Watershed Report for Biological Impairment of the Lower Monocacy River Watershed, Frederick, Carroll, and Montgomery 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
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
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
MH	Mantel-Haenzel
mg/L	Milligrams per liter
NH_3	Ammonia
NPDES	National Pollution Discharge Elimination System
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TDN	Total Dissolved Nitrogen
TN	Total Nitrogen
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

Executive Summary

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

The Maryland Department of the Environment (MDE) has identified the waters of the Lower Monocacy River watershed (basin number 02140302) on the State's Integrated Report as impaired by sediments, nutrients (1996 listings), fecal bacteria, and impacts to biological communities (2002 listings)(MDE 2008). An impoundment located within the watershed, Lake Linganore, was also identified as impaired by sediments (1996) and nutrients (1996). All impairments are listed for non-tidal streams. The 1996 nutrients 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 TMDL for sediments and phosphorus for the Lake Linganore impoundment was approved by the USEPA in 2003. TMDLs for fecal bacteria and sediments were submitted to the USEPA and approved in 2009.

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, 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 Lower Monocacy River, upstream of US Route 40, and its tributary Israel Creek are designated as Use IV-P - *recreational trout waters and public water supply*; downstream of US Route 40, the Lower Monocacy River is designated as a Use I-P - *water contact recreation, protection of aquatic life, and public water supply*. Additional tributaries of the Lower Monocacy River – Ballenger Creek, Bear Branch, Carroll Creek, Furnace Branch, Little Bennett Creek, and Rocky Fountain Run – are designated as Use III-P - *non-tidal cold water and public water supply* (COMAR 2009 a,b,c,d). The Lake Linganore watershed is designated as Use IV-P. The Lower Monocacy River watershed is not attaining its designated use of protection of aquatic life

because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, which will enable the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact these stressors would have on 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 Lower Monocacy 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 Lower Monocacy River is strongly influenced by urban and agricultural land use and its concomitant effects: altered hydrology and elevated levels of sediments, nutrients, and conductivity (a measure of the presence of dissolved substances). The development 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 and agricultural landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

The results of the BSID process, and the probable causes and sources of the biological impairments of the Lower Monocacy River can be summarized as follows:

- The BSID process has determined that biological communities in Lower Monocacy River are also likely degraded due to sediment and in-stream habitat related stressors. Specifically, altered hydrology and increased runoff from urban impervious surfaces have resulted in channel erosion and subsequent elevated suspended sediment in the watershed, which are in turn, the probable causes of impacts to biological communities. The BSID results confirm that the establishment of a USEPA approved sediment TMDL in 2009 was an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Lower Monocacy River.

- The BSID analysis has determined that both orthophosphates and nitrogen are probable causes of impacts to biological communities in the Lower Monocacy River watershed. Elevated concentrations of orthophosphate show association with degraded biological conditions; as much as 14% of the biologically impacted stream miles in the watershed may be degraded due to high orthophosphate. Similarly, according to the BSID analysis, 37% of the biologically impacted stream miles in the Lower Monocacy River watershed are associated with high total nitrogen concentrations. An analysis of observed TN:TP ratios, however, indicate that phosphorus is the limiting nutrient in the watershed. Because nitrogen generally exists in quantities greater than necessary to sustain algal growth, excess nitrogen per se is not the cause of the biological impairment in the Lower Monocacy River, and the reduction of nitrogen loads would not be an effective means of ensuring that the watershed is free from impacts on aquatic life from eutrophication. Therefore, load allocations for the Lower Monocacy River Nutrient TMDL will apply only to total phosphorus. The BSID results thus confirm the 2010 Category 5 listing for phosphorus as an impairing substance in the Lower Monocacy River watershed, and link this pollutant to biological conditions in these waters.

- The BSID process has also determined that biological communities in the Lower Monocacy River watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards as a result of pollution. MDE recommends a Category 4c listing for the Lower Monocacy River watershed based on inadequate riparian buffer zones in approximately 27% of degraded stream miles.

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 blackwater 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 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 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 Lower Monocacy River watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Lower Monocacy River Watershed Characterization

2.1 Location

The Monocacy River is a free flowing stream that originates in Pennsylvania and flows fifty-eight miles through Maryland to ultimately empty into the Potomac River. The watershed covers approximately 966 square miles, with approximately 224 square miles located in Pennsylvania and 742 square miles in Maryland. The basin can be subdivided into three distinct watersheds: the Upper Monocacy River, Lower Monocacy River, and Double Pipe Creek. The Lower Monocacy River watershed is situated primarily in Frederick County but includes a small portion of Carroll and Montgomery County as well (see Figure 1). The largest urban center within the watershed is the City of Frederick, and the total population within the watershed is estimated to be approximately 136,000 (MDE 2009b). The watershed is located in Highland region of three distinct eco-regions identified in the MBSS indices of biological integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

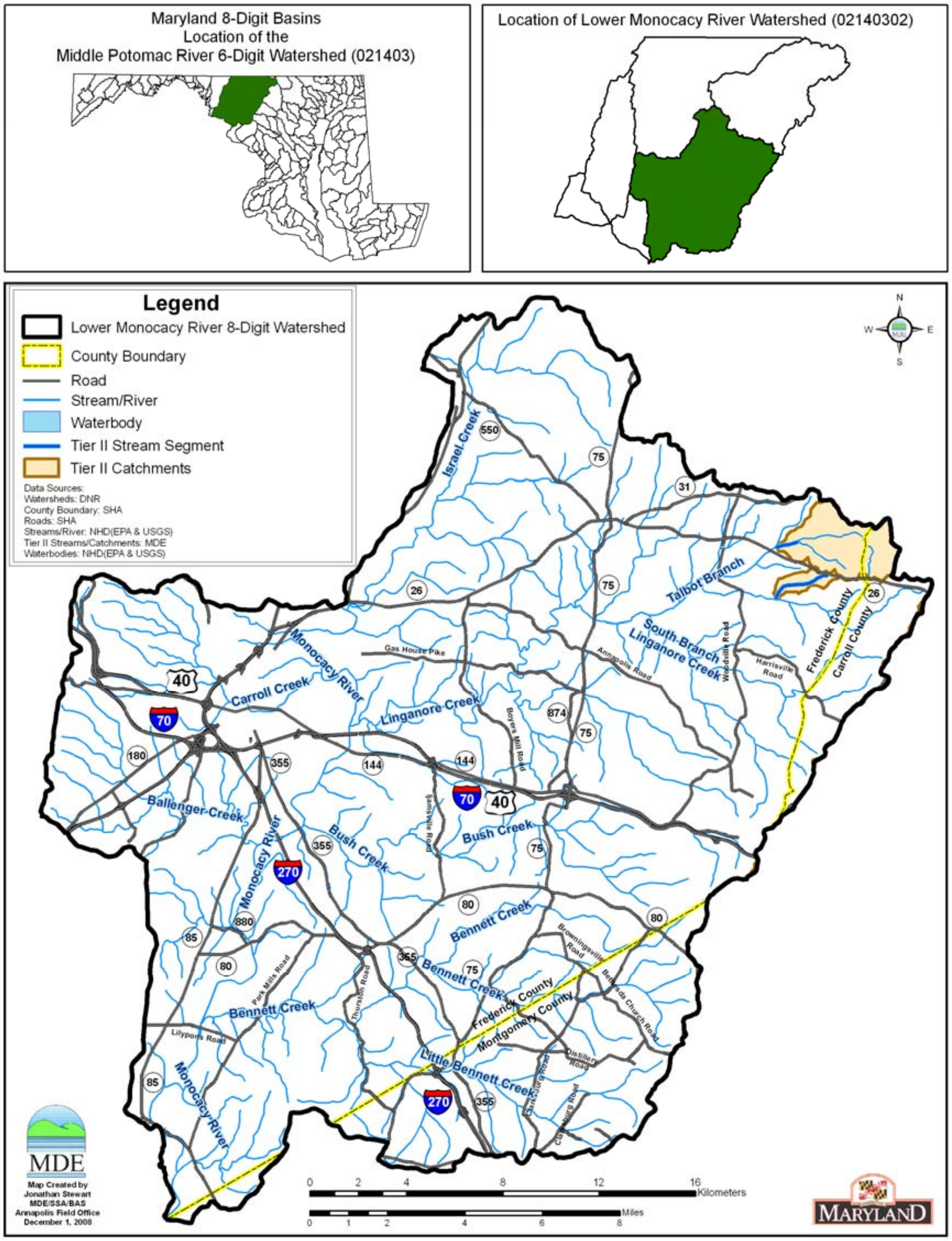

Figure 1. Location Map of the Lower Monocacy River Watershed

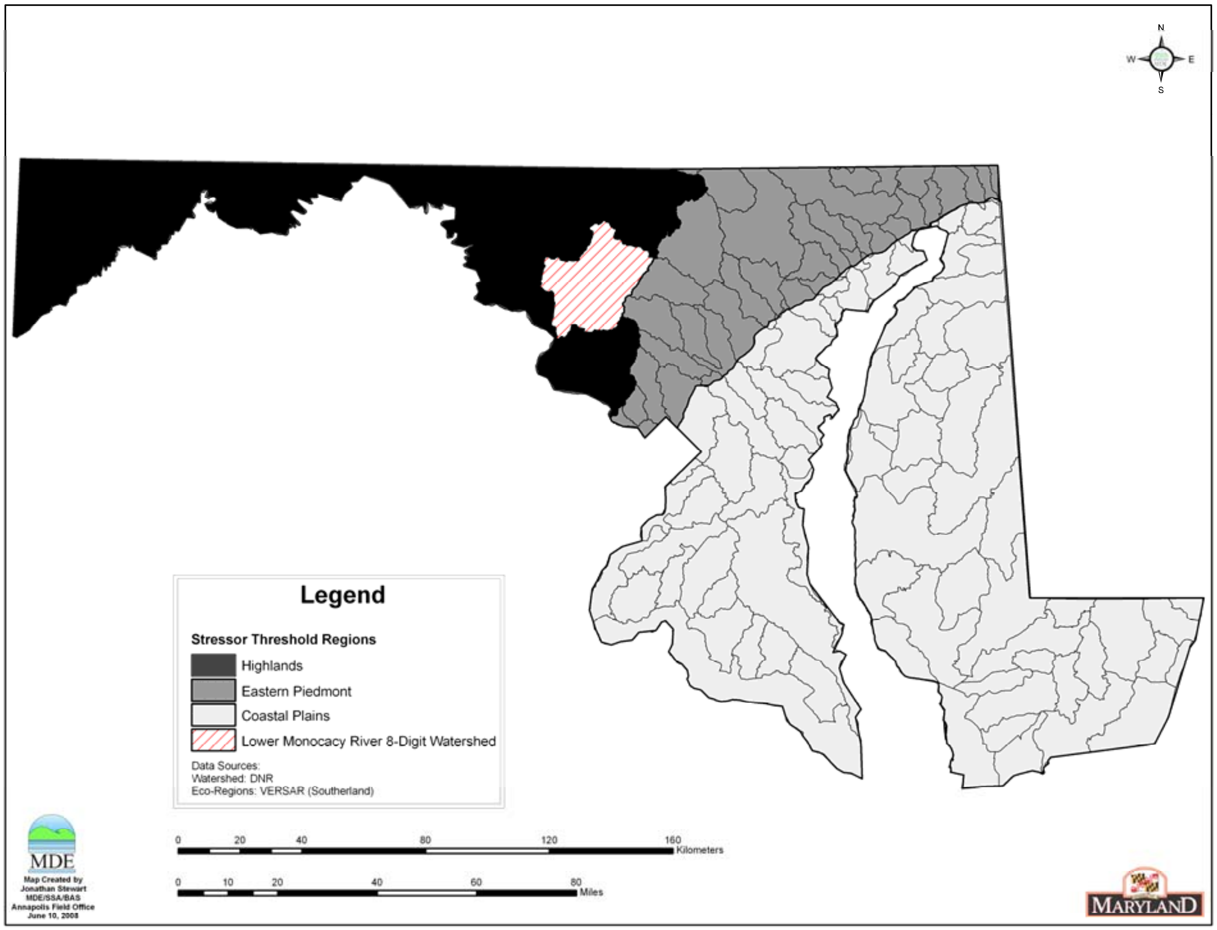

Figure 2. Eco-Region Location Map of the Lower Monocacy River Watershed

2.2 Land Use

The Lower Monocacy River is a tributary of the Potomac River. The watershed covers approximately 194,790 acres of land in Frederick, Carroll, and Montgomery Counties, Maryland. The watershed contains numerous urban centers including, Frederick, New Market, Walkersville, and Woodsboro. Many of these areas were built before modern stormwater runoff controls were required by the State. There is also a significant amount of agriculture within the watershed, which consists mostly of pasture /hay, row crop, but also includes dairy production. Lower Monocacy River watershed contains urban, agricultural, and forested land use (see Figure 3). The land use distribution in the Lower Monocacy River watershed consists of agricultural (37%), forest (31%), and urban (32%) land uses. (see Figure 4) (MDP 2002).

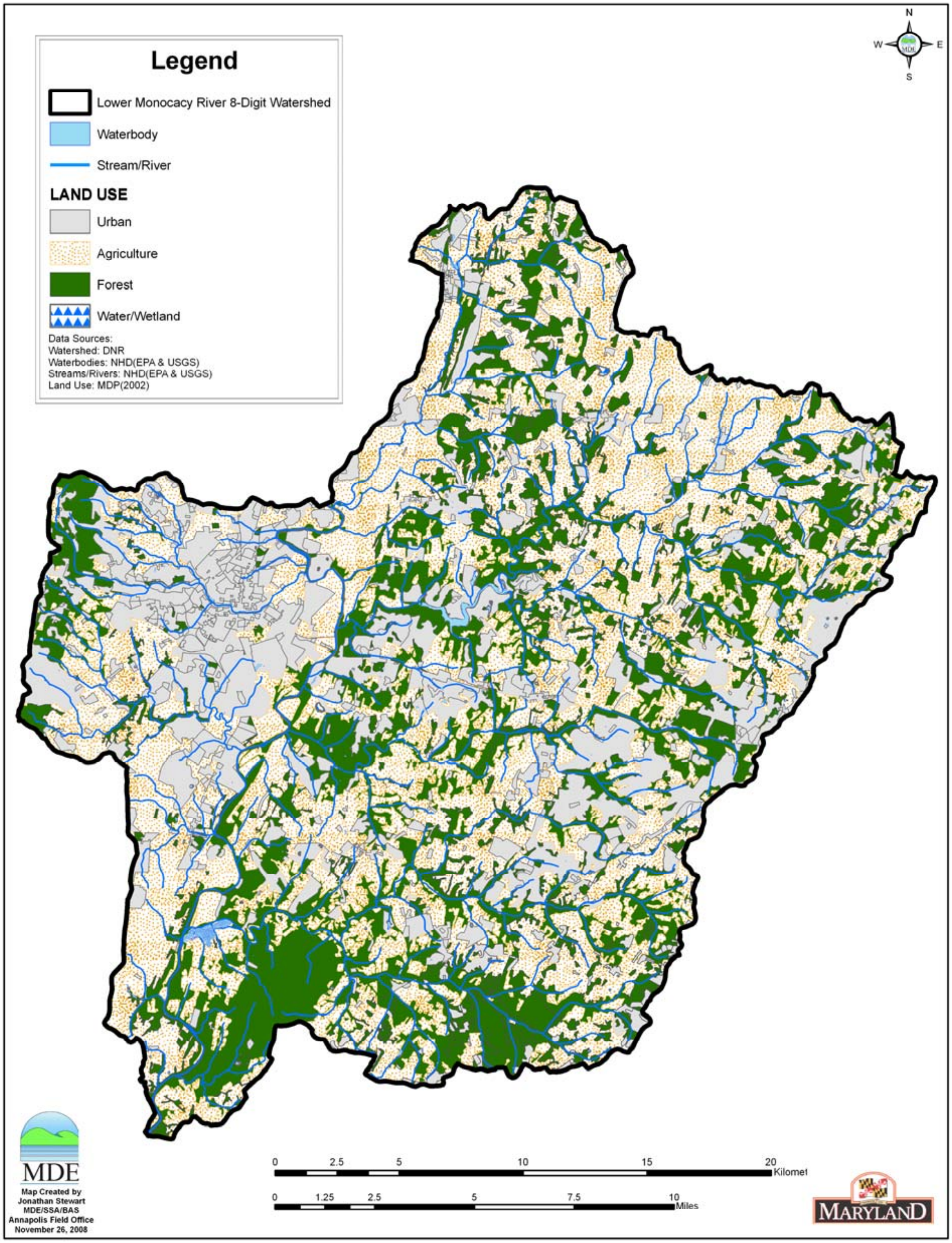

Figure 3. Land Use Map of the Lower Monocacy River Watershed

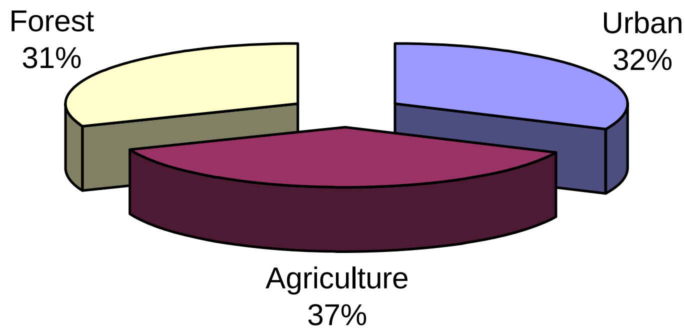

Figure 4. Proportions of Land Use in the Lower Monocacy River Watershed

2.3 Soils/hydrology

The Lower Monocacy River watershed lies within the Western Division of the Piedmont Plateau Province of Central Maryland. The Piedmont Plateau province is characterized by gentle to steep rolling topography, low hills and ridges (MGS 2007). The outstanding features of the Piedmont's Western Division are the Frederick Valley and the Triassic Upland. The broad, flat Frederick Valley is underlain by limestone as well as dolomite, and has an average elevation of 300 feet. The Triassic Upland borders much of the Frederick Valley. The low to moderate relief of the Triassic Upland is underlain by layered sandstone, siltstone, and red shale. The average elevation of the Upland is approximately 500 feet. A prominent topographic feature of the Piedmont is an erosion resistant monadnock, known as Sugarloaf Mountain, which is composed of highly weather resistant quartz (DNR 2007; MGS 2007; MDE 2000).

3.0 Lower Monocacy River Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment (MDE) has identified the waters of the Lower Monocacy River watershed (basin number 02140302) on the State's Integrated Report as impaired by sediments, nutrients (1996 listings), fecal bacteria , and impacts to biological communities (2002 listings)(MDE 2008). An impoundment located within the watershed, Lake Linganore, was also identified as impaired by sediments (1996) and nutrients (1996). All impairments are listed for non-tidal streams. The 1996 nutrients 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 TMDL for sediments and phosphorus for the Lake Linganore impoundment was approved by the USEPA in 2003. TMDLs for fecal bacteria and sediments were submitted to the USEPA and approved in 2009.

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Lower Monocacy River, upstream of US Route 40, and its tributary Israel Creek are designated as Use IV-P - *recreational trout waters and public water supply*; downstream of US Route 40, the Lower Monocacy River is designated as a Use I-P - *water contact recreation, protection of aquatic life, and public water supply*. Additional tributaries of the Lower Monocacy River – Ballenger Creek, Bear Branch, Carroll Creek, Furnace Branch, Little Bennett Creek, and Rocky Fountain Run – are designated as Use III-P - *non-tidal cold water and public water supply* (COMAR 2009 a,b,c,d). The Lake Linganore watershed is designated as Use IV-P. 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 Lower Monocacy River watershed is listed under Category 5 of the 2008 Integrated Report as impaired for impacts to biological communities. Approximately 61% of stream miles in the Lower Monocacy River basin 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 eighty-three sites. Fifty-one of the eighty-three 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 fifty MBSS sites with thirty-four having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Lower Monocacy River watershed.

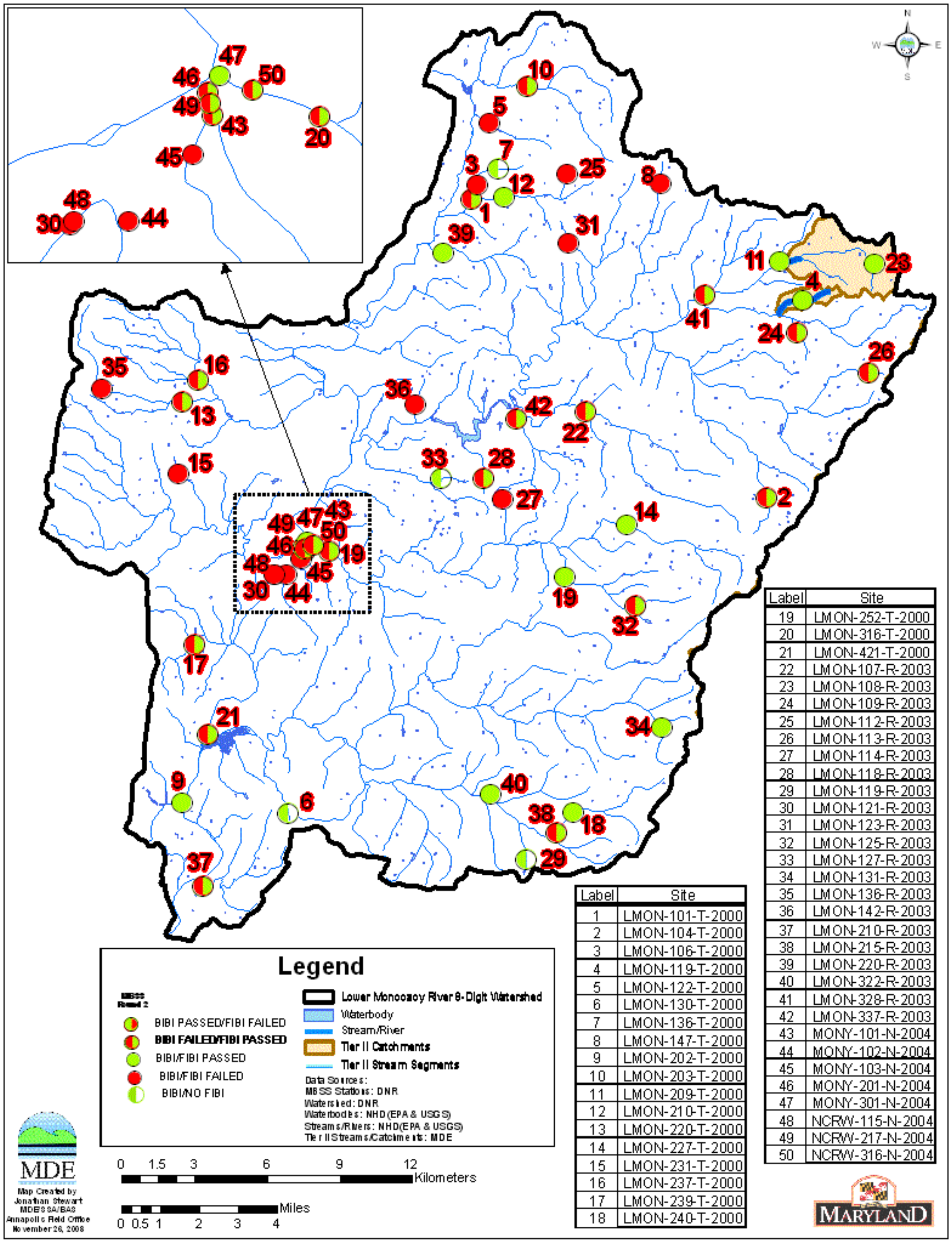

Figure 5. Principle Dataset Sites for the Lower Monocacy River Watershed

4.0 Stressor Identification Results

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

The BSID data analysis tests for the strength of association between stressors and degraded biological conditions by determining if there is an increased risk associated with the stressor being present. More specifically, the assessment compares the likelihood that a stressor is present, given that there is a degraded biological condition, by using the ratio of the incidence within the case group as compared to the incidence in the control group (odds ratio). The case group is defined as the sites within the assessment unit with BIBI/FIBI scores 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 – 1st and 2nd- 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 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).

Through the BSID analysis, MDE identified sediment/in-stream habitat parameters, riparian habitat parameters, water chemistry parameters, and potential sources significantly associated with poor to very poor benthic and/or fish 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 Lower Monocacy River. Parameters identified as representing possible sources are listed in Table 4 and include various urban land use types. A summary of combined AR values for each stressor group is shown in Table 5. A summary of combined AR values for each source group is shown in Table 6.

Table 1. Sediment Biological Stressor Identification Analysis Results for Lower Monocacy River 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 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	50	34	80	6%	10%	No	----
	moderate bar formation present	49	34	77	38%	45%	No	----
	bar formation present	49	34	77	82%	89%	No	----
	channel alteration marginal to poor	49	34	77	44%	43%	No	----
	channel alteration poor	49	34	77	12%	9%	No	----
	high embeddedness	49	34	77	15%	4%	Yes	11%
	epifaunal substrate marginal to poor	49	34	77	44%	20%	Yes	25%
	epifaunal substrate poor	49	34	77	12%	4%	Yes	8%
	moderate to severe erosion present	49	34	77	62%	25%	Yes	37%
	severe erosion present	49	34	77	9%	2%	Yes	7%
	poor bank stability index	49	34	77	21%	4%	Yes	16%
	silt clay present	49	34	77	100%	99%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for the Lower Monocacy River 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 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	50	34	80	18%	10%	No	----
	instream habitat structure marginal to poor	49	34	77	53%	23%	Yes	31%
	instream habitat structure poor	49	34	77	3%	2%	No	----
	pool/glide/eddy quality marginal to poor	49	34	77	50%	48%	No	----
	pool/glide/eddy quality poor	49	34	77	9%	7%	No	----
	riffle/run quality marginal to poor	49	34	77	35%	34%	No	----
	riffle/run quality poor	49	34	77	3%	7%	No	----
	velocity/depth diversity marginal to poor	49	34	77	56%	52%	No	----
	velocity/depth diversity poor	49	34	77	3%	8%	No	----
	concrete/gabion present	50	34	80	3%	3%	No	----
	beaver pond present	49	34	77	0%	2%	No	----
Riparian Habitat	no riparian buffer	50	34	80	50%	24%	Yes	27%
	low shading	49	34	77	21%	11%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for the Lower Monocacy River 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 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	50	34	159	44%	8%	Yes	37%
	high total dissolved nitrogen	21	12	50	42%	6%	Yes	36%
	ammonia acute with salmonid present	50	34	159	9%	2%	Yes	7%*
	ammonia acute with salmonid absent	50	34	159	9%	1%	Yes	8%*
	ammonia chronic with salmonid present	50	34	159	9%	4%	No	----
	ammonia chronic with salmonid absent	50	34	159	9%	2%	Yes	7%*
	low lab pH	50	34	159	0%	5%	No	----
	high lab pH	50	34	159	18%	1%	Yes	17%
	low field pH	49	34	154	3%	14%	No	----
	high field pH	49	34	154	3%	0%	No	----
	high total phosphorus	50	34	159	6%	3%	No	----
	high orthophosphate	50	34	159	18%	4%	Yes	14%
	dissolved oxygen < 5mg/l	49	34	154	3%	3%	No	----
	dissolved oxygen < 6mg/l	49	34	154	6%	7%	No	----
	low dissolved oxygen saturation	44	31	138	3%	4%	No	----
	high dissolved oxygen saturation	44	31	138	0%	1%	No	----
	acid neutralizing capacity below chronic level	50	34	159	0%	6%	No	----
	acid neutralizing capacity below episodic level	50	34	159	3%	43%	No	----
	high chlorides	50	34	159	15%	7%	No	----
	high conductivity	50	34	159	15%	4%	Yes	11%
	high sulfates	50	34	159	9%	4%	No	----

*** Due to minimal sampling for ammonia in MBSS data set in order to make an accurate determination of acute and chronic ammonia toxicity, MDE reviewed additional data to determine if there is ammonia toxicity impairment in these waters. (See page 23)**

Table 4. Stressor Source Identification Analysis Results for the Lower Monocacy River 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 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	50	34	156	6%	1%	Yes	5%
	high % of high intensity urban in watershed	50	34	159	35%	4%	Yes	32%
	high % of low intensity urban in watershed	50	34	159	56%	8%	Yes	48%
	high % of transportation in watershed	50	34	159	47%	9%	Yes	38%
	high % of high intensity urban in 60m buffer	50	34	159	29%	6%	Yes	24%
	high % of low intensity urban in 60m buffer	50	34	159	44%	7%	Yes	37%
	high % of transportation in 60m buffer	50	34	159	29%	9%	Yes	21%
Sources Agriculture	high % of agriculture in watershed	50	34	159	18%	6%	Yes	12%
	high % of cropland in watershed	50	34	159	0%	6%	No	----
	high % of pasture/hay in watershed	50	34	159	38%	8%	Yes	31%
	high % of agriculture in 60m buffer	50	34	159	21%	6%	Yes	15%
	high % of cropland in 60m buffer	50	34	159	3%	4%	No	----
	high % of pasture/hay in 60m buffer	50	34	159	29%	8%	Yes	22%
Sources Barren	high % of barren land in watershed	50	34	159	26%	7%	Yes	20%
	high % of barren land in 60m buffer	50	34	159	12%	6%	No	----

Table 4. Stressor Source Identification Analysis Results for the Lower Monocacy 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 that odds or 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	50	34	159	56%	5%	Yes	51%
	low % of forest in 60m buffer	50	34	159	56%	6%	Yes	50%
Sources Acidity	atmospheric deposition present	50	34	159	0%	39%	No	----
	AMD acid source present	50	34	159	0%	4%	No	----
	organic acid source present	50	34	159	0%	3%	No	----
	agricultural acid source present	50	34	159	3%	1%	No	----

Table 5. Summary of Combined AR Values for Stressor Groups for the Lower Monocacy River 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	71%	92%
In-Stream Habitat	31%	
Riparian Habitat	27%	
Water Chemistry	76%	

Table 6. Summary of Combined AR Values for Source Groups for the Lower Monocacy River 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	64%	84%
Agriculture	38%	
Barren Land	20%	
Anthropogenic	60%	
Acidity	----	

<u>Sediment Conditions</u>

BSID analysis results for the Lower Monocacy River identified six sediment parameters that have a statistically significant association with poor to very poor stream biological condition: *high embeddedness, epifaunal substrate (marginal to poor* & *poor), erosion present (moderate to severe & severe),* and *poor bank stability index.*

High embeddedness was identified as significantly associated with degraded biological conditions in the Lower Monocacy River, and found to impact approximately 11% 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 in the Lower Monocacy River, and found to impact approximately 25% (*marginal to poor* rating) and 8% (*poor* rating) of the stream miles with poor to very poor biological conditions. Epifaunal substrate is a visual observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. The varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates. Like embeddedness and in-stream habitat, epifaunal substrate is confounded by natural variability (i.e., streams will naturally have more or less available productive substrate). Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. Epifaunal substrate conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, where stable substrate is lacking, or particles are over 75% surrounded by fine sediment and/or flocculent material; and 2) marginal to poor, where large boulders and/or bedrock are prevalent and cobble, woody debris, or other preferred surfaces are uncommon.

Erosion Present was identified as significantly associated with degraded biological conditions in the Lower Monocacy River, and found to impact approximately 37% (*moderate to severe* rating) and 7% (*severe* rating) of the stream miles with poor to very poor biological conditions. Erosion Severity represents a visual observation that the stream discharge is frequently exceeding the ability of the channel and/or floodplain to attenuate flow energy, resulting in channel instability, which in turn affects bank stability. Where such conditions are observed, flow energy is considered to have increased in frequency or intensity, accelerating channel and bank erosion. Increased flow energy suggested by this measure is also expected to negatively influence stream biology. Erosion severity is described categorically as minimal, moderate, or severe. Conditions indicating biological degradation are set at two levels, moderate and severe. A level of moderate indicates that a marginal amount of stream banks show erosion and the stream segment shows elevated levels of instability due to erosion. A level of *severe* indicates that a substantial amount of stream banks show severe erosion and the stream segment exhibits high levels of instability due to erosion.

Poor bank stability index was identified as significantly associated with degraded biological conditions in the Lower Monocacy River, and found to impact approximately 16% of the stream miles with poor to very poor biological conditions. Bank stability index is a composite score that combines a visual rating based on the presence or absence of riparian vegetation and other stabilizing bank materials (e.g., boulders, root-wads) with quantitative measures of erosion extent and erosion severity. Banks Stability Index is based on a numeric score from 0-20, with low values as poor and high values as optimal. A poor bank stability index score indicates that the amount of stream bank soil that is being eroded and deposited in the stream is likely different from sites with fair to good biological conditions. In short, bank stability is a measure of channel erosion. Lower scores on this index are considered to demonstrate that discharge is frequently exceeding the ability of the channel and/or floodplain to attenuate flow energy. The index may further identify conditions, in which stream banks are vulnerable regardless of flood severity or frequency, thus demonstrate increased probability of high sediment loadings.

The Lower Monocacy River and its tributaries pass through low to high-density urban areas including: Frederick, Walkersville, New Market, and Woodsboro. Many portions of these areas were built before modern stormwater runoff controls were required by the State. The realization that human activities can seriously harm and degrade waterways led to the authorization of sediment control regulations in the early 1960s but a statewide sediment and erosion control program did not exist until 1970. About ten years later, in 1982, the Maryland General Assembly passed the State Stormwater Management Act, designed to address stormwater runoff generated during the land development process. Stormwater management helps to settle and filter many pollutants before runoff is discharged into a receiving body of water. But research indicates that most conventional stormwater management controls can still harm streams and rivers. Accelerated flow from stormwater management discharges can scour streams banks, deposit sediments, and decrease overall stream health, stability, and habitat diversity (FCG 2009).

As development and urbanization increased in the Lower Monocacy 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 and streambed scouring. The scouring associated with these increased flows leads to accelerated channel and bank 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 sedimentation are smothering of benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from embedding of the stream bottom (Hoffman et al. 2003). All of the stressors identified for the sedimentation parameter groups (e.g., high embeddedness, poor epifauanal substrate, erosion, and poor bank stability) are the typical effects of the scouring associated with a "flashy" hydrological regime.

The Lower Monocacy River watershed also contains a significant amount of agriculture within the watershed, which consists mostly of pasture /hay, row crop, but also includes dairy production. An average of ten times as much soil erodes from agricultural fields in the United States as is replaced by natural soil formation processes (Trautmann et al. 2009). Eroded soil clogs streams and rivers, resulting in increased flooding, and destruction of habitats for many species of fish and other aquatic life. The eroded soils contain nutrients and other pollutants that are beneficial on agricultural fields, but can impair water quality when carried away by erosion. Agricultural land use degrades streams by increasing inputs of sediments, impacting riparian and stream channel habitat, and altering flows (Cooper 1993). 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 loss of habitat heterogeneity, a continuous displacement of biological communities 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 with very poor to poor biological conditions. The combined AR for the sediment stressor group is approximately 71% suggesting these stressors impact a considerable proportion of the degraded stream miles in the Lower Monocacy River (See Table 5).

In-stream Habitat Conditions

BSID analysis results for the Lower Monocacy River identified one in-stream habitat parameter that has a statistically significant association with poor to very poor stream biological condition: *instream habitat structure (marginal to poor).*

Instream habitat structure (marginal to poor) was identified as significantly associated with degraded biological conditions in the Lower Monocacy River and found to impact approximately 31% 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 habit 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.

The stressor in-stream habitat structure is intricately linked to altered hydrology and a result of streams that experience "flashy" flow events. Streams that are degraded by high embeddeness, erosion, collapsing banks, and poor epifaunal substrate ratings normally have poor in-stream habitat structure. Sediments contained in run-off from the agricultural areas in the watershed could also contribute to lower in-stream habitat structure ratings.

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 31% suggesting this stressor impacts a moderate proportion of the degraded stream miles in the Lower Monocacy River (See Table 5).

Riparian Habitat Conditions

BSID analysis results for the Lower Monocacy River identified one riparian habitat parameter that has a statistically significant association with poor to very poor stream biological condition: *no riparian buffer.*

No riparian buffer was identified as significantly associated with degraded biological conditions in the Lower Monocacy River, and found to impact approximately 27% of the stream miles with poor to very poor biological conditions. Riparian Buffer Width represents the minimum width of vegetated buffer in meters, looking at both sides of the stream. Riparian buffer width is measured from 0 m to 50 m, with 0 m having no buffer and 50 m having a full buffer. Riparian buffers serve a number of critical ecological functions. They control erosion and sedimentation, modulate stream temperature, provide organic matter, and maintain benthic macroinvertebrate communities and fish assemblages (Lee et al. 2004). Natural forested headwater streams generally rely on allochthonous input of leaf litter as the major energy source, but agricultural land use typically reduces or eliminates the trees in the riparian area that would contribute detritus. This reduction can have strong impacts on stream communities; exclusion of leaf litter can decrease invertebrate biomass and/or abundance in many of the invertebrate shredder, collector and predator taxa (Wallace et al. 1997). Decreased riparian buffer also leads to reduced amounts of large wood in the stream. Stable wood substrate in streams performs multiple functions, influencing channel features, flow, habitat, and providing cover for fish.

A Stream Corridor Assessment survey was conducted in the Upper Linganore and Bennett Creek 12-digit watersheds of the Lower Monocacy River watershed by MD DNR to identify potential environmental problems in or along the edge of the streams. The survey was completed in the fall of 2003, and over eighty-five miles of stream were walked and assessed. Inadequate buffer sites were the most common problems observed in the two surveyed sub-watersheds (reported at 115 sites or 27.99 miles of stream). These sites typically ran through agricultural areas and at numerous sites, livestock had direct access to the stream. Excessive stream bank erosion was another problem common in the areas identified as having inadequate buffers (DNR 2004).

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 riparian habitat stressor group is approximately 27 %, suggesting this stressor impacts a moderate proportion of the degraded stream miles in the Lower Monocacy River (See Table 5).

Water Chemistry

BSID analysis results for the Lower Monocacy River identified eight 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 improved biological community). These parameters are *high total nitrogen*, *high total dissolved nitrogen*, *ammonia acute with salmonid present & absent*, *ammonia chronic with salmonid absent*, *high lab pH*, *high orthophosphate*, and *high conductivity*.

High total nitrogen concentrations were identified as significantly associated with degraded biological conditions in the Lower Monocacy River and found to impact approximately 37% of the stream miles with poor to very poor biological conditions. The total nitrogen (TN) parameter is the measure of the amount of TN in the water column. TN is comprised of organic nitrogen, ammonia nitrogen, nitrite and nitrate. Nitrogen plays a crucial role in primary production. Elevated levels of nitrogen can lead to excessive growth of filamentous algae and aquatic plants. Excessive nitrogen input also can lead to increased primary production, which potentially results in species tolerance exceedances of dissolved oxygen and pH levels. Runoff and leaching from agricultural land can generate high in-stream levels of nitrogen.

High total dissolved nitrogen concentrations were identified as significantly associated with degraded biological conditions in the Lower Monocacy River and found to impact approximately 36% of the stream miles with poor to very poor biological conditions. The total dissolved nitrogen (TDN) parameter is the measure of the amount of dissolved nitrogen in the water column. Nitrogen plays a crucial role in primary production. Dissolved nitrogen is the most readily available form of nitrogen for uptake by aquatic organisms.

Ammonia acute concentrations were identified as significantly associated with degraded biological conditions in the Lower Monocacy River, and found to impact approximately 7% (*with salmonid present*) and 8% (*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 one-time, sudden, high exposure of ammonia. Ammonia acute with salmonid present and absent is a USEPA water quality criterion for ammonia concentrations causing acute toxicity in surface waters where salmonid species of fish are present and absent (USEPA 2006). The ammonia (NH_3) parameter is the measure of the amount of NH_3 in the water column. NH_3 is a nitrogen nutrient species; in excessive amounts it has potential toxic effects on aquatic life. Ammonia is associated with increased primary production, increased pH, increased sunlight exposure, and high water temperature. 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.

Ammonia chronic with salmonid absent concentrations were identified as significantly associated with degraded biological conditions and found to impact approximately 7% of the degraded stream miles within the Lower Monocacy River. Chronic ammonia toxicity refers to potential exceedences of species tolerance caused by repeated exposure over a long period of time. Ammonia chronic with salmonid absent is a USEPA water quality criteria for NH_3 concentrations causing acute toxicity in surface waters where salmonid species of fish are absent (USEPA 2006).

High lab pH levels above 8.5 were identified as significantly associated with degraded biological conditions in the Lower Monocacy River, and found to impact approximately 17% of the stream miles with poor to very poor biological conditions. pH is a measure of the acid balance of a stream and uses a logarithmic scale range from 0 to 14, with 7 being neutral. MDDNR MBSS collects pH samples once during the spring, which are analyzed in the laboratory (*pH lab*), and measured once *in situ* during the summer (*pH field*). Most stream organisms prefer a pH range of 6.5 to 8.5. Exceedances of pH may allow concentrations of toxic elements (such as ammonia, nitrite, and aluminum) and high amounts of dissolved heavy metals (such as copper and zinc) to be mobilized for uptake by aquatic plants and animals. The pH threshold values, at which levels below 6.5 and above 8.5 may indicate biological degradation, are established from state regulations (COMAR 2007). Intermittent high pH (greater than 8.5) is often associated with elevated nutrient concentrations and eutrophication related to increased algal blooms.

High orthophosphate concentrations were identified as significantly associated with degraded biological conditions in the Lower Monocacy River, and found to impact approximately 14% of the stream miles with poor to very poor biological conditions. The orthophosphate (OP) parameter is the measure of the amount of OP in the water column. OP is the most readily available form of phosphorus for uptake by aquatic organisms. Phosphorus forms the basis of a very large number of compounds, the most important class of which are the phosphates. For every form of life, phosphates play an essential role in all energy-transfer processes such as metabolism and photosynthesis. Excessive phosphorus concentrations in surface water can accelerate eutrophication, resulting in increased growth of undesirable algae and aquatic weeds. Eutrophication can potentially result in low dissolved oxygen and high pH levels, which can exceed tolerance levels of many biological organisms. OP loads to surface waters typically increases in watersheds where urban and agricultural developments are predominant.

High conductivity levels were identified as significantly associated with degraded biological conditions in the Lower Monocacy River and found to impact approximately 11% 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 and Agricultural runoffs (i.e., fertilizers) as well as leaking wastewater infrastructure are typical sources of inorganic compounds.

Water chemistry is another major determinant of the integrity of surface waters that is strongly influenced by land-use. Agricultural land uses comprise 37 % of the Lower Monocacy River watershed. Agricultural land uses within the watershed as well as within the sixty meter riparian zone were found to be significantly associated with poor to very poor biological conditions in the watershed. Developed landscapes, particularly the proportion of agriculture in the catchments and the riparian zone, often results in increased inputs of nitrogen, phosphorus, and suspended sediments to surface waters. Elevated nutrient concentrations often result in greater algal production and changes in autotrophic community composition. However, the hypoxic conditions that high nutrient loading causes in lentic and coastal waters are uncommon in streams located in the highlands region and are likely to occur only in localized areas of slow-moving water (Carpenter et al. 1998). Although low dissolved oxygen was not found to have significant association with degraded biology in the Lower Monocacy River, the BSID analysis did identify high lab pH values. Intermittent high pH is often associated with elevated nutrient concentrations and eutrophication related to increased algal blooms.

Identification of ammonia toxicity by the BSID analysis is also indicative of degradation to water quality due to nutrient loading in the Lower Monocacy River watershed. Under natural conditions, nitrate and nitrite occur in moderate concentrations and are not generally harmful to most aquatic life. Ammonia, on the other hand, is highly toxic to aquatic organisms. Exposure to ammonia can produce acute and chronic toxic effects, including inhibition of growth, gill damage, and plasma ion disturbance in fish (Van De Nieuwegiessen 2008; Randall and Tsui 2002). A stream corridor assessment conducted by MD DNR in the Lower Monocacy River watershed found a number of incidences of livestock having direct access to the stream. One of the primary agricultural sources of ammonia to surface waters is livestock waste (Oemke and Borrello 2008).

There are fifty MBSS stations in the Lower Monocacy River watershed and minimal sampling for ammonia was conducted (onetime sample) at each station. Acute ammonia toxicity refers to potential exceedences of species tolerance caused by a one-time, sudden, high exposure of ammonia. However, chronic ammonia toxicity refers to potential exceedences of species tolerance caused by repeated exposure over a long period of time. To make an accurate determination of acute and chronic ammonia toxicity, MDE reviewed additional data to determine if there is ammonia toxicity impairment in these waters. During the years of 2000, 2001, 2002, 2003, 2004, 2005, and 2008, MDE collected eight hundred and thirty-seven water quality samples from the Lower Monocacy River watershed. Samples were collect at thirty-six stations through out the watershed, with most stations being sampled monthly for approximately a year. Of these samples, only one sample (<0.12%) had ammonia values above the USEPA water quality criteria for chronic toxicity, and there were no exceedances to the ammonia acute toxicity criteria (USEPA 2006). Due to these results from the MDE water quality data analysis, it was determined that ammonia toxicity is not a problem in the Lower Monocacy River watershed.

The BSID results demonstrate that orthophosphate (14%) concentrations are less of an impact on stream miles with poor to very poor biological conditions in the watershed, as compared to nitrogen concentrations (37%); this suggests phosphorus may be a limiting nutrient in the watershed (Allan 1996). Due to anthropogenic sources, the watershed is vulnerable to nutrient fluxes (e.g., rain events and stormwater) that could be detrimental to the biological community, additional analysis of available data (i.e., TN:TP ratio) is necessary to confirm if phosphorus concentrations are limiting in the watershed.

Nitrogen and phosphorus are essential nutrients for algae growth. If one nutrient is available in great abundance relative to the other, then the nutrient that is less available limits the amount of plant matter that can be produced; this is known as the "limiting nutrient." The amount of the abundant nutrient does not matter because both nutrients are needed for algae growth. In general, a Nitrogen: Phosphorus (TN:TP) ratio in the range of 5:1 to 10:1 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the TN:TP ratio is greater than 10:1, phosphorus tends to be limiting; if the TN:TP ratio is less than 5:1, nitrogen tends to be limiting (Chiandani and Vighi 1974).

To make an accurate determination of whether phosphorus or nitrogen concentrations are limiting in the watershed, MDE reviewed additional data. Out of 629 samples collected between 1998 and 2007, 7.9% had TN:TP ratio less than 10 and 1.4% had TN:TP ratios less than 5. The median TN:TP ratio for the samples was 38 and the average ratio was 69.2. Only one of the 50 samples collected by MBSS had a TN:TP less than 10 and none had a ratio less than 5. The median TN:TP ratio for MBSS samples was 53 and the average ratio was 179. Low TN:TP samples are more prevalent in the growing season: about 15% of the samples collected during the growing season over that time period were less than 10, although most of those samples were collected from the mainstem Monocacy River. Only about 2% of the 141 samples collected during the growing season in the smaller order streams had TN:TP ratios below 10. The observed data imply that the Lower Monocacy River watershed is phosphorus limited, particularly in smaller order streams and tributaries to the mainstem river (MDE 2012).

Point source discharges are a potential source of nutrient to surface waters. There are seventeen municipal and thirteen industrial discharges in the Lower Monocacy River watershed. Nutrient loads from any wastewater treatment facility are dependent on discharge volume, level of treatment process, and sophistication of the processes and equipment.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the water chemistry stressor group is approximately 76% suggesting that these stressors impact a substantial proportion of degraded stream miles in the Lower Monocacy River (Table 5).

Sources

All sixteen stressor parameters, identified in Tables 1-3, that are significantly associated with biological degradation in the Lower Monocacy River watershed BSID analysis are representative of impacts from urban and agricultural landscapes. The watershed contains numerous urban centers including, Frederick, New Market, Walkersville, and Woodsboro. Many of these areas were built before modern stormwater runoff controls were required by the State. There is also a significant amount of agriculture within the watershed, which consists mostly of pasture /hay, row crop, but also includes dairy production.

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. Numerous studies have also documented declines in water quality, habitat, and biological assemblages as the extent of agricultural land increases within catchments (Roth et al. 1996, Wang et al. 1997, & Bis et al. 2000). Researchers commonly report that streams draining agricultural lands support fewer species of sensitive benthic and fish taxa than streams draining forested catchments (Wang et al. 1997). Agricultural land use degrades streams by increasing nonpoint inputs of pollutants, impacting riparian and stream channel habitat, and altering flows.

Increases in impervious surface cover that accompany urbanization alters 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 by adding sediments, nutrients, road salts, toxics, and inorganic pollutants to surface waters. 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).

Changes to stream hydrology due to increased agricultural land use are variable, depending on crop evapotranspiration rates compared with natural vegetation, changes to soil infiltration capacity, extent of drainage systems, and, if there is irrigation. Storm event flows commonly increase in magnitude and frequency, especially where runoff is enhanced due to drainage ditches, subsurface drains, and loss of wetland area (Allan 2004). In addition to the impact of flow extremes on erosion and habitat, high flows can also eliminate taxa if such events occur during sensitive life stages. Macroinvertebrates that are able to withstand dislodgement or that have short and fast life cycles and good colonizing ability tend to be the dominant species in highly agricultural streams (Richards et al. 1997). Alterations to flow regime affect stream fishes by downstream displacement of early life stages and disruption of spawning (Schlosser 1985).

Streams in highly agricultural landscapes tend to have poor habitat quality, reflected in declines in habitat indexes and bank stability, as well as greater deposition of sediments on and within the streambed (Roth et al. 1996 & Wang et al. 1997). Sediments in runoff from cultivated land and livestock trampling are considered to be particularly influential in stream impairment (Waters 1995). The BSID analysis identified pasture/hay land use as significant not only in the watershed but also in the riparian buffer zone. Numerous studies have identified the most extreme effect of pasture/hay land use were due to animals being allowed access to streams causing increased bank erosion and concurrent increases in sediment and ammonia loads (Lyons et al. 2000).

Agricultural land use is an important source of pollution when rainfall carries sediment, fertilizers, manure, and pesticides into streams. The three major nutrients in fertilizers and manure are nitrogen, phosphorus, and potassium. The agricultural land uses in the Lower Monocacy River watershed are potential sources for the elevated levels of TN, TDN, OP, and conductivity.

The BSID source analysis (Table 4) identifies various types of urban and agricultural land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for this source group is approximately 84% suggesting that urban and agricultural development potentially impacts a substantial proportion of the degraded stream miles in Lower Monocacy River (Table 6).

Summary

The BSID analysis results suggest that degraded biological communities in the Lower Monocacy River watershed are a result of increased urban and agricultural land uses causing alteration to hydrology and increased sedimentation, resulting in an unstable stream ecosystem that eliminates habitat heterogeneity. High proportions of these land uses, specifically within the riparian buffer zones, also typically results in increased contaminant loads of sediments and nutrients to surface waters, resulting in levels of nutrients that can potentially be toxic to aquatic organisms. Alterations to the hydrologic regime, physical habitat, riparian buffer, and water chemistry have all combined to degrade the Lower Monocacy River, leading to a loss of diversity in the biological community. The combined AR for all the stressors is approximately 92%, suggesting that altered hydrology/sediment, habitat, and water chemistry stressors adequately account for the biological impairment in the Lower Monocacy River.

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 Lower Monocacy 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 ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr, 1991and USEPA 2009). 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 Lower Monocacy River, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

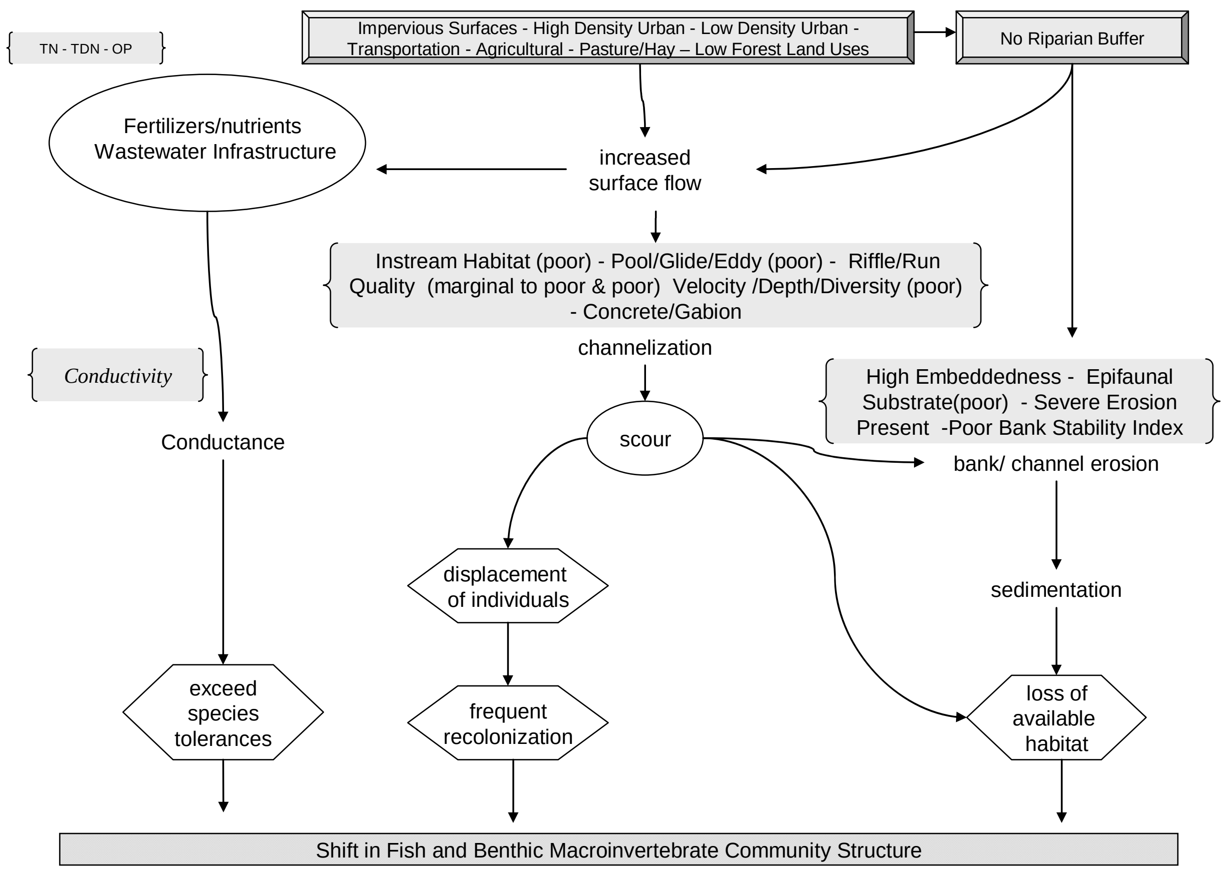

Figure 6. Final Causal Model for the Lower Monocacy River Watershed

5.0 Conclusion

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

- The BSID process has determined that biological communities in Lower Monocacy River are also likely degraded due to sediment and in-stream habitat related stressors. Specifically, altered hydrology and increased runoff from urban impervious surfaces have resulted in channel erosion and subsequent elevated suspended sediment in the watershed, which are in turn, the probable causes of impacts to biological communities. The BSID results confirm that the establishment of a USEPA approved sediment TMDL in 2009 was an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Lower Monocacy River.

- The BSID analysis has determined that both orthophosphates and nitrogen are probable causes of impacts to biological communities in the Lower Monocacy River watershed. Elevated concentrations of orthophosphate show association with degraded biological conditions; as much as 14% of the biologically impacted stream miles in the watershed may be degraded due to high orthophosphate. Similarly, according to the BSID analysis, 37% of the biologically impacted stream miles in the Lower Monocacy River watershed are associated with high total nitrogen concentrations. An analysis of observed TN:TP ratios, however, indicate that phosphorus is the limiting nutrient in the watershed. Because nitrogen generally exists in quantities greater than necessary to sustain algal growth, excess nitrogen per se is not the cause of the biological impairment in the Lower Monocacy River, and the reduction of nitrogen loads would not be an effective means of ensuring that the watershed is free from impacts on aquatic life from eutrophication. Therefore, load allocations for the Lower Monocacy River Nutrient TMDL will apply only to total phosphorus. The BSID results thus confirm the 2010 Category 5 listing for phosphorus as an impairing substance in the Lower Monocacy River watershed, and link this pollutant to biological conditions in these waters.

- The BSID process has also determined that biological communities in the Lower Monocacy River watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards as a result of pollution. MDE recommends a Category 4c listing for the Lower Monocacy River watershed based on inadequate riparian buffer zones in approximately 27% of degraded stream miles.

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