Watershed Report for Biological Impairment of the Patuxent River Lower Watershed in Anne Arundel, Prince George's, Calvert, Charles, and St. Mary's Counties, Maryland
Biological Stressor Identification Analysis Results and Interpretation

FINAL

DEPARTMENT OF THE ENVIRONMENT
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Submitted to:

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1650 Arch Street
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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
IR	Integrated Report
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MH	Mantel-Haenzel
mg/L	Milligrams per liter
µS/cm	Micro Siemens per centimeter
P/G/E	Pool/Glide/Eddy
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

Executive Summary

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. For each WQLS listed on the *Integrated Report of Surface Water Quality in Maryland* (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 Lower watershed (basin code 02131101), located in Anne Arundel, Prince George's, Calvert, Charles, and St. Mary's Counties, is associated with five assessment units in the Integrated Report: non-tidal (8-digit basin), and four estuary portions - the Lower Patuxent River, Lower Patuxent River Mesohaline, Middle Patuxent River Oligohaline, and Lower Chesapeake Bay Mesohaline segments (MDE 2012). Below is a table identifying the listings associated with this watershed.

Table E1. 2012 Integrated Report Listings for the Patuxent River Lower watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year Listed	Identified Pollutant	Listing Category
Patuxent River Lower	02131101	Non-Tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
Lower Patuxent River	02131101	Tidal	Aquatic Life and Wildlife		Chlorpyrifos	2
			Fishing	2008	PCB in Fish Tissue	5
			Fishing		Mercury in Fish Tissue	2
	Lake Lariat		Fishing	2002	Mercury in Fish Tissue	4a

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

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year Listed	Identified Pollutant	Listing Category
Middle Patuxent River Oligohaline	PAXOH	Tidal	Shellfishing	2012	Fecal Coliform	5
			Aquatic Life and Wildlife	2010	Impacts to Estuarine Biological Communities	5
			Open-Water Fish and Shellfish subcategory	1996	Total Nitrogen	4a
			Open-Water Fish and Shellfish subcategory	1996	Total Phosphorus	4a
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	Total Nitrogen	4a
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	Total Phosphorus	4a
			Seasonal Shallow-Water Submerged Aquatic Vegetation Subcategory	2010	TSS	4a
Lower Patuxent River Mesohaline	PAXMH	Tidal	Seasonal Deep-Water Fish and Shellfish subcategory	1996	Total Nitrogen	4a
			Seasonal Deep-Water Fish and Shellfish subcategory	1996	Total Phosphorus	4a
			Open-Water Fish and Shellfish subcategory	1996	Total Nitrogen	4a
			Open-Water Fish and Shellfish subcategory	1996	Total Phosphorus	4a
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	Total Nitrogen	4a
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	Total Phosphorus	4a
			Seasonal Shallow-Water Submerged Aquatic Vegetation Subcategory	1996	TSS	4a
			Aquatic Life and Wildlife	2002	Oil-Spill-PAHs	4b
			Aquatic Life and Wildlife	2002	Oil-Spill-PAHs	4b
			Aquatic Life and Wildlife	2006	Impacts to Estuarine Biological Communities	5

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

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year Listed	Identified Pollutant	Listing Category
Lower Patuxent River Mesohaline	Buzzard Island Creek	Tidal	Shellfishing	2012	Fecal Coliform	5
	Cuckold Creek		Shellfishing	1996	Fecal Coliform	5
	Washington-Persimmon Creek		Shellfishing	1998	Fecal Coliform	4a
	Mill Creek		Shellfishing	1998	Fecal Coliform	4a
	Island Creek		Shellfishing	2012	Fecal Coliform	4a
	St. Thomas Creek		Shellfishing	1998	Fecal Coliform	4a
	Town Creek		Shellfishing	1998	Fecal Coliform	4a
	Indian Creek		Shellfishing	2012	Fecal Coliform	4a
	Solomons Island Harbor		Shellfishing	1998	Fecal Coliform	4a
	Trent Hall Creek		Shellfishing	1998	Fecal Coliform	4a
	Wells Cove		Shellfishing	2010	Fecal Coliform	5
	Battle Creek 2		Shellfishing	2010	Fecal Coliform	5
	Battle Creek		Shellfishing		Fecal Coliform	2
	Golden Beach Boat Ramp		Water Contact Sport		Enterococcus	2
	Golden Beach Community		Water Contact Sport		Enterococcus	2

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

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year Listed	Identified Pollutant	Listing Category
Lower Chesapeake Bay Mesohaline	CB5MH	Tidal	Aquatic Life and Wildlife	2006	Impacts to Estuarine Biological Communities	5
			Seasonal Deep-Channel Refuge Use	1996	Total Phosphorus	4a
			Seasonal Deep-Channel Refuge Use	1996	Total Nitrogen	4a
			Seasonal Deep-Water Fish and Shellfish subcategory	1996	Total Nitrogen	4a
			Seasonal Deep-Water Fish and Shellfish subcategory	1996	Total Phosphorus	4a
			Open-Water Fish and Shellfish subcategory	1996	Total Nitrogen	4a
			Open-Water Fish and Shellfish subcategory	1996	Total Phosphorus	4a
			Seasonal Shallow-Water Submerged Aquatic Vegetation Subcategory	2008	TSS	4a
	St. Jeromes Creek		Shellfishing	2010	Fecal Coliform	5
	Goose Creek		Shellfishing	1998	Fecal Coliform	4a
	Harper Pearson Creeks		Shellfishing	1998	Fecal Coliform	4a

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 Lower mainstem and all tributaries is Use I designation - w*ater contact recreation, and protection of nontidal warmwater aquatic life.* In addition most of the mainstem of the Patuxent River Lower mainstem and some tributaries are Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, b, c). The Patuxent River Lower 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 Lower 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 Lower watershed are strongly influenced by current and historical land use and its concomitant effects of increasing sedimentation and resulting loss of in-stream habitat quality. The development of landscapes creates broad and interrelated forms of degradation that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between anthropogenically 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 Lower watershed can be summarized as follows:

- The BSID process has determined that biological communities in Patuxent River Lower watershed are likely degraded due to sediment and in-stream habitat related stressors. Specifically, altered habitat, and increased runoff from residential and historical agricultural landscapes have resulted in changes to stream geomorphology and subsequent elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results support the identification of the non-tidal portion of this watershed in Category 5 of the Integrated Report as impaired by TSS to begin addressing the impacts of this stressor on the biological communities in the Patuxent River Lower watershed. The BSID results confirm the tidal 1996 Category 5 listing for total suspended solids (TSS) as an appropriate management action in the watershed, and links this pollutant to biological conditions in these waters and extend the impairment to the watershed's non-tidal waters. Therefore, the establishment of total suspended solids TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin addressing this stressor to the biological communities in the Patuxent River Lower watershed.

1.0 Introduction

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

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

The MDE biological stressor identification (BSID) analysis applies a case-control, risk-based approach that uses the principal dataset, with considerations for ancillary data, to identify potential causes of the biological impairment. Identification of stressors responsible for biological impairments was limited to the round two and three Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) dataset (2000–2009) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists.

Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

The remainder of this report provides a characterization of the Patuxent River Lower watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Patuxent River Lower watershed Characterization

2.1 Location

The Patuxent River is located on Maryland's Western Shore and drains portions of Anne Arundel, Calvert, Charles, Fredrick, Howard, Montgomery, Prince George's, and St. Mary's Counties, Maryland. The river has a length of approximately 44 miles, and flows in a south/southeast direction until it empties into the Chesapeake Bay (MDDNR 2007). The Patuxent River Lower watershed is part of the Patuxent River 6-digit watershed, and is located in Anne Arundel, Calvert, Charles, St. Mary's, and Prince George's Counties, and it drains an area of approximately 207,400 acres. The watershed starts at the outlet of the Patuxent River Middle watershed, and encompasses all of the Patuxent River mainstem just south of the town of Nottingham, and tributaries until the confluence with the Chesapeake Bay. A considerable portion of the watershed is tidal, and the navigable portion is crossed by two bridges. One bridge is located on RT 231 in the town of Benedict which is approximately the middle of the watershed. The other bridge is located on RT 4 near the confluence of the Patuxent River and the Chesapeake Bay (Figure 1).

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).

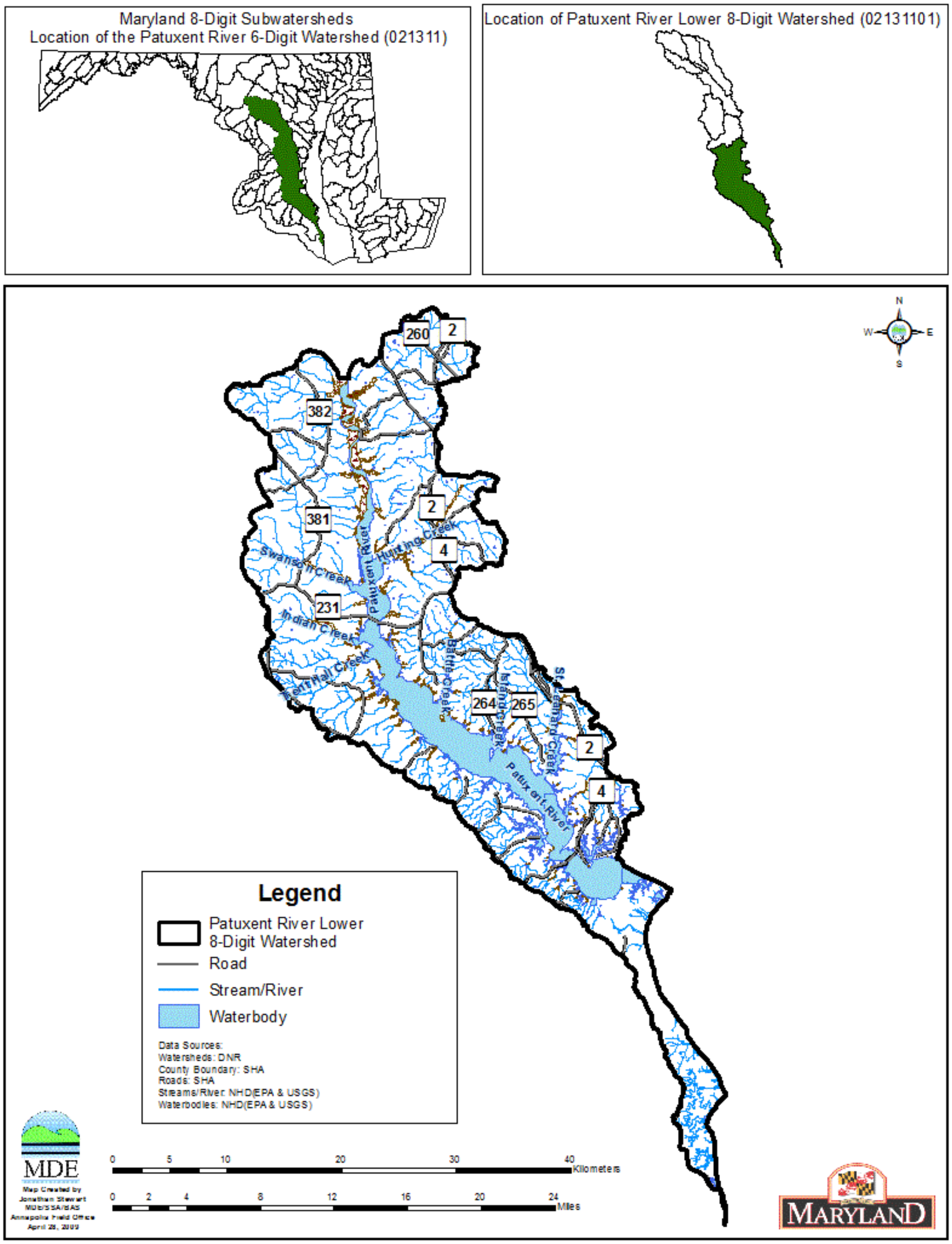

Figure 1. Location Map of the Patuxent River Lower watershed

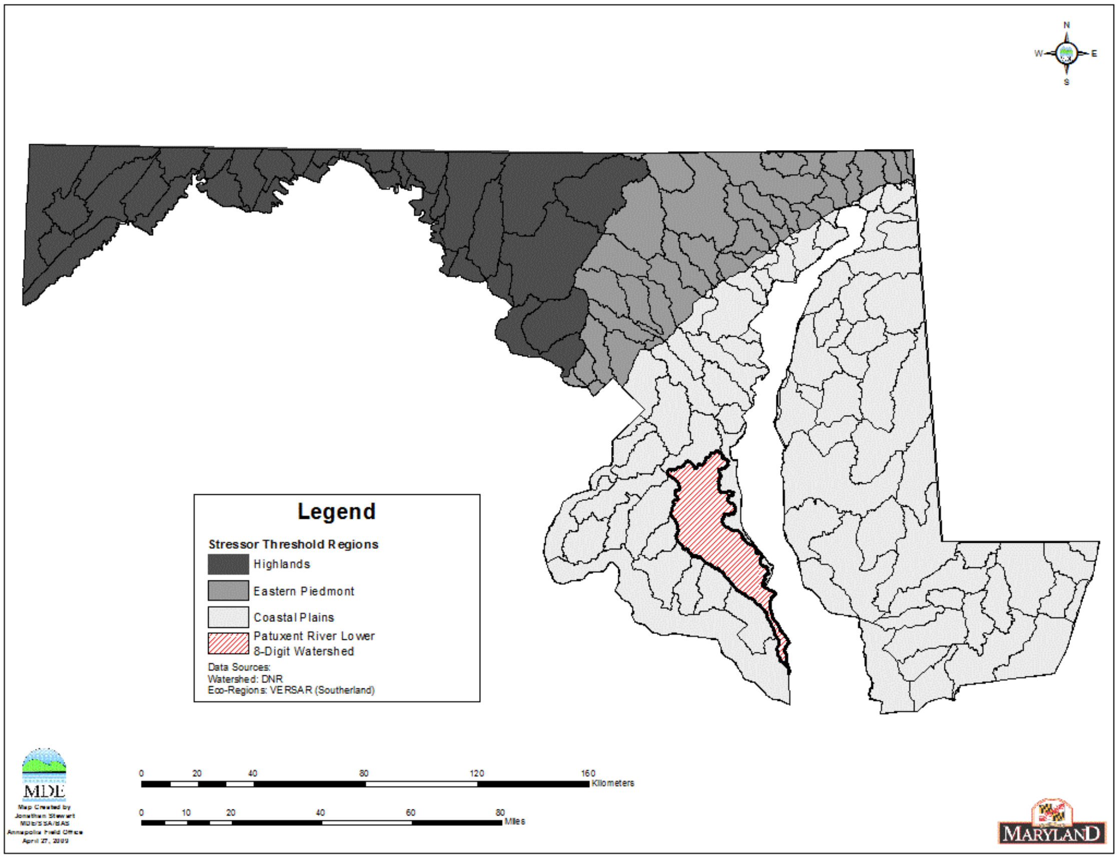

Figure 2. Eco-Region Location Map of the Patuxent River Lower watershed

2.2 Land Use

The Patuxent River Lower watershed is predominantly scattered forest with localized areas of residential/urban land, and agriculture. There is one large area of non-residential urban land, which consists of the Patuxent River Navel Air Station. There are a number small residential areas including: Benedict, Golden Beach, White Sands, Chesapeake Ranch Estates, and Solomon's Island. According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the Patuxent River Lower watershed's land use is approximately 62% forest, 23% mixed urban, and 15% agricultural (USEPA 2010) (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 residents in the Patuxent's Calvert

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

Although more than 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 that 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.

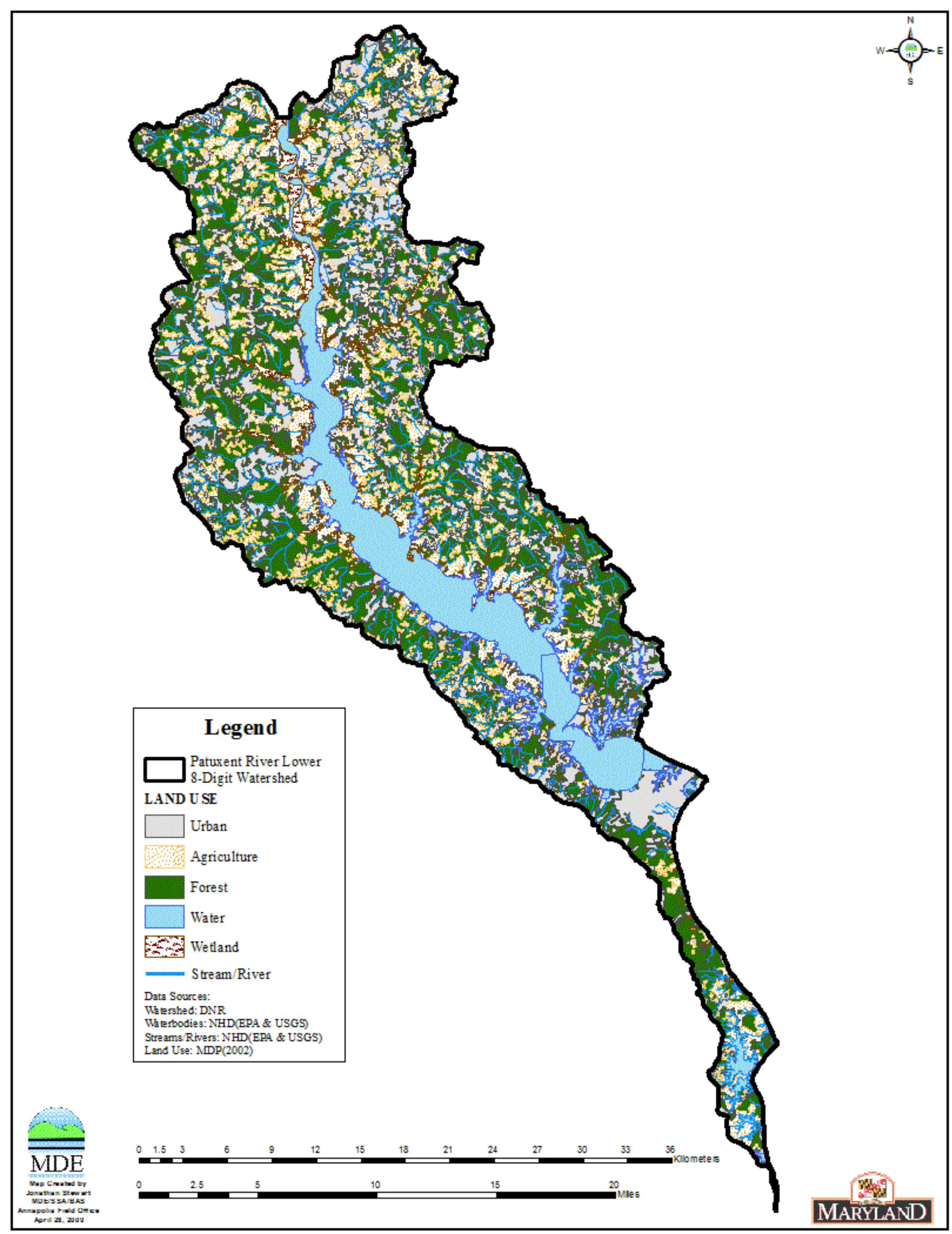

Figure 3. Land Use Map of the Patuxent River Lower watershed

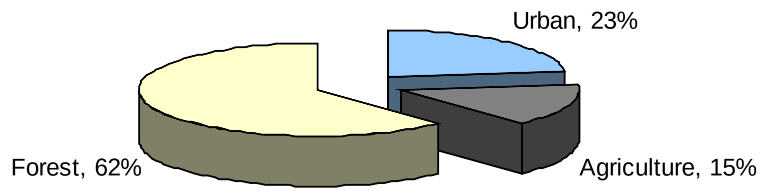

Figure 4. Proportions of Land Use in the Patuxent River Lower watershed

2.3 Soils/hydrology

The Patuxent River Lower 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 of 3 degrees, 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 two predominant soil types in the Patuxent River Lower watershed are the Sassafras and Westphalia soil associations. The Sassafras association makes up the majority of the southeastern portion of the Patuxent River Lower watershed, while the Westphalia association makes up the majority of the western and northeastern portions of the watershed. 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 Sassafras soil association is characterized by gently sloping to steep, welldrained, moderately to severely eroded soils, consisting of either a sandy clay loam or a silt 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 St. Mary's, Charles, and Prince George's Counties, along with the Galestown, Othello, and Bibb soil associations, which are predominantly found around the mainstem of the Patuxent River itself (USDA 1967, 1971, 1973, 1974, and 1978).

3.0 Patuxent River Lower watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Patuxent River Lower watershed (basin code 02131101), located in Anne Arundel, Prince Georges, Calvert, Charles, and St. Mary's Counties, is associated with five assessment units in the Integrated Report (IR): non-tidal (8-digit basin), and estuary portions, the Lower Patuxent River, Lower Patuxent River Mesohaline, Middle Patuxent River Oligohaline, and Lower Chesapeake Bay Mesohaline segment (MDE 2012). Below is a table identifying the listings associated with this watershed.

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Lower Patuxent River	02131101	Tidal	Aquatic Life and Wildlife		Chlorpyrifos	2
			Fishing	2008	PCB in Fish Tissue	5
			Fishing		Mercury in Fish Tissue	2
	Lake Lariat		Fishing	2002	Mercury in Fish Tissue	4a

Table 1. 2012 Integrated Report Listings for the Patuxent River Lower watershed (cont)

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year Listed	Identified Pollutant	Listing Category
Middle Patuxent River Oligohaline	PAXOH	Tidal	Shellfishing	2012	Fecal Coliform	5
			Aquatic Life and Wildlife	2010	Impacts to Estuarine Biological Communities	5
			Open-Water Fish and Shellfish subcategory	1996	Total Nitrogen	4a
			Open-Water Fish and Shellfish subcategory	1996	Total Phosphorus	4a
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	Total Nitrogen	4a
			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	Total Phosphorus	4a
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			Seasonal Deep-Water Fish and Shellfish subcategory	1996	Total Phosphorus	4a
			Open-Water Fish and Shellfish subcategory	1996	Total Nitrogen	4a
			Open-Water Fish and Shellfish subcategory	1996	Total Phosphorus	4a
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			Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	Total Phosphorus	4a
			Seasonal Shallow-Water Submerged Aquatic Vegetation Subcategory	1996	TSS	4a
			Aquatic Life and Wildlife	2002	Oil-Spill-PAHs	4b
			Aquatic Life and Wildlife	2002	Oil-Spill-PAHs	4b
			Aquatic Life and Wildlife	2006	Impacts to Estuarine Biological Communities	5

Table 1. 2012 Integrated Report Listings for the Patuxent River Lower watershed (cont)

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	Washington-Persimmon Creek		Shellfishing	1998	Fecal Coliform	4a
	Mill Creek		Shellfishing	1998	Fecal Coliform	4a
	Island Creek		Shellfishing	2012	Fecal Coliform	4a
	St. Thomas Creek		Shellfishing	1998	Fecal Coliform	4a
	Town Creek		Shellfishing	1998	Fecal Coliform	4a
	Indian Creek		Shellfishing	2012	Fecal Coliform	4a
	Solomons Island Harbor		Shellfishing	1998	Fecal Coliform	4a
	Trent Hall Creek		Shellfishing	1998	Fecal Coliform	4a
	Wells Cove		Shellfishing	2010	Fecal Coliform	5
	Battle Creek 2		Shellfishing	2010	Fecal Coliform	5
	Battle Creek		Shellfishing		Fecal Coliform	2
	Golden Beach Boat Ramp		Water Contact Sport		Enterococcus	2
	Golden Beach Community		Water Contact Sport		Enterococcus	2

Table 1. 2012 Integrated Report Listings for the Patuxent River Lower watershed (cont)

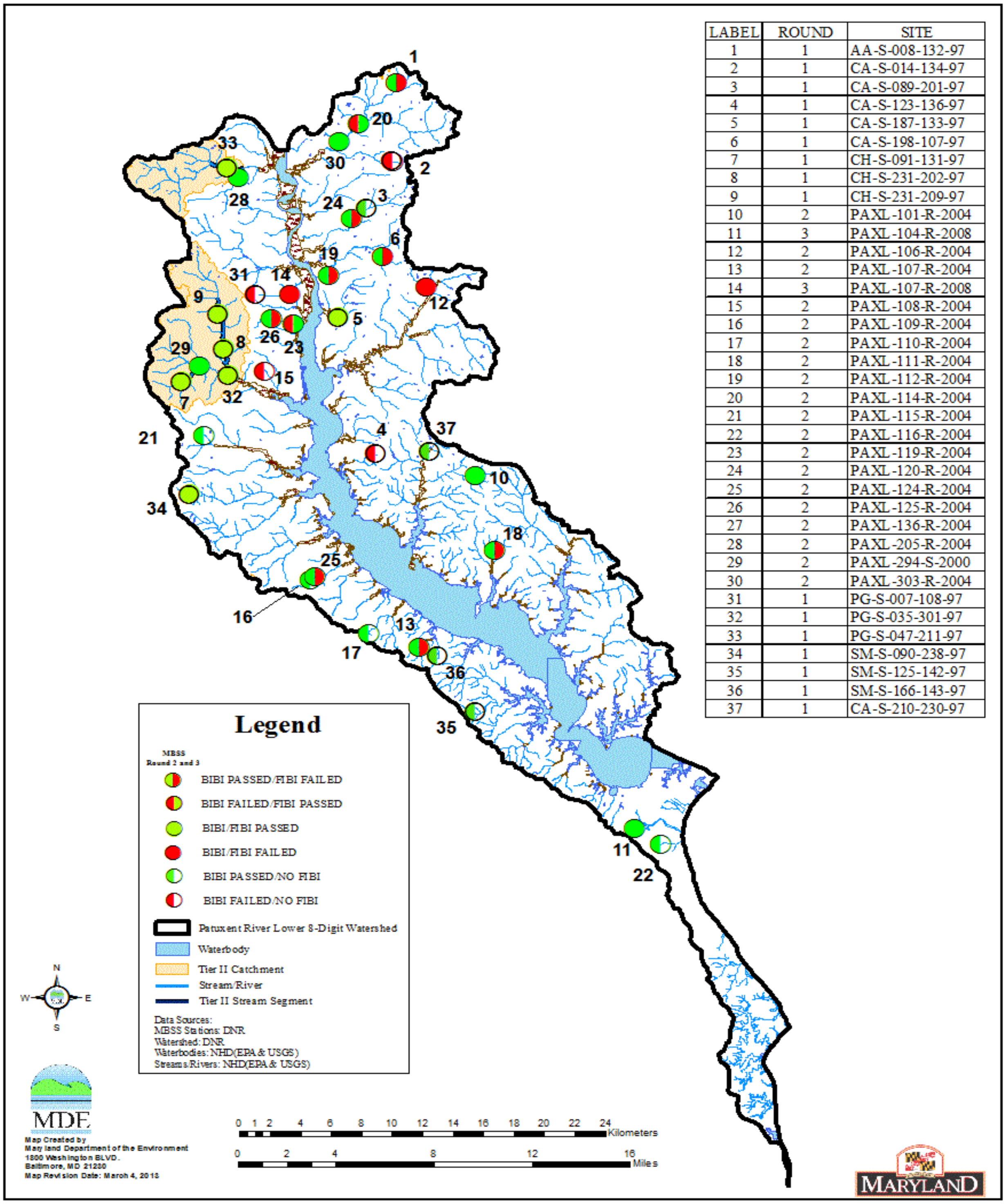
Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year Listed	Identified Pollutant	Listing Category
Lower Chesapeake Bay Mesohaline	CB5MH	Tidal	Aquatic Life and Wildlife	2006	Impacts to Estuarine Biological Communities	5
			Seasonal Deep-Channel Refuge Use	1996	Total Phosphorus	4a
			Seasonal Deep-Channel Refuge Use	1996	Total Nitrogen	4a
			Seasonal Deep-Water Fish and Shellfish subcategory	1996	Total Nitrogen	4a
			Seasonal Deep-Water Fish and Shellfish subcategory	1996	Total Phosphorus	4a
			Open-Water Fish and Shellfish subcategory	1996	Total Nitrogen	4a
			Open-Water Fish and Shellfish subcategory	1996	Total Phosphorus	4a
			Seasonal Shallow-Water Submerged Aquatic Vegetation Subcategory	2008	TSS	4a
	St. Jeromes Creek		Shellfishing	2010	Fecal Coliform	5
	Goose Creek		Shellfishing	1998	Fecal Coliform	4a
	Harper Pearson Creeks		Shellfishing	1998	Fecal Coliform	4a

3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Patuxent River Lower mainstem and all tributaries is Use I designation - w*ater contact recreation, and protection of nontidal warmwater aquatic life.* In addition most of the mainstem of the Patuxent River Lower and some tributaries are Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, b, c). A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life; primary or secondary contact recreation, drinking water supply, and trout waters. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Patuxent River Lower watershed is listed under Category 5 of the 2012 Integrated Report for impacts to biological communities. Approximately 43% of stream miles in the Patuxent River Lower 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 thirty-four stations. Sixteen of the thirty-four stations have benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor).

For the Patuxent River Lower watershed, MDE chose to include all the MBSS data rounds (1995-2009) in the BSID analysis, which contains thirty-seven MBSS sites with seventeen having BIBI and/or FIBI scores lower than 3.0. The reason for this management decision was the results of the BSID analysis of MBSS round two and three data did not yield an acceptable attributable risk (AR) value for all identified stressors (67% AR). By including the sixteen MBSS round one sites to the BSID analysis, the AR value for all stressors identified was increased to a more acceptable value, which MDE considers would sufficiently account for the biological degradation in the watershed. The BSID analysis and AR calculations will be explained in the next section. Figure 5 illustrates principal dataset (round one, two, and three) site locations for the Patuxent River Lower watershed.



LABEL	ROUND	SITE
1	1	AA-S-008-132-97
2	1	CA-S-014-134-97
3	1	CA-S-089-201-97
4	1	CA-S-123-136-97
5	1	CA-S-187-133-97
6	1	CA-S-198-107-97
7	1	CH-S-091-131-97
8	1	CH-S-231-202-97
9	1	CH-S-231-209-97
10	2	PAXL-101-R-2004
11	3	PAXL-104-R-2008
12	2	PAXL-106-R-2004
13	2	PAXL-107-R-2004
14	3	PAXL-107-R-2008
15	2	PAXL-108-R-2004
16	2	PAXL-109-R-2004
17	2	PAXL-110-R-2004
18	2	PAXL-111-R-2004
19	2	PAXL-112-R-2004
20	2	PAXL-114-R-2004
21	2	PAXL-115-R-2004
22	2	PAXL-116-R-2004
23	2	PAXL-119-R-2004
24	2	PAXL-120-R-2004
25	2	PAXL-124-R-2004
26	2	PAXL-125-R-2004
27	2	PAXL-136-R-2004
28	2	PAXL-205-R-2004
29	2	PAXL-294-S-2000
30	2	PAXL-303-R-2004
31	1	PG-S-007-108-97
32	1	PG-S-035-301-97
33	1	PG-S-047-211-97
34	1	SM-S-090-238-97
35	1	SM-S-125-142-97
36	1	SM-S-166-143-97
37	1	CA-S-210-230-97

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

4.0 Stressor Identification Results

The BSID process uses results from the BSID data analysis to evaluate each biologically impaired watershed and determine potential stressors and sources. Interpretation of the BSID data analysis results is based upon components of Hill's Postulates (Hill 1965), which propose a set of standards that could be used to judge when an association might be causal. The components applied are: 1) the strength of association which is assessed using the odds ratio; 2) the specificity of the association for a specific stressor (risk among controls); 3) the presence of a biological gradient; 4) ecological plausibility which is illustrated through final causal models; and 5) experimental evidence gathered through literature reviews to help support the causal linkage.

The BSID data analysis tests for the strength of association between stressors and degraded biological conditions by determining if there is an increased risk associated with the stressor being present. More specifically, the assessment compares the likelihood that a stressor is present, given that there is a degraded biological condition, by using the ratio of the incidence within the case group as compared to the incidence in the control group (odds ratio). The case group is defined as the sites within the assessment unit with BIBI/FIBI scores lower than 3.0 (i.e., poor to very poor). The controls are sites with similar physiographic characteristics (Highland, Eastern Piedmont, and Coastal region), and stream order for habitat parameters (two groups – 1st and 2nd-4th order), that have fair to good biological conditions.

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenzel (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are poor to very poor biological conditions (cases) than when there are fair to good biological conditions (controls). This result suggests a statistically significant positive association between the stressor and poor to very poor biological conditions and is used to identify potential stressors.

Once potential stressors are identified (i.e., odds ratio significantly greater than one), the risk attributable to each stressor is quantified for all sites with poor to very poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with poor to very poor biological conditions that are associated with the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present.

Once the AR is calculated for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR calculation for each stressor, the AR calculation for a group of stressors is also summed over the case sites using the individual site characteristics (i.e., stressors present at that site).

The only difference is that the absolute risk for the controls at each site is estimated based on the stressor present at the site that has the lowest absolute risk among the controls.

After determining the AR for each stressor and the AR for groups of stressors, the AR for all potential stressors is calculated. This value represents the proportion of cases, sites in the watershed with poor to very poor biological conditions, which would be improved if the potential stressors were eliminated (Van Sickle and Paulsen 2008). The purpose of this metric is to determine if stressors have been identified for an acceptable proportion of cases (MDE 2009).

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

Table 2. Stressor Source Identification Analysis Results for the Patuxent River Lower watershed

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Sources - Acidity	Agricultural acid source present	37	17	426	0%	6%	0.614	No	_
	AMD acid source present	37	17	426	0%	0%	1	No	_
	Organic acid source present	37	17	427	0%	5%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	37	17	430	0%	3%	1	No	_
	High % of agriculture in 60m buffer	37	17	430	0%	4%	1	No	_
Sources - Anthropogenic	Low % of forest in watershed	37	17	430	0%	5%	1	No	_
	Low % of wetland in watershed	37	17	430	12%	8%	0.643	No	_
	Low % of forest in 60m buffer	37	17	430	0%	7%	0.624	No	_
	Low % of wetland in 60m buffer	37	17	430	35%	8%	0.002	Yes	27%
Sources - Impervious	High % of impervious surface in watershed	37	17	430	0%	7%	0.615	No	_
	High % of impervious surface in 60m buffer	37	17	430	0%	10%	0.395	No	_
	High % of roads in watershed	37	17	430	0%	0%	1	No	_
	High % of roads in 60m buffer	37	17	430	0%	6%	0.614	No	_
Sources - Urban	High % of high-intensity developed in watershed	37	17	430	0%	8%	0.383	No	_
	High % of low-intensity developed in watershed	37	17	430	0%	6%	0.614	No	_
	High % of medium-intensity developed in watershed	37	17	430	0%	3%	1	No	_
	High % of early-stage residential in watershed	37	17	430	6%	4%	0.489	No	_
	High % of residential developed in watershed	37	17	430	0%	6%	0.614	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	37	17	430	6%	5%	0.599	No	_
	High % of high-intensity developed in 60m buffer	37	17	430	0%	7%	0.615	No	_
	High % of low-intensity developed in 60m buffer	37	17	430	0%	6%	0.615	No	_
	High % of medium-intensity developed in 60m buffer	37	17	430	0%	6%	0.615	No	_
	High % of early-stage residential in 60m buffer	37	17	430	0%	5%	1	No	_
	High % of residential developed in 60m buffer	37	17	430	0%	6%	0.615	No	_
	High % of rural developed in 60m buffer	37	17	430	0%	4%	1	No	_

Table 3. Summary of Combined Attributable Risk Values of the Source Group in the Patuxent River Lower watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Anthropogenic	27%
All Sources	***27%***

4.1 Sources Identified by BSID Analysis

The BSID source analysis (Table 2) only identified loss of wetlands within the sixty meter riparian buffer zone as a potential source of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 27% suggesting land use sources are not the most probable cause of biological impairments in the Patuxent River Lower watershed (Table 3).

The Lower Patuxent River watershed has lost a relatively large amount of wetlands as compared with other similar Maryland watersheds. In most of Maryland's watersheds, extensive wetland areas have been converted to other land uses by draining and filling. This conversion unavoidably reduces or eliminates the natural functions that wetlands provide.

Non-tidal wetlands, although similar in function to tidal wetlands, differ greatly in their range of habitats, and species composition. Non-tidal wetlands are often referred to as inland or upland wetlands and include freshwater swamps, bogs and bottomland hardwood forests. As in the case of tidal wetlands, they provide habitat for plants, fish, and wildlife, maintain water quality, act as ground water recharge areas, and control flooding and erosion.

The first settlers to the area cleared large expanses of forest and wetlands for agricultural production, predominantly to cultivate corn, tobacco, small grain, and hay. Immediately preceding the Civil War, a large percentage of the original forest land had been cleared for agricultural uses, but during the first half of the 20th century there was a gradual reversion back to forest cover. In the past few decades the watershed has had a loss of forest cover. Unlike the clearing that took place during colonization, the current pressure is for residential development, not for agriculture. Land which is developed residentially is permanently committed to some form of development and reversion to forest cover is unlikely (MDDNR 1998).

The remainder of this section will discuss the six 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 the Patuxent River Lower 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	21	12	161	17%	21%	1	No	_
	Moderate bar formation present	21	12	160	58%	49%	0.766	No	_
	Channel alteration moderate to poor	34	16	163	75%	62%	0.418	No	_
	Channel alteration poor	34	16	163	25%	27%	1	No	_
	High embeddedness	36	17	192	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	36	17	192	76%	48%	0.04	Yes	29%
	Epifaunal substrate poor	36	17	192	18%	17%	1	No	_
	Moderate to severe erosion present	21	12	160	25%	43%	0.363	No	_
	Severe erosion present	21	12	160	0%	13%	0.364	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Patuxent River Lower 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	37	17	207	6%	13%	0.701	No	_
	Concrete/gabion present	37	17	183	0%	2%	1	No	_
	Beaver pond present	37	17	193	0%	6%	0.606	No	_
	Instream habitat structure marginal to poor	36	17	192	82%	44%	0.004	Yes	39%
	Instream habitat structure poor	36	17	192	47%	7%	0	Yes	40%
	Pool/glide/eddy quality marginal to poor	36	17	192	94%	47%	0	Yes	47%
	Pool/glide/eddy quality poor	36	17	192	18%	4%	0.049	Yes	13%
	Riffle/run quality marginal to poor	36	17	192	35%	53%	0.207	No	_
	Riffle/run quality poor	36	17	192	6%	19%	0.321	No	_
	Velocity/depth diversity marginal to poor	36	17	192	94%	61%	0.007	Yes	33%
	Velocity/depth diversity poor	36	17	192	6%	16%	0.478	No	_
Riparian Habitat	No riparian buffer	34	16	172	13%	14%	1	No	_
	Low shading	36	17	192	0%	3%	1	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Patuxent River Lower 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	21	12	279	0%	8%	0.608	No	_
	High conductivity	37	17	431	0%	5%	1	No	_
	High sulfates	37	17	431	12%	8%	0.638	No	_
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	36	17	405	0%	14%	0.145	No	_
	Dissolved oxygen < 6mg/l	36	17	405	0%	22%	0.03	No	_
	Low dissolved oxygen saturation	36	17	405	0%	5%	1	No	_
	High dissolved oxygen saturation	36	17	405	12%	6%	0.266	No	_
	Ammonia acute with salmonid present	21	12	279	0%	0%	1	No	_
	Ammonia acute with salmonid absent	21	12	279	0%	0%	1	No	_
	Ammonia chronic with early life stages present	21	12	279	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	21	12	279	0%	0%	1	No	_
	High nitrites	21	12	279	0%	3%	1	No	_
	High nitrates	37	17	431	0%	6%	0.615	No	_
	High total nitrogen	21	12	279	0%	6%	1	No	_
	High total phosphorus	21	12	279	25%	9%	0.106	No	_
	High orthophosphate	21	12	279	0%	5%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	37	17	431	6%	8%	1	No	_
	Low field pH	36	17	406	18%	33%	0.289	No	_
	High field pH	36	17	406	0%	0%	1	No	_
	Low lab pH	37	17	431	12%	35%	0.065	No	_
	High lab pH	37	17	431	0%	0%	1	No	_

Table 7. Summary of Combined Attributable Risk Values of the Stressor Group in the Patuxent River Lower watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	29%
Instream Habitat	73%
All Stressors	***73%***

4.2 Stressors Identified by BSID Analysis

Sediment Conditions

BSID analysis results for Patuxent River Lower watershed identified only one sediment parameter that had statistically significant association with a poor to very poor stream biological condition. The parameter was *epifaunal substrate (marginal to poor)* (Table 4).

Epifaunal substrate (marginal to poor) was identified as significantly associated with degraded biological conditions in the Patuxent River Lower watershed, and found to impact approximately 29% of the stream miles with poor to very poor biological conditions. Epifaunal substrate is a visual observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. The varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates. Epifaunal substrate is confounded by natural variability (i.e., streams will naturally have more or less available productive substrate). Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. Epifaunal substrate conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, where stable substrate is lacking, or particles are over 75% surrounded by fine sediment and/or flocculent material; and 2) marginal to poor, where large boulders and/or bedrock are prevalent and cobble, woody debris, or other preferred surfaces are uncommon.

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 (MDDNR 1998). 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 have become developed for residential uses. As the land in these small areas was developed, many miles of stream channels were altered and destabilized, as evidenced by poor epifaunal substrate quality. 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. Another confounding factor is the threshold value for embeddedness in the Coastal Plains eco-region is 100%. Twenty-six of the thirty-seven stations had stream beds that were 50-100% embedded. Eighteen stations were 100% embedded.

Elevated sediment loads tend to reduce the stability and complexity of stream bottoms, which results in the loss of habitat for aquatic organisms. Another consequence of sedimentation is the coating or burial of stones by silt and sand in riffle areas. Since many benthic organisms such as mayflies and stoneflies use the spaces between stones and sand as living quarters, high sediment loads reduce the amount of available habitat and reduce benthic macroinvertebrate diversity and abundance.

Even though there are lower levels of urban and agricultural land uses in the watershed as compared to forested lands, it is probable that the combination of erodible soils, steep slopes, and unmanaged residential/urban runoff 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 29% suggesting these stressors are probable causes of biological impairments in the Patuxent River Lower watershed (See Table 7).

In-stream Habitat Conditions

BSID analysis results for Patuxent River Lower watershed identified five in-stream habitat parameters that have statistically significant association with a poor to very poor stream biological condition. These parameters are *in-stream habitat structure (marginal to poor & poor), pool/glide/eddy quality (marginal to poor & poor), and velocity/depth/diversity quality (marginal to poor)* (Table 5).

In-stream habitat structure (marginal to poor & poor) was identified as significantly associated with degraded biological conditions in the Patuxent River Lower watershed, and found to impact approximately 39% (*marginal to poor* rating) and 40% (*poor* rating) of the stream miles with poor to very poor biological conditions. In-stream habitat is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. In-stream habitat is confounded by natural variability (i.e., some streams will naturally have more or less in-stream habitat). High in-stream habitat scores are evidence of the lack of sediment deposition. Low in-stream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats. In-stream habitat conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, which is defined as less than 10% stable habitat where lack of habitat is obvious; and 2) marginal to poor, where there is a 10-30% mix of stable habitat but habitat availability is less than desirable.

Pool/glide/eddy quality (marginal to poor & poor) was identified as significantly associated with degraded biological conditions in the Patuxent River Lower watershed, and found to impact approximately 47% (*marginal to poor* rating) and 13% (*poor* rating) of the stream miles with poor to very poor biological conditions. Pool/glide/eddy (P/G/E) quality is a visual observation and quantitative measurement of the variety and spatial complexity of slow or still water habitat and cover within a stream segment referred to as P/G/E. Stream morphology complexity directly increases the diversity and abundance of fish species found within the stream segment. The increase in heterogeneous habitat such as a variety in depths of pools, slow moving water, and complex covers likely provide valuable habitat for fish species; conversely, a lack of heterogeneity within the pool/glide/eddy habitat decreases valuable habitat for fish species. P/G/E quality conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels 1) poor, defined as minimal heterogeneous habitat with a max depth of <0.2 meters or being absent completely; and 2) marginal, defined as <10% heterogeneous habitat with shallow areas (<0.2 meters) prevalent and slow moving water areas with little cover.

Velocity/depth diversity (marginal to poor) was identified as significantly associated with degraded biological conditions in the Patuxent River Lower watershed, and found to impact approximately 33% of the stream miles with poor to very poor biological conditions. Velocity/depth diversity is a visual observation and quantitative measurement based on the variety of velocity/depth regimes present at a site (i.e., slow-shallow, slow-deep, fast-shallow, and fast-deep). Like riffle/run quality, the increase in the number of different velocity/depth regimes likely increases the abundance and diversity of fish species within the stream segment. The decrease in the number of different velocity/depth regimes likely decreases the abundance and diversity of fish species within the stream segment. The poor velocity/depth/diversity category could identify the absence of available habitat to sustain a diverse aquatic community. This measure may reflect natural conditions (e.g., bedrock), anthropogenic conditions (e.g., widened channels, dams, channel dredging, etc.), or excessive erosional conditions (e.g., bar formation, entrenchment, etc.). Poor velocity/depth diversity conditions are defined as the stream segment being dominated by one velocity/depth regime. Velocity is one of the critical variables that controls the presence and number of species (Gore 1978). Many invertebrates depend on certain velocity ranges for either feeding or breathing (Brookes 1988).

All the in-stream habitat parameters identified by the BSID analysis are intricately linked with habitat heterogeneity, the presence of these stressors indicates a lower diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. Substrate is an essential component of in-stream habitat to macroinvertebrates for several reasons. First, many organisms are adapted to living on or obtaining food from specific types of substrate, such as cobble or sand. The group of organisms known as scrapers, for instance, cannot easily live in a stream with no large substrate because there is nothing from which to scrape algae and biofilm. Hence substrate diversity is strongly correlated with macroinvertebrate assemblage composition (Cole, Russel, and Mabee 2003). Second, obstructions in the stream such as cobble or boulders slow the movement of coarse particulate organic matter, allowing it to break down and feed numerous insects in its vicinity (Hoover, Richardson, and Yonesmitsu 2006). Also the presence of a well-developed pool/glide/eddy system is indicative of different types of habitat, and is typically assumed to have a higher biodiversity of organisms (Richards, Host, and Arthur 1993). Often sedimentation and increased flooding can disrupt pool/glide/eddy sequences (Richards, Host, and Arthur 1993).

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the in-stream habitat stressor group is approximately 73% suggesting these stressors are probable causes of biological impairments in the Patuxent River Lower watershed (Table 7).

Riparian Habitat Conditions

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

Water Chemistry Conditions

BSID analysis results for the Patuxent River Lower watershed did not identify any water chemistry parameters that have a statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community) (Table 6).

4.3 Discussion

The BSID analysis results suggest that degraded biological communities in the Patuxent River Lower watershed are a result of stressors associated with sedimentation and loss of in-stream habitat diversity. Watersheds in the Coastal Plain physiographic region are naturally impacted by sediment deposition due to the region's soil types and hydrology. Streams with a lack of diverse substrates, typically the case with streams in this region, have little habitat heterogeneity because of high embeddedness, marginal epi-faunal quality, low gradients, and low flow/velocities. Historical loss of forest cover in the watershed and its replacement with agricultural land uses and then residential development have exacerbated loss of habitat heterogeneity and lowered aquatic species diversity. After analysis of MBSS data, sedimentation in the watershed is associated with natural conditions of the Coastal Plains eco-region and historical land use changes, as well as present residential development. Hopefully with continued efforts in implementing and enforcing the 2010 Chesapeake Bay TMDL by State and local agencies, sediment loads in the Patuxent River Lower watershed will decrease and stream habitat will improve.

The combined AR for all the stressors is approximately 73%, suggesting that the stressors identified in the BSID analysis would account for a substantial portion of the degraded stream miles within the Patuxent River Lower 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 Lower watershed, with pathways to show the watershed's probable stressors as indicated by the BSID analysis.

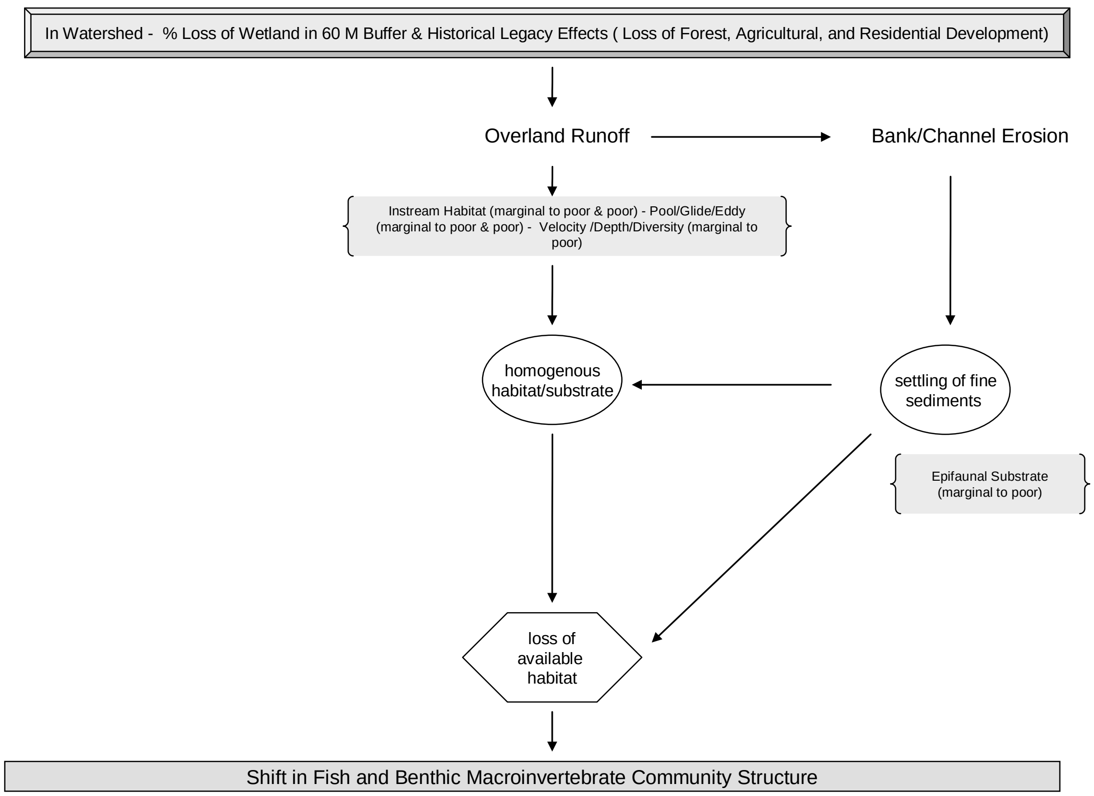


Figure 6. Final Causal Model for the Patuxent River Lower watershed

5.0 Conclusions

Data suggest that the biological communities of the Patuxent River Lower watershed are strongly influenced by current and historical land use and its concomitant effects increasing sedimentation and resulting loss of in-stream habitat quality. The development of landscapes creates broad and interrelated forms of degradation that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between anthropogenically 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 Lower watershed can be summarized as follows:

- The BSID process has determined that biological communities in Patuxent River Lower watershed are likely degraded due to sediment and in-stream habitat related stressors. Specifically, altered habitat, and increased runoff from residential and historical agricultural landscapes have resulted in changes to stream geomorphology and subsequent elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results support the identification of the non-tidal portion of this watershed in Category 5 of the Integrated Report as impaired by TSS to begin addressing the impacts of this stressor on the biological communities in the Patuxent River Lower watershed. The BSID results confirm the tidal 1996 Category 5 listing for total suspended solids (TSS) as an appropriate management action in the watershed, and links this pollutant to biological conditions in these waters and extend the impairment to the watershed's non-tidal waters. Therefore, the establishment of total suspended solids TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin addressing this stressor to the biological communities in the Patuxent River Lower watershed.

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