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**Watershed Report for Biological Impairment of the  
Patuxent River Middle Watershed in Anne Arundel, Calvert,  
and Prince George's Counties, Maryland  
Biological Stressor Identification Analysis  
Results and Interpretation**

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Submitted to:

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1650 Arch Street  
Philadelphia, PA 19103-2029

May 2013

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**List of Abbreviations**

ANC	Acid Neutralizing Capacity
AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
IR	Integrated Report
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MH	Mantel-Haenzel
SO <sub>4</sub> <sup>2-</sup>	Sulfate
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
TP	Total Phosphorus

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**Executive Summary**

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency’s (USEPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. For each WQLS listed on the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a Water Quality Analysis (WQA) that water quality standards are being met.

The Patuxent River Middle watershed (basin code 02131102), located in Anne Arundel, Prince George’s, and Calvert Counties, is associated with two assessment units in the Integrated Report (IR): non-tidal (8-digit basin) and an estuary portion, which is part of the Upper Patuxent River Tidal Fresh Chesapeake Bay segment. A WQA was developed for chlorpyrifos (pesticide) and approved by the USEPA in 2003. Below is a table identifying the listings associated with this watershed.

**Table E1. 2012 Integrated Report Listings for the Patuxent River Middle Watershed (MDE 2012)**

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Patuxent River Middle	02131102	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
					Chlorpyrifos	2
Upper Patuxent River Tidal Fresh	PAXTF	Tidal	Seasonal Migratory fish spawning and nursery Subcategory		TN	3
					TP	3
			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	2008	TSS	4a

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

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Patuxent River Middle and all tributaries is Use I designation - *water contact recreation, and protection of nontidal warmwater aquatic life*. In addition the mainstem of the Patuxent River Middle and some tributaries are Use II designation - *support of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, b, c). The Patuxent River Middle watershed is not attaining its nontidal warmwater aquatic life use designations due to impacts to biological communities. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

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

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

This Patuxent River Middle 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 biological communities of the Patuxent River Middle watershed are strongly influenced by altered stream hydrology, channel erosion and elevated levels of sulfates. The development of landscapes creates broad and interrelated

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forms of degradation that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between agricultural and urban developed landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

The results of the BSID analysis, and the probable causes and sources of the biological impairments in the Patuxent River Middle watershed can be summarized as follows:

- The BSID process has determined that biological communities in the Patuxent River Middle watershed are likely degraded due to sediment related stressors. Specifically, urban and agricultural runoff has led to altered hydrology which has led to severe erosion and channel alteration throughout the watershed. The BSID results thus confirm 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 Patuxent River Middle watershed. The BSID results also support a Category 5 listing of TSS for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Patuxent River Middle.
- The BSID process has also determined that the biological communities in the Patuxent River Middle watershed are likely degraded due to inorganic water chemistry related stressors. Specifically, current and historical legacy effects of agricultural land use practices have resulted in the potential elevation of sulfate inputs throughout the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus support a Category 5 listing of sulfates for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of this stressor on the biological communities in the Patuxent River Middle watershed. Discharges of inorganic compounds like sulfates are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of this parameter will help in determining the spatial and temporal extent of these impairments in the watershed.

## 1.0 Introduction

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS listed on the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a Water Quality Analysis (WQA) that water quality standards are being met. In 2002, the State began listing biological impairments on the Integrated Report. Maryland Department of the Environment (MDE) has developed a biological assessment methodology to support the determination of proper category placement for 8-digit watershed listings.

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2012). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or black water streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is still considered impaired but has a TMDL that has been completed or submitted to EPA it will be listed as Category 4a. If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary.

The MDE biological stressor identification (BSID) analysis applies a case-control, risk-based approach that uses the principal dataset, with considerations for ancillary data, to identify potential causes of the biological impairment. Identification of stressors responsible for biological impairments was limited to the round two 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.

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

## **2.0 Patuxent River Middle Watershed Characterization**

### **2.1 Location**

The Patuxent River is the largest river completely located in Maryland, and the basin lies between two large nearby metropolitan areas Baltimore, Maryland and Washington, D.C. The Patuxent River is comprised of eight separated sub-watersheds. The Patuxent River Middle watershed is located in Anne Arundel, Calvert, and Prince George's Counties, and it drains an area of approximately 66,478 acres ([Figure 1](#)). The watershed comprises an area located between the 8-digit Upper Patuxent watershed and the Lower Patuxent watershed. The Patuxent River Middle mainstem is tidal throughout its reach, which extends from its confluence with the Patuxent River Lower watershed for approximately 16 miles upstream to the start of the Patuxent River Upper watershed. The watershed contains the low density residential urban centers of Marlboro Meadows, Wayson's Corner, Lyons Creek, and portions of Dunkirk.

The watershed is entirely located within the Coastal Plains physiographic region. There are three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005) (see [Figure 2](#)).

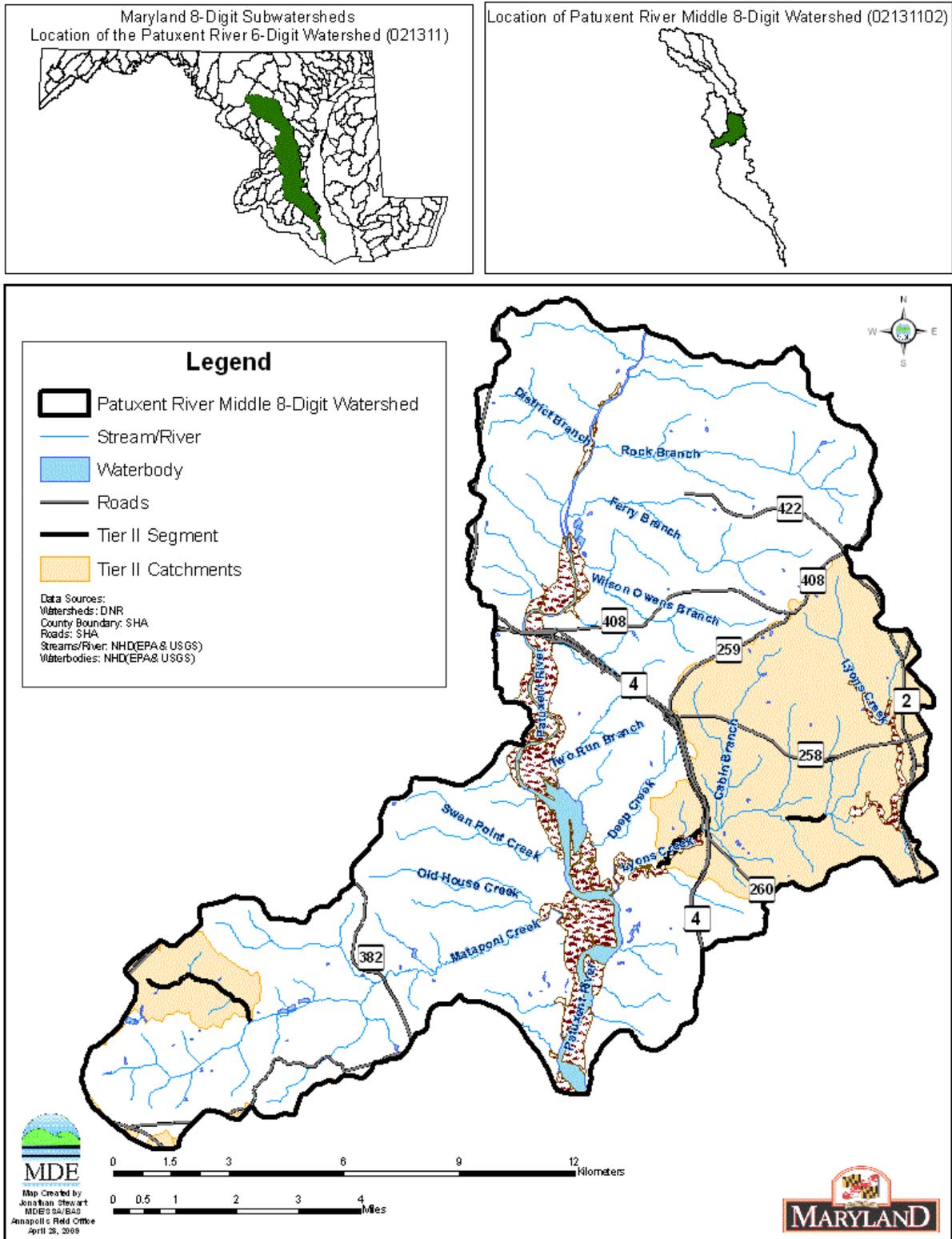
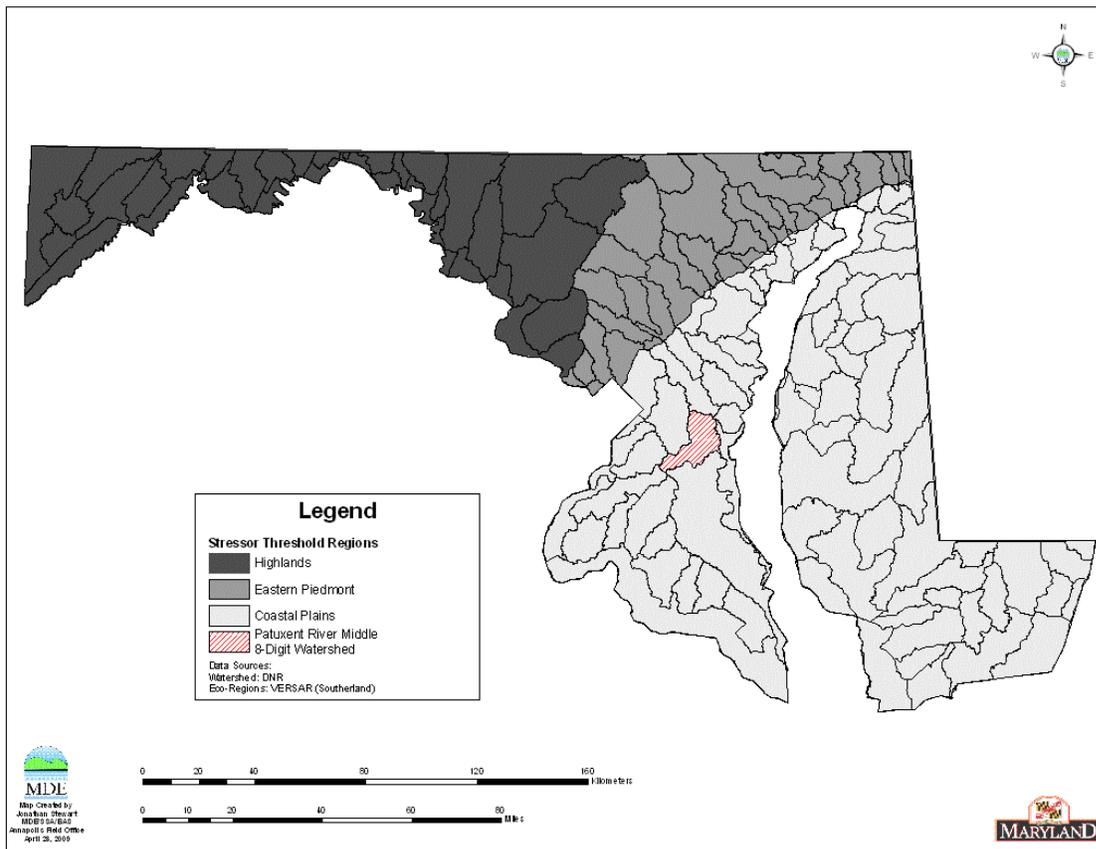


Figure 1. Location Map of the Patuxent River Middle watershed



**Figure 2. Eco-Region Location Map of the Patuxent River Middle watershed**

## 2.2 Land Use

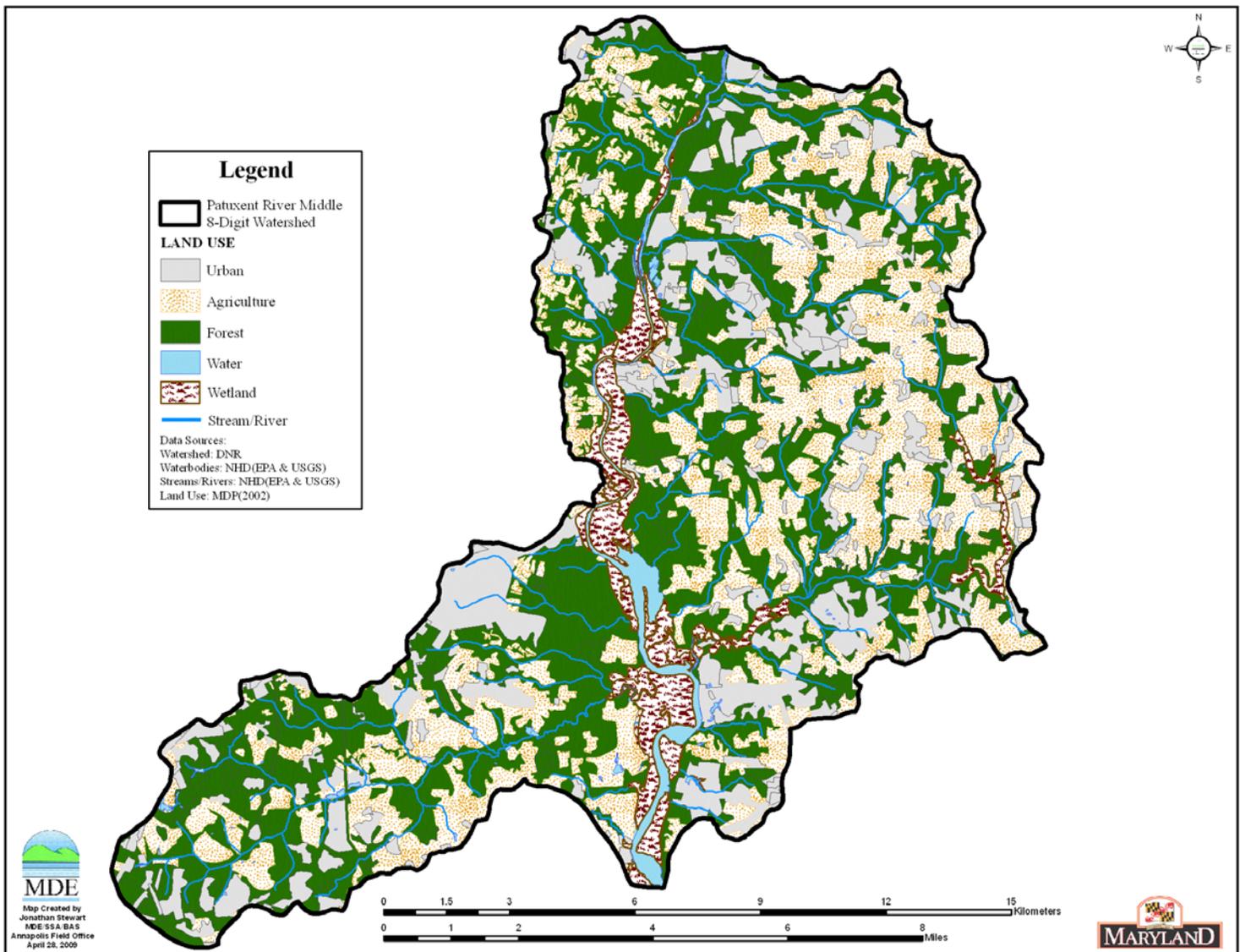
According to the Chesapeake Bay Program’s Phase 5.2 watershed model land use, the Patuxent River Middle watershed is primarily forested, with forest comprising 33,300 acres of the total 55,000 acres (60%) in the watershed. Urban and agricultural land uses make up the majority of the remaining land area in the Patuxent River Middle watershed (USEPA 2010). Agricultural land use comprises 12,700 acres (23%) and urban land use (predominately residential) comprises 8,500 acres (17%) of the watershed (see [Figure 3](#) and [Figure 4](#)).

Historically, land use changes in the Patuxent River watershed have been drastic and could provide clues to possible legacy effects on present biological conditions in the watershed. The area was settled in the early and mid 1600s, predominately by English settlers. As more people moved into the watershed, most of the forests, including riparian buffer zones, were cut for either timber or to prepare the land for agriculture (MDDNR 1998). Tobacco farming was the most dominant agricultural practice for the two centuries following settlement. Destruction of the soils by centuries of tobacco farming brought the mid and lower Patuxent valley into a period of decline that would last until the 1930s, when there were fewer resident in the Patuxent’s Calvert

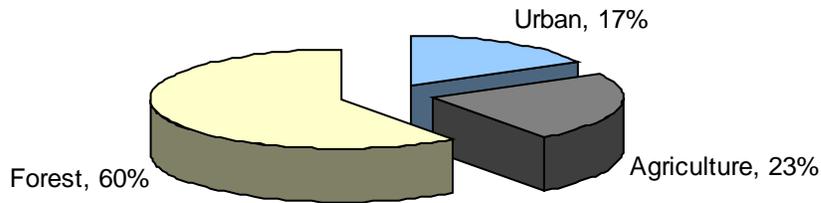
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County than there were in the 1840s (Wikipedia 2013). After the decline of agriculture and the population in the watershed, land use began to shift back to forest.

Although half the watershed remains forested today, all of the original old growth forests have been destroyed. With the watershed being in such close proximity to two major urban centers (Washington D.C. and Baltimore) there has been significant suburban development in the past few decades. The Maryland Department of Planning (1984) reported the population growth was the primary force driving land use changes in the watershed. As the population of the basin increased, more houses, apartments, and shopping centers were built to meet the needs of new residents. Highways and roads were constructed or enlarged to carry increased traffic.



**Figure 3. Land Use Map of the Patuxent River Middle watershed**



**Figure 4. Proportions of Land Use in the Patuxent River Middle watershed**

### 2.3 Soils/hydrology

The Patuxent River Middle watershed is located solely within the Coastal Plain Province of Maryland. The Coastal Plain province is characterized by unconsolidated sediments, which include sand, gravel, silt, and clay. These unconsolidated sediments overlap the rocks of the Piedmont Plateau along the fall line that separates these two geologic provinces. The sediments of the coastal plain dip toward the east at a very low angle, and some of the younger formations in the province crop out to the surface with increasing frequency in a southeasterly direction. The majority of the province, however, consists of older formations, which are covered by a thin layer of Quaternary Gravel (MGS 2007). The predominant soil type in the Patuxent River Middle watershed is the Westphalia. The Westphalia soil association is characterized by rolling to steep, moderate to well-drained, severely eroded soils, consisting of either a sandy clay loam or fine sandy loam. The remaining watershed area is made up of the Beltsville soil association, which is found predominantly on the western edge of the watershed in Prince George's County, along with the Galestown, and Bibb soil associations, which are predominantly found around the mainstem of the Patuxent River itself (USDA 1977).

### 3.0 Patuxent River Middle Watershed Water Quality Characterization

#### 3.1 Integrated Report Impairment Listings

The Patuxent River Middle Watershed (basin code 02131102), located in Anne Arundel, Prince George's, and Calvert Counties, has two different bay listing segments in the Integrated Report (IR): non-tidal and an estuary portion, which is part of the Upper Patuxent River Tidal Fresh bay segment. A WQA was developed for chlorpyrifos (pesticide) and approved by the USEPA in 2003. Below is a table identifying the listings associated with this watershed.

**Table 1. 2012 Integrated Report Listings for the Patuxent River Middle Watershed**

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Patuxent River Middle	02131102	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
					Chlorpyrifos	2
Upper Patuxent River Tidal Fresh	PAXTF	Tidal	Seasonal Migratory fish spawning and nursery Subcategory		TN	3
					TP	3
			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	2008	TSS	4a			

#### 3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Patuxent River Middle watershed and all tributaries is Use I designation - *water contact recreation, and protection of nontidal warmwater aquatic life*. In addition the mainstem of the Patuxent River Middle watershed and some tributaries are Use II designation - *support of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, b, c). A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life; primary or secondary contact recreation, drinking water supply, and trout waters. Water

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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.

A portion of the Patuxent River Middle watershed is designated as a Tier II (i.e., Maryland's antidegradation policy) waterbody; this Tier II designation protects surface water that is better than the minimum requirements specified by water quality standards. Middle Patuxent River watershed's Tier II catchments are the majority of Lyons Creek and all of Cabin Branch (COMAR 2009d).

The Patuxent River Middle watershed is listed under Category 5 of the 2012 Integrated Report for impacts to biological communities. Approximately 47% of stream miles in the Patuxent River Middle watershed are estimated as having benthic and/or fish indices of biological integrity in the poor to very poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include seventeen stations. Seven of the seventeen stations have benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, MBSS Round two and three (2000-2009), contains fifteen MBSS sites, with seven having BIBI and/or FIBI scores lower than 3.0. [Figure 5](#) illustrates principal dataset site locations for the Patuxent River Middle watershed.

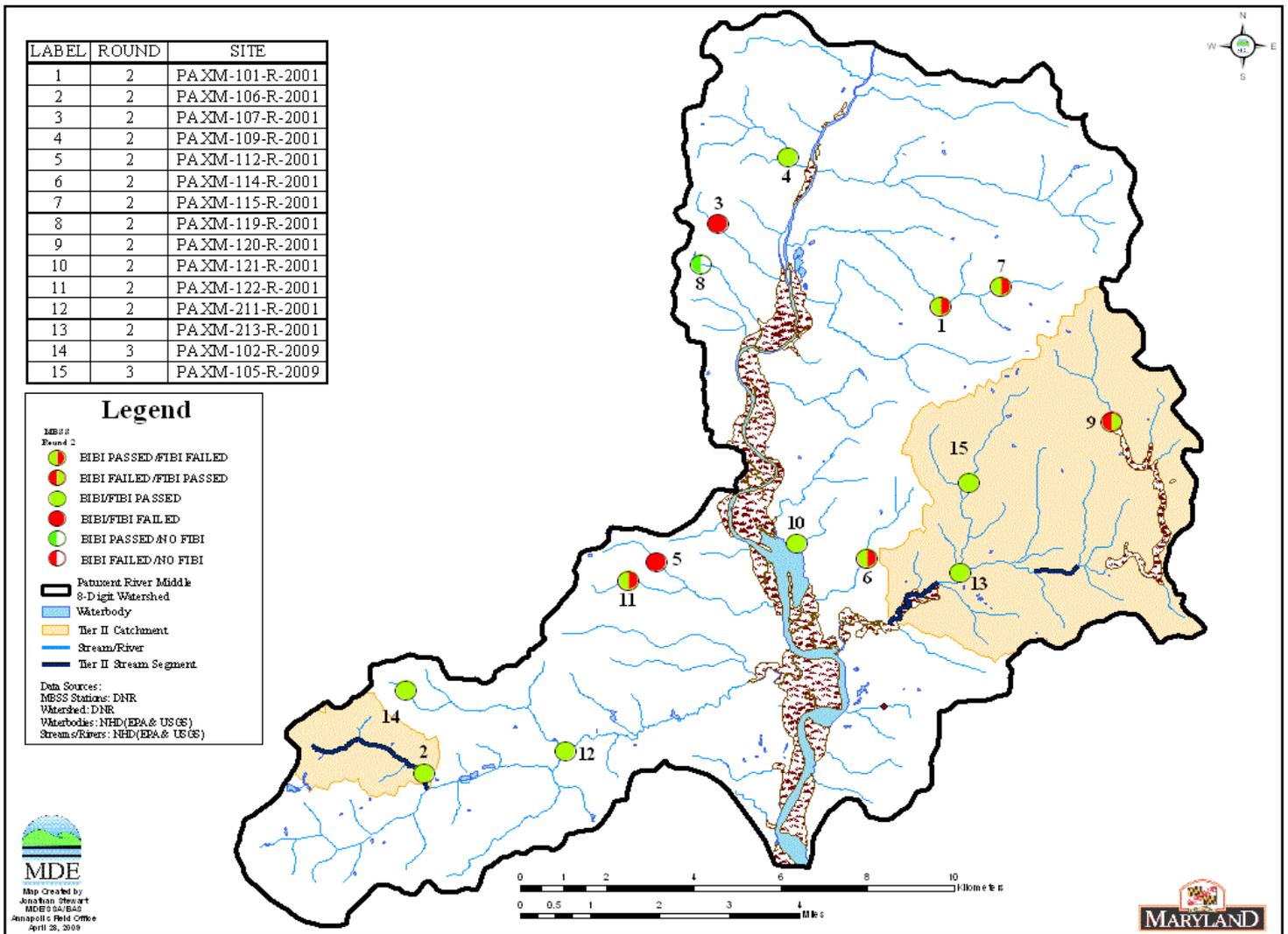


Figure 5. Principal Dataset Sites for the Patuxent River Middle watershed

#### 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<sup>st</sup> and 2<sup>nd</sup>-4<sup>th</sup> 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 (MH) (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.

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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 Patuxent River Middle watershed, MDE identified sources, sediment, 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](#). The only land use source identified was agricultural acid source present. [Table 3](#) shows the summary of combined AR values for the source groups in the Patuxent River Middle watershed. As shown in [Table 4](#) and [Table 6](#), numerous parameters from the sediment, 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 Patuxent River Middle watershed.

**Table 2. Stressor Source Identification Analysis Results for the Patuxent River - Middle Watershed**

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Sources - Acidity	Atmospheric deposition present	15	7	272	29%	37%	1	No	–
	Agricultural acid source present	15	7	272	57%	7%	0.001	Yes	51%
	AMD acid source present	15	7	272	0%	0%	1	No	–
	Organic acid source present	15	7	272	0%	7%	1	No	–
Sources - Agricultural	High % of agriculture in watershed	15	7	277	0%	3%	1	No	–
	High % of agriculture in 60m buffer	15	7	277	0%	4%	1	No	–
Sources - Anthropogenic	Low % of forest in watershed	15	7	277	0%	6%	1	No	–
	Low % of wetland in watershed	15	7	277	29%	11%	0.18	No	–
	Low % of forest in 60m buffer	15	7	277	0%	8%	1	No	–
	Low % of wetland in 60m buffer	15	7	277	29%	10%	0.171	No	–
Sources - Impervious	High % of impervious surface in watershed	15	7	277	0%	4%	1	No	–
	High % of impervious surface in 60m buffer	15	7	277	0%	5%	1	No	–
	High % of roads in watershed	15	7	277	0%	0%	1	No	–
	High % of roads in 60m buffer	15	7	277	0%	4%	1	No	–
Sources - Urban	High % of high-intensity developed in watershed	15	7	277	0%	7%	1	No	–
	High % of low-intensity developed in watershed	15	7	277	0%	6%	1	No	–
	High % of medium-intensity developed in watershed	15	7	277	0%	2%	1	No	–
	High % of early-stage residential in watershed	15	7	277	0%	5%	1	No	–
	High % of residential developed in watershed	15	7	277	0%	6%	1	No	–

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using $p < 0.1$ )	% of case sites associated with the stressor (attributable risk)
	High % of rural developed in watershed	15	7	277	0%	5%	1	No	–
	High % of high-intensity developed in 60m buffer	15	7	277	0%	6%	1	No	–
	High % of low-intensity developed in 60m buffer	15	7	277	0%	4%	1	No	–
	High % of medium-intensity developed in 60m buffer	15	7	277	0%	3%	1	No	–
	High % of early-stage residential in 60m buffer	15	7	277	14%	7%	0.419	No	–
	High % of residential developed in 60m buffer	15	7	277	0%	4%	1	No	–
	High % of rural developed in 60m buffer	15	7	277	0%	5%	1	No	–

**Table 3. Summary of Combined Attributable Risk Values for Source Groups in the Patuxent River - Middle Watershed**

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Acidity	51%
<b>All Sources</b>	<b>51%</b>

#### 4.1 Sources Identified by BSID Analysis

Agricultural acid source was the only source identified by the BSID analysis ([Table 2](#)). Starting in the 1600s and persisting for two centuries agriculture was the dominant land use within the Patuxent River Middle watershed; however, presently, there is significantly less percentages of agricultural land uses (23%).

The BSID analysis identified agricultural sources of acidity as having significant association with degraded biological conditions. Fertilizers used in agricultural practices often contain high levels of nitrogen, sulfates, and other acidifying compounds, which are sources of acidification in surface waters. The historical use of acidifying compounds for agricultural activities in the watershed has potentially affected stream chemistry by lowering the acid neutralizing capacity (ANC).

The BSID source analysis ([Table 2](#)) identified agricultural acid sources as a potential source of the stressors that may be causing negative biological impacts. The combined AR for the source group is approximately 51% suggesting this source is the probable cause of biological impairments in Patuxent River Middle watershed ([Table 3](#)).

All the stressors identified in the BSID analysis ([Table 4](#) and [6](#)) for the Patuxent River Middle watershed are typically linked to the typical consequences of agricultural and urban 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 the Patuxent River - Middle 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	15	7	160	14%	21%	1	No	–
	Moderate bar formation present	15	7	160	86%	49%	0.118	No	–
	Bar formation present	15	7	160	100%	78%	0.348	No	–
	Channel alteration moderate to poor	13	7	131	100%	59%	0.042	Yes	41%
	Channel alteration poor	13	7	131	29%	26%	1	No	–
	High embeddedness	15	7	160	0%	0%	1	No	–
	Epifaunal substrate marginal to poor	15	7	160	71%	46%	0.253	No	–
	Epifaunal substrate poor	15	7	160	0%	13%	1	No	–
	Moderate to severe erosion present	15	7	160	86%	43%	0.045	Yes	43%
	Severe erosion present	15	7	160	43%	13%	0.055	Yes	30%
Silt clay present	15	7	160	100%	99%	1	No	–	

**Table 5. Habitat Biological Stressor Identification Analysis Results for the Patuxent River - Middle 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	15	7	172	14%	13%	1	No	–
	Concrete/gabion present	13	7	148	0%	1%	1	No	–
	Beaver pond present	15	7	159	0%	7%	1	No	–
	Instream habitat structure marginal to poor	15	7	160	71%	39%	0.122	No	–
	Instream habitat structure poor	15	7	160	0%	6%	1	No	–
	Pool/glide/eddy quality marginal to poor	15	7	160	43%	46%	1	No	–
	Pool/glide/eddy quality poor	15	7	160	0%	3%	1	No	–
	Riffle/run quality marginal to poor	15	7	160	86%	53%	0.125	No	–
	Riffle/run quality poor	15	7	160	14%	21%	1	No	–
	Velocity/depth diversity marginal to poor	15	7	160	43%	61%	0.44	No	–
	Velocity/depth diversity poor	15	7	160	14%	16%	1	No	–
Riparian Habitat	No riparian buffer	13	7	140	29%	15%	0.301	No	–
	Low shading	15	7	160	0%	3%	1	No	–

**Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Patuxent River - Middle 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	15	7	277	0%	8%	1	No	–
	High conductivity	15	7	277	0%	6%	1	No	–
	High sulfates	15	7	277	71%	8%	0	Yes	63%
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	15	7	261	0%	17%	0.605	No	–
	Dissolved oxygen < 6mg/l	15	7	261	0%	25%	0.199	No	–
	Low dissolved oxygen saturation	15	7	261	0%	6%	1	No	–
	High dissolved oxygen saturation	15	7	261	0%	3%	1	No	–
	Ammonia acute with salmonid present	15	7	277	0%	0%	1	No	–
	Ammonia acute with salmonid absent	15	7	277	0%	0%	1	No	–
	Ammonia chronic with salmonid present	15	7	277	0%	0%	1	No	–
	Ammonia chronic with salmonid absent	15	7	277	0%	0%	1	No	–
	High total nitrogen	15	7	277	0%	6%	1	No	–
	High total phosphorus	15	7	277	43%	9%	0.025	Yes	33%
	High orthophosphate	15	7	277	0%	5%	1	No	–
	Chemistry - pH	Acid neutralizing capacity below chronic level	15	7	277	0%	9%	1	No
Acid neutralizing capacity below episodic level		15	7	277	86%	45%	0.052	Yes	40%
Low field pH		15	7	262	43%	40%	1	No	–
High field pH		15	7	262	0%	1%	1	No	–
Low lab pH		15	7	277	29%	38%	0.714	No	–
High lab pH	15	7	277	0%	0%	1	No	–	

**Table 7. Summary of Combined Attributable Risk Values for Stressor Groups in the Patuxent River - Middle Watershed**

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	68%
Chemistry - Inorganic	63%
Chemistry - Nutrients	33%
Chemistry - pH	40%
All Chemistry	81%
<b>All Stressors</b>	<b>86%</b>

#### 4.2 Stressors Identified by BSID Analysis

Below is an analysis of the six stressor parameters identified by the BSID analysis ([Table 4](#) and [6](#)), as being significantly associated with biological degradation in the Patuxent River Middle watershed. Any form of anthropogenic change to natural landscapes can create broad and interrelated forms of degradation that can affect stream ecology and biological composition. Also historical changes in land uses of a watershed can cause legacy effects on aquatic health of non-tidal stream ecosystems.

##### Sediment Conditions

BSID analysis results for Patuxent River Middle watershed identified three sediment parameters that had statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community). The parameters are *channel alteration (moderate to poor)* and *erosion present (moderate to severe & severe)* ([Table 4](#)).

*Channel alteration present (moderate to poor)* was identified as significantly associated with degraded biological conditions in the Patuxent River Middle watershed, and found to impact approximately 41% 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

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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).

*Erosion present (moderate to severe & severe)* was identified as significantly associated with degraded biological conditions in the Patuxent River Middle watershed, and found to impact approximately 43% (*moderate to severe* rating) and 30% (*severe* rating) of the stream miles with poor to very poor biological conditions. Erosion Severity represents a visual observation that the stream discharge is frequently exceeding the ability of the channel and/or floodplain to attenuate flow energy, resulting in channel instability, which in turn affects bank stability. Where such conditions are observed, flow energy is considered to have increased in frequency or intensity, accelerating channel and bank erosion. Increased flow energy suggested by this measure is also expected to negatively influence stream biology. Erosion severity is described categorically as minimal, moderate, or severe. Conditions indicating biological degradation are set at two levels, moderate and severe. A level of *severe* indicates that a substantial amount of stream banks show severe erosion and the stream segment exhibits high levels of instability due to erosion. A level of *moderate* indicates that a marginal amount of stream banks show erosion and the stream segment shows elevated levels of instability due to erosion.

The predominant types of soils in the watershed are highly erodible and the watershed contains areas with steep slopes along the stream banks. This combination has led to excessive erosion at many anthropogenically developed sites. Before the English settled the area, the highly erodible soils were held together by forested land. As previously mentioned, most of the forest was cleared by farming practices as far back as the 1800s. The erosion from cropland filled wetlands and scoured streambanks and beds.

After the decline of agriculture in the watershed much of the land was converted back to forest; however, many areas were urbanized. As the land in these small areas was developed, many miles of stream channels were altered and destabilized, as evidenced by highly eroded stream banks. Stream Corridor Assessments conducted by MDDNR revealed several residential developments in the watershed that were built prior to significant stormwater regulations. As a result, there are several unmanaged stormwater outfalls that discharge directly into the stream (CWP 2004). Some creeks in the watershed are experiencing significant shoreline erosion due to improperly managed stormwater associated with increased development. Since this watershed contains highly erodible soils it is naturally more susceptible to surface erosion, sedimentation, streambank erosion, stream channel modification, and other problems related to soil movement.

Elevated sediment loads tend to reduce the stability and complexity of stream bottoms, which results in the loss of habitat for aquatic organisms. Since many benthic organisms such as mayflies and stoneflies use the spaces between stones and sand as living quarters,

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high sediment loads reduce the amount of available habitat and reduce benthic macroinvertebrate diversity and abundance.

Even though there are lower levels of urban, impervious, or agricultural land uses in the watershed as compared to forested lands, it is probable that the combination of erodible soils, steep slopes, and unmanaged stormwater outfalls are enough to cause streambank degradation. 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 68% suggesting these stressors are the probable causes of biological impairments in the Patuxent River Middle watershed (See [Table 7](#)).

### In-stream Habitat Conditions

BSID analysis results for Patuxent River Middle watershed 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 Patuxent River Middle 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 Conditions

BSID analysis results for Patuxent River Middle 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 *high total phosphorus*, *sulfates*, and *acid neutralizing capacity below episodic level* ([Table 6](#)).

*High total phosphorus* levels were identified as significantly associated with degraded biological conditions and found to impact approximately 33% of the degraded stream miles within the Patuxent River Middle watershed. Total Phosphorus (TP) is a measure of the amount of TP in the water column. Phosphorus occurs naturally in rocks and other mineral deposits, and is usually found in the form of phosphates in natural waters. The majority of phosphate mined in the United States is used for fertilizers, with a minor component used for animal feed supplements and other products. Anthropogenic sources

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of phosphorus are fertilizers, chemicals, animal waste and municipal sewage. TP input to surface waters typically increases in watersheds where urban and agricultural land uses are predominant.

*High sulfates* concentrations are significantly associated with degraded biological conditions and found in 63% of the stream miles with poor to very poor biological conditions in the Patuxent River Middle watershed. Sulfate is the amount of dissolved sulfate ( $\text{SO}_4^{2-}$ ) in the water column. Sulfur is an essential plant nutrient. Sulfate loads to surface waters can be naturally occurring or originate from urban runoff, agricultural runoff, acid mine drainage, atmospheric deposition, and wastewater dischargers. When naturally occurring, they are often the result of the breakdown of leaves that fall into a stream, of water passing through rock or soil containing gypsum and other common minerals.

Point source discharges are a potential source of nutrients and sulfates to surface waters. There are numerous minor industrial and municipal National Pollutant Discharge Elimination System permitted dischargers in the watershed. There are also a substantial number of on-site septic systems in the watershed, which could be a potential non-point source of loads. Nutrient and sulfate loads from any wastewater treatment facility or on-site septic system are dependent upon the discharge volume, the level of treatment process, and the sophistication of the processes and equipment.

*Acid neutralizing capacity below episodic level* are significantly associated with degraded biological conditions and found in 40% of the stream miles with poor to very poor biological conditions in the Patuxent River Middle watershed. Acid Neutralizing Capacity (ANC) is a measure of the capacity of dissolved constituents in the water to react with and neutralize acids. MDDNR MBSS measures ANC in the spring and reports it as  $\mu\text{eq/L}$ . ANC can be used as an index of the sensitivity of surface waters to acidification. The higher the ANC, the more acid a system can assimilate before experiencing a decrease in pH. An ANC value above  $200\mu\text{eq/l}$  is considered normal (Southerland et al 2007). Repeated additions of acidic materials may cause a decrease in ANC. ANC values less than  $50\mu\text{eq/l}$  are considered to demonstrate chronic (highly sensitive to acidification) exposures for aquatic organisms, and less than 200 are considered to demonstrate episodic (sensitive to acidification) exposures. The ANC threshold values, at which levels below 50 (chronic) and below 200 (episodic) may indicate biological degradation, are established from peer-reviewed literature (Kazyak, Ladell, and Thompson 2005, Southerland et al 2007). Low ANC results from agricultural land use, acid mine drainage, atmospheric deposition and organic sources.

The capacity of soil and surface waters to absorb acids without changing the ion balance is known as buffering capacity, measured as ANC. Streams with less than  $0\mu\text{eq/l}$  are acidic and have no buffering capacity. Streams with baseflow ANC between 0 and  $200\mu\text{eq/l}$  are only moderately buffered and may periodically have low pH levels during

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rainfall or snowmelts. Acidity in streams is typically affected by atmospheric deposition, acid mine drainage, organic matter, and agricultural runoff.

The source of the acids in atmospheric deposition is largely the result of the combustion of fossil fuels that produce waste by-products including gases such as oxides of sulfur and nitrogen. Acid mine drainage is the result of mineral pyrite oxidation of mine spoils left in abandoned mine shafts. The third source of acidity, organic acidity caused by the decay of organic matter, often arises from blackwater streams, freshwater wetlands and coastal marshes. The last source is surface runoff from agricultural lands fertilized with high levels of nitrogen, sulfates, or other acidifying compounds (MDDNR 2005).

Current agricultural practices, along with historical legacy effects, are likely the cause of the agricultural acid source identified by the BSID analysis.

Buffering capacity of natural water is determined by the soil and bedrock through which it passes. The soil and bedrock strata in the Patuxent River Middle watershed is dominated by unconsolidated mud and clay with mixtures of quartz, silt, sand, weathered residium, organic rich deposits, and iron rich greensand. These rock types also tend to provide relatively little acid-neutralizing capacity and are highly porous (McCartan et. al. 1998).

Low pH values were not identified as a significant stressor in the watershed. Neither MBSS data nor monthly routine surface water sampling conducted by the State shows significant percentage of low pH values (< 7%). However, with watersheds experiencing episodic low pH, routine monthly monitoring is often not sufficient in characterizing this condition. Further intensive or synoptic monitoring in the watershed is warranted to determine if episodic low pH is occurring in the watershed.

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 81% suggesting these stressors are the probable causes of biological impairments in the Patuxent River Middle watershed ([Table 7](#)).

### 4.3 Discussion

The BSID analysis results suggest that degraded biological communities in the Patuxent River Middle watershed are a result of stressors associated with sedimentation, high phosphorus, low ANC, and elevated sulfate concentrations. Even though agricultural land use was not identified in the BSID analysis, approximately 23% of the Patuxent River Middle watershed contains various types of this land use. Historical legacy impacts to water quality and stream habitat from agricultural land use is prevalent in the watershed. Also, with the watershed being in such close proximity to two major urban

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centers (Washington D.C. and Baltimore) there has been significant suburban development in the past few decades.

The embeddedness and severe erosion present identified by the BSID can be indicative of anthropogenic activities that lead to altered hydrologic/flow regimes. Altered flow regimes often result in increased surface flow and flashiness during rain events. The scouring associated with increased flows leads to accelerated channel erosion and increased fine sediment deposition throughout the impacted streambed. Streambed sedimentation affects the habitat available for macroinvertebrates, quality of gravel for fish spawning, and amount of habitat for fish rearing (Waters 1995).

Channel alterations and erosion of streambanks identified by the BSID are likely caused by a combination of erodible soils, steep streambank slopes, and unmanaged stormwater outfalls. Channel erosion results in increased fine sediment deposition throughout the streambed and the resulting sedimentation affects the habitat available for aquatic communities to thrive.

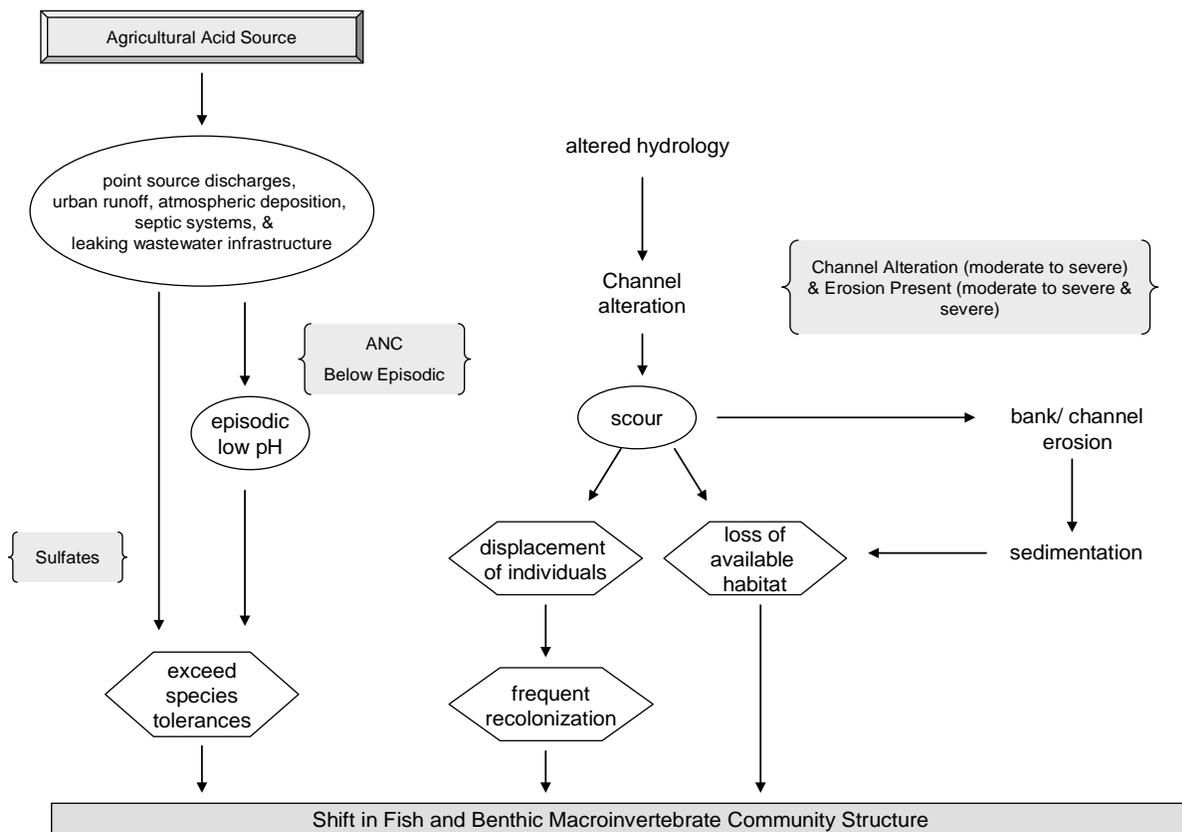
Agricultural and urban land uses are the probable sources of phosphorus and sulfates in the watershed. Atmospheric deposition is also a likely contributor of sulfates. Since nitrogen and low dissolved oxygen were not identified as significant stressors, it is unlikely that phosphorus levels are contributing to eutrophication in the watershed. High levels of sulfates in the watershed do appear to be a significant stressor and potentially contributing to low ANC levels and toxic conditions that may exceed species tolerances.

The combined AR for all the stressors is approximately 86%, suggesting these stressors impact a considerable proportion of the degraded stream miles in Patuxent River Middle watershed ([Table 7](#)).

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

#### 4.4 Final Causal Model for the Patuxent River Middle Watershed

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr 1991; USEPA 2013). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. [Figure 6](#) illustrates the final causal model for the Patuxent River Middle watershed, with pathways to show the watershed’s probable stressors as indicated by the BSID analysis.



**Figure 6. Final Causal Model for the Patuxent River Middle watershed**

## 5.0 Conclusions

Data suggest that the Patuxent River Middle watershed's biological communities are strongly influenced by urban and agricultural land use, which has altered the stream geomorphology, resulting in loss of diverse and stable habitat. There is an abundance of scientific research that documents the 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). Based upon the results of the BSID analysis, the probable causes and sources of the impacts to biological communities in the Patuxent River Middle watershed are summarized as follows:

- The BSID process has determined that biological communities in the Patuxent River Middle watershed are likely degraded due to sediment related stressors. Specifically, urban and agricultural runoff has led to altered hydrology which has led to severe erosion and channel alteration throughout the watershed. The BSID results thus confirm 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 Patuxent River Middle watershed. The BSID results also support a Category 5 listing of TSS for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Patuxent River Middle.
- The BSID process has also determined that the biological communities in the Patuxent River Middle watershed are likely degraded due to inorganic water chemistry related stressors. Specifically, current and historical legacy effects of agricultural land use practices have resulted in the potential elevation of sulfate inputs throughout the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus support a Category 5 listing of sulfates for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing these stressor's impacts on the biological communities in the Patuxent River Middle watershed. Discharges of inorganic compounds like sulfates are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of this parameter will help in determining the spatial and temporal extent of these impairments in the watershed.

## References

- Bolton, S., and J. Shellberg. 2001. *Ecological Issues in Floodplains and Riparian Corridors*. University of Washington, Center for Streamside Studies, Olympia, Washington. pp. 217-263.
- COMAR (Code of Maryland Regulations). 2013a. 26.08.02.02.  
<http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.02.htm>  
(Accessed February, 2013).
- \_\_\_\_\_. 2013b. 26.08.02.08 M(1).  
<http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.08.htm>  
(Accessed February, 2013).
- \_\_\_\_\_. 2013c. 26.08.02.08 M(2)(a).  
<http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.02-1.htm>  
(Accessed February, 2013).
- \_\_\_\_\_. 2009d. 26.08.02.04-1.  
<http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.04-1.htm> (Accessed December, 2013).
- CWP (Center for Watershed Protection). 2004. *Lower Patuxent River in Clavert County Watershed Restoration Action Strategy*. Ellicott City, MD.
- Hill, A. B. 1965. *The Environment and Disease: Association or Causation?* Proceedings of the Royal Society of Medicine, 58: 295-300.
- Karr, J. R. 1991. *Biological integrity - A long-neglected aspect of water resource management*. Ecological Applications. 1:66-84.
- Kazyak, J. Kilian, J. Ladell, and J. Thompson. 2005. *Maryland Biological Stream Survey 2000 – 2004 Volume 14: Stressors Affecting Maryland Streams*. Prepared for the Department of Natural Resources. CBWP-MANTA-EA-05-11.  
[http://www.dnr.state.md.us/streams/pdfs/ea-05-11\\_stressors.pdf](http://www.dnr.state.md.us/streams/pdfs/ea-05-11_stressors.pdf)  
(Accessed February, 2013).
- Mantel, N. and W. Haenszel. 1959. *Statistical aspects of the analysis of data from retrospective studies of disease*. Journal of the National Cancer Institute. 22: 719-748.

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McCartan, L., J.D. Peper, L.J. Bachman, and J.W. Horton. 1998. *Application of geologic map information to water quality issues in the southern part of the Chesapeake Bay watershed, Maryland and Virginia, eastern United States*. Journal of Geochemical Exploration 00(1998) 1-22.

MDDNR (Maryland Department of Natural Resources). 1998. *Patuxent River Basin Environmental Assessment of Stream Conditions*. CBWP-MANTA-EA-98-7. Annapolis, MD.

\_\_\_\_\_. 2005. *Maryland Biological Stream Survey 2000-2004 Stressors Affecting Maryland Streams. Volume XIV*. Annapolis, MD.

MDE (Maryland Department of the Environment). 2010. *Final 2010 Integrated Report of Surface Water Quality in Maryland*. Baltimore, MD: Maryland Department of the Environment. Also Available at:  
[http://www.mde.state.md.us/programs/Water/TMDL/Integrated303dReports/Documents/Integrated\\_Report\\_Section\\_PDFs/IR\\_2012/MD\\_Final\\_2012\\_IR\\_Parts\\_A-E.pdf](http://www.mde.state.md.us/programs/Water/TMDL/Integrated303dReports/Documents/Integrated_Report_Section_PDFs/IR_2012/MD_Final_2012_IR_Parts_A-E.pdf) (Accessed February, 2013).

\_\_\_\_\_. 2009. *Maryland Biological Stressor Identification Process*. Baltimore, MD: Maryland Department of the Environment. Also available at:  
[http://www.mde.state.md.us/programs/Water/TMDL/Documents/www.mde.state.md.us/assets/document/BSID\\_Methodology\\_Final.pdf](http://www.mde.state.md.us/programs/Water/TMDL/Documents/www.mde.state.md.us/assets/document/BSID_Methodology_Final.pdf)

MDP (Maryland Department of Planning) 1984. *Patuxent River Policy Plan, Land Management Strategy*. Baltimore, MD: Maryland Department of Planning.  
<http://www.mdp.state.md.us/PDF/OurWork/PRC/OriginalPolicyPlan.pdf>  
(Accessed February, 2013).

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

Roth N. E., J.D. Allan, and D. L. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. *Landscape Ecology* 11: 141–56.

Southerland, M. T., G. M. Rogers, R. J. Kline, R. P. Morgan, D. M. Boward, P. F. Kazyak, R. J. Klauda and S. A. Stranko. 2005. *New biological indicators to better assess the condition of Maryland Streams*. Columbia, MD: Versar, Inc. with Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Division. CBWP-MANTA-EA-05-13. Also Available at  
[http://www.dnr.state.md.us/streams/pdfs/ea-05-13\\_new\\_ibi.pdf](http://www.dnr.state.md.us/streams/pdfs/ea-05-13_new_ibi.pdf)  
(Accessed February, 2013).

- Southerland, M. T., J. Volstad, E. Weber, R. Morgan, L. Currey, J. Holt, C. Poukish, and M. Rowe. 2007. *Using MBSS Data to Identify Stressors for Streams that Fail Biocriteria in Maryland*. Columbia, MD: Versar, Inc. with Maryland Department of the Environment and University of Maryland.  
[http://www.mde.state.md.us/assets/document/MDE\\_Stressor\\_ID\\_report\\_complete\\_final\\_061507\(1\).pdf](http://www.mde.state.md.us/assets/document/MDE_Stressor_ID_report_complete_final_061507(1).pdf) (Accessed February, 2013).
- USDA (U.S. Department of Agriculture, Soil Conservation Service) (SCS). 1977.  
<https://soilseries.sc.egov.usda.gov/osdname.asp> (Accessed February, 2013).
- USEPA (United States Environmental Protection Agency). 2013. *The Causal Analysis/Diagnosis Decision Information System (CADDIS)*.  
<http://www.epa.gov/caddis> (Accessed February, 2013).
- \_\_\_\_\_. 2010. *Chesapeake Bay Phase 5 Community Watershed Model*. Annapolis MD:Chesapeake Bay Program Office.  
<http://ches.communitymodeling.org/models/CBPhase5/documentation.php>  
(Accessed February, 2013).
- Van Sickle, J. and Paulson, S.G. 2008. *Assessing the attributable risks, relative risks, and regional extents of aquatic stressors*. *Journal of the North American Benthological Society*. 27:920-931.
- Wang, L., J. Lyons, P. Kanehl, and R. Gatti. 1997. Influence of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams. *Fisheries* 22(6): 6-12.
- Waters, T.F. 1995. *Sediment in streams – Sources, biological effects and control*. American Fisheries Society Monograph 7, 249 p.
- Wikipedia 2013. *Patuxent River*. [http://en.wikipedia.org/wiki/Patuxent\\_River](http://en.wikipedia.org/wiki/Patuxent_River) (Accessed February, 2013).