Watershed Report for Biological Impairment of the Upper Monocacy River Watershed in Frederick and Carroll Counties, Maryland Biological Stressor Identification Analysis Results and Interpretation

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
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
mg/L	Milligrams per liter
NH_3	Ammonia
OP	Orthophosphate
SCA	Stream Corridor Assessment
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
µeq/L	Micro equivalent per liter
µS/cm	Micro Seimens per centimeter
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
WRAS	Watershed Restoration Action Strategy

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 Upper Monocacy River watershed (basin code 02140303) has multiple listings on the 2010 Integrated Report (MDE 2010). Below is a table identifying the listings associated with this watershed.

Table E1. 2010 Integrated Report Listings for Upper Monocacy River Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Upper Monocacy River	02140303	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
				1996	TP	5
				1996	TSS	4a
			Fishing		PCB in Fish Tissue	3
					Mercury in Fish Tissue	3
			Water Contact Sport	2002	Fecal Coliform	4a
		Impoundment Hunting Creek Lake	Aquatic Life and Wildlife		TP	3

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 with poor to very poor biological conditions, and calculating whether they differ significantly from a reference condition watershed (i.e., healthy stream, less than 10% stream miles poor to very poor biological conditions).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Upper Monocacy River and tributaries is Use IV-P *recreational trout waters and public water supply*, except for Fishing Creek, Hunting Creek, Owens Creek, Tuscarora Creek, and Friends Creek, which are designated as Use III-P - *nontidal cold water and public water supply* (COMAR 2009 a,b,c). The Upper 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 Upper 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 Upper Monocacy River watershed is strongly influenced by agricultural land use and its concomitant effects: altered hydrology and elevated levels of sediments and nutrients. 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

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 Upper Monocacy River watershed can be summarized as follows:

- The BSID process has determined that biological communities in the Upper Monocacy River watershed are likely degraded due to sediment, in-stream, and riparian habitat related stressors. Specifically, altered hydrology and increased runoff from agricultural uses 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 sediment TMDL was an appropriate management action to begin addressing this stressor to the biological communities in the Upper Monocacy River.

- The BSID analysis has determined that both phosphorus and nitrogen are probable causes of impacts to biological communities in the Upper Monocacy River watershed. Both total phosphorus and orthophosphate show a significant association with degraded biological conditions; as much as 33% of the biologically impacted stream miles in the watershed may be degraded due to high total phosphorus (TP) and high orthophosphate (OP). Similarly, according to the BSID analysis, 20% of the biologically impacted stream miles in the Upper Monocacy River watershed are associated with high total nitrogen (TN) 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 watershed, and the reduction of nitrogen loads would not be an effective means of ensuring that the Upper Monocacy River watershed is free from impacts on aquatic life from eutrophication. Therefore, load allocations for the Upper 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 Upper Monocacy River watershed, and link this pollutant to biological conditions in these waters.

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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 2010). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or black water streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is still considered impaired but has a TMDL that has been completed or submitted to EPA it will be listed as Category 4a). If the state can demonstrate that watershed impairment is a result of pollution, but not a pollutant the watershed is listed under Category 4c. 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 Upper Monocacy River watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Upper 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 Maryland portion of the Upper Monocacy River watershed totals 244.5 square miles in parts of Frederick and Carroll Counties (see Figure 1). The watershed is located in the Highland region of three distinct eco-regions identified in the MBSS Index of Biotic Integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

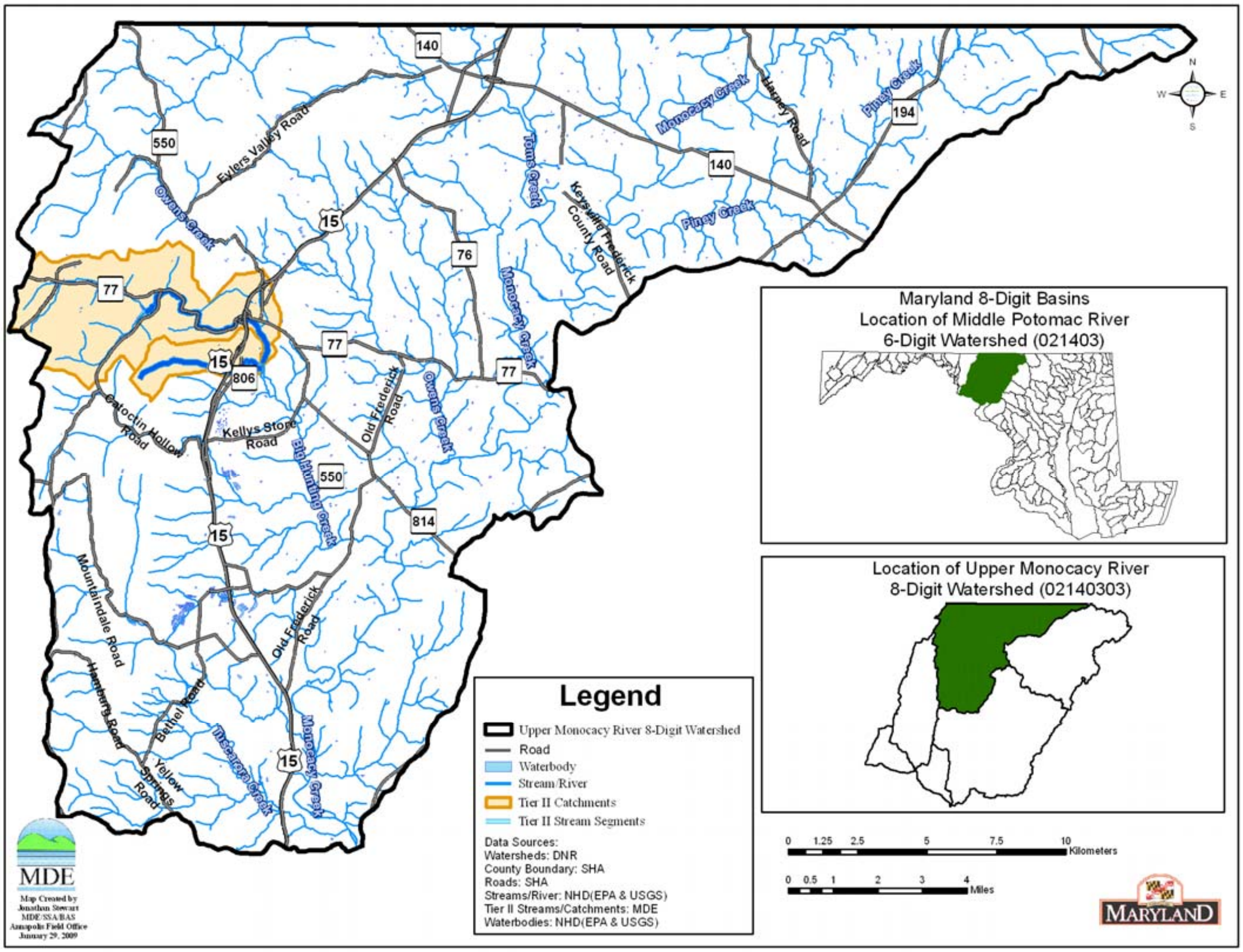

Figure 1. Location Map of the Upper Monocacy River Watershed

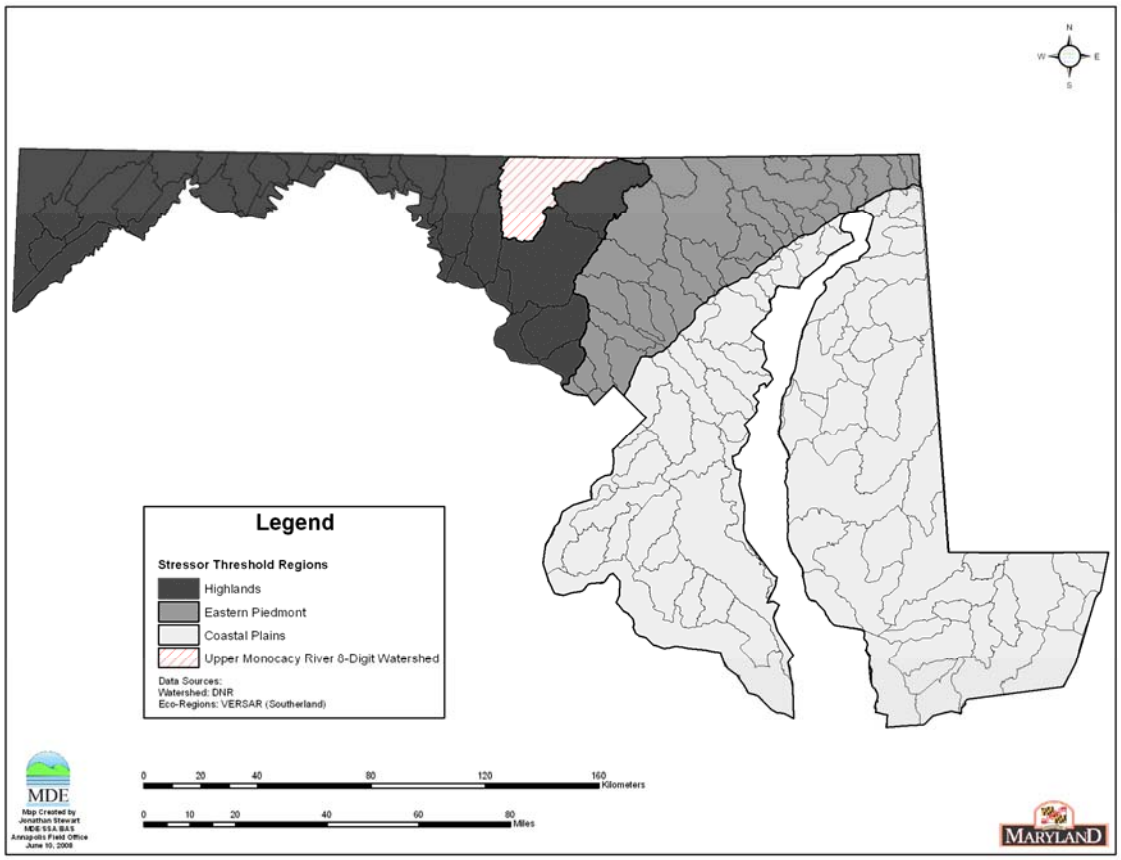

Figure 2. Eco-Region Location Map of the Upper Monocacy River Watershed

2.2 Land Use

The majority of the Upper Monocacy River watershed is located in Frederick County, with a small portion located in Carroll County. The Upper Monocacy River and its tributaries flow through several small towns, including Thurmont, Taneytown, and Emmitsburg. The basin receives drainage from the Double Pipe Creek basin, as well as from areas in Pennsylvania. The Upper Monocacy River watershed contains mostly agricultural and forested land uses (see Figure 3). The land use distribution in the watershed is approximately 45% agricultural, 41% forest, and 14% urban (see Figure 4) (USEPA 2010).

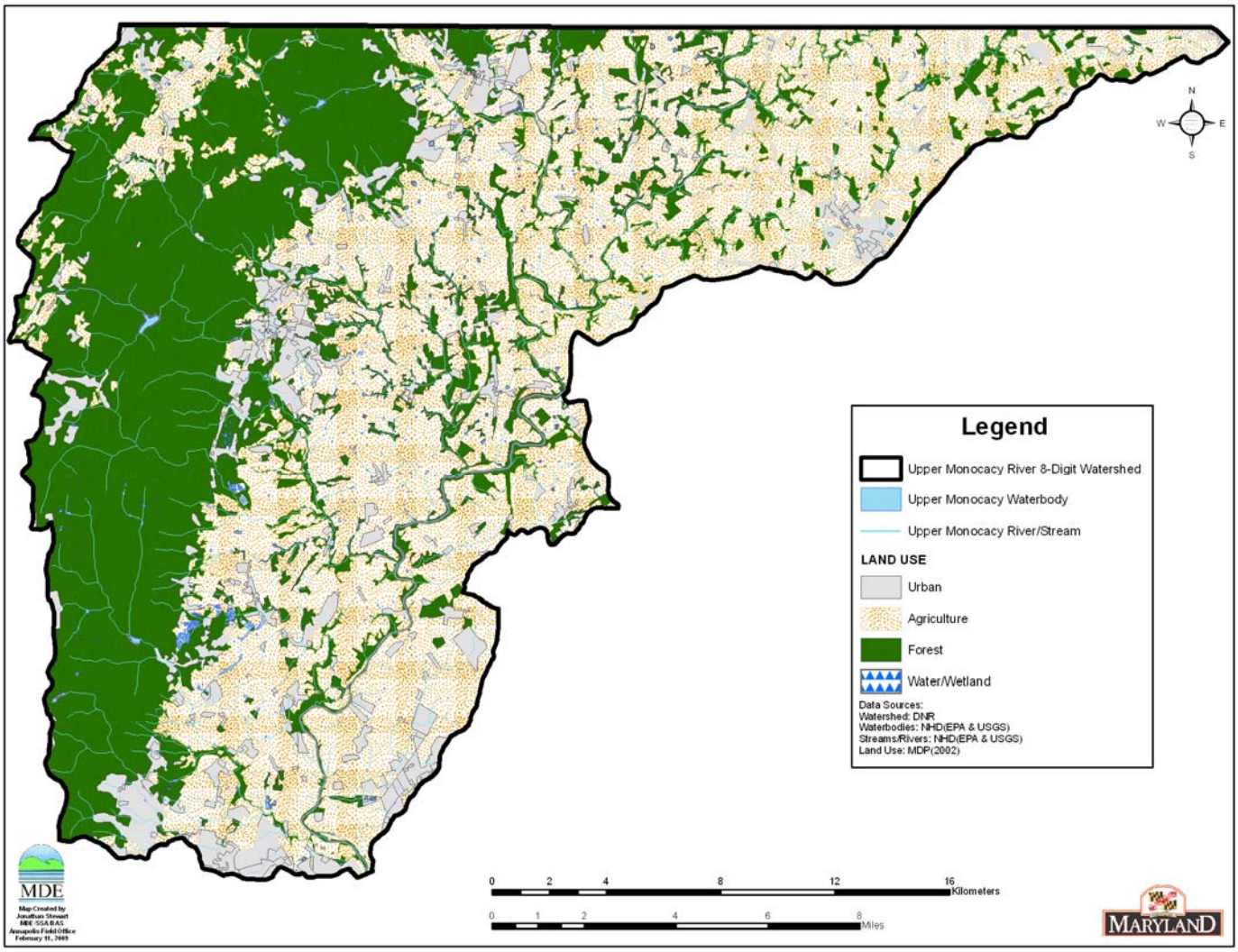

Figure 3. Land Use Map of the Upper Monocacy River Watershed

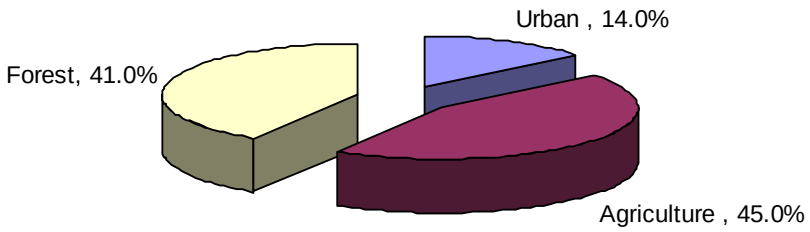

Figure 4. Proportions of Land Use in the Upper Monocacy River Watershed

2.3 Soils/hydrology

The Upper Monocacy River watershed lies within the both the Piedmont Plateau and Blue Ridge physiographic provinces of Maryland. The Piedmont Plateau Province is located west of the Fall Line and extends to Braddock Mountain/the Catoctin Mountains, with elevations ranging from 400 to 800 feet above sea level. The Blue Ridge Province extends from Braddock Mountain/the Catoctin Mountains in the east, to South Mountain in the west, with a maximum elevation of 2145 feet at Quirauk Mountain, which is located just south of the Mason-Dixon line in Maryland (MGS 2007; MDE 2000). The Upper Monocacy River watershed is composed of hard, crystalline igneous and metamorphic rocks underlying the Piedmont Plateau Province, and folded and faulted sedimentary rocks underlying the Blue Ridge Province. Soils of the Piedmont Plateau Province are derived from granite rock and consist of loams and clays with rock fragments and gravel; soils in the Blue Ridge Province are mountainous soils composed of sandy or stony loams (MDDNR 2007; MGS 2007). The soils in the Upper Monocacy River watershed are in the Klinesville, Catoctin, Athol, and Codorus Associations, which are all loamy, mixed, and methic soil types (USDA 1960, 1969).

3.0 Upper Monocacy River Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Upper Monocacy River watershed (basin code 02140303) has multiple listings on the 2010 Integrated Report (MDE 2010). Below is a table identifying the listings associated with this watershed.

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Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
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			Water Contact Sport	2002	Fecal Coliform	4a
		Impoundment Hunting Creek Lake	Aquatic Life and Wildlife		TP	3

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Upper Monocacy River and tributaries is Use IV-P *recreational trout waters and public water supply*, except for Fishing Creek, Hunting Creek, Owens Creek, Tuscarora Creek, and Friends Creek, which are designated as Use III-P - *nontidal cold water and public water supply* (COMAR 2009 a,b,c). 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 Upper Monocacy River watershed is listed under Category 5 of the 2008 Integrated Report as impaired for evidence of biological impacts. Approximately 62% of stream miles in the Upper 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 fifty-seven sites. Forty-three of the fifty-seven have degraded benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., very poor to poor). The principal dataset (i.e., MBSS Round 2) contains twenty-one MBSS sites with eleven having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations in the Upper Monocacy River watershed.

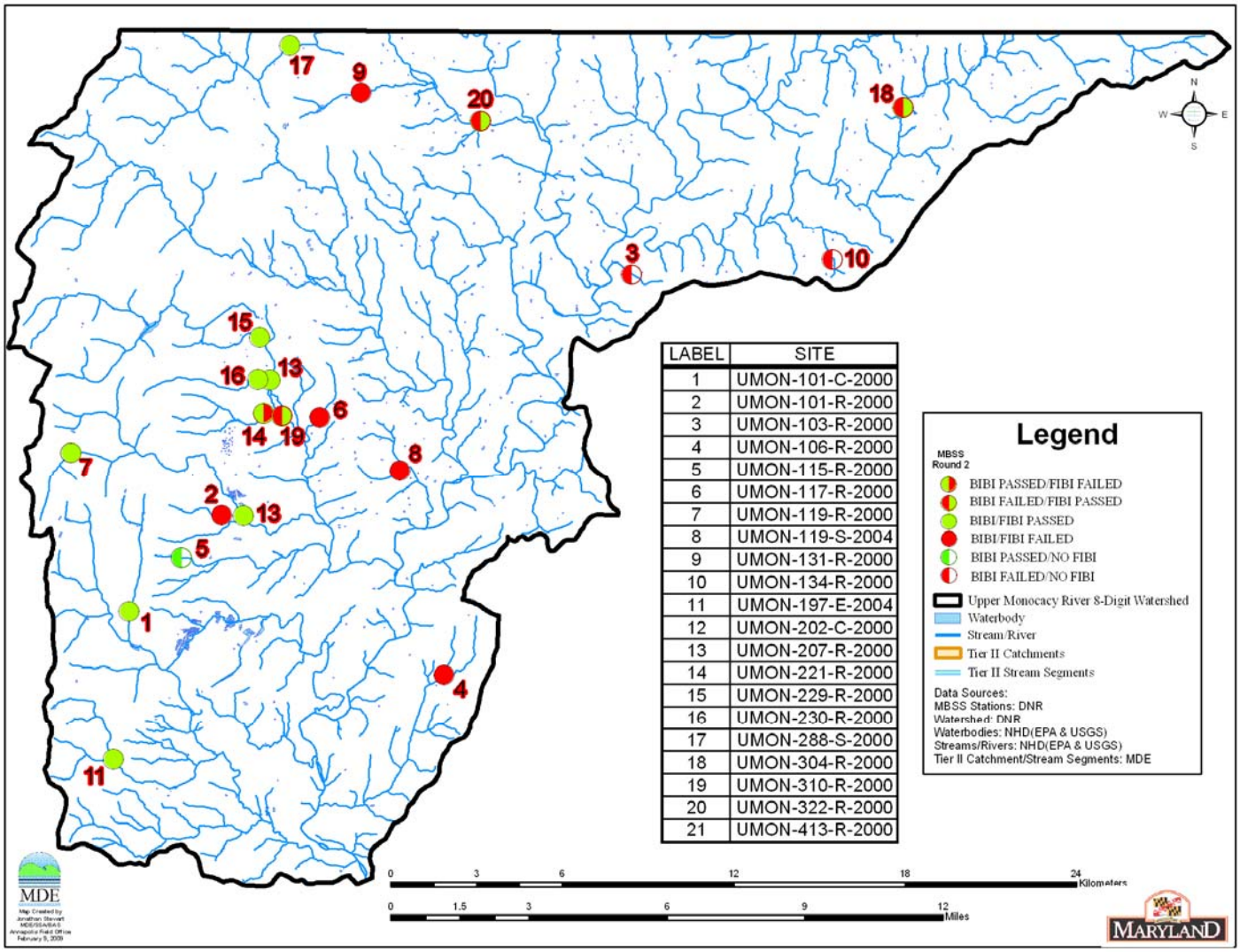

Figure 5. Principal Dataset Sites for the Upper Monocacy River Watershed

4.0 Upper Monocacy River Watershed 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 fair to good biological conditions.

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenzel (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are 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 analysis, MDE identified various agricultural land uses, sediment, habitat, and water chemistry parameters significantly associated with degraded fish and/or benthic biological conditions. Parameters identified as representing sources are listed in Table 2. A summary of combined AR values for each source group is shown in Table 3. As shown in Table 4 through Table 6, are the parameters identified as possible biological stressors in the Upper Monocacy River watershed. A summary of combined AR values for each stressor group is shown in Table 7.

Table 2. Stressor Source Identification Analysis Results for the Upper 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 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 - Urban	high impervious surface in watershed	21	11	156	0%	1%	No	----
	high % of high intensity urban in watershed	21	11	159	9%	4%	No	----
	high % of low intensity urban in watershed	21	11	159	9%	8%	No	----
	high % of transportation in watershed	21	11	159	9%	9%	No	----
	high % of high intensity urban in 60m buffer	21	11	159	9%	6%	No	----
	high % of low intensity urban in 60m buffer	21	11	159	9%	7%	No	----
	high % of transportation in 60m buffer	21	11	159	18%	9%	No	----
Sources - Agr	high % of agriculture in watershed	21	11	159	55%	6%	Yes	49%
	high % of cropland in watershed	21	11	159	9%	6%	No	----
	high % of pasture/hay in watershed	21	11	159	55%	8%	Yes	47%
	high % of agriculture in 60m buffer	21	11	159	55%	6%	Yes	49%
	high % of cropland in 60m buffer	21	11	159	0%	4%	No	----
	high % of pasture/hay in 60m buffer	21	11	159	55%	8%	Yes	47%

Table 4. Stressor Source Identification Analysis Results for the Upper 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 - Barren	high % of barren land in watershed	21	11	159	55%	7%	Yes	48%
	high % of barren land in 60m buffer	21	11	159	45%	6%	Yes	39%
Sources - Anthropogenic	low % of forest in watershed	21	11	159	55%	5%	Yes	50%
	low % of forest in 60m buffer	21	11	159	27%	6%	Yes	22%
Sources - Acidity	atmospheric deposition present	21	11	159	0%	39%	No	----
	AMD acid source present	21	11	159	0%	4%	No	----
	organic acid source present	21	11	159	0%	3%	No	----
	agricultural acid source present	21	11	159	0%	1%	No	----

Table 3. Summary of Combined AR Values for Source Groups for the Upper 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	----	76%
Agriculture	49%	
Barren Land	48%	
Anthropogenic	50%	
Acidity	----	

4.1 Sources Identified by BSID Analysis

All eight source parameters, identified in Tables 1-3, that are significantly associated with biological degradation in the Upper Monocacy River watershed BSID analysis, are representative of impacts from agricultural landscapes.

The land sources identified (a *high percentage of agriculture, pasture/hay, barren land and a low percentage of forest*) in both the watershed and buffer zones are indicative of anthropogenic activities that result in altered natural landscapes and flow regimes, and increased inputs of nutrients and contaminants to streams. Approximately half of the land uses in the Upper Monocacy watershed are agricultural. Agricultural land use degrades streams by increasing nonpoint inputs of pollutants, impacting riparian and stream channel habitat, and altering flows (Allan, 2004).

Agricultural land uses are the leading sources of impairment in assessed streams throughout the United States (USEPA 2009). Agricultural land uses that cause or accelerate destabilization of streambanks, such as channelization or livestock trampling, can increase the delivery of sediment. Unrestricted livestock access to streams results in the destruction of the buffering capacity of the riparian zone, and ultimately sedimentation of the streambed (Waters 1995).

The BSID source analysis (Table 2) identifies various types of agricultural land uses in the watershed and buffer zones as potential sources of stressors that may cause negative biological impacts. The *low percentage of forest land use* and *high percentage of barren land* are likely a result of the increased agriculture in the watershed. Therefore, increases in agricultural land uses are a possible source at approximately 76% of stream miles with very poor to poor biological conditions (Table 3).

All the stressors identified in the BSID analysis for the Upper Monocacy River watershed (Table 4, Table 5, and Table 6) can be linked to the typical consequences of agricultural development. The remainder of this section will discuss identified stressors and their link to degraded biological conditions in the watershed.

Table 4. Sediment Biological Stressor Identification Analysis Results for the Upper 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 that odds or 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	21	11	81	9%	9%	No	----
	moderate bar formation present	21	11	77	45%	44%	No	----
	bar formation present	21	11	81	82%	89%	No	----
	channel alteration marginal to poor	21	11	77	45%	42%	No	----
	channel alteration poor	21	11	77	9%	9%	No	----
	high embeddedness	20	11	77	18%	4%	Yes	14%
	epifaunal substrate marginal to poor	21	11	77	36%	20%	No	----
	epifaunal substrate poor	21	11	77	0%	4%	No	----
	moderate to severe erosion present	21	11	77	27%	25%	No	----
	severe erosion present	21	11	77	18%	2%	Yes	16%
	poor bank stability index	21	11	77	0%	4%	No	----
	silt clay present	21	11	77	100%	99%	No	----

Table 5. Habitat Biological Stressor Identification Analysis Results for the Upper 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 that odds or 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	21	11	81	9%	10%	No	----
	instream habitat structure marginal to poor	21	11	77	27%	23%	No	----
	instream habitat structure poor	21	11	77	0%	2%	No	----
	pool/glide/eddy quality marginal to poor	21	11	77	73%	50%	No	----
	pool/glide/eddy quality poor	21	11	77	9%	7%	No	----
	riffle/run quality marginal to poor	21	11	77	64%	35%	Yes	29%
	riffle/run quality poor	21	11	77	18%	7%	No	----
	velocity/depth diversity marginal to poor	21	11	77	73%	54%	No	----
	velocity/depth diversity poor	21	11	77	9%	9%	No	----
	concrete/gabion present	21	11	81	0%	3%	No	----
	beaver pond present	21	11	77	0%	2%	No	----
Riparian Habitat	no riparian buffer	21	11	81	27%	24%	No	----
	low shading	21	11	77	27%	10%	Yes	17%

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Upper 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 that odds or 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	21	11	159	27%	8%	Yes	20%
	high total disolved nitrogen	19	10	50	20%	6%	No	----
	ammonia acute with salmonid present	21	11	159	36%	2%	Yes	34%*
	ammonia acute with salmonid absent	21	11	159	36%	1%	Yes	35%*
	ammonia chronic with salmonid present	21	11	159	36%	4%	Yes	33%*
	ammonia chronic with salmonid absent	21	11	159	36%	2%	Yes	34%*
	low lab pH	21	11	159	0%	5%	No	----
	high lab pH	21	11	159	0%	1%	No	----
	low field pH	21	11	154	0%	14%	No	----
	high field pH	21	11	154	0%	0%	No	----
	high total phosphorus	21	11	159	36%	3%	Yes	33%
	high orthophosphate	21	11	159	36%	4%	Yes	33%
	dissolved oxygen < 5mg/l	21	11	154	0%	3%	No	----
	dissolved oxygen < 6mg/l	21	11	154	0%	7%	No	----
	low dissolved oxygen saturation	20	10	138	0%	4%	No	----
	high dissolved oxygen saturation	20	10	138	0%	1%	No	----
	acid neutralizing capacity below chronic level	21	11	159	0%	6%	No	----
	acid neutralizing capacity below episodic level	21	11	159	0%	43%	No	----
	high chlorides	21	11	159	0%	7%	No	----
	high conductivity	21	11	159	9%	4%	No	----
	high sulfates	21	11	159	0%	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 21)**

Table 7. Summary of Combined AR Values for Stressor Groups for the Upper 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	34%	67%
In-Stream Habitat	29%	
Riparian Habitat	17%	
Water Chemistry	52%	

4.2 Stressors Identified by BSID Analysis

Sediment Conditions

BSID analysis results for the Upper Monocacy River watershed identified two sediment parameters that have a statistically significant association with poor to very poor stream biological condition: *high embeddedness and severe erosion present.*

High embeddedness was identified as significantly associated with degraded biological conditions in the Upper Monocacy River watershed, and found to impact approximately 14% 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 evidence of excessive sediment deposition. 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.

Severe erosion present was identified as significantly associated with degraded biological conditions in the Upper Monocacy River watershed, and found to impact approximately 16% 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. 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.

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

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 34% suggesting these stressors impact a moderate proportion of the degraded stream miles in the Upper Monocacy River watershed (Table 7).

In-stream Habitat Conditions

BSID analysis results for the Upper Monocacy River watershed identified one in-stream habitat parameter that has a statistically significant association with poor to very poor stream biological condition: *riffle run quality marginal to poor*.

Riffle run quality was identified as significantly associated with degraded biological conditions in the Upper Monocacy River watershed, and found to impact approximately 29% (*marginal to poor* rating) 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. Marginal to poor and poor ratings are expected in unstable stream channels that experience frequent high flows.

The marginal to poor riffle run quality identified by the BSID can be indicative of anthropogenic activities that result in increased high flows and sediment deposition. Altered flow regimes can disrupt the natural pattern of riffles and pools in a stream (MDDNR 2005a). In conjunction with the sediment stressors identified above, the *marginal to poor riffle run quality* rating further supports an altered hydrology characterized by frequent high flows, accelerated channel erosion, and sediment deposition.

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 29%, suggesting these stressors impact a moderate proportion of the degraded stream miles in the Upper Monocacy River watershed (Table 7).

Riparian Habitat Conditions

BSID analysis results for the Upper Monocacy River watershed identified one riparian habitat parameter that has a statistically significant association with poor to very poor stream biological condition: *low shading.*

Low shading was identified as significantly associated with degraded biological conditions in the Upper Monocacy River watershed, and found to impact approximately 17% of the stream miles with poor to very poor biological conditions. Low shading indicates the percentage of the stream segments that are shaded, taking duration into account. Solar radiation can increase the temperature of stream segments causing thermal stress on fish and invertebrates. Low shading indicates a lack of forested buffers along the streambank.

The low shading identified by the BSID can be indicative of anthropogenic activities within the stream buffer zones (i.e, agriculture, hay/pasture, barren land) that have replaced forests with low-lying vegetation. This vegetation is characterized by less extensive root systems that are not as efficient as mature forests in controlling runoff. The MDDNR evaluated the extent and condition of riparian buffers throughout Maryland and found that the land use immediately adjacent to the riparian buffer may affect the volume of pollutants in runoff. Forested watersheds tend to have the lowest nutrient output and runoff, while agricultural lands tend to have much higher nutrient loads and higher runoff (MDDNR 2005b).

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 17% suggesting this stressor impacts a minimal proportion of the degraded stream miles in the Upper Monocacy River watershed (Table 7).

Water Chemistry

BSID analysis results for the Upper Monocacy River watershed identified seven 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, ammonia acute with salmonid present and absent, ammonia chronic with salmonid present and absent, high total phosphorus, and high orthophosphate.*

High total nitrogen concentrations levels were identified as significantly associated with degraded biological conditions and found to impact approximately 20% of the degraded stream miles within the Upper Monocacy River watershed. Total nitrogen (TN) is a measure of the amount of TN in the water column. TN is comprised of organic nitrogen, ammonia nitrogen, nitrite and nitrate. Elevated levels of bioavailable forms of nitrogen can be toxic to aquatic organisms. Application of fertilizers and manure can runoff and leach from agricultural land and generate high in-stream levels of nitrogen compounds. Nitrogen in manure is primarily in the form of organic nitrogen and ammonia nitrogen compounds.

Ammonia acute concentrations were identified as significantly associated with degraded biological conditions in the Upper Monocacy River watershed, and found to impact approximately 34% (*with salmonid present*) and 35% (*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 criteria for ammonia concentrations causing acute toxicity in surface waters where salmonid species of fish are present and absent (USEPA 2006). Ammonia (NH_3) is a 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. Increased nutrient loads from urban and agricultural land uses are a source of NH_3.

Ammonia chronic concentrations were identified as significantly associated with degraded biological conditions in the Upper Monocacy River watershed, and found to impact approximately 33% (*with salmonid present*) and 34% (*with salmonid absent*) of the stream miles with poor to very poor biological conditions. 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 ammonia concentrations causing acute toxicity in surface waters where salmonid species of fish are absent (USEPA 2006) (see ‘ *ammonia acute*’ above).

High total phosphorus levels were identified as significantly associated with degraded biological conditions and found to impact approximately 33% of the degraded stream miles within the Upper Monocacy River watershed. Total Phosphorus (TP) is a measure of the amount of TP in the water column. Phosphorus occurs naturally in rocks and other mineral deposits, and is usually found in the form of phosphates in natural waters. The majority of phosphate mined in the United States is used for fertilizers, with a minor component used for animal feed supplements and other products. Anthropogenic sources of phosphorus are fertilizers, chemicals, animal waste and municipal sewage. TP input to surface waters typically increases in watersheds where urban and agricultural land uses are predominant.

High orthophosphate concentrations were identified as significantly associated with degraded biological conditions and found to impact approximately 33% of the degraded stream miles within the Upper Monocacy River watershed. Orthophosphate (OP) is the

most readily available form of phosphorus for uptake by aquatic organisms, and is usually found in low concentrations in natural waters. Anthropogenic sources of OP are partially treated and untreated sewage, agricultural runoff and fertilizer applications. OP readily binds to sediment, and can be transported in runoff; consequently, OP input to surface waters typically increases in watersheds where urban and agricultural land uses are predominant.

The water chemistry stressors (TN, TP, OP, and NH_3 both acute and chronic) identified by the BSID can be indicative of anthropogenic activities that degrade water quality by causing an increase in contaminant loads from various point and nonpoint sources. These sources can add sediments, nutrients, fertilizers, and inorganic pollutants to surface and ground waters at levels potentially toxic to aquatic organisms.

Point source discharges are a potential source of nutrient and suspended solids to surface waters. There are eleven municipal and eight industrial discharges in the Upper Monocacy River watershed. Nutrient and suspended solid loads from any wastewater treatment facility is dependent upon the discharge volume, the level of treatment process, and the sophistication of the processes and equipment. Four urban areas influencing the Upper Monocacy River watershed are Thurmont, Emmitsburg, Walkersville, and Frederick. The Watershed Restoration Action Strategy (WRAS), conducted in the Frederick County portion of the watershed, reported critical problems in four municipalities and other urbanized areas including degraded sewer system infrastructure that has resulted in raw or partially treated sewage entering streams; antiquated or nonexistent stormwater management in older subdivisions; and inadequately maintained septic systems in older communities and floodplains (FCDPW 2005).

Non-point sources, stemming from land use activities in the watershed and the riparian zone, often result in increased inputs of nutrients to surface waters as rainfall carries sediment, fertilizers, manure, and pesticides into streams. A stream corridor assessment (SCA) was conducted as part of the WRAS mentioned above. Survey crews evaluated over 130 miles of stream within 6 sub-watersheds in November 2004. During the SCA, the most frequently observed problems were inadequately forested buffers and erosion (MDDNR 2004). As described earlier in this section, the BSID analysis identified sediment, and in-stream and riparian habitat stressors that support this finding. The SCA also observed 15 instances of livestock with direct access to streams within 4 of the 6 sub-watersheds (MDDNR 2004). This activity, along with application of manure as a nutrient-rich soil amendment, contributes to the elevated nutrient levels identified by the BSID water chemistry stressors.

There are twenty-one MBSS stations in the Upper 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 1989, 2000, 2001, 2002, 2003, 2004, and 2008, MDE collected seven hundred and twenty water quality samples from the Upper Monocacy River watershed. Samples were collect at forty-eight stations through out the watershed, with most stations being sampled monthly for multiple years. Of these samples, no samples had ammonia values above the USEPA water quality criteria for acute and chronic 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 Upper Monocacy River 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).

Although over 80% of the samples collected in the Upper Monocacy River watershed 1998-2007 have TN:TP ratios above 10, about 6% of the samples have ratios below 5. Low TN:TP samples are more prevalent in the growing season: almost 30% of the samples have ratios below 10, although less than 3% have ratios below 5. In contrast, only one of the 31 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 40 and the average ratio was 77.

The significant fraction of samples with TN:TP ratios below 10 seems to be a function of the large number of samples collected under the extremely low flow conditions in 2002. Significant denitrification occurs under extremely low flows, reducing TN:TP ratios (Borchardt 1996). The effect is compounded in the Upper Monocacy River mainstem and some of the larger tributaries because under extremely low flow conditions, much of the flow is derived from WWTPs which tend to have low TN:TP ratios. Nearly 35% of the samples taken in tributaries during the growing season have TN:TP ratios below 10; 12% have ratios below 5. All of the samples with ratios below 5, and all but three of the samples with ratios below 10, were collected under the extremely dry conditions in 2002. When samples from 2002 are excluded, less than 5% of the samples have ratios below 10 and none have ratios below 5; the median ratio is 27 and the average is 38, indicating that outside of extremely low flow conditions, the tributaries and smaller order streams in the Upper Monocacy River are predominately phosphorus limited (MDE 2012).

The conjunction of this analysis with the analysis of the TN:TP ratios from MBSS samples strongly supports the conclusion that phosphorus is the limiting nutrient in the

tributaries and smaller order streams in the Upper Monocacy River watershed (MDE 2012).

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 52% suggesting these stressors impact a considerable proportion of the degraded stream miles in the Upper Monocacy River watershed (Table 7).

4.3 Discussion of Stressors Identified by BSID Analysis

The BSID analysis was designed to evaluate the land use sources and related stressors that are the probable causes for the degraded biological conditions in the Upper Monocacy River watershed. The sediment stressors identified (*high embeddedness and severe erosion present*), and in-stream habitat stressor (*marginal to poor riffle run quality*) are indicative of how the altered flow regimes (related to anthropogenic activities) have led to increased flows that have resulted in sedimentation and nutrient contaminant loads throughout the Upper Monocacy watershed. During rain events, runoff from agricultural land uses results in sediment, fertilizers, manure and pesticide loads to streams. Three major nutrients in fertilizers and manure are nitrogen, phosphorus, and potassium. The BSID analysis identified elevated levels of TN, TP, and OP. The agricultural land uses in the Upper Monocacy River watershed are potential sources for these elevated levels of contaminants.

Cooper (1993) conducted a review on the biological effects of agriculturally derived surface water pollutants. The review identified sediments, nutrients, organic enrichment, and pesticides as the major stressors (contaminants) to aquatic life, and concluded that impacts from these stressors, along with alteration or destruction of habitat are the largest problems associated with evaluating agricultural impacts on aquatic systems. The high percentage of agricultural land use in the Upper Monocacy watershed has led to an altered hydrology characterized by frequent high flows that lead to increased sediment and nutrient (contaminant) loads throughout the watershed. These stressors have impacted the habitat necessary to sustain the life cycles and feeding requirements necessary for diverse biological communities to thrive.

The combined AR for the altered hydrology/sediment, habitat and water chemistry stressors is approximately 67% (Table 7), at this time MDE considers this AR value to be too low to adequately account for the biological impairment in the Upper Monocacy River watershed. MDE anticipates that inclusion of MBSS round three data into the BSID analysis will increase the AR values in order to allow the Department to address the Category 5 biological listing.

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 Upper 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 the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr, 1991 and USEPA – CADDIS 2012). 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 Upper Monocacy River watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

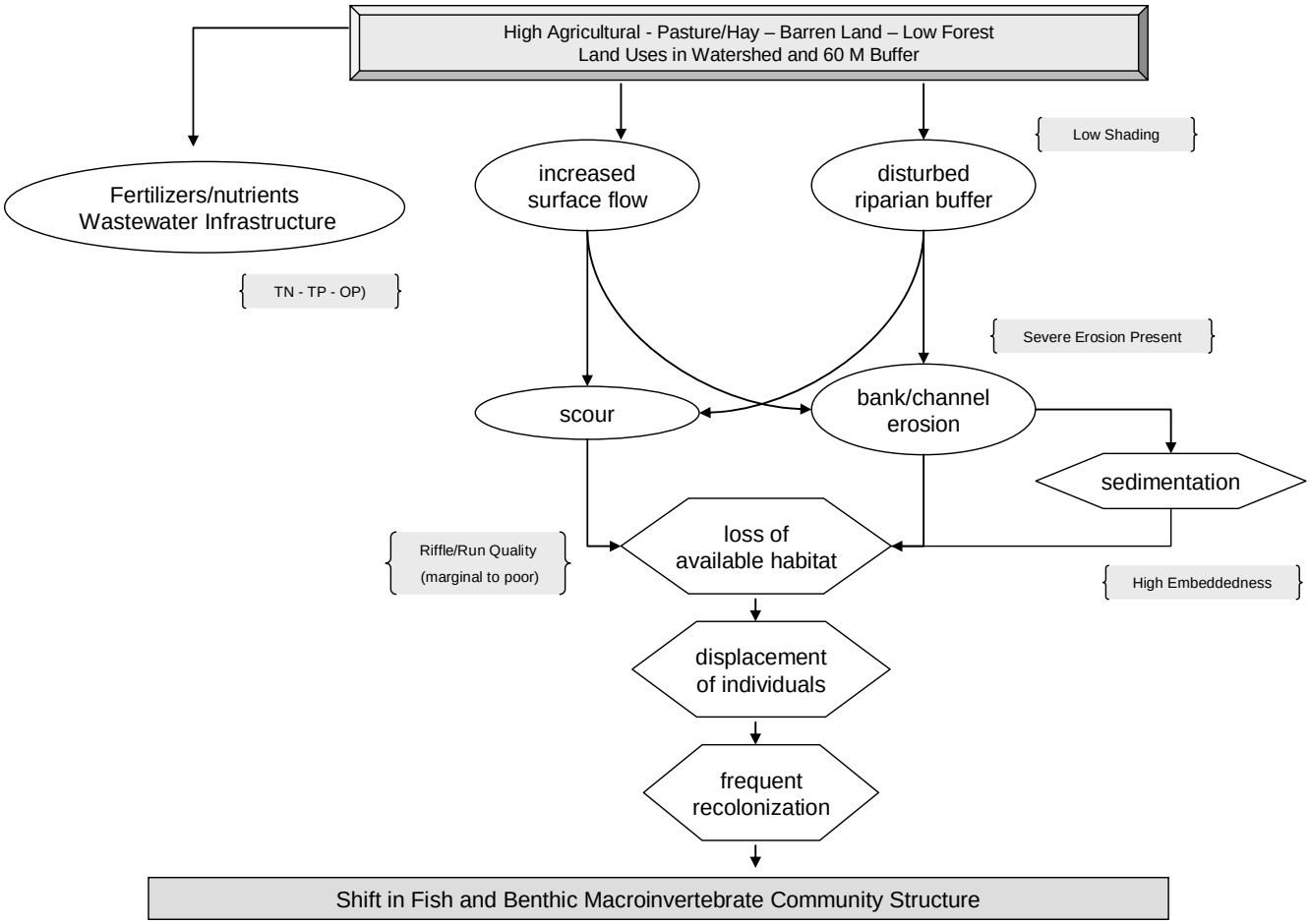

Figure 6. Final Causal Model for the Upper Monocacy River Watershed

5.0 Conclusions

Data suggest that the Upper Monocacy River watershed's biological communities are strongly influenced by 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 agricultural landscapes, which often cause altered 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 Upper Monocacy River are summarized as follows:

- The BSID process has determined that biological communities in the Upper Monocacy River watershed are likely degraded due to sediment in-stream, and riparian habitat related stressors. Specifically, altered hydrology and increased runoff from agricultural uses 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 sediment TMDL was an appropriate management action to begin addressing this stressor to the biological communities in the Upper Monocacy River.

- The BSID analysis has determined that both phosphorus and nitrogen are probable causes of impacts to biological communities in the Upper Monocacy River watershed. Both total phosphorus and orthophosphate show a significant association with degraded biological conditions; as much as 33% of the biologically impacted stream miles in the watershed may be degraded due to high total phosphorus and high orthophosphate. Similarly, according to the BSID analysis, 20% of the biologically impacted stream miles in the Upper 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 watershed, and the reduction of nitrogen loads would not be an effective means of ensuring that the Upper Monocacy River watershed is free from impacts on aquatic life from eutrophication. Therefore, load allocations for the Upper 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 Upper Monocacy River watershed, and link this pollutant to biological conditions in these waters.

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