forested riparian zones were found to retain 86% of the nitrogen reaching them in runoff, while nearby cropland retained only 8% in a coastal plains basin (Peterjohn and Correll 1984). The agricultural land uses in the Middle Chester River watershed are potential sources for the elevated levels of nutrients identified in the BSID analysis.

The BSID source analysis (Table 2) identifies agricultural land uses as potential sources of stressors that may cause negative biological impacts. The *low % of forest land use* is the result of the increased agricultural development in the watershed. The combined AR for this source group is approximately 85% suggesting that agricultural land uses are the probable causes of biological impairments in the Middle Chester River (Table 3).

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.

Table 4. Sediment Biological Stressor Identification Analysis Results for Middle Chester River

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	19	10	115	0%	21%	0.214	No	_
	Moderate bar formation present	19	10	114	10%	51%	0.019	No	_
	Bar formation present	19	10	114	80%	79%	1	No	_
	Channel alteration moderate to poor	19	10	114	10%	59%	0.006	No	_
	Channel alteration poor	19	10	114	0%	23%	0.122	No	_
	High embeddedness	19	10	114	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	19	10	114	20%	40%	0.318	No	_
	Epifaunal substrate poor	19	10	114	0%	10%	1	No	_
	Moderate to severe erosion present	19	10	114	40%	43%	1	No	_
	Severe erosion present	19	10	114	0%	12%	0.603	No	_
	Silt clay present	19	10	114	100%	99%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for Middle Chester River

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	20	10	121	0%	13%	0.619	No	_
	Concrete/gabion present	20	10	121	0%	2%	1	No	_
	Beaver pond present	19	10	112	10%	8%	0.574	No	_
	Instream habitat structure marginal to poor	19	10	114	30%	35%	1	No	_
	Instream habitat structure poor	19	10	114	0%	5%	1	No	_
	Pool/glide/eddy quality marginal to poor	19	10	114	30%	38%	1	No	_
	Pool/glide/eddy quality poor	19	10	114	0%	3%	1	No	_
	Riffle/run quality marginal to poor	19	10	114	30%	45%	0.518	No	_
	Riffle/run quality poor	19	10	114	20%	20%	1	No	_
	Velocity/depth diversity marginal to poor	19	10	114	60%	53%	0.742	No	_
	Velocity/depth diversity poor	19	10	114	10%	12%	1	No	_
Riparian Habitat	No riparian buffer	20	10	121	20%	13%	0.618	No	_
	Low shading	19	10	114	0%	2%	1	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for Middle Chester River

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	20	10	218	10%	6%	0.501	No	_
	High conductivity	20	10	218	30%	5%	0.017	Yes	25%
	High sulfates	20	10	218	0%	8%	1	No	_
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	20	10	205	10%	14%	1	No	_
	Dissolved oxygen < 6mg/l	20	10	205	50%	22%	0.06	Yes	28%
	Low dissolved oxygen saturation	20	10	205	10%	5%	0.444	No	_
	High dissolved oxygen saturation	20	10	205	20%	2%	0.036	Yes	18%
	Ammonia acute with salmonid present	20	10	218	0%	0%	1	No	_
	Ammonia acute with salmonid absent	20	10	218	0%	0%	1	No	_
	Ammonia chronic with early life stages present	20	10	218	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	20	10	218	0%	0%	1	No	_
	High nitrites	20	10	218	40%	3%	0.001	Yes	37%
	High nitrates	20	10	218	10%	7%	0.524	No	_
	High total nitrogen	20	10	218	10%	6%	0.501	No	_
	High total phosphorus	20	10	218	40%	8%	0.008	Yes	32%
	High orthophosphate	20	10	218	30%	5%	0.014	Yes	25%
Chemistry - pH	Acid neutralizing capacity below chronic level	20	10	218	0%	10%	0.605	No	_
	Acid neutralizing capacity below episodic level	20	10	218	10%	47%	0.024	No	_
	Low field pH	20	10	206	40%	40%	1	No	_
	High field pH	20	10	206	0%	0%	1	No	_
	Low lab pH	20	10	218	20%	38%	0.329	No	_
	High lab pH	20	10	218	20%	0%	0.002	Yes	20%

Table 7. Summary of Combined AR Values for Source Groups for the Middle Chester River Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Chemistry - Inorganic	25%
Chemistry - Nutrients	79%
Chemistry - pH	20%
All Chemistry	82%
All Stressors	***82%***

4.2 Stressors Identified by BSID Analysis

Sediment and Habitat Conditions

BSID analysis results for Middle Chester River did not identify any sediment 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 4).

In-stream Habitat Conditions

BSID analysis results for Middle Chester River did not identify any 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) (Table 5).

Riparian Habitat Conditions

BSID analysis results for Middle Chester River 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 Middle Chester River identified seven 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 *high conductivity, low dissolved oxygen below >6.0 mg/l, high oxygen saturation, high nitrites, high total phosphorus, high orthophosphate,* and *high lab pH* (Table 6).

High conductivity levels were identified as significantly associated with degraded biological conditions in the Middle Chester River, and found to impact approximately 25% of the stream miles with poor to very poor biological conditions. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Urban (i.e., road salts) and agricultural (i.e., fertilizers) runoffs, as well as leaking wastewater infrastructure are typical sources of inorganic compounds in surface waters. Since agricultural land uses are so prevalent the Middle Chester River watershed, it is likely the various constituents found in fertilizers are the source of high conductivity levels.

Low dissolved oxygen (DO) < *6mg/L* concentrations were identified as significantly associated with degraded biological conditions and found to impact approximately 28% (< *6mg/L)* of the stream miles with poor to very poor biological conditions in the Middle Chester 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.

High dissolved oxygen saturation was identified as significantly associated with degraded biological conditions in Middle Chester River and found in approximately 18% of the stream miles with poor to very poor biological conditions. DO saturation accounts for physical solubility limitations of oxygen in water and provides a more targeted assessment of oxygen dynamics than concentration alone. Percent saturation is relative to the amount of oxygen that water can hold, as determined by temperature and atmospheric pressure. MDDNR MBSS only measures DO concentrations expressed in mg/L; therefore, MDE calculated DO saturation percentages (MDE 2009). DO saturation, expressed in mg/L, depends on water temperature and salinity. Percent saturation is the ratio of observed DO to DO saturation value, expressed as a percent. The DO saturation threshold values, at which concentrations below 60% and above 125% may indicate biological degradation are established from peer-reviewed literature (CIESE 2008).

High nitrites concentration was identified as significantly associated with degraded biological conditions in Middle Chester River and found in approximately 37% of the stream miles with poor to very poor biological conditions. Nitrites (NO_2) are a measure of the amount of NO_2 in the water column. Nitrites are found naturally in the environment, and are generally present in surface waters and shallow ground water. Nitrites are essential nutrients needed for plant growth, and when plants die and decompose they naturally release nitrogen. The nitrogen from the rotting plants oxidize (combine with oxygen) to form nitrites. Because nitrites are needed for plants to grow, concentrated man-made nitrogen-containing fertilizers are used on golf courses, residential lawns, and are heavily used in agricultural regions to grow vegetable crops. Elevated levels of nitrogen compounds like nitrites can lead to excessive growth of filamentous algae and aquatic plants. Excessive nitrogen input can also lead to increased primary production, which potentially results in species tolerance exceedances of dissolved oxygen and pH levels.

High total phosphorus concentration was identified as significantly associated with degraded biological conditions in Middle Chester River and found in approximately 32% of the stream miles with poor to very poor biological conditions. Total Phosphorus (TP) is a measure of the amount of TP in the water column. Phosphorus forms the basis of a very large number of compounds, the most important class of which is the phosphates. For every form of life, phosphates play an essential role in all energy-transfer processes such as metabolism and photosynthesis. Elevated levels of phosphorus can lead to excessive growth of filamentous algae and aquatic plants. Excessive phosphorus input can also lead to increased primary production, which potentially results in species tolerance exceedences of dissolved oxygen and pH levels. Phosphorus is added to the soil from crop residue, manure, synthetic fertilizer, and phosphorus-bearing minerals. Nationally, fertilizers account for four-fifths of the phosphorus added to cropland and over seventy-five percent of its loss from cropland is in runoff to surface water (USDA NRCS 1997). If land use includes livestock pastures, the addition of phosphorus from manures can be significant. The primary transport of phosphorus from terrestrial to aquatic environments is runoff and erosion. TP input to surface waters typically increases in watersheds where agricultural developments are predominant.

High orthophosphate concentration was identified as significantly associated with degraded biological conditions in Middle Chester River and found in approximately 25% of the stream miles with poor to very poor biological conditions. Orthophosphate (OP) is a measure of the amount of OP in the water column and is the most readily available form of phosphorus for uptake by aquatic organisms (see '*high total phosphorus'* above). OP input to surface waters typically increases in watersheds where agricultural developments are predominant.

High lab pH levels above 8.5 was identified as significantly associated with degraded biological conditions in the Middle Chester River, and found to impact approximately 20% of the stream miles with poor to very poor biological conditions. pH is a measure of the acid balance of a stream and uses a logarithmic scale range from 0 to 14, with 7 being neutral. MDDNR MBSS collects pH samples once during the spring, which are analyzed in the laboratory (*pH lab*), and measured once in situ during the summer (*pH field*). Most stream organisms prefer a pH range of 6.5 to 8.5. Exceedances of pH may allow concentrations of toxic elements (such as ammonia, nitrite, and aluminum) and high amounts of dissolved heavy metals (such as copper and zinc) to be mobilized for uptake by aquatic plants and animals. The pH threshold values, at which levels below 6.5 and above 8.5 may indicate biological degradation, are established from state regulations (COMAR 2013d). Intermittent high pH (greater than 8.5) is often associated with elevated nutrient concentrations and eutrophication related to increased algal blooms.

Water chemistry is another major determinant of the integrity of surface waters that is strongly influenced by land use. Agricultural land uses comprise sixty-nine percent of the Middle Chester River watershed. Agricultural land uses within the watershed as well as within the sixty-meter riparian zone were found to be significantly associated with poor to very poor biological conditions in the watershed. Developed landscapes, particularly the proportion of agriculture in the catchments and the riparian zone, often results in increased inputs of nitrogen and phosphorus, to surface waters. Elevated nutrient concentrations are reported to result in greater algal production and changes in autotrophic community composition (Allan 2004 and Quinn 2000). Intermittent high pH and low DO concentrations is often associated with elevated nutrient concentrations and eutrophication related to increased algal blooms. Elevated lab pH values, low DO, and high oxygen saturation were identified as having significant association with degraded biological conditions in the watershed.

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 Middle Chester 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. The Eastern Coastal Plain Province, in which the Middle Chester River watershed is located, has the highest diversity of emergent estuarine and palustrine wetland communities relative to other Maryland physiographic regions because both tidal and nontidal freshwater marshes occur here. Wetlands are most abundant in the Coastal Plain due to the low topographic relief and high groundwater table characteristic of the region. Forested wetlands are the most abundant and widely distributed palustrine wetland type on the Coastal Plain. These wetlands are found on floodplains along the freshwater tidal and nontidal portions of rivers and streams, in upland depressions, and in broad flat areas between otherwise distinct watersheds (MDDNR 2001a). Many of the palustrine nontidal wetland areas are depicted as forest on the land use maps. This difference is simply the result of two differing views of the landscape. For example, wooded nontidal wetlands can be viewed as "wetlands" from a habitat /regulatory perspective and they can be viewed as "forest" from a land use perspective. From a land use perspective, 506 acres of wetlands in the Middle Chester River watershed were identified by the Maryland Department of Planning. From a habitat / regulatory perspective, there are approximately 16,816 acres of wetlands in the watershed (MDDNR 2001a). Wetlands foster the decomposition of plant and animal material that involves the consumption of oxygen. Also, 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.

Point source discharges are a potential source of nutrients to surface waters. There are three minor municipal and three industrial discharges in the Middle Chester River watershed. Nutrient loads from any wastewater treatment facility are dependent on discharge volume, level of treatment process, and sophistication of the processes and equipment.

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 82% suggesting these stressors are the probable causes of biological impairments in the Middle Chester River watershed (Table 7).

4.3 Discussion

The BSID analysis results suggest that degraded biological communities in the Middle Chester River watershed are a result of increased agricultural land use causing an increase in contaminant loads from nonpoint sources by adding nutrients to surface waters. Alterations to natural landscapes and water chemistry have all combined to degrade Middle Chester River, leading to a loss of diversity in the biological community. The combined AR for all stressors is approximately 82%, suggesting that water chemistry stressors adequately account for the biological impairment in Middle Chester River (Table 7).

According to a 2002 MDDNR Watershed Restoration Action Strategy, nutrient related water quality parameters in the Middle Chester were generally poor. However, several water quality parameters, including water clarity, algae, and phosphorus, show a recent trend toward improvement (MDDNR 2002). Hopefully with continued efforts in implementing and enforcing the 2006 nutrient TMDL for the Middle and Upper Chester, and the 2010 Chesapeake Bay TMDL by State and local agencies, nutrient loads in the Middle Chester River watershed will decrease and aquatic health will improve.

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 Middle Chester River

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 and 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 Middle Chester River, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

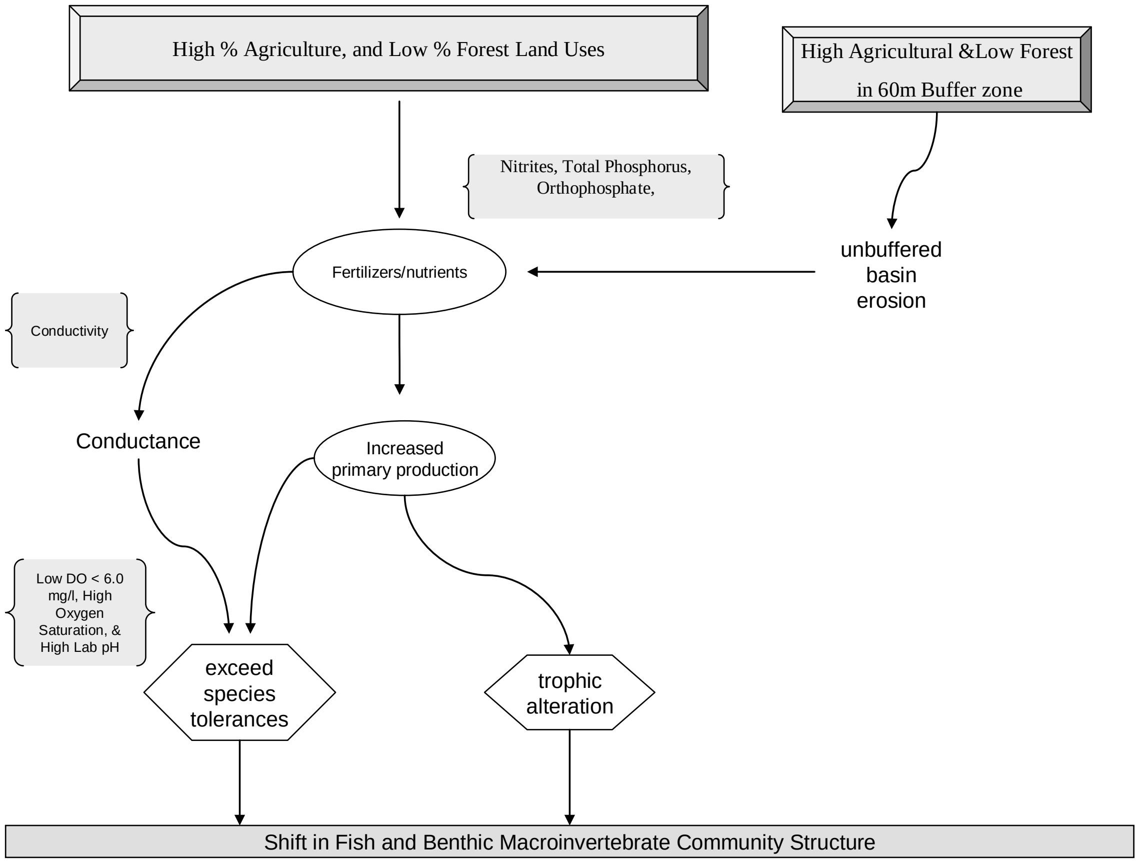


Figure 6. Final Causal Model for the Middle Chester River Watershed

5.0 Conclusions

Data suggest that the Middle Chester River watershed's biological communities are strongly influenced by agricultural land use resulting in increased nutrient pollutant loading. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to agricultural landscapes, particularly when those land uses are present within the riparian buffer zone, which often results in even larger contaminant loads from runoff. The results of the BSID process, and the probable causes and sources of the biological impairments of Middle Chester River can be summarized as follows:

- The BSID process has determined that the biological communities in the Middle Chester River watershed are likely degraded due to water chemistry related stressors. Specifically, agricultural land use practices have resulted in the potential elevation of nitrites and phosphorus inputs throughout the watershed, which are in turn the probable causes of impacts to biological communities. In addition, the BSID process identified low dissolved oxygen below <6.0 mg/l as significantly associated with degraded biological conditions. Low dissolved oxygen levels in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, and elevated nutrient concentrations. Thus, the BSID results confirm that the establishment of nitrogen and phosphorus TMDL in 2006 for the Middle and Upper Chester River, as well as, 2010 Chesapeake Bay TMDL were appropriate management action to begin addressing this stressor to the biological communities in the Middle Chester River watershed. The BSID results also confirms the 1996 Category 4a listing for phosphorus as an appropriate management action in the Middle Chester River watershed, and links this pollutant to biological conditions in these waters, and extend the impairment to the watershed's non-tidal waters.

- Although there is presently a Category 4a listing for total suspended sediments (Urieville Lake) in Maryland's 2012 Integrated Report, the BSID analysis did not identify any sediment stressors present showing a significant association with degraded biological conditions.

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