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

FINAL

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List of Abbreviations

ANC	Acid Neutralizing Capacity
AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MH	Mantel-Haenzel
mg/L	Milligrams per liter
µS/cm	Micro Siemens per centimeter
NH_3	Ammonia
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service, U.S. Department of Agriculture
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
USDA	United States Department of Agriculture
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 Upper watershed (basin code 02131104), located in Anne Arundel, Prince George's, Montgomery, and Howard Counties, was identified on the States list of WQLSs and listed in the Integrated Report under Category 5 as impaired by nutrients, sediments (1996), fecal coliform (2002 & 2008) and impacts to biological communities (2006). The impoundment of Cash Lake located with in the watershed was listed in 2004 under Category 5 for methylmercury in fish tissue. The 2002 fecal coliform listing was moved to Category 2 in 2004 and the listing was moved to Category 5 in 2008, but only a portion of the basin was identified: Patuxent River mainstem from the Old Queen Anne Bridge Road to the confluence with the Little Pauxent River. The Patuxent River Upper watershed was de-listed for nutrients in 2007 following USEPA concurrence with Maryland Department of the Environment's (MDE) WQA of nutrient data collected during 1998-2004, which showed no nutrient impairment.

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

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Patuxent River Upper watershed is Use I Designation - *water contact recreation, and protection of nontidal warmwater aquatic life* (COMAR 2010 a, b). The Patuxent River Upper watershed is not attaining its Use I designation 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 have on the degraded sites in the watershed.

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

This Patuxent River Upper 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 Upper watershed are strongly influenced by urban land use and its concomitant effects: altered hydrology and increased pollutant loading from urban runoff resulting in elevated levels of sediment, ammonia, chlorides, and sulfates. 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 Patuxent River Upper watershed can be summarized as follows:

- The BSID analysis has determined that biological communities in the Patuxent River Upper watershed are likely degraded due to flow/sediment related stressors. Specifically, altered hydrology and increased urban runoff have resulted in degradation to streambed morphology, streambed scouring and subsequent elevated suspended sediment transport through the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus support the 1996 Category 5 listing for total suspended solids as an impairing substance in the Patuxent River Upper watershed, and links this pollutant to biological conditions in these waters.

- The BSID analysis has determined that biological communities in the Patuxent River Upper watershed are also likely degraded due to water chemistry related stressors. Specifically, acute ammonia, chloride, and sulfate toxicity are a probable cause of impacts to biological communities. Impacts on water quality due to elevated concentrations of these stressors are dependent on prolonged exposure; future monitoring of these stressors will help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID analysis did not identify any nutrient stressors present and/or nutrient stressors showing a significant association with degraded biological conditions; therefore, the 2007 WQA for nitrogen and phosphorus was an appropriate management action.

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 Maryland Biological Stream Survey (MDDNR 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 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 Upper watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Patuxent River Upper Watershed Characterization

2.1 Location

The Patuxent River Upper watershed is located within the Patuxent River basin and drains into the Patuxent River Middle watershed (see Figure 1). The drainage area of Patuxent River Upper watershed is approximately 56,300 acres (88 square miles). Most of the watershed lies in Anne Arundel and Prince George's Counties with a small portion (3 %) of the watershed extending into Howard and Montgomery Counties**.** The watershed is located in northeastern Prince George's County and western Anne Arundel County, with the Patuxent River mainstem serving as the geographic boundary between the two counties. Ninety-five percent of the land area is located within the Coastal Plain eco-region with the remainder located within the Piedmont 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).

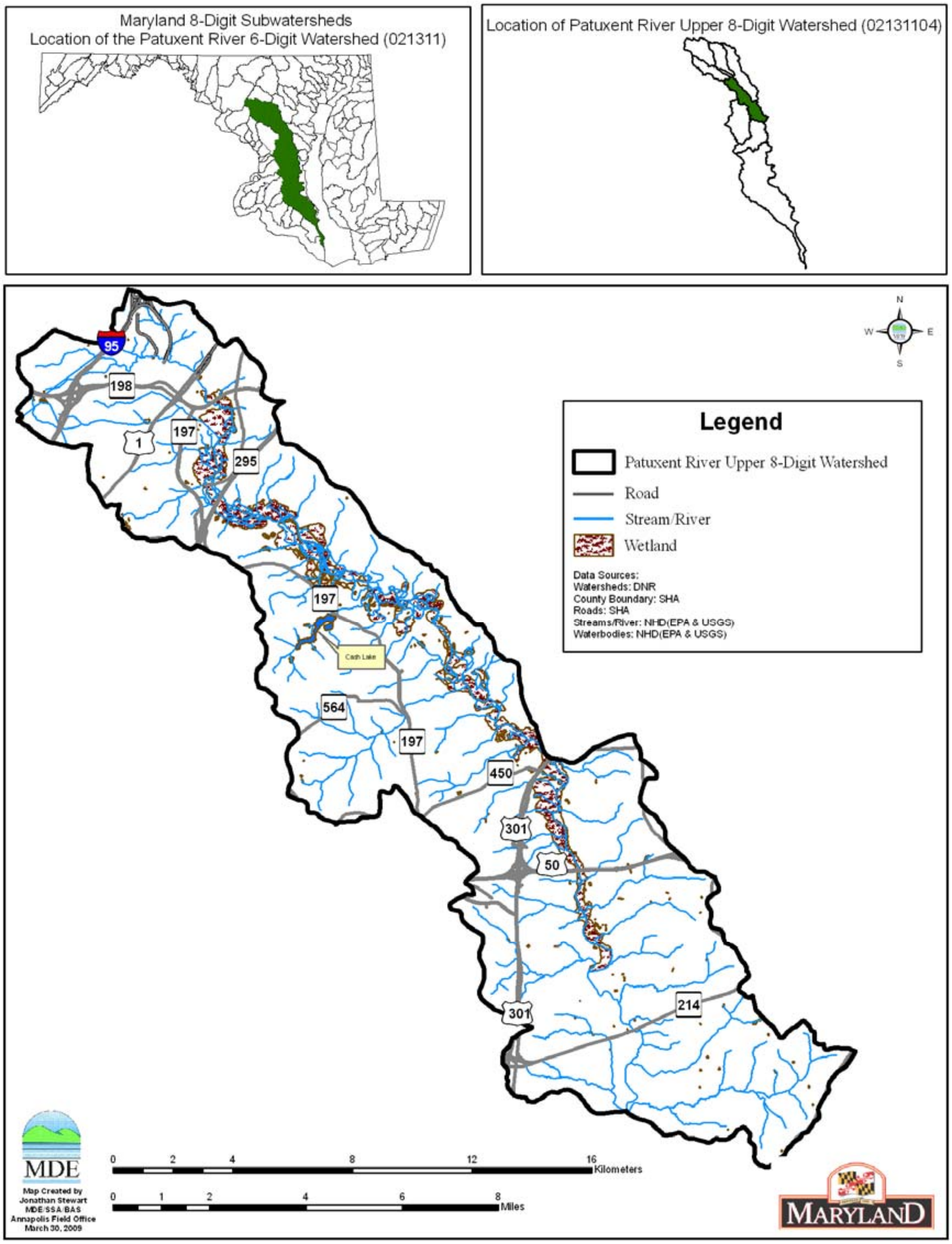

Figure 1. Location Map of the Patuxent River Upper Watershed

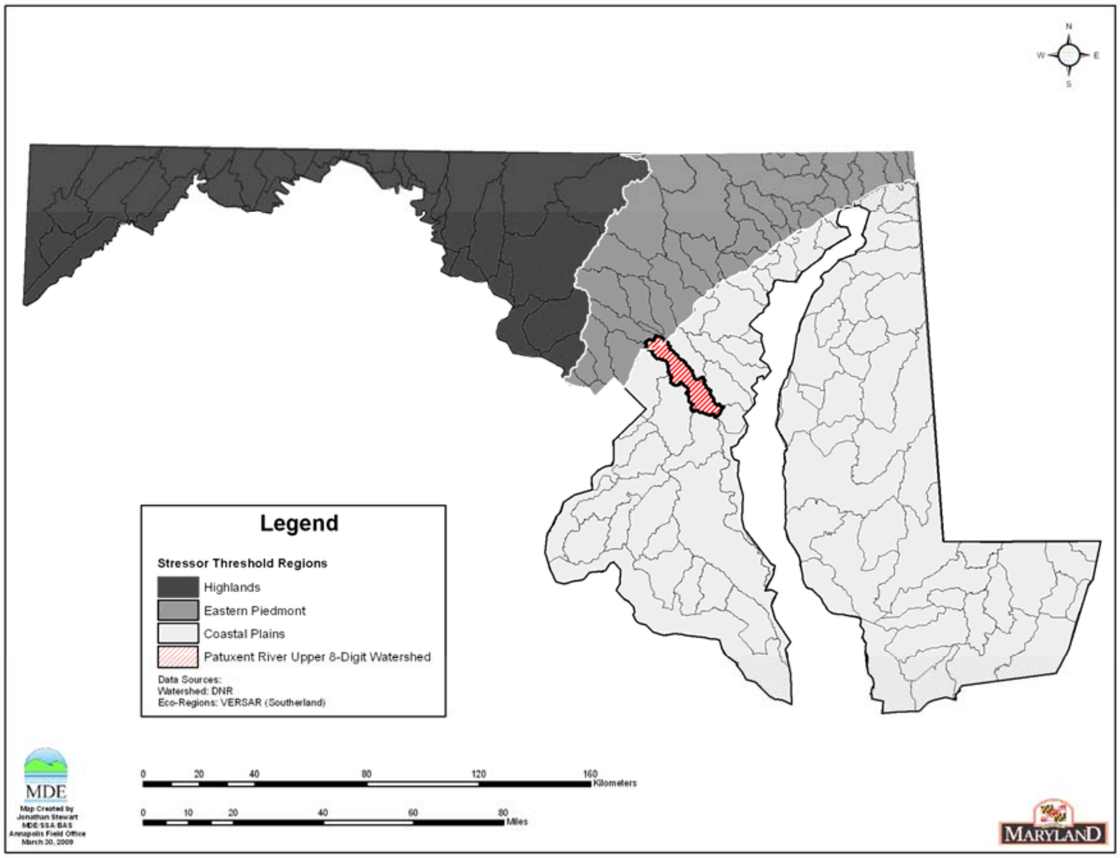

Figure 2. Eco-Region Location Map of the Patuxent River Upper Watershed

2.2 Land Use

The land use in the Patuxent River Upper watershed is predominately forest and developed urban land (see Figure 3). Much of the forest land in the watershed has been classified as Green Infrastructure or, in Anne Arundel County, as part of the county adopted Greenways Master Plan. A large forest block, found in the upper-mid portion of the watershed, is part of the federally owned Patuxent Research Refuge (MDDNR 2002). The 2000 land use data developed by the Maryland Department of Planning indicates 274 acres of wetlands in the watershed (MDP 2000). However, nontidal wetland areas are often depicted as forest in land use designations. This difference is simply the result of two differing views of the landscape depictions. For example, wooded nontidal wetlands can be viewed as “wetlands” from a habitat /regulatory perspective and they can be viewed as “forest” from a land use perspective. From a land use perspective, 274 acres of wetlands are identified by the Maryland Department of Planning. From a habitat / regulatory perspective, there are approximately 4,605 acres of wetlands in the watershed (MDDNR 2002). The acreages for various wetland types in the Patuxent River Upper watershed show that palustrine forested wetlands are the most common and are found predominantly along the floodplain of the Patuxent River (DNR 2002).

Developed land occurs most predominantly in Prince George’s County, with urbanized regions concentrated around the cities of Bowie, Laurel and Maryland City. The main transportation corridors in the watershed are Interstate 95, Route 198 and 1 across the northern section, and Routes 301, 50, and 214 across the southern section of the watershed. According to the Chesapeake Bay Program’s Phase 5.2 Model (2010)the land use distribution in the watershed is approximately 48% forest/herbaceous, 30% urban pervious, 10% urban impervious surfaces, and 12% agricultural (see Figure 4).

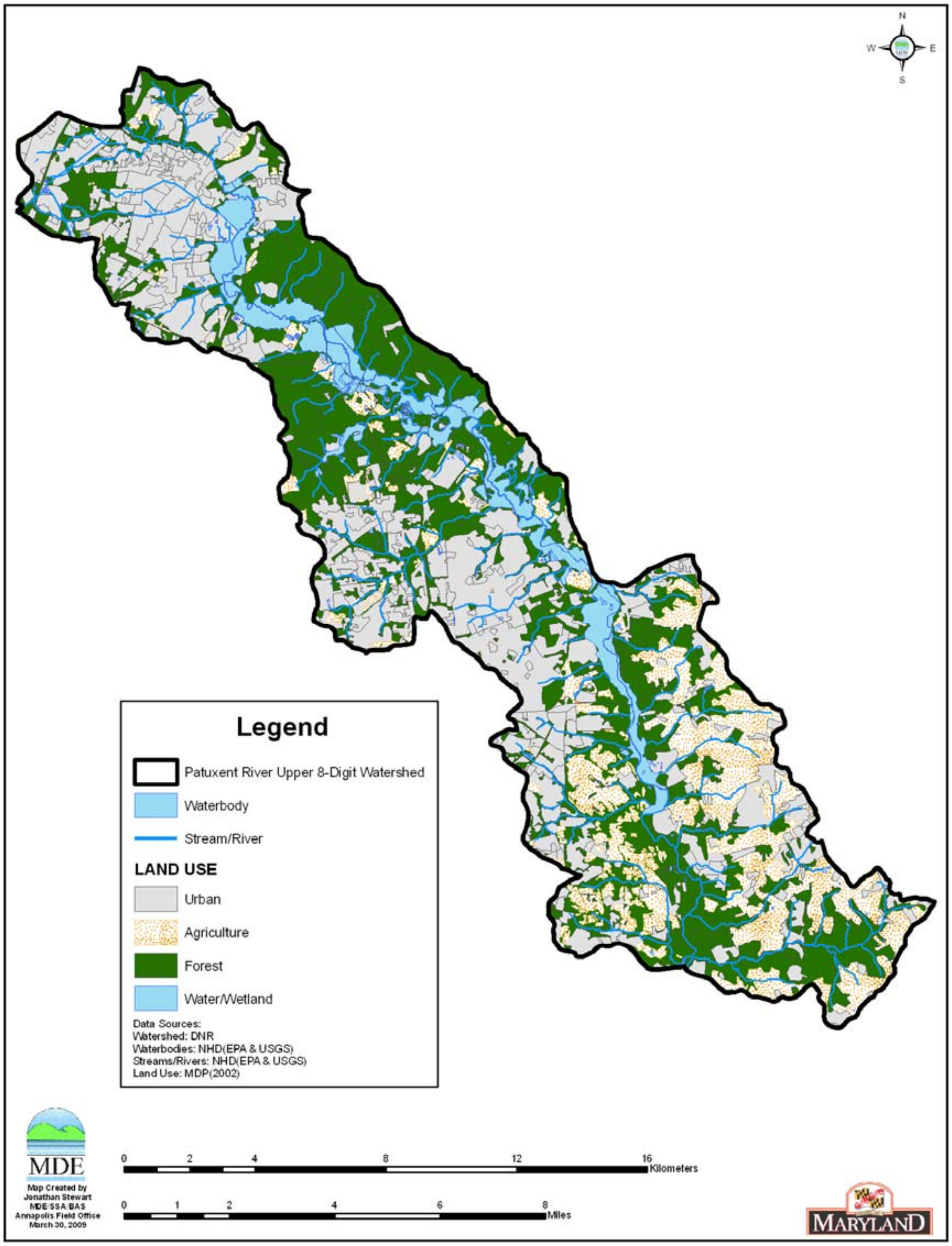

Figure 3. Land Use Map of the Patuxent River Upper Watershed

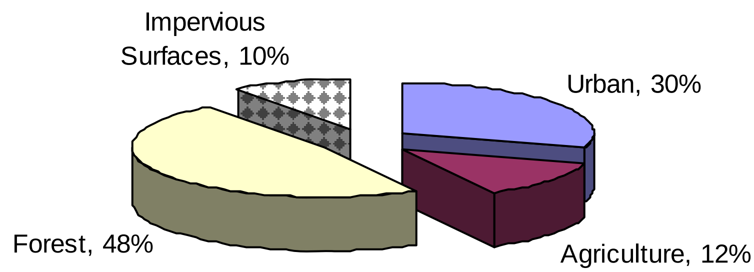

Figure 4. Proportions of Land Use in the Patuxent River Upper Watershed

2.3 Soils/hydrology

The Patuxent River Upper watershed lies almost entirely within the Coastal Plains Physiographic Province of Maryland with the northern tip extending slightly into the Piedmont Plateau Physiographic Province. Broad upland areas with low slopes and gentle drainage characterize the Coastal Plains Province. The Piedmont Plateau Physiographic Province is characterized by gentle to steep rolling topography, low hills and ridges. The Patuxent River Upper watershed drains from northwest to southeast, where it transforms from the headwaters in the Eastern Piedmont Province into the Coastal Plains. The sediments of the Coastal Plain dip eastward at a low angle, generally less than one degree, and range in age from Triassic to Quaternary. Mineral resources of the Coastal Plain are chiefly sand and gravel, and are used as aggregate materials by the construction industry. The Piedmont Plateau Province is composed of hard, crystalline igneous and metamorphic rocks and extends from the inner edge of the Coastal Plain westward to Catoctin Mountain, the eastern boundary of the Blue Ridge Province. Bedrock in the eastern part of the Piedmont consists of schist, gneiss, gabbro, and other highly metamorphosed sedimentary and igneous rocks of probable volcanic origin. The Piedmont Plateau Province contains a variety of mineral resources. Formerly, building stone, slate, and small deposits of nonmetallic minerals, base-metal sulfides, gold, chromite, and iron ore were mined. Currently, crushed stone is an important for aggregate, cement, and lime (Edwards 1981).

Soils typically found in the Patuxent River Upper watershed are the Baile, Chester, and Beltsville series. The Baile series consists of very deep, poorly drained, moderately low to moderately high saturated hydraulic conductivity, soils on upland depressions and footslopes. The Chester series consists of very deep well drained soils on uplands. Saturated hydraulic conductivity is moderately high to high. They formed in materials weathered from micaceous schist. The Beltsville series consist of very deep, moderately well drained soils on uplands. Saturated hydraulic conductivity is moderately low or low in the fragipan (NRCS 1977).

3.0 Patuxent River Upper Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Patuxent River Upper watershed (basin code 02131104), located in Anne Arundel, Prince George's, Montgomery, and Howard Counties, was identified on the States list of WQLSs and listed in the Integrated Report under Category 5 as impaired by nutrients, sediments (1996 listings), fecal coliform (2002 & 2008) and impacts to biological communities (2006 listing). The impoundment of Cash Lake located within the watershed was listed in 2004 under Category 5 for methylmercury in fish tissue. The 2002 fecal coliform listing was moved to Category 2 in 2004 and the basin was moved to Category 5 in 2008, but only a portion of the basin was identified: Patuxent River main-stem from the Old Queen Anne Bridge Road to the confluence with the Little Patuxent River. The Patuxent River Upper watershed was de-listed for nutrients in 2007 following USEPA concurrence with Maryland Department of the Environment's (MDE) WQA of nutrient data collected during 1998-2004, which showed no nutrient impairment.

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Patuxent River Upper watershed is Use I designation - *water contact recreation, and protection of nontidal warmwater aquatic life* (COMAR 2010 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 Patuxent River Upper watershed is listed under Category 5 of the 2008 Integrated Report for impacts to biological communities. Approximately 73% of stream miles in the Patuxent River Upper watershed are estimated as having benthic and/or fish indices of biological impairment in the poor to very poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include fifteen stations. Eleven of the fifteen have benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, i.e. MBSS Round 2 contains ten MBSS sites; with eight having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Patuxent River Upper watershed.

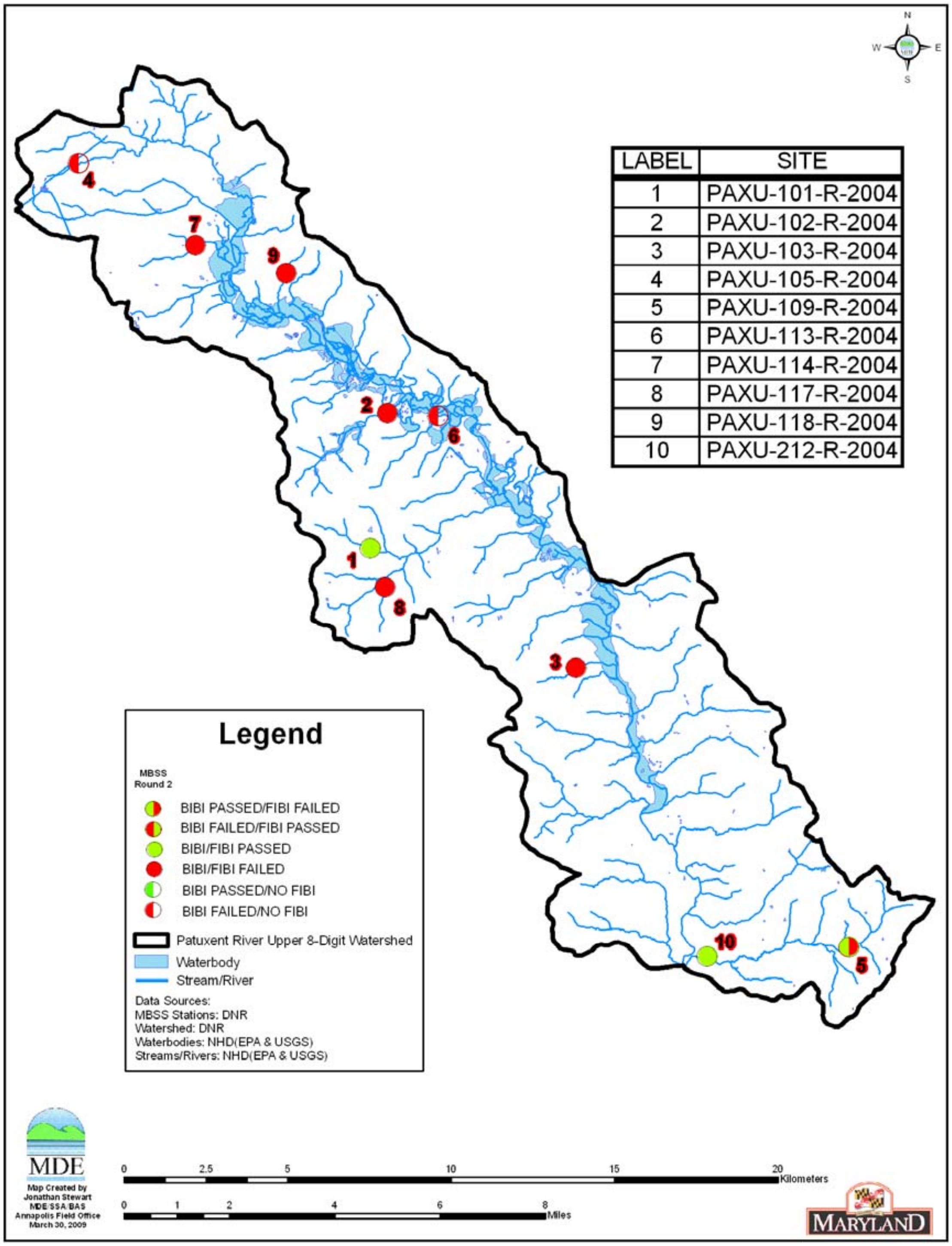

Figure 5. Principal Dataset Sites for the Patuxent River Upper Watershed

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 (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 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 Upper watershed, MDE identified sources, sediment, in-stream habitat, and water chemistry stressors as having significant association with poor to very poor fish and/or benthic biological conditions. Parameters identified as representing possible sources are listed in Table 1 and include various urban land use types. Table 2 shows the summary of combined AR values for the source groups in the Patuxent River Upper watershed. As shown in Table 3 through Table 5, parameters from the sediment, in-stream habitat, and water chemistry groups are identified as possible biological stressors. Table 6 shows the summary of combined AR values for the stressor groups in the Patuxent River Upper watershed.

Table 1. Stressor Source Identification Analysis Results for the Patuxent River Upper Watershed

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 with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites 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	10	8	208	38%	5%	Yes	33%
	high % of high intensity urban in watershed	10	8	208	25%	10%	No	----
	high % of low intensity urban in watershed	10	8	208	38%	4%	Yes	34%
	high % of transportation in watershed	10	8	208	25%	8%	No	----
	high % of high intensity urban in 60m buffer	10	8	206	38%	7%	Yes	31%
	high % of low intensity urban in 60m buffer	10	8	206	50%	5%	Yes	45%
	high % of transportation in 60m buffer	10	8	206	25%	9%	No	----

Table 1. Stressor Source Identification Analysis Results for the Patuxent River Upper Watershed (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 with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites 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 Agriculture	high % of agriculture in watershed	10	8	208	0%	19%	No	----
	high % of cropland in watershed	10	8	208	0%	25%	No	----
	high % of pasture/hay in watershed	10	8	208	13%	8%	No	----
	high % of agriculture in 60m buffer	10	8	206	0%	8%	No	----
	high % of cropland in 60m buffer	10	8	206	0%	16%	No	----
	high % of pasture/hay in 60m buffer	10	8	206	0%	10%	No	----
Sources Barren	high % of barren land in watershed	10	8	208	38%	22%	No	----
	high % of barren land in 60m buffer	10	8	206	25%	6%	No	----
Sources Anthropogenic	low % forest in watershed	10	8	208	25%	5%	Yes	20%
	low % of forest in 60m buffer	10	8	206	50%	5%	Yes	45%

Table 1. Stressor Source Identification Analysis Results for the Patuxent River Upper Watershed (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 with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites 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 Acidity	atmospheric deposition present	10	8	203	38%	36%	No	----
	AMD acid source present	10	8	203	0%	0%	No	----
	organic acid source present	10	8	203	0%	6%	No	----
	agricultural acid source present	10	8	203	0%	6%	No	----

Table 2. Summary of Combined Attributable Risk Values of the Source Group in the Patuxent River Upper Watershed

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Urban	46%	46%
Agriculture	----	
Barren Land	----	
Anthropogenic	45%	
Acidity	----	

Sources Identified by BSID Analysis

All the sources identified by the BSID analysis (Table 1), can be categorized as urban development within the Patuxent River Upper watershed. A significant amount of the watershed is comprised of urban land uses (40% (with 10% being impervious surfaces)). BSID results also show urban development within the 60 meter riparian buffer zone has having significant association with degraded biological conditions. Developed land occurs predominantly in Prince George's County portion of the watershed, with urbanized regions concentrated around the cities of Bowie, Laurel and Maryland City. The upper northern portion of the watershed has an average impervious surface cover above 25%, which is comprised of industrial, commercial, and residentially developed land uses associated with the City of Laurel and Maryland City. In addition, the southern portion of the watershed in Prince George's County contains localized hot spots of high impervious surface cover, particularly in the Bowie area. Consequently, streams draining these areas are impacted by degraded biological conditions (MDDNR 2002).

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. Although symptoms of the urban stream syndrome correlate to watershed imperviousness and drainage connectivity, the symptoms are often a result of complex interactions; many responses are inconsistent; therefore, an individual stream may not show all the symptoms.

Even though the BSID analysis did not identify transportation land use in the 60 meter riparian buffer zone as a significant source, three MBSS sites with BIBI and/or FIBI below 3.0 were located in close proximity to major transportation routes. According to Forman and Deblinger (2000), there is a "road-effect zone" over which significant ecological effects extend outward from a road; these effects extend 100 to 1,000 meters (average of 300m) on each side of four-lane roads. Roads tend to capture and export more stormwater pollutants than other land covers. There are five main transportation corridors (four-lane roads) in the watershed: Maryland-Routes 1, 295, 301, 50, and Interstate-95 in the northern portion.

The BSID source analysis (Table 1) 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 46% suggesting that urban development potentially impact a moderate proportion of the degraded stream miles in Patuxent River Upper (Table 2).

Stressors Identified by BSID Analysis

All the stressors identified in the BSID analysis for the Patuxent River Upper watershed (Table 2, 3, and 4), can be linked to the typical symptoms of "urban stream syndrome". The remainder of this section will discuss the identified stressors and their link to degraded biological conditions in the watershed.

Table 3. Sediment Biological Stressor Identification Analysis Results for the Patuxent River Upper 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 Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressor 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	9	7	127	29%	22%	No	----
	moderate bar formation present	9	7	127	57%	54%	No	----
	bar formation present	9	7	127	86%	83%	No	----
	channel alteration marginal to poor	9	7	123	71%	59%	No	----
	channel alteration poor	9	7	123	43%	26%	No	----
	high embeddedness	9	7	127	14%	1%	Yes	13%
	epifaunal substrate marginal to poor	9	7	127	71%	42%	No	----
	epifaunal substrate poor	9	7	127	43%	9%	Yes	34%
	moderate to severe erosion present	9	7	127	43%	47%	No	----
	severe erosion present	9	7	127	29%	14%	No	----
	poor bank stability index	9	7	127	29%	22%	No	----
	silt clay present	9	7	127	100%	99%	No	----

Table 4. Habitat Biological Stressor Identification Analysis Results for the Patuxent River Upper 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 Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressor 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	10	8	129	25%	12%	No	----
	instream habitat structure marginal to poor	9	7	127	71%	38%	Yes	35%
	instream habitat structure poor	9	7	127	29%	4%	Yes	25%
	pool/glide/eddy quality marginal to poor	9	7	127	57%	46%	No	----
	pool/glide/eddy quality poor	9	7	127	29%	3%	Yes	26%
	riffle/run quality marginal to poor	9	7	127	100%	43%	Yes	58%
	riffle/run quality poor	9	7	127	14%	16%	No	----
	velocity/depth diversity marginal to poor	9	7	127	57%	59%	No	----
	velocity/depth diversity poor	9	7	127	0%	12%	No	----
	concrete/gabion present	10	8	133	25%	1%	Yes	24%
	beaver pond present	9	7	126	0%	6%	No	----
Riparian Habitat	no riparian buffer	10	8	129	13%	15%	No	----
	low shading	9	7	127	0%	9%	No	----

Table 5. Water Chemistry Biological Stressor Identification Analysis Results for the Patuxent River Upper 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 Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressor 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	10	8	203	0%	27%	No	----
	high total dissolved nitrogen	0	0	0	0%	0%	No	----
	ammonia acute with salmonid present	10	8	203	75%	35%	Yes	40%
	ammonia acute with salmonid absent	10	8	203	63%	24%	Yes	39%
	ammonia chronic with salmonid present	10	8	203	75%	62%	No	----
	ammonia chronic with salmonid absent	10	8	203	75%	51%	No	----
	low lab pH	10	8	203	38%	35%	No	----
	high lab pH	10	8	203	0%	0%	No	----
	low field pH	9	7	201	29%	35%	No	----
	high field pH	9	7	201	0%	1%	No	----
	high total phosphorus	10	8	203	13%	4%	No	----
	high orthophosphate	10	8	203	0%	12%	No	----
	dissolved oxygen < 5mg/l	9	7	200	0%	12%	No	----
	dissolved oxygen < 6mg/l	9	7	200	0%	20%	No	----
	low dissolved oxygen saturation	6	4	184	0%	18%	No	----
	high dissolved oxygen saturation	6	4	184	0%	0%	No	----
	acid neutralizing capacity below chronic level	10	8	203	25%	8%	No	----
	acid neutralizing capacity below episodic level	10	8	203	38%	44%	No	----
	high chlorides	10	8	203	25%	6%	Yes	19%
	high conductivity µS/cm	10	8	203	25%	5%	Yes	20%
	high sulfates	10	8	203	25%	4%	Yes	21%

Table 6. Summary of Combined Attributable Risk Values of the Stressor Group in the Patuxent River Upper Watershed

Stressor Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Sediment	40%	72%
In-Stream Habitat	65%	
Riparian Habitat	----	
Water Chemistry	59%	

<u>Sediment and Habitat Conditions</u>

BSID analysis results for the Patuxent River Upper watershed identified two sediment parameters that have statistically significant association with poor to very poor stream biological condition: *high embeddedness* and *epifaunal substrate (poor)* (Table 3).

High embeddedness was identified as significantly associated with degraded biological conditions in the Patuxent River Upper, and found to impact approximately 13% of the stream miles with poor to very poor biological conditions. Embeddedness is determined by the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. Embeddedness is categorized as a percentage from 0% to 100% with low values as optimal and high values as poor. High embeddedness is a result of excessive sediment deposition. High embeddedness suggests that sediment may interfere with feeding or reproductive processes and result in biological impairment. Although embeddedness is confounded by natural variability (e.g., Coastal Plain streams will naturally have more embeddedness than Highlands streams), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow or stream channel erosion.

Epifaunal substrate was identified as significantly associated with degraded biological conditions and found in 34% *(poor* rating) of the stream miles with poor to very poor biological conditions in the Patuxent River Upper watershed. This stressor measures the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. 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. Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates.

As development and urbanization increase in a watershed, so do 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 causing streams to become more. "flashy", i.e., they have more frequent, larger flow events (Walsh et al. 2005). The scouring associated with these increased flows can lead to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed and the settling of fine sediment in the stream substrate. These processes create an unstable stream ecosystem that can result in a loss of available habitat, continuous displacement of biological communities, frequent re-colonization of biological communities, and a shift in biological communities (i.e., sensitive taxa replaced by more tolerant species).

According to a MDDNR Watershed Characterization for the Patuxent River Upper there are thirteen permitted sand and gravel mining operations (active & closed) in Anne Arundel and Prince George's Counties. Before 1976, sand and gravel mining operations did not require a permit, so the total extent of previous mining operations in the watershed is not known. Most of the sites in Anne Arundel County are located in the floodplain region which is underlain with extensive sand and gravel deposits. Sand and gravel sites mined prior to implementation of the 1976 Surface Mining Law were not required to have exposed subsoil areas graded, covered with topsoil, and revegetated. Some of those abandoned sites were a source of sediment pollution (MDP 1984). Even though altered hydrology is the predominate cause of sedimentation in the watershed, it is possible the legacy effect of old mining operations could play a role in sedimentation in localized streams.

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 40 % suggesting these stressors impact a moderate proportion of the degraded stream miles in Patuxent River Upper (See Table 6).

In-stream Habitat Conditions

BSID analysis results for the Patuxent River Upper watershed identified five habitat parameters that have a statistically significant association with poor to very poor stream biological condition: *in-stream habitat structure (marginal to poor and poor), pool/glide/eddy quality (poor), riffle/run quality (marginal to poor), concrete/gabion present* (Table 4).

In-stream habitat structure was identified as significantly associated with degraded biological conditions in the Patuxent River Upper watershed, and found to impact approximately 36% (*marginal to poor* rating) and 25% (*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. High in-stream habitat scores are evidence of the lack of sediment deposition. Like embeddedness, in-stream habitat is confounded by natural variability (i.e., some streams will naturally have more or less in-stream habitat). Low in-stream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats. In-stream habitat conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, which is defined as less than 10% stable habitat where lack of habitat is obvious; and 2) marginal to poor, where there is a 10-30% mix of stable habitat but habitat availability is less than desirable.

Riffle/run quality (marginal to poor) was identified as significantly associated with degraded biological conditions in the Patuxent River Upper, and found to impact approximately 58% of the stream miles with poor to very poor biological conditions. Riffle/run quality is a visual observation including quantitative measurements based on the depth, complexity, and functional importance of riffle/run habitat within the stream segment. An increase of heterogeneity of riffle/run habitat within the stream segment likely increases the abundance and diversity of fish species, while a decrease in heterogeneity likely decreases abundance and diversity. Also, high quality riffle/run habitat is evidence of lack of sediment deposition. Riffle/run quality conditions indicating biological degradation are set at two levels: 1) poor, defined as riffle/run depths < 1 cm or riffle/run substrates concreted; and 2) marginal to poor, defined as riffle/run depths generally 1 – 5 cm with a primarily single current velocity. Marginal to poor and poor ratings are expected in unstable stream channels that experience frequent high flows.

Concrete/gabion present was identified as significantly associated with degraded biological conditions in the Patuxent River Upper , and found to impact approximately 24% of the stream miles with poor to very poor biological conditions. Concrete/gabion present, like ‘channelized’, inhibits the heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities. Concrete channelization increases flow and provides a homogeneous substrate, conditions which are detrimental to diverse and abundant colonization.

All the stressors identified for the in-stream habitat parameter group are intricately linked with habitat heterogeneity. The lower ratings for these habitat parameters indicate a lower diversity of a stream’s microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. The “flashy” hydrologic regime of the watershed has resulted in alterations to stream geomorphology thereby decreasing habitat heterogeneity.

Concrete and/or gabion channelization has been used in the Patuxent River Upper watershed for flood control. There were two degraded MBSS sites were 75% and 100%

of the stream segment had a concreted channel. The purpose is to increase channel capacity and flow velocities so water moves more efficiently downstream. However, this type of channel alteration is extremely detrimental for the "well being" of streams and rivers through the elimination of suitable habitat and the creation of excessive flows. Stream bottoms are made more uniform. Habitats of natural streams contain numerous bends, riffles, runs, pools and varied flows, and tend to support healthier and more diversified plant and animal communities than those in channelized streams. The natural structures impacting stream hydrology, which were removed for channelization, also provide critical habitat for stream species and impact nutrient availability in stream microhabitats (Bolton and Schellberg 2001). The refuge cavities removed by channelization not only provide concealment for fish, but also serve as traps for detritus, and are areas colonized by benthic macroinvertebrates. Subsequently, channelized streams retained less leaf litter and supported lower densities of detritivore invertebrates than natural streams. The overall densities and biomasses of macroinvertebrates in channelized streams are very low by comparison with intact natural streams (Laasonen et al. 1998; Haapala and Muotka 1998).

The combination of the altered flow regime, increased sedimentation, and concrete channelization in Patuxent River Upper has resulted in loss of available habitat (poor ratings on habitat parameters) and an unstable stream ecosystem. Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the in-stream habitat stressor group is approximately 65 % suggesting this stressor impacts a considerable proportion of the degraded stream miles in the Patuxent River Upper (Table 6).

Riparian Habitat Conditions

BSID analysis results for Patuxent River Upper did not identify any riparian habitat parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community) (Table 4).

Water Chemistry Conditions

BSID analysis results for the Patuxent River Upper watershed identified five water chemistry parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in an improved biological community). These parameters are *ammonia acute (with salmonid present & absent), high conductivity, high chlorides, and high sulfates* (Table 5).

Ammonia acute concentrations were identified as significantly associated with degraded biological conditions in Patuxent River Upper , and found to impact approximately 40% (*with salmonid present*) and 39% (*with salmonid absent*) of the stream miles with poor to very poor biological conditions. Acute ammonia toxicity refers to potential exceedences of species tolerance caused by a one-time, sudden, high exposure of ammonia. Ammonia acute with salmonid present or absent is a USEPA water quality criteria for ammonia concentrations causing acute toxicity in surface waters where salmonid species of fish are present or absent (USEPA 2006).

Ammonia (NH_3) is a measure of the amount of NH_3 in the water column. Ammonia is a nitrogen nutrient species; in excessive amounts it has potential toxic effects on aquatic life. Most nutrients under natural conditions occur in moderate concentrations and are not generally harmful to aquatic life. Ammonia, on the other hand, is highly toxic to aquatic organisms. Acute ammonia toxicity interferes with physiological processes and leads to cell death in the central nervous system of vertebrates (Randall and Tsui 2002; Van De Nieuwegiessen 2008).

National Pollutant Discharge Elimination System (NPDES) permitted discharges, urban runoff, atmospheric deposition, fertilizers, animal waste, failing septic systems, and leaking wastewater infrastructure are potential sources of ammonia to surface waters. There are three minor municipal, three major municipal, fifteen general permitted discharges, and sixteen permitted stormwater dischargers in the Patuxent River Upper watershed. Ammonia loads from any NPDES discharge facility is dependent on discharge volume, level of treatment process, and sophistication of the processes and equipment.

There is no supporting evidence that the ammonia toxicity is related to elevated nutrient concentrations or that excessive eutrophication is occurring in the watershed. The Upper Patuxent River watershed was de-listed for nutrients in 2007 following USEPA concurrence with Maryland Department of the Environment’s (MDE) WQA of nutrient data collected during 1998-2004, which showed no nutrient impairment. Additional analysis of historical, as well as future monitoring data for ammonia will help determine the spatial and temporal extent of this impairment in the watershed.

High conductivity levels was identified as significantly associated with degraded biological conditions in the Patuxent River Upper , and found to impact approximately 20% of the stream miles with poor to very poor biological conditions. Conductivity is a measure of water’s ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Urban runoff, road salts, agricultural runoffs (i.e., fertilizers), and leaking wastewater infrastructure are typical sources of inorganic compounds.

High chloride levels are significantly associated with degraded biological conditions in the Patuxent River Upper, and found to impact approximately 19% of the stream miles with poor to very poor biological conditions. High concentrations of chlorides can result from natural causes, metals contamination, industrial discharges, impervious surface runoff, and application of road salts. There is no known metals impairment in the Patuxent River Upper watershed. There are numerous NPDES industrial dischargers in the watershed. Since National Pollution Discharge Elimination System (NPDES) permitting enforcement does not require chlorides testing at these facilities, data was not available to verify/identify chlorides as a specific pollutant. Smith et al. (1987) have identified that, although chloride can originate from natural sources, in urban watersheds road salts can be a likely source of high chloride and conductivity levels. Since both MBSS sites with chloride concentrations above threshold values were located within close proximity to major highways, application of road salts is the likely source. Road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality. When the dissolved salts in runoff from highways and bridges enter soils, ground water, and surface waters, salinity levels increase and can become toxic to aquatic organisms.

High sulfates concentrations are significantly associated with degraded biological conditions and found in 21% of the stream miles with poor to very poor biological conditions in the Patuxent River Upper watershed. Sulfates in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities. There are six municipal wastewater treatment plants in the watershed, and numerous industrial facilities. Since NPDES permitting enforcement does not require sulfate testing at any of these facilities, data was not available to verify/identify sulfates as a specific pollutant in this watershed.

Ammonia, chloride, and sulfate toxicity identified by the BSID analysis can be indicative of anthropogenic activities that degrade water quality by causing an increase in contaminant loads from various point and nonpoint sources especially during storm events. These sources can add nutrients and inorganic pollutants to surface waters at levels potentially toxic to aquatic organisms.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the water chemistry stressor group is approximately 59 % suggesting this stressor impacts a considerable proportion of the degraded stream miles in the Patuxent River Upper (Table 6).

Summary

The BSID stressor analysis indicates that the Patuxent River Upper watershed has been significantly impacted by urban development (46% of the impaired sites associated with urban land use sources). The BSID analysis results suggest that a portion of the degraded biological communities in the Patuxent River Upper watershed are a result of increased urban land use causing alterations to hydrologic regime and stream morphology. Increased urbanization has caused "flashy" hydrologic regime, degradation to in-stream habitat quality, and increased sediment loads, resulting in an unstable stream ecosystem that eliminates optimal habitat. High percentages of urban land use in the watershed has also increased contaminant loads from point and nonpoint sources, resulting in levels of ammonia, chlorides, and sulfates that can be extremely toxic to aquatic organisms.

The land-use in the Patuxent River Upper watershed is almost evenly split between urban (40%) and forest (48%). Of the eight MBSS sites that have BIBI/ FIBI scores significantly lower than 3.0 (i.e., poor to very poor) four are located in urban developed areas. However, three stations have predominately forested/wetland catchments. MBSS sites labeled 2, 6, and 9 (Figure 5) have acid neutralizing capacity (ANC) values below 70 µeq/L, and pH values below the COMAR numeric criteria of 6.5. MBSS sites 2 and 9 have ammonia concentrations at acute levels. Sites 6 and 9 have lab pH values below 5.0 and ANC below 35µeq/L. In the entire round two MBSS dataset there are no sites that have BIBI/ FIBI scores higher than 3.0 with pH values below 5.0. It is not uncommon for surface waters in wetland areas to have low ANC, low pH, and elevated ammonia values due to natural ecological processes. In wetlands, organic matter accumulates due to the inhibition of decomposition caused by the long-term anaerobic conditions. The low pH values observed in natural wetlands are likely the result of saturated soils, low oxygen levels, and subsequent inhibition of organic matter decomposition (Bantilan-Smith et al. 2009). The decomposition of organic materials in wetlands also involves the release of ammonia, which subsequently influences nutrient cycling resulting in increased ammonia concentrations.

The combined AR for all the stressors is approximately 72%, suggesting that sediment, in-stream habitat and water chemistry stressors identified in the BSID analysis would adequately account for the biological impairment in the Patuxent River Upper watershed (Table 6).

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.

Final Causal Model for the Patuxent River Upper 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 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 conceptual model for the Patuxent River Upper watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

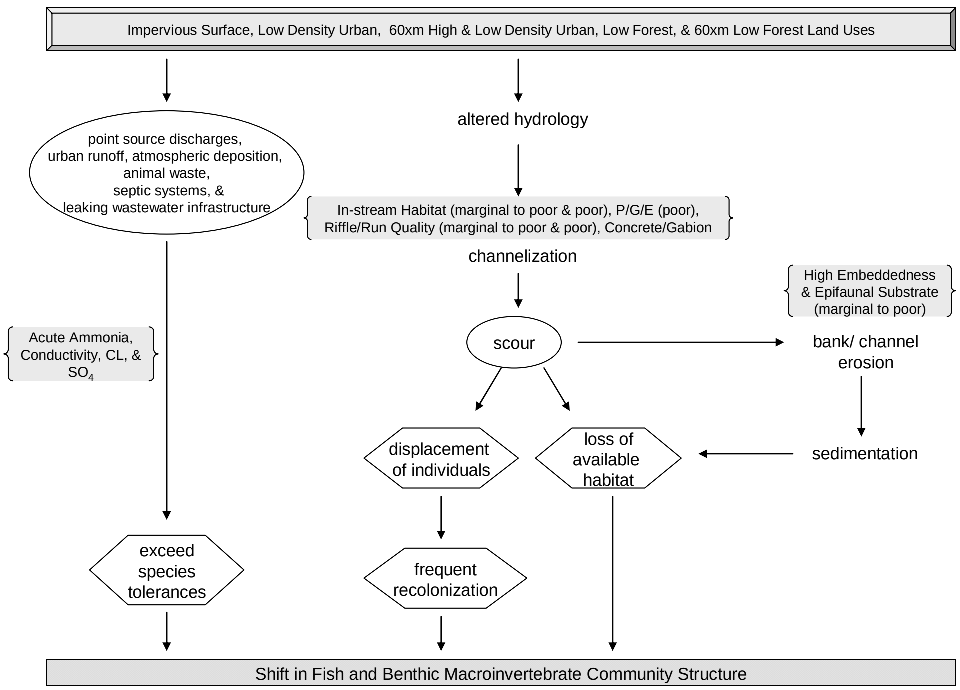

Figure 6. Final Causal Model for the Patuxent River Upper Watershed

5.0 Conclusions

Data suggest that the Patuxent River Upper watershed's biological communities are strongly influenced by urban land use, which has altered the hydrologic regime resulting in increased sedimentation, as well as ammonia, chloride, and sulfate toxicity. 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 Patuxent River Upper watershed are summarized as follows:

- The BSID analysis has determined that biological communities in the Patuxent River Upper watershed are likely degraded due to flow/sediment related stressors. Specifically, altered hydrology and increased urban runoff have resulted in degradation to streambed morphology, streambed scouring and subsequent elevated suspended sediment transport through the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus support the 1996 Category 5 listing for total suspended solids as an impairing substance in the Patuxent River Upper watershed, and links this pollutant to biological conditions in these waters.

- The BSID analysis has determined that biological communities in the Patuxent River Upper watershed are also likely degraded due to water chemistry related stressors. Specifically, acute ammonia, chloride, and sulfate toxicity are a probable cause of impacts to biological communities. Impacts on water quality due to elevated concentrations of these stressors are dependent on prolonged exposure; future monitoring of these stressors will help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID analysis did not identify any nutrient stressors present and/or nutrient stressors showing a significant association with degraded biological conditions; therefore, the 2007 WQA for nitrogen and phosphorus was an appropriate management action.

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