REVISED FINAL

Watershed Report for Biological Impairment of the Little Patuxent River in Anne Arundel and Howard Counties, Maryland
Biological Stressor Identification Analysis Results and Interpretation

REVISED FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
Cd	Cadmium
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
mg/L	Milligrams per liter
NPDES	National Pollutant Discharge Elimination System
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
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. 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 Little Patuxent River (basin code 02131105) located in Anne Arundel and Howard Counties, was identified in Maryland's Integrated Report as impaired by cadmium (Cd), sediments, nutrients (1996 listings), and impacts to biological communities (2002) (MDE 2008). Centennial Lake located within the watershed was identified as impaired by phosphorus and sediments (1998 listings). Except for Centennial Lake, all impairments are listed for non-tidal streams. The 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 sediments listing was refined in the 2008 Integrated Report to a listing for total suspended solids. A 2008 WQA addressing the Cd impairment is pending USEPA approval and will remove the Little Patuxent watershed from Category 5 for Cd impairment to Category 2. Phosphorus and sediment TMDLs for Centennial Lake were approved in 2001.

In 2002, the State began listing biological impairments on the Integrated Report. The current Maryland Department of 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, how TMDLs are developed, and how implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds with multiple impacted sites by measuring the percentage of stream miles that have an Index of Biotic Integrity (IBI) score less than 3, and calculating whether this is significant from a reference condition watershed (i.e., healthy stream, <10% stream miles degraded).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Little Patuxent River is Use I – P – *water contact recreation, protection of nontidal warmwater aquatic life and public water supply* (COMAR 2009a,b). The Little Patuxent River watershed is not attaining its designated use of supporting aquatic life because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

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

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

This Little Patuxent River watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the degradation of biological communities in the Little Patuxent River is strongly associated with urban land use and its concomitant effects: altered hydrology and elevated levels of chlorides and conductivity (a measure of the presence of dissolved substances). The urbanization of landscapes creates broad and interrelated forms of degradation (i.e., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between highly urbanized 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 Little Patuxent River, can be summarized as follows:

- The BSID analysis has determined that the biological communities are likely degraded due to flow/sediment related stressors. Specifically, altered hydrology and increased runoff from urban impervious surfaces have resulted in channel erosion and subsequent elevated suspended sediment transport through the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results confirm the establishment of a USEPA approved sediment TMDL in 2011 was an appropriate management action to begin addressing the impact of these stressors on the biological communities in Little Patuxent River.
- The BSID analysis has determined that the biological communities are likely degraded due to inorganic pollutants (i.e., chlorides). Inorganic pollutants levels are significantly associated with degraded biological conditions and found in approximately 39% of the stream miles with very poor to poor biological conditions in the Little Patuxent River watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds 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 these parameters will help in determining the spatial and temporal extent of these impairments in the watershed. The BSID results thus support Category 5 listings of chloride as an appropriate

management action to begin addressing the impacts of these stressors on the biological communities in the Little Patuxent River watershed.

- Although there is presently a Category 5 listing for phosphorus in Maryland’s 2010 Integrated Report, the BSID analysis did not identify any nutrient stressors (i.e., total nitrogen, total phosphorus, dissolved oxygen, etc.) present and/or nutrient stressors showing a significant association with degraded biological conditions.

1.0 Introduction

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

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2008). 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 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 (MDDNR) Maryland Biological Stream Survey (MBSS) dataset (2000 – 2004) 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 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 Little Patuxent River watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Little Patuxent River Watershed Characterization

2.1 Location

The Little Patuxent River watershed is located in the Patuxent River region of the Chesapeake Bay watershed within Maryland (see Figure 1). The Little Patuxent River originates just north of Route 70 near the Howard County Landfill. The River flows southeast through the heavily suburbanized area of Columbia crossing under Route 29 just south of Lake Kittamaqundi. The Little Patuxent River continues southeast crossing under Route 32 where the Middle Patuxent River joins the Little Patuxent River in the town of Savage. The Little Patuxent River, now larger due to the influx of the Middle Patuxent River, continues flowing southeast crossing under Route 295 and flowing through the southwest corner of the Fort Meade Military Reservation and the northeast section of the Patuxent Research Refuge. The Little Patuxent River joins the Patuxent River just southeast of the Patuxent Research Refuge between the towns of Bowie and Crofton just before Routes 3 and 450. The drainage area of the Little Patuxent River watershed is approximately 66,000 acres. The watershed area is located in two of three distinct eco-regions, the Eastern Piedmont and Coastal Plains, identified in the MBSS Index of Biotic Integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

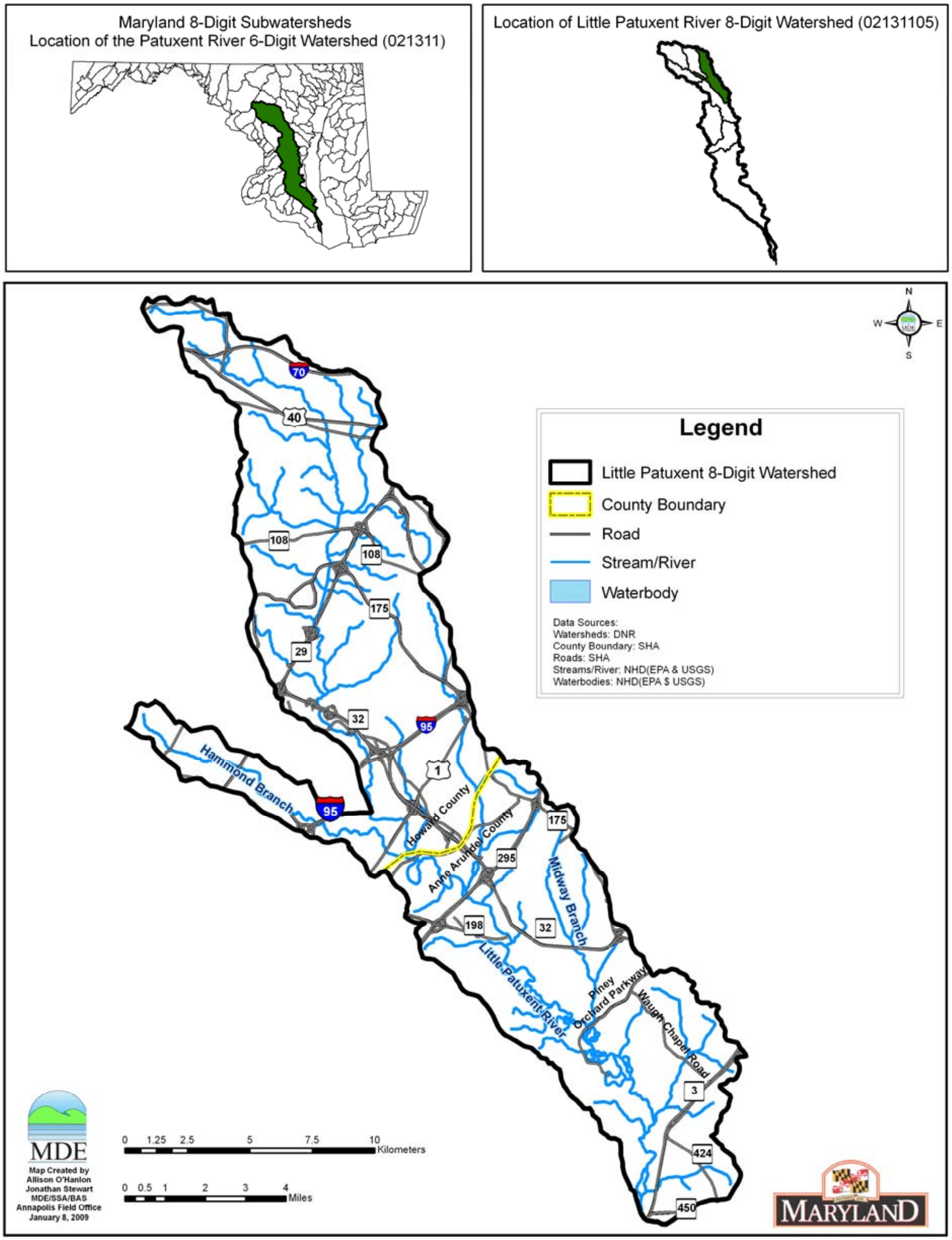

Figure 1. Location Map of the Little Patuxent River Watershed

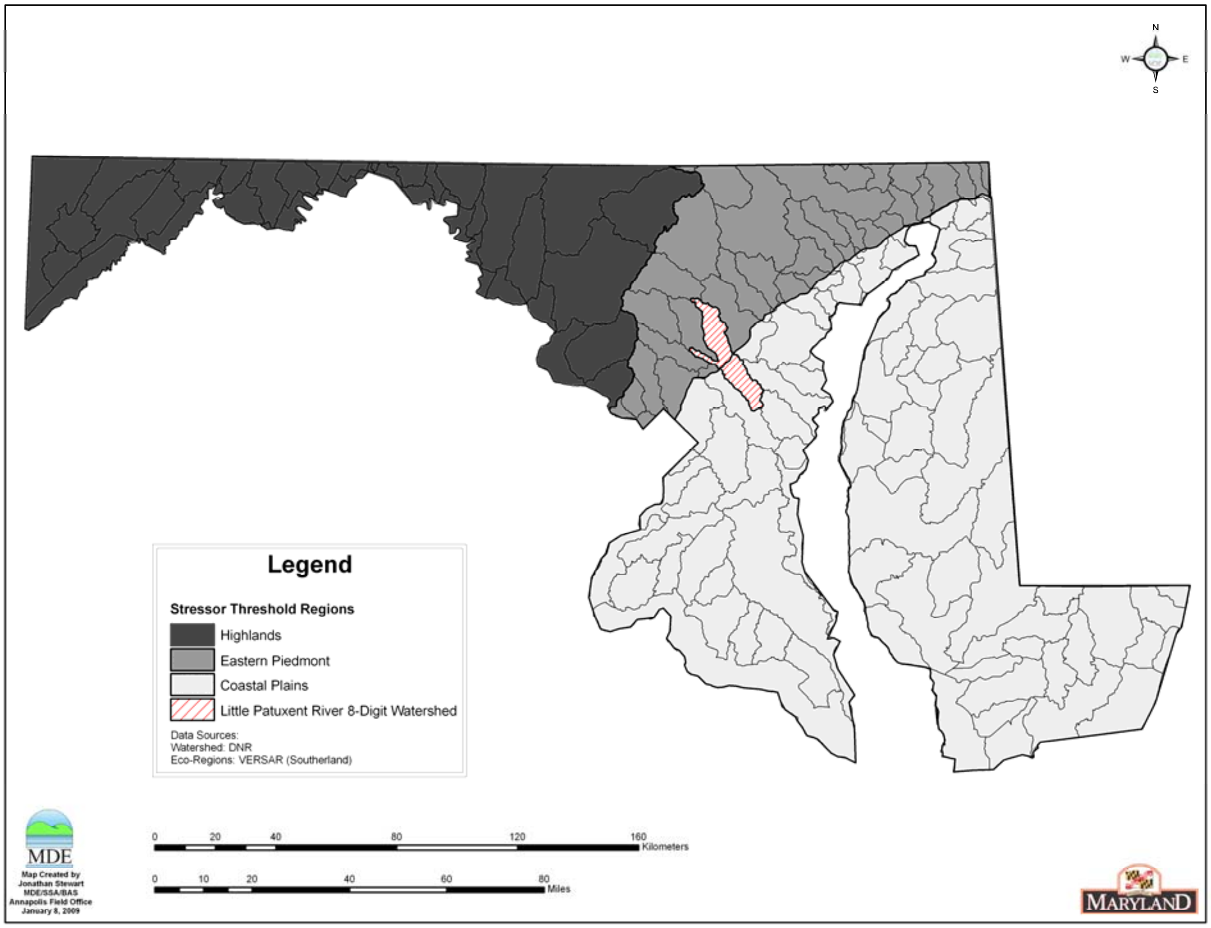

Figure 2. Eco-Region Location Map of Little Patuxent River Watershed

2.2 Land Use

The Little Patuxent River watershed contains mostly urban and forest land use (see Figure 3). The land use distribution in the watershed is approximately composed of forested lands encompassing 23,700 acres (36%). Urban land use comprises 35,000 acres (53%) of the watershed mixed between low density, medium density, high-density residential housing, commercial/industrial, institutional, and open urban land. The watershed contains 7,200 acres (11%) of agricultural used land distributed between cropland, pasture, orchard/horticulture, garden crops, and feed operations. The remaining acreage of 249 is water and wetlands. (Figure 4, MDP 2002).

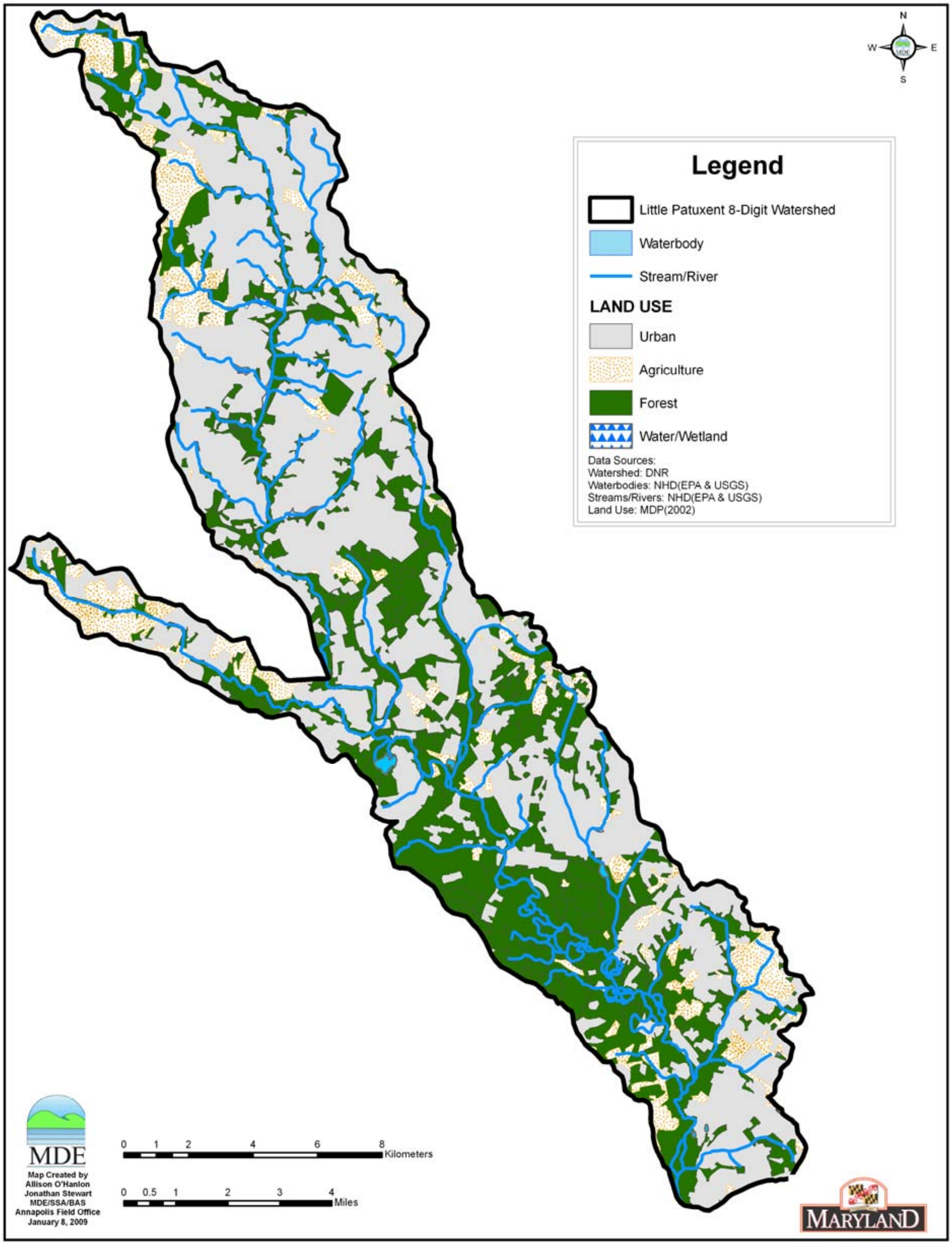

Figure 3. Land Use Map of the Little Patuxent River Watershed

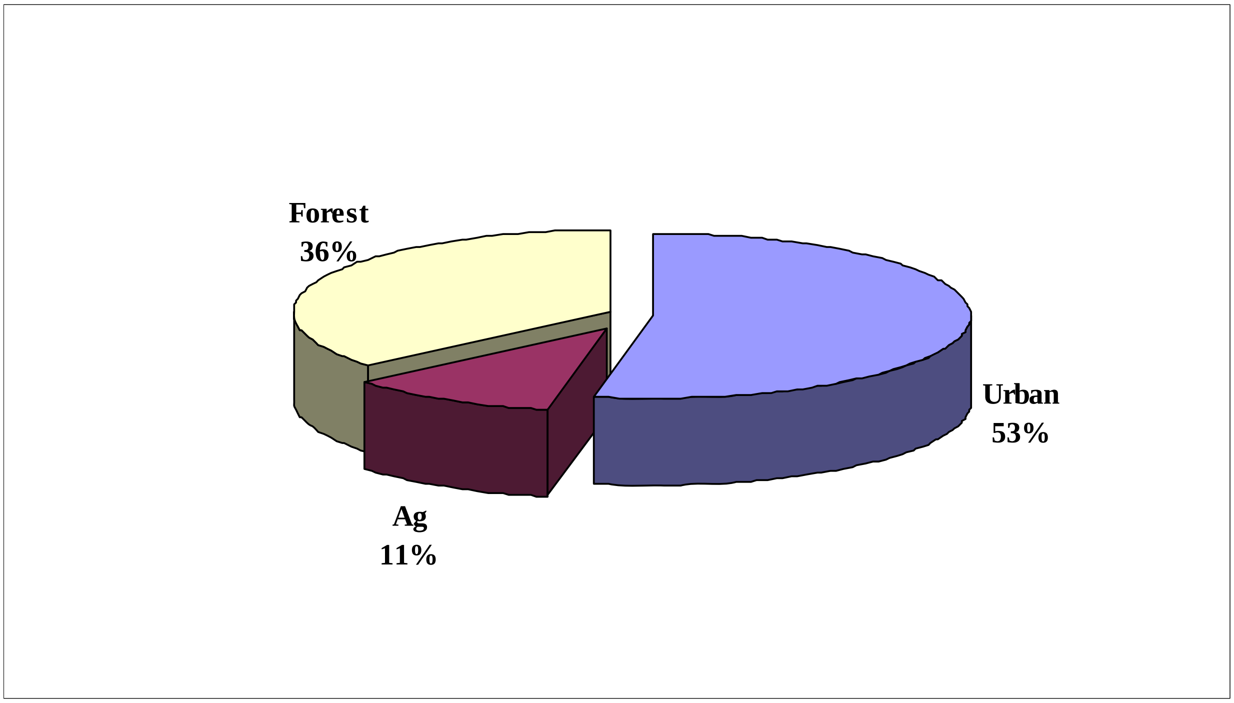

Figure 4. Proportions of Land Use in the Little Patuxent River Watershed

2.3 Soils/hydrology

The Little Patuxent River watershed is situated within the Northern Piedmont and Northern Coastal Plain Provinces in central Maryland. Sedimentary and igneous rocks that have been metamorphosed characterize the surficial geology of the Northern Piedmont Province. Most of the Northern Piedmont Province is located above the "fall line" on the east coast. Unconsolidated sand, silt, and clay sediments underlie the Northern Coastal Plain Province. The Coastal Plain Province sediments are a source of groundwater for nearby cities. The topography in the watershed is mostly characterized by rolling hills, gently sloping terrain, and broad valleys with small streams.

The Little Patuxent River watershed is comprised of several different soil series including the Chester, Beltsville, and Collington. The Chester series consists of very deep, well-drained soils on upland divides and upper slopes in the Northern Piedmont Province. Saturated hydraulic conductivity is moderately high to high. The Chester soils formed in materials weathered from micaceous schist. The Beltsville soil series consist of very deep, moderately well drained soils in the Northern Coastal Plain Province on uplands and coastal plain landscapes. Saturated Hydraulic Conductivity is high above the fragipan to moderately low or low in the fragipan. The

Collington series consist of very deep well drained soils in the Northern Coastal Plain Province on a coastal plain landscape. Saturated Hydraulic Conductivity is low to moderate (USDA SCS 1973, USDA SCS 2008).

3.0 Little Patuxent River Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Little Patuxent River (basin code 02131105) was identified in Maryland's Integrated Report as impaired by cadmium (Cd), sediments, nutrients (1996 listings), and impacts to biological communities (2002) (MDE 2008). Centennial Lake located within the watershed, was identified as impaired by phosphorus and sediments (1998 listings). With the exception of Centennial Lake, all impairments are listed for non-tidal streams. The 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. A 2008 WQA addressing the Cd impairment is pending USEPA approval and will remove the Little Patuxent watershed from Category 5 for Cd impairment to Category 2. All impairments are listed for non-tidal streams. Phosphorus and sediment TMDLs for Centennial Lake were completed in 2001.

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Little Patuxent River is Use I – P – *water contact recreation, protection of nontidal warmwater aquatic life and public water supply* (COMAR 2009 a,b). 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 shellfish propagation and harvest. 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 Little Patuxent River watershed is listed under Category 5 of the 2008 Integrated Report as impaired for evidence of biological impacts. Approximately 70% of stream miles in the Little Patuxent River watershed are estimated as having fish and and/or benthic indices of biological impairment in the very poor to poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include twenty-seven sites. Nineteen of the twenty-seven have benthic and/or fish index of biotic integrity (BIBI/FIBI) scores significantly lower than 3.0 (i.e., very poor to poor). The BSID analysis uses the principal data set, containing MBSS Round 2 data only, which includes thirteen sites in the Little Patuxent River watershed. Nine of the thirteen sites have BIBI/FIBI scores lower than 3.0. Figure 5 illustrates the location of principal dataset sites within the Little Patuxent River Watershed.

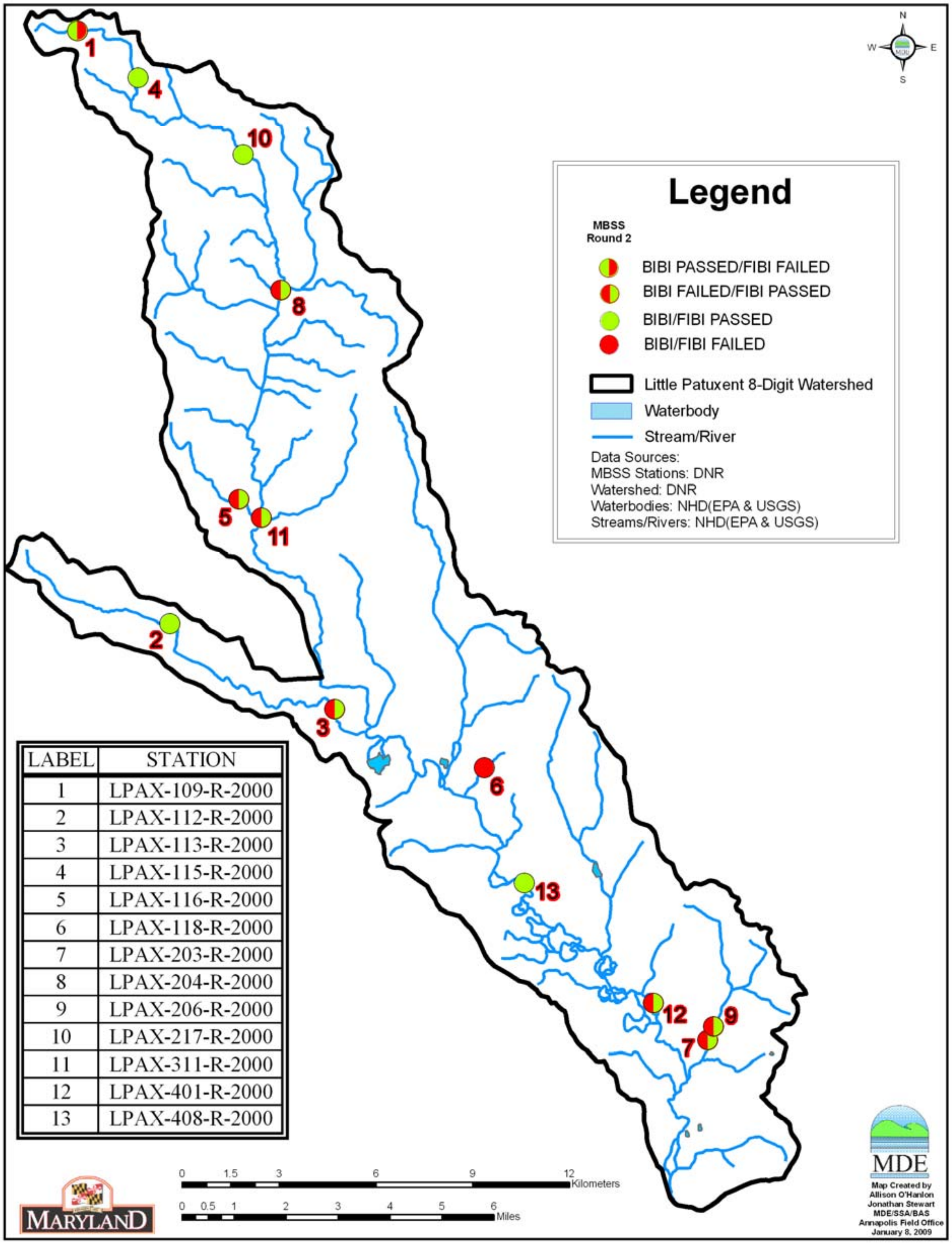

Figure 5: Little Patuxent Watershed Primary Dataset Site Locations

4.0 Stressor Identification Results

The BSID process uses results from the BSID analysis to evaluate each biologically impaired watershed and determine potential stressors and sources. Interpretation of the BSID 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 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 significantly lower than 3.0 (i.e., poor to very poor). The controls are sites with similar physiographic characteristics (Highland, Eastern Piedmont, and Coastal region), and stream order for habitat parameters (two groups – 1^{st} and 2^{nd}-4th order), that have 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 very poor to 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 very poor to 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 very poor to poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with very poor to 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 defined 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).

Through the BSID analysis, MDE identified habitat parameters, water chemistry parameters, and potential sources significantly associated with poor to very poor fish and/or benthic biological conditions. As shown in Table 1 through Table 3, parameters from the sediment, habitat, and water chemistry groups are identified as possible biological stressors in the Little Patuxent River. Parameters identified as representing possible sources are listed in Table 4 and include various urban land use types. Table 5 and Table 6 show the summary of combined attributable risk (AR) values for the Little Patuxent River watershed.

Table 1. Sediment Biological Stressor Identification Analysis Results for the Little Patuxent River

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Sediment	extensive bar formation present	13	9	82	89%	14%	Yes	75%
	moderate bar formation present	13	9	82	89%	44%	Yes	44%
	bar formation present	13	9	82	100%	85%	No	----
	channel alteration marginal to poor	13	9	81	89%	46%	Yes	42%
	channel alteration poor	13	9	81	89%	12%	Yes	76%
	high embeddedness	13	9	82	11%	6%	No	----
	epifaunal substrate marginal to poor	13	9	82	44%	16%	Yes	28%
	epifaunal substrate poor	13	9	82	11%	2%	No	----
	moderate to severe erosion present	13	9	82	89%	56%	Yes	33%
	severe erosion present	13	9	82	33%	11%	Yes	23%
	poor bank stability index	13	9	82	11%	10%	No	----
	silt clay present	13	9	82	100%	100%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for the Little Patuxent River

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
In-Stream Habitat	channelization present	13	9	83	11%	12%	No	----
	instream habitat structure marginal to poor	13	9	82	33%	14%	No	----
	instream habitat structure poor	13	9	82	11%	1%	No	----
	pool/glide/eddy quality marginal to poor	13	9	82	22%	37%	No	----
	pool/glide/eddy quality poor	13	9	82	0%	1%	No	----
	riffle/run quality marginal to poor	13	9	82	11%	22%	No	----
	riffle/run quality poor	13	9	82	0%	7%	No	----
	velocity/depth diversity marginal to poor	13	9	82	22%	44%	No	----
	velocity/depth diversity poor	13	9	82	0%	1%	No	----
	concrete/gabion present	13	9	84	0%	2%	No	----
	beaver pond present	13	9	81	0%	5%	No	----
Riparian Habitat	no riparian buffer	13	9	83	33%	19%	No	----
	low shading	13	9	82	0%	8%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for the Little Patuxent River

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Water Chemistry	high total nitrogen	13	9	179	22%	38%	No	----
	high total disolved nitrogen	13	9	52	22%	39%	No	----
	ammonia acute with salmonid present	13	9	179	0%	18%	No	----
	ammonia acute with salmonid absent	13	9	179	0%	12%	No	----
	ammonia chronic with salmonid present	13	9	179	0%	35%	No	----
	ammonia chronic with salmonid absent	13	9	179	0%	25%	No	----
	low lab pH	13	9	179	0%	16%	No	----
	high lab pH	13	9	179	11%	1%	No	----
	low field pH	13	9	178	0%	18%	No	----
	high field pH	13	9	178	0%	1%	No	----
	high total phosphorus	13	9	179	11%	5%	No	----
	high orthophosphate	13	9	179	11%	10%	No	----
	dissolved oxygen < 5mg/l	13	9	178	0%	6%	No	----
	dissolved oxygen < 6mg/l	13	9	178	0%	10%	No	----
	low dissolved oxygen saturation	12	9	163	0%	7%	No	----
	high dissolved oxygen saturation	12	9	163	0%	0%	No	----
	acid neutralizing capacity below chronic level	13	9	179	0%	4%	No	----
	acid neutralizing capacity below episodic level	13	9	179	0%	23%	No	----
	high chlorides	13	9	179	44%	6%	Yes	39%
	high conductivity	13	9	179	67%	6%	Yes	61%
	high sulfates	13	9	179	0%	4%	No	----

Table 4. Stressor Source Identification Analysis Results for the Little Patuxent River

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Urban	high impervious surface in watershed	13	9	181	33%	4%	Yes	30%
	high % of high intensity urban in watershed	13	9	181	89%	16%	Yes	72%
	high % of low intensity urban in watershed	13	9	181	22%	5%	Yes	17%
	high % of transportation in watershed	13	9	181	11%	8%	No	----
	high % of high intensity urban in 60m buffer	13	9	180	44%	5%	Yes	39%
	high % of low intensity urban in 60m buffer	13	9	180	44%	6%	Yes	39%
	high % of transportation in 60m buffer	13	9	180	33%	7%	Yes	26%
Sources Agriculture	high % of agriculture in watershed	13	9	181	0%	21%	No	----
	high % of cropland in watershed	13	9	181	0%	13%	No	----
	high % of pasture/hay in watershed	13	9	181	11%	20%	No	----
	high % of agriculture in 60m buffer	13	9	180	11%	11%	No	----
	high % of cropland in 60m buffer	13	9	180	0%	9%	No	----
	high % of pasture/hay in 60m buffer	13	9	180	33%	17%	No	----
Sources Barren	high % of barren land in watershed	13	9	181	33%	15%	No	----
	high % of barren land in 60m buffer	13	9	180	11%	8%	No	----

Table 4. Stressor Source Identification Analysis Results for the Little Patuxent River (Cont.)

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Anthropogenic	low % of forest in watershed	13	9	181	33%	7%	Yes	26%
	low % of forest in 60m buffer	13	9	180	56%	7%	Yes	48%
Sources Acidity	atmospheric deposition present	13	9	179	0%	18%	No	----
	AMD acid source present	13	9	179	0%	0%	No	----
	organic acid source present	13	9	179	0%	2%	No	----
	agricultural acid source present	13	9	179	0%	4%	No	----

Table 5. Summary of Combined AR Values for Stressor Groups for the Little Patuxent River Watershed

Parameter Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (AR)	
Sediment	84%	87%
In-Stream Habitat	----	
Riparian Habitat	----	
Water Chemistry	61%	

Table 6. Summary of Combined AR Values for Source Groups for the Little Patuxent River Watershed

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (AR)	
Urban	82%	83%
Agriculture		
Barren Land		
Lack of Forest	49%	
Acidity		

<u>Sediment and Habitat Conditions</u>

BSID analysis results for the Little Patuxent River identified seven sediment parameters that have a statistically significant association with poor to very poor stream biological condition: *channel alteration moderate to poor, channel alteration poor, extensive bar formation present, moderate bar formation present, moderate to severe erosion present, severe erosion present and epifauanl substrate marginal to poor.*

Channel alteration was identified as significantly associated with degraded biological conditions in the Little Patuxent River, and found to impact approximately 42% (*marginal to poor* rating) and 76% (*poor* rating) of the stream miles with poor to very poor biological conditions. *Channel alteration* measures large-scale modifications in the shape of the stream channel due to the presence of artificial structures (channelization) and/or bar formations. Marginal to poor and poor ratings are expected in unstable stream channels that experience frequent high flows.

Bar formation was identified as significantly associated with degraded biological conditions and found in 44% (*moderate* rating) and 75% (*extensive* rating) of the stream miles with very poor to poor biological conditions in the Little Patuxent River. This stressor measures the movement of sediment in a stream system, and typically results from significant deposition of gravel and fine sediments and its presence is a metric for the channel alteration rating. Although some bar formation is natural, extensive bar formation indicates channel instability related to frequent and intense high flows that quickly dissipate and rapidly lose the capacity to transport the sediment loads downstream. Excessive sediment loading is expected to reduce and homogenize available feeding and reproductive habitat, degrading biological conditions.

Erosion Severity was identified as significantly associated with degraded biological conditions and found in 33% (*moderate to severe* rating*)* and 23% (severe rating) of the stream miles with very poor to poor biological conditions in the Little Patuxent River. This stressor 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 degrade biological conditions.

Epifaunal Substrate was identified as significantly associated with degraded biological conditions and found in 28% (*marginal to poor* rating) of the stream miles with very poor to poor biological conditions in the Little Patuxent River. This stressor 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. High flow conditions, typically occurring in urban areas, can possibly scour the stream bottom decreasing available substrate availability. Less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates.

Fifty-three percent of the Little Patuxent River watershed is comprised of urban land uses. As development and urbanization increase in the Little Patuxent River watershed so did the morphological changes that affect a stream's habitat. The most critical of these environmental changes are those that alter the watershed's hydrologic regime. Increases in impervious surface cover that accompanies urbanization alters stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, thus decreasing the amount of time it takes water to reach streams causing urban streams to be more "flashy" (Walsh et al. 2005). When stormwater flows through stream channels faster, more often, and with more force, the results are stream channel widening, erosion, and streambed scouring. The scouring associated with these increased flows leads to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed either through the formation of bars or settling of sediment in the stream substrate.

Some of the impacts associated with erosion and sedimentation smothering the benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from embedding of stream bottom (Hoffman et al. 2003). All of these processes result in an unstable stream ecosystem that impacts habitat and the dynamics (structure and abundance) of stream benthic organisms (Allan 2004). An unstable stream ecosystem often results in a continuous displacement of biological communities from scouring that require frequent re-colonization and the loss of sensitive taxa, with a shift in biological communities to more tolerant species.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, very poor to poor biological conditions. The combined AR for the sediment stressor group is approximately 84% suggesting that these stressors impact the majority of degraded stream miles in the Little Patuxent River (See Table 5).

In-stream Habitat Conditions

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

Riparian Habitat Conditions

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

Water Chemistry Conditions

BSID analysis results for the Little Patuxent River identified two water chemistry parameters that have statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in an improved biological community). These parameters are *high conductivity and high chlorides.*

High conductivity levels was identified as significantly associated with degraded biological conditions in the Little Patuxent River, and found to impact approximately 61% of the stream miles with poor to very poor biological conditions. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Elevated conductivity can result from inorganic compounds found in point and non-point sources such as, wastewater, fertilizers, urban runoff, and road salts. Conductivity and chlorides are closely related. Streams with elevated levels of chlorides typically display high conductivity.

High chloride levels was identified as significantly associated with degraded biological conditions in the Little Patuxent River, and found to impact approximately 39% of the stream miles with very poor to poor biological conditions. High concentrations of chlorides can result from industrial discharges, metals contamination, and application of road salts in urban landscapes. There are no major National Pollutant Discharge Elimination System (NPDES) permitted municipal or industrial discharges in the watershed; however, there are eight minor and one major industrial facility, Maryland/Virginia Milk Producers, which is regulated for various parameters. None of the facilities are regulated for metals discharge. MD/VA Milk Producers, which is located upstream from the failing MBSS site #2 (see Figure 5), is in permit compliance. Since there is no significant metals impairment, as indicated by the 2008 Cd WQA (pending USEPA approval), application of road salts in the watershed is a likely source of the chlorides and high conductivity levels. Although chloride can originate from natural sources, most of the chloride that enters the environment is associated with the storage and application of road salt. A significant portion of the mainstem of the Little Patuxent River parallels Route 29 and 32, which are primary transportation routes in Howard and Anne Arundel counties. Road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality. Approximately 55% of road-salt chlorides are transported in surface runoff, with the remaining 45% infiltrating through soils and into groundwater aquifers (Church and Friesz, 1993).

In summary, water chemistry is another major determinant of the integrity of surface waters that is strongly influenced by land-use. Land development causes an increase in contaminant loads from point and nonpoint sources by adding sediments, nutrients, road salts, toxics, petroleum products, and inorganic pollutants to surface waters. Increased levels of many pollutants like chlorides can be toxic to aquatic organisms and lead to exceedences in species tolerances.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, very poor to poor biological conditions. The combined AR for the water chemistry stressor group is approximately 61% suggesting that these stressors impact a number of the degraded stream miles in the Little Patuxent River (See Table 5).

Currently in Maryland there are no specific numeric criteria that quantify the impact of conductivity and chlorides on the aquatic health of non-tidal stream systems. Since the exact sources and extent of inorganic pollutant loadings are not known, MDE determined that current data are not sufficient to enable identification of the specific pollutant(s) from the array of potential inorganic pollutants inferred from the BSID analysis.

Sources

All nine stressor parameters, identified in Tables 1-3, that are significantly associated with biological degradation in the Little Patuxent River watershed BSID analysis are representative of impacts from urban landscapes. The scientific community (Booth 1991, Konrad and Booth 2002, and Meyer et al. 2005) has consistently identified negative impacts to biological conditions as a result of increased urbanization. A number of systematic and predictable environmental responses have been noted in streams affected by urbanization, and this consistent sequence of effects has been termed “urban stream syndrome” (Meyer et al. 2005). Symptoms of urban stream syndrome include flashier hydrographs, altered habitat conditions, degradation of water quality, and reduced biotic richness, with increased dominance of species tolerant to anthropogenic (and natural) stressors.

Increases in impervious surface cover that accompany urbanization alter stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, decreasing the time it takes water to reach streams and causing them to be more “flashy” (Walsh et al. 2005). Land development can also cause an increase in contaminant loads from point and nonpoint sources. In virtually all studies, as the amount of impervious area in a watershed increases, fish and benthic communities exhibit a shift away from sensitive species to assemblages consisting of mostly disturbance-tolerant taxa (Walsh et al. 2005).

The BSID source analysis (Table 4) identifies various types of urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 83% suggesting that urban development potentially impact a significant percentage of degraded stream miles in the Little Patuxent River (See Table 6).

Summary

According to the Maryland Department of Planning data, about fifty-three percent of the Little Patuxent watershed was urban land use in 2002. This development, much of which occurred prior to the adoption of stormwater management and environmental protection regulations, has eliminated and degraded habitat for both land and aquatic species, as wetlands were filled, forests were cleared, and streams received polluted runoff at an increased volume and frequency (HCDPW 2002). The BSID analysis results suggest that degraded biological communities in the Little Patuxent River watershed are a result of increased urban land use causing alterations to the hydrologic regime. The altered hydrology has caused frequent high flow events and increased sediment loads, resulting in an unstable stream ecosystem that eliminates optimal habitat. Due to the increased proportions of urban land use in the Little Patuxent River, the watershed has experienced an increase in contaminant loads from point and nonpoint sources, resulting in levels of inorganic pollutants that can potentially be extremely toxic to aquatic organisms. Alterations to the hydrologic regime, sediment loads, and water chemistry, have all combined to degrade the

Little Patuxent River, leading to a loss of diversity in the biological community. The combined AR for all the stressors is approximately 87%, suggesting that sediment and water chemistry stressors identified in the BSID analysis would adequately account for the biological impairment in the Little Patuxent River watershed (Table 5).

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 scenarios (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.

Final Causal Model for the Little Patuxent River

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr, 1991 and USEPA 2007). 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 Little Patuxent River, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

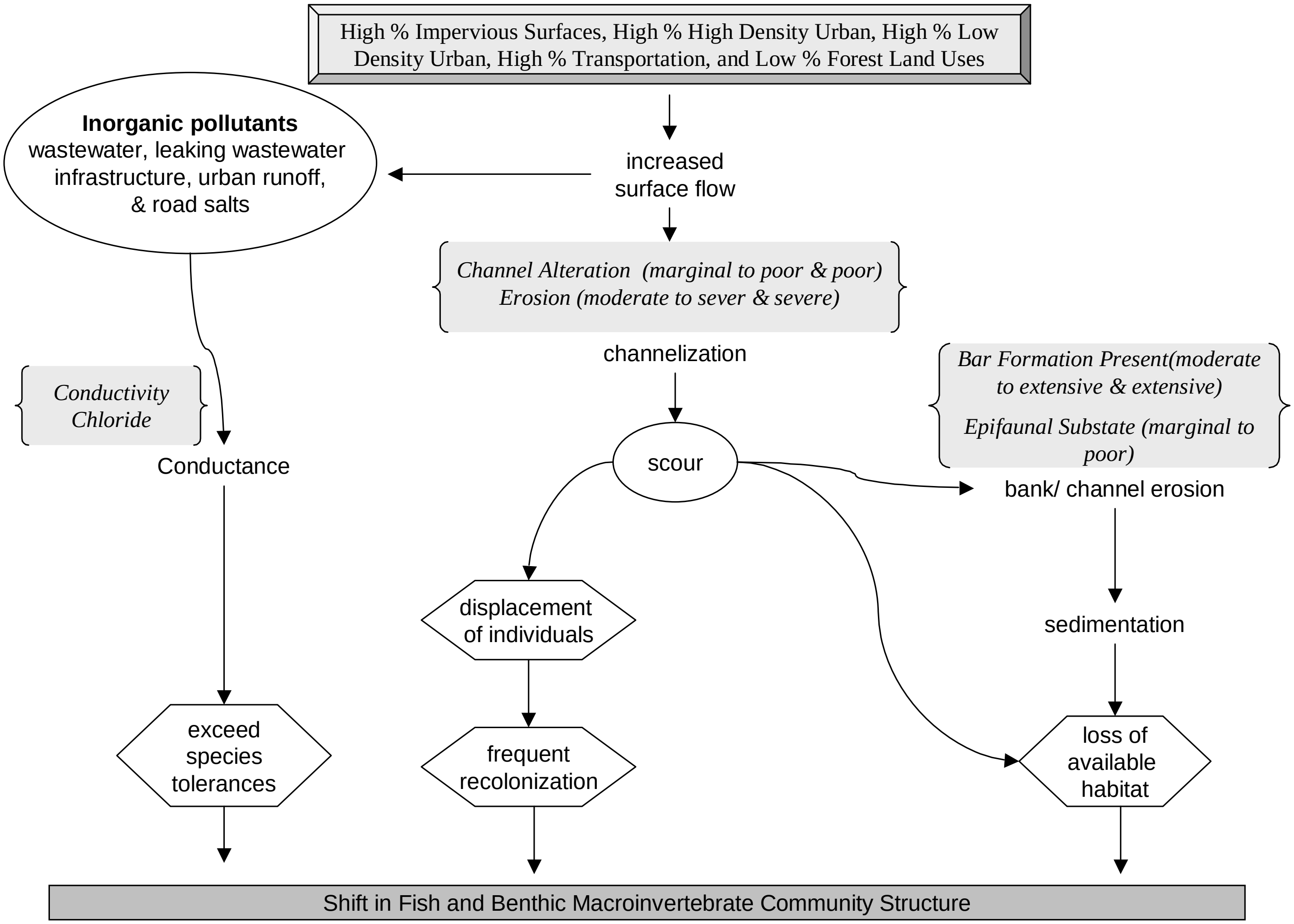

Figure 6. Final Causal Model for the Little Patuxent River Watershed

Conclusions

Data suggest that the Little Patuxent River watershed's biological communities are strongly influenced by urban land use, which alters the hydrologic regime resulting in increased erosion, sediment, and inorganic pollutant loading. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to urban landscapes, which often cause flashy hydrology in streams and increased contaminant loads from runoff. Based upon the results of the BSID analysis, the probable causes and sources of the biological impairments of the Little Patuxent River watershed are summarized as follows:

- The BSID analysis has determined that the biological communities are likely degraded due to flow/sediment related stressors. Specifically, altered hydrology and increased runoff from urban impervious surfaces have resulted in channel erosion and subsequent elevated suspended sediment transport through the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results confirm the establishment of a USEPA approved sediment TMDL in 2011 was an appropriate management action to begin addressing the impact of these stressors on the biological communities in Little Patuxent River.

- The BSID analysis has determined that the biological communities are likely degraded due to inorganic pollutants (i.e., chlorides). Inorganic pollutants levels are significantly associated with degraded biological conditions and found in approximately 39% of the stream miles with very poor to poor biological conditions in the Little Patuxent River watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds 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 these parameters will help in determining the spatial and temporal extent of these impairments in the watershed. The BSID results thus support Category 5 listings of chloride as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Little Patuxent River watershed.

- Although there is presently a Category 5 listing for phosphorus in Maryland's 2010 Integrated Report, the BSID analysis did not identify any nutrient stressors (i.e., total nitrogen, total phosphorus, dissolved oxygen, etc.) present and/or nutrient stressors showing a significant association with degraded biological conditions.

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